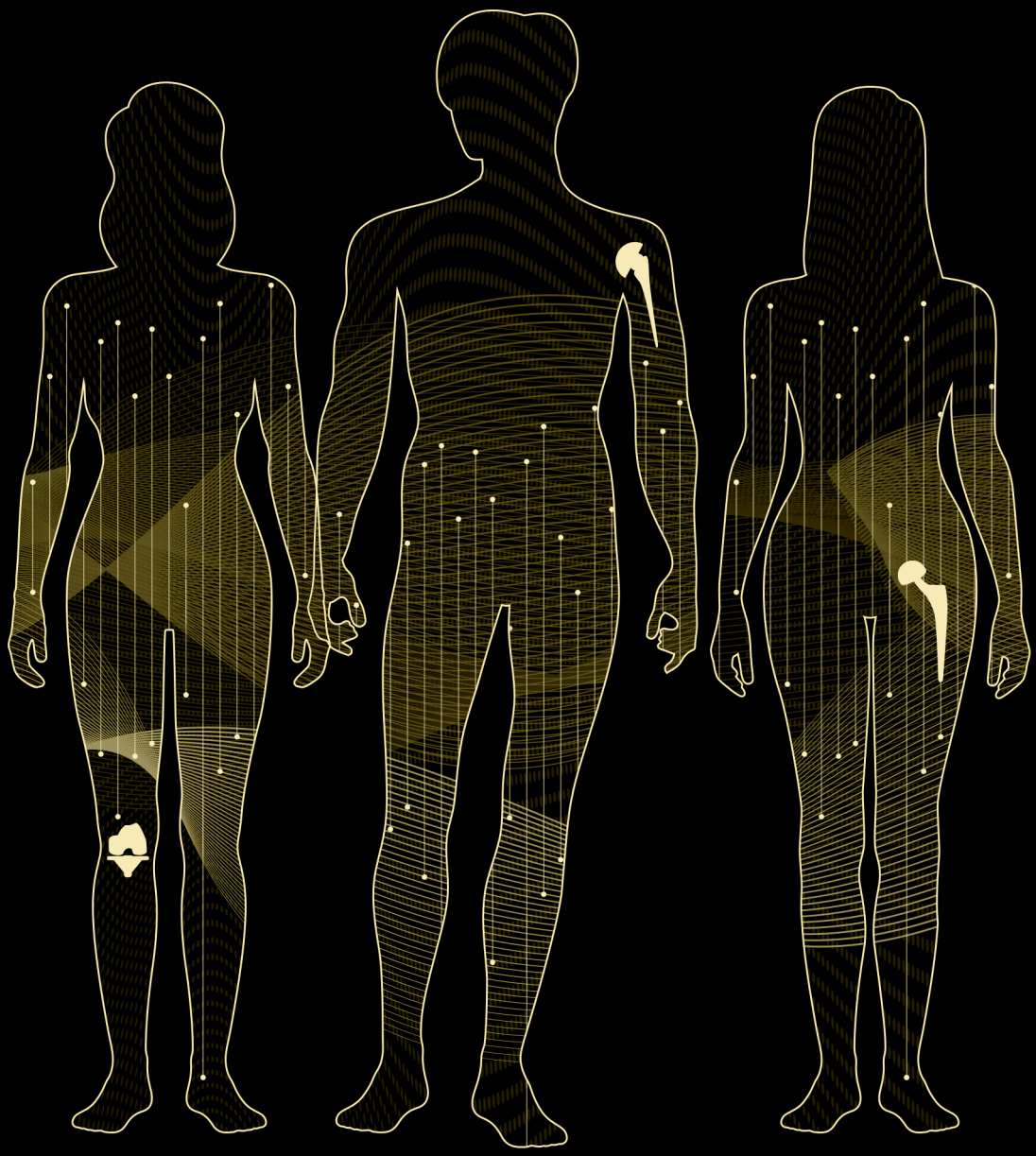
ADVANCING JOINT REPLACEMENT CARE

Insights gained from registry data



Mirthe van Veghel

Advancing joint replacement care

Insights gained from registry data

Mirthe van Veghel

The work presented in this thesis was conducted at the Orthopaedic Research Laboratory within the Department of Orthopedics at the Radboud university medical center. This department is part of the Research Institute for Medical Innovation.

The studies in this thesis were made possible by a grant from the Landelijke Registratie Orthopedische Interventies.

The publication of this thesis was financially supported by
Radboud universitair medisch centrum
Landelijke Registratie Orthopedische Interventies

Author
Mirthe van Veghel

ISBN
978-94-93431-98-0

Design/lay-out and print
Promotie In Zicht | www.promotie-inzicht.nl

Advancing joint replacement care

Insights gained from registry data

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. dr. J.M. Sanders,
volgens besluit van het college voor promoties
in het openbaar te verdedigen op

dinsdag 18 november 2025
om 14.30 uur precies

door

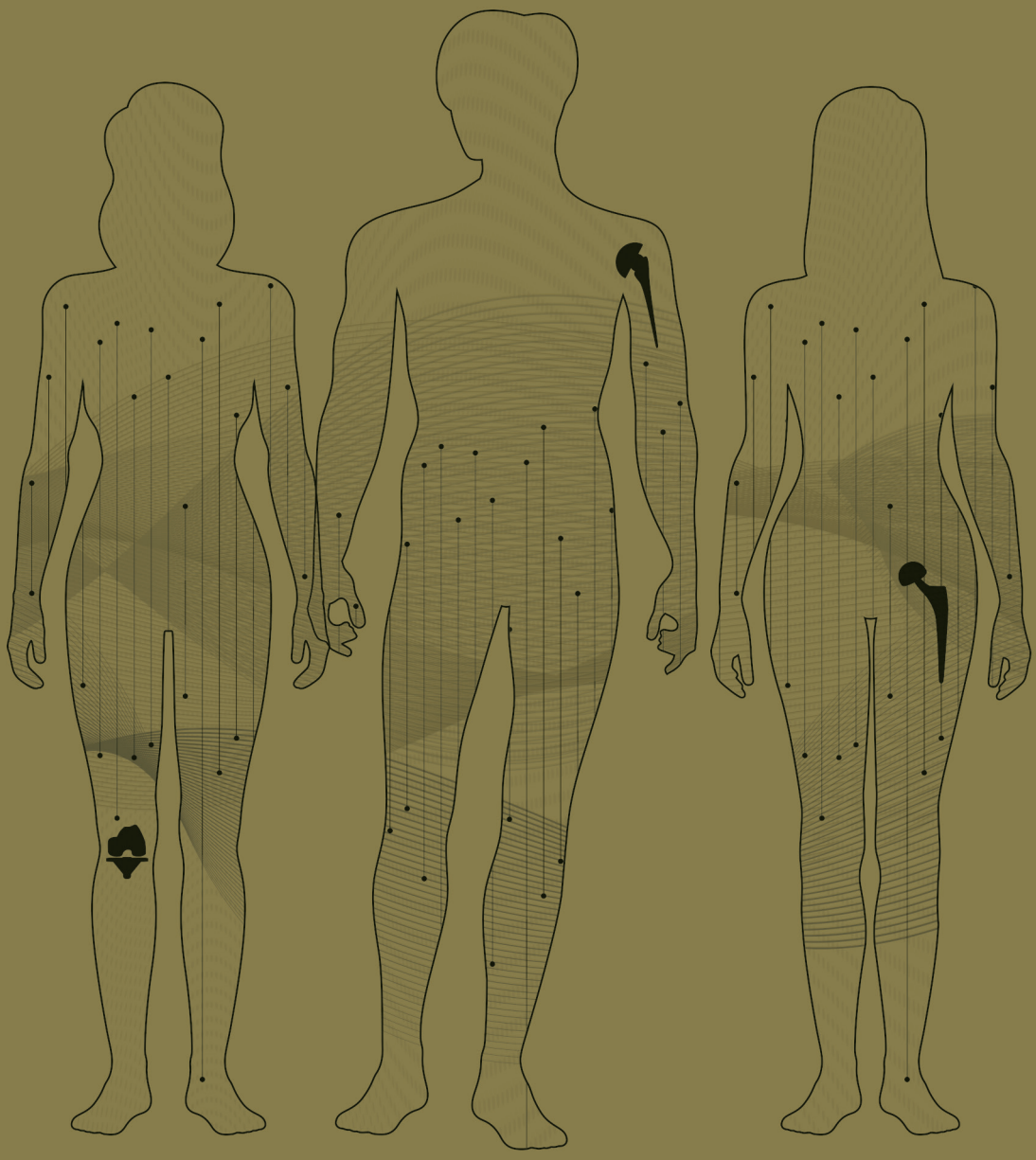
Mirthe Henrica Wilhelmina van Veghel
geboren op 29 november 1995
te Uden

Promotor
Prof. dr. B.W. Schreurs

Copromotoren
Dr. G.J. Hannink
Dr. ir. L.N. van Steenbergen (Landelijke Registratie Orthopedische Interventies)

Manuscriptcommissie
Prof. dr. R. van Crevel
Prof. dr. D.L. Gerritsen
Prof. dr. R.W. Poolman (Universiteit Leiden)

Table of Contents



1

General introduction and thesis outline

General introduction

Joint arthroplasty is a surgical procedure that replaces a dysfunctional or arthritic joint with an artificial implant. Although hip and knee arthroplasties are the most common procedures, arthroplasties in other joints, including the shoulder, ankle, elbow, wrist, and fingers, are also performed. Joint arthroplasty is considered one of the most cost-effective surgical interventions, as it relieves pain, improves joint function, and enhances the quality of life for patients with advanced joint diseases or joint damage after injuries [1,2]. In recent decades, the number of joint arthroplasties has increased both globally and in the Netherlands [1-3]. The annual number of hip and knee arthroplasties in the Netherlands increased from 50,000 in 2010 to 85,000 in 2023. For shoulder arthroplasties, the annual numbers doubled from 2,300 in 2014 to 4,600 in 2023. With an aging population and the increasing use of joint arthroplasties in both younger and more vulnerable elderly patients, annual procedure volumes are expected to increase even further in the coming years [4-6].

History of joint arthroplasty

One of the first attempts to perform joint arthroplasty was done in the late 19th century by placing ivory implants into the hips of patients with tuberculosis [7,8]. These ivory implants were also used to replace other tuberculous joints, including knees, shoulder, ankles, elbows, and wrists. However, most of these implants failed due to infection. In the late 19th and early 20th centuries, several other attempts at joint arthroplasty were made using materials such as glass, rubber, acryl, stainless steel, cobalt-chrome, and platinum [9,10]. From the late 20th century to the present, modern joint arthroplasty has been introduced and evolved into a routine procedure with high success rates, with total hip arthroplasty (THA), total knee arthroplasty (TKA), and total shoulder arthroplasty (TSA) being the most common procedures.

Nowadays, a THA consists of a femoral stem with an exchangeable femoral head and an acetabular cup, often with an exchangeable inlay (Figure 1). A TKA includes a femoral component, a tibial component, a polyethylene insert and optional, a patella button (Figure 2). TSA incorporates anatomical and reversed TSAs (ATSA and RTSA). An ATSA involves a humeral stem with a humeral head and a glenoid cup (Figure 3), whereas an RTSA features a reversed glenohumeral articulation, using a humeral stem without a humeral head and a glenoid component with a head (Figure 4).

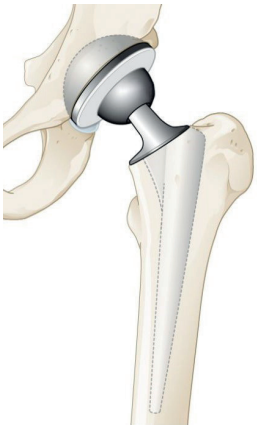


Figure 1. Illustration of a total hip arthroplasty

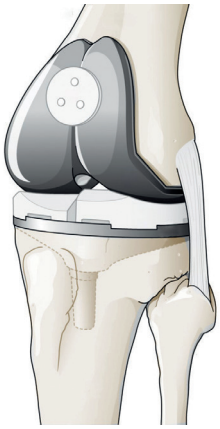


Figure 2. Illustration of a total knee arthroplasty

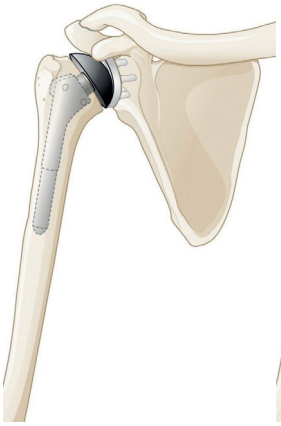


Figure 3. Illustration of an anatomical total shoulder arthroplasty

Figure 4. Illustration of a reversed total shoulder arthroplasty

Figures 1-4 *are modified with permission from the Netherlands Orthopaedic Association (NOV) – Zorg voor Beweging. Illustrator: Myrthe Boijmans.*

Several severe complications can occur after insertion of a joint arthroplasty, including infections, implant loosening, breakage of the implant, periprosthetic fractures, and wear, leading to pain, reduced physical function, decreased quality of life, and mortality [11]. Most of these complications occur years after the primary procedure. In many of these cases, revision surgery of the failed arthroplasty is necessary. However, revision surgery is more complex than primary surgery, is associated with more complications, and often yields less optimal outcomes than the primary arthroplasty. Therefore, preventing these complications is essential, and recording and monitoring the complication rates for each type of implant is crucial. This resulted in the need for systematic monitoring and evaluation of joint arthroplasties, leading to the establishment of local, and later, national arthroplasty registries.

Local, regional and national arthroplasty registries

The Mayo Clinic Total Joint Registry, starting in 1969, was the first arthroplasty registry that collected data on primary and revision joint arthroplasties performed at the Mayo Clinic in Rochester, Minnesota, USA [11]. However, Sweden was the first country that established national arthroplasty registries for knee and hip arthroplasties in 1975 and 1979, respectively [12,13]. Several other countries followed in the next decades, including Finland in 1980, Norway in 1987, Denmark in 1995 (hip) and 1997 (knee), New Zealand in 1998, Australia in 1999, England, Wales & Northern Ireland in 2002, and the Netherlands in 2007 [11,14]. Although national arthroplasty registries are the most attractive, as they capture all arthroplasties within a country, local and regional registries have also been established, such as the Geneva Arthroplasty Register (Geneva, Switzerland) in 1996, the Register of Orthopaedic Prosthetic Implants (Emilia-Romagna, Italy) in 2000, the Kaiser Permanente National Total Joint Registry (a health maintenance organization with eight regions, USA) in 2001, and the Catalan Arthroplasty Register (Catalonia, Spain) in 2005 [14,15].

Arthroplasty registries serve as comprehensive databases that systematically collect and store detailed information on joint arthroplasties performed in a given region or country, which has several benefits [16]. Firstly, the implant and patient information in an arthroplasty registry enables case identification in the event of a product recall or the necessity for patient identification. Arthroplasty registries also offer real-time surveillance of both implant and surgical performance. The extensive continuous observational dataset facilitates the monitoring of temporal changes in practice at the local, regional or national population level. Therefore, results of arthroplasty registries are usually generalizable to standard care. Moreover, the magnitude of the dataset enables the evaluation of rare events unsuitable for clinical trials, such as revision surgery and mortality. Finally, the use of patient identifiers enables

linkage to other datasets, enriching analyses and expanding the outcomes available, all in accordance with applicable legislation and privacy regulations [16]. Therefore, arthroplasty registries are considered valuable data sources for joint arthroplasties performed in a specific region or country.

Arthroplasty registries can be classified into different levels of maturity, which are pre-registration, incomplete registration, early complete registration, and mature complete registration [17]. Pre-registration refers to the initial stage where some efforts may have been made to establish an arthroplasty registry, but it is not yet operational. Incomplete registration is the phase where the arthroplasty registry has not yet achieved high levels of completeness. However, the registry can provide insights into practice variations, trace patients in case of recalls, and offer feedback to hospitals and surgeons using dashboards. Early complete registration indicates arthroplasty registries that have achieved a high level of completeness over a relatively short period. These registries can conduct general outcome assessments, such as comparing prosthesis designs or evaluating patient and procedure characteristics. Mature complete registration includes arthroplasty registries with high levels of completeness over an extended period, enabling outlier assessments for hospitals and implants [17].

The presence of national arthroplasty registries has had several impacts on orthopaedic care. The Norwegian Arthroplasty Register observed inferior short-term outcomes with Boneloc cement compared to other types of cement, which could not be explained by patient or procedure characteristics, contributing to the withdrawal of this bone cement [18,19]. Another important finding was that the Australian Orthopaedic Association National Joint Replacement Registry identified a significantly higher revision rate for prostheses with metal-on-metal bearing surfaces, including the 'ASR Hip Resurfacing System' and the 'ASR XL Acetabular System' [20]. These findings were confirmed by other national arthroplasty registries, leading the Netherlands Orthopaedic Association to advise against the use of all metal-on-metal large-head implants, as well as to the worldwide near-complete withdrawal of prostheses with metal-on-metal articulations [21].

Collaborations between arthroplasty registries

Arthroplasty registries may differ in data collection methods, registered variables, definitions, and statistical analyses, which can limit collaborations between registries [22]. In 2004, the International Society of Arthroplasty Registries (ISAR) was established to improve outcomes of joint arthroplasties by promoting cooperation and sharing information between registries, further enhancing the capacity of individual registries, supporting both established and developing registries, encouraging collaborative

activities, establishing consistency in terminology, and standardizing statistical analyses [11]. Members of ISAR include national, regional, and local arthroplasty registries.

Another registry-based collaboration was initiated in 2007 by Denmark, Norway, and Sweden to improve research opportunities for joint arthroplasties, resulting in the Nordic Arthroplasty Register Association (NARA), the first multinational arthroplasty register [22]. Finland became a full member in 2010. NARA has developed common minimal datasets for hip, knee, and shoulder arthroplasties to compare patient, procedure, and prosthesis characteristics, including outcomes, across the Nordic countries, and to study patient groups that are too small to be analyzed in each country. Furthermore, NARA seeks to achieve consensus on methodology and to facilitate quality improvements in data capture and analysis.

Dutch Arthroplasty Register (LROI)

In 2007, the Netherlands Orthopaedic Association founded the Dutch Arthroplasty Register (LROI [Landelijke Registratie Orthopedische Interventies]) to begin the registration of hip and knee arthroplasties in the Netherlands, following an unsuccessful attempt in 1992 due to funding issues [3,23]. The registry was expanded in 2014 to include data on shoulder, elbow, and ankle arthroplasties as well as patient-reported outcome measures (PROMs). Wrist and finger arthroplasties became part of the LROI in 2016. The main goals of the LROI include: a) monitoring of the quality of implants, hospitals and surgeons; b) educating and informing the public and society; c) identifying outlier implants and hospitals; d) ensuring traceability of implants to patients in the case of an emergency or recall; e) facilitating scientific research; and f) optimizing the LROI database [24].

Since 2012, 100% coverage of Dutch hospitals has been achieved, with a completeness rate of more than 95% for primary THAs and TKAs [25]. Nowadays, completeness rates are 97% for hip arthroplasties, 98% for knee arthroplasties, and 96% for shoulder arthroplasties, even though registration is not mandatory [3]. Additionally, validity rates for these procedures range between 94% and 97%. Therefore, the LROI can be considered a mature complete registration, especially now that its registration period exceeds 15 years.

The LROI contains data on patient (e.g., sex, age, diagnosis, body mass index), procedure (e.g., side, surgical approach, fixation), and prosthesis (e.g., size, brand, type) characteristics of primary and revision arthroplasties [26]. These data are collected using joint-specific electronic registration forms, which are completed by the orthopedic surgeon during or shortly after the surgical procedure. The data

can be entered into the LROI database either through the LROI portal or via an upload using a data broker. Each prosthesis component inserted during the procedure has a product and batch number. Prosthesis characteristics are obtained from an implant library, which is based on the product and batch number of the component, and consists among others of data on type, brand, name, and material of the component provided by the manufacturer. Prothesis survival, one of the most important outcomes in national arthroplasty registries, is determined by linking the revisions to the primary arthroplasties of individual patients, considering both joint- and side-specific data [25]. For accurate linkage, a personal identification number is required. A Trusted Third Party (ZorgTTP, Houten, the Netherlands) encrypts the patient's Citizen Service Number, which is a unique personal identification number used in the Netherlands, to ensure patient privacy within the LROI [25]. The vital status of all patients is actively obtained at regular time intervals from Vektis (Zeist, the Netherlands), which is the national insurance database on health care in the Netherlands, recording all deaths of Dutch inhabitants [26]. The LROI uses the opt-out system to require informed consent from patients.

Both generic and joint-specific PROMs have been registered in the LROI since 2014 for THAs and TKAs, and since 2016 for TSAs, to assess outcomes after joint arthroplasty from the patient's perspective [3,27]. In general, PROMs are measured preoperatively, at 3 months postoperatively for THAs and TSAs or at 6 months post-operatively for TKAs, and at 12 months postoperatively. Generic PROMs registered in the LROI include the EuroQol 5 Dimensions index score (EQ-5D), the EuroQol Visual Analog Scale (EQ VAS), and the Numeric Rating Scale for pain during activity (NRS activity) and at rest (NRS rest). Hip-specific PROMs in the LROI are the Hip disability and Osteoarthritis Outcome Score – Physical function Short form (HOOS-PS), the Oxford Hip Score (OHS), and the Anchor hip score for daily functioning (only postoperatively). Knee-specific PROMs in the LROI are the Knee injury and Osteoarthritis Outcome Score – Physical function Short form (KOOS-PS), the Oxford Knee Score (OKS), the Anchor knee score for daily functioning and pain (only postoperatively), and the NRS satisfaction score (only postoperatively) [27]. Shoulder-specific PROMs in the LROI are the Oxford Shoulder Score (OSS), the Anchor shoulder score for daily functioning and pain (only postoperatively), and the recommendation score (only postoperatively). The PROM response rates reach up to 37% for complete PROM scores, which are defined as scores collected at all 3 time points [3].

Thesis outline

The increasing number of joint arthroplasties highlights the importance of systematically collecting and storing data on patient, procedure, and prosthesis characteristics in arthroplasty registries. Effective use of these registries has the potential to improve health outcomes, as identifying factors related to adverse outcomes, such as higher revision rates, may reduce morbidity, the need for subsequent surgical procedures, and mortality [11,16]. Data from arthroplasty registries can facilitate several research initiatives aimed at improving patient outcomes.

In this thesis, various aspects of population-based registry studies are explored, using hip, knee, and shoulder data from the LROI. These aspects include combining and comparing data from multiple national arthroplasty registries to study an infrequently used type of prosthesis, linking LROI data with data from another medical registry and a local database to validate and enrich analyses, and conducting epidemiological studies to explore trends, patterns, and associations. The thesis is divided into 3 parts: 1) Collaboration & comparison between national arthroplasty registries; 2) Enrichment & linking with other (non-)arthroplasty registries; and 3) Prevalence & patterns.

Part 1: Collaboration & comparison between national arthroplasty registries

The first part of this thesis explores the international collaboration between the LROI, the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR), and the Swedish Arthroplasty Register (SAR), using short-stem and standard-stem THAs as case study (Figure 5). In recent years, short-stem THAs have been increasingly performed, although currently still representing a small proportion of all THAs [28,29]. Given the currently small but increasing numbers of short-stem THAs, combining and comparing data from multiple national arthroplasty registries could provide valuable insights into the efficacy of these short stems.

Although short-stem THAs are designed to preserve proximal femoral bone stock, which may be valuable if a revision is required, the bone-preserving features have yet to be confirmed [30,31]. Bone preservation may allow for the use of standard-length stems rather than longer revision stems during the first stem revision. However, this advantage will become irrelevant if short-stem THAs result in higher revision rates than standard-stem THAs.

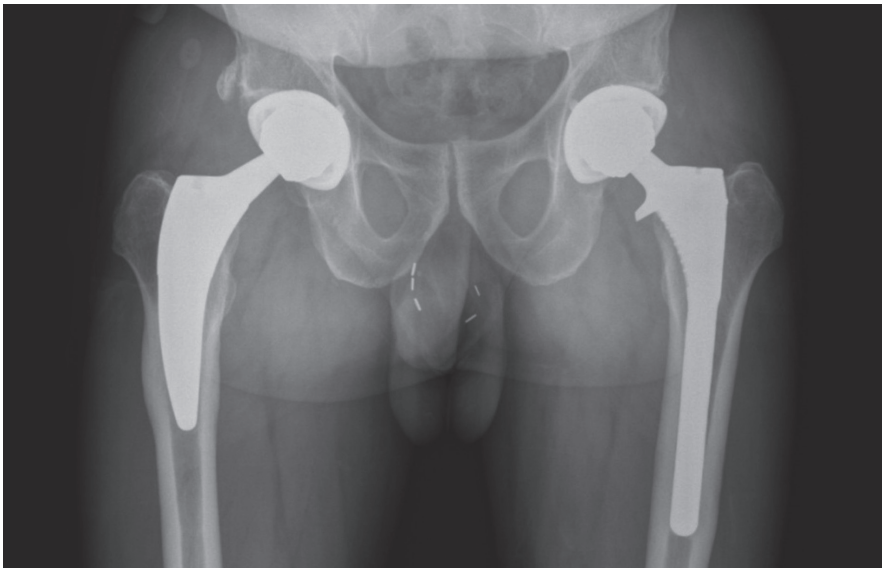


Figure 5. Radiograph of a short-stem and standard-stem total hip arthroplasty

Reproduced with permission and copyright © of the British Editorial Society of Bone & Joint Surgery [Gustke K. Short stems for total hip arthroplasty: initial experience with the Fitmore™ stem. J Bone Joint Surg Br. 2012;94-B(11 Supple A):47-51.].

Chapter 2 provides an overview of the uncemented short stems used in the Netherlands as well as the patient, procedure and prosthesis characteristics, 10-year overall and femoral stem revision rates, and patient-reported quality of life, pain and physical functioning in patients with primary uncemented short-stem and standard-stem THAs performed between 2009 and 2021 in the Netherlands.

In **Chapter 3**, the comparison is extended by incorporating data from the LROI and AOANJRR, where all primary uncemented short-stem THAs registered in the LROI and AOANJRR between 2009 and 2021 are compared in terms of patient, procedure and prosthesis characteristics, as well as the incidence and 10-year overall revision rates.

Chapter 4 combines data from the LROI, AOANJRR and SAR, focusing on the stems used in the first stem revision of primary uncemented short-stem and standard-stem THAs performed between 2007 and 2022 in the Netherlands, Australia, and Sweden. Additionally, 12-year overall revision rates and 5-year overall re-revision rates of uncemented short-stem and standard-stem THAs are presented.

Part 2: Enrichment & linking with other (non-)arthroplasty registries

In this part, LROI data are linked with data from the Dutch National Nosocomial Surveillance Network (PREZIES [PREventie van ZIEkenhuisinfecties door Surveillance]), and LROI data are used to complete and cross-check a local database of the Radboud university medical center (Radboudumc).

National arthroplasty registries are known to underreport the incidence of periprosthetic joint infections (PJIs) by up to 50% [32-36]. PJIs are a major complication, as they can lead to higher revision rates and even higher mortality rates that may be associated with the responsible microorganism [37-39]. PREZIES is the national surveillance system for surgical site infections, such as PJIs in THAs and TKAs, in the Netherlands. By combining data from the LROI and PREZIES databases, the capture rate of PJIs in THAs and TKAs in the LROI can be evaluated to quantify the possible underreporting of PJIs in the Netherlands. Furthermore, combining data from the LROI and PREZIES databases allows the evaluation of early PJIs with responsible microorganisms in THAs and TKAs in the Netherlands, as the LROI collects data on patient, procedure, and prosthesis characteristics of primary and revision arthroplasties, while PREZIES collects data on early PJIs and their associated microorganisms.

In **Chapter 5**, the incidence of reported PJIs in THAs and TKAs between 2012 and 2018 in the LROI is validated, using data from PREZIES as a reference standard.

Chapter 6 describes the microorganisms that cause early PJIs in primary THAs and TKAs performed between 2012 and 2018 in the Netherlands, using data from both the LROI and PREZIES. Moreover, the 5-year mortality rates and re-revision rates after a PJI are examined. Additionally, the most common microorganisms causing PJIs are categorized based on patient and implant survival.

Furthermore, data from the LROI are used to complete and enrich a local database of the Radboudumc on THA, addressing challenges due to changes in documentation practices that have occurred over the past decades within the hospital's electronic patient records. **Chapter 7** applies LROI data in the evaluation of the long-term survival and complications of cemented short Exeter (Stryker, UK) stems used in primary THAs performed between 1993 and 2021 in the Radboudumc.

Part 3: Prevalence & patterns

In this part, LROI data are used to estimate the prevalence of people with a joint arthroplasty in the Netherlands, and to identify recovery patterns after TSA along with their potential risk factors.

Registry data, such as LROI data, can be used to estimate the number of people living with a joint arthroplasty, providing insight into the number of individuals at risk for complications associated with these joint arthroplasties [40]. Moreover, the prevalence of people living with a joint arthroplasty can be used to project future demand for primary and revision joint arthroplasty, which is crucial for policy makers in government, education and industry [41-43]. In **Chapter 8**, the prevalence of people living in the Netherlands in 2022 with at least one hip, knee or shoulder arthroplasty is estimated.

Registry data can also be used to identify recovery trajectories of patient-reported outcomes after joint arthroplasty, as has been successfully done for THA and TKA using LROI data [44,45]. However, recovery trajectories have not been identified following TSA using national registry data. Although TSA usually leads to substantial improvements in both pain and physical functioning, certain patients do not experience improvement or continue to report persistent pain 1 year after the procedure, indicating different recovery trajectories [46-48]. Insight into these recovery trajectories, as well as the patient and procedure characteristics associated with them, may provide valuable guidance for clinical decision-making. **Chapter 9** presents the recovery trajectories following TSAs performed between 2016 and 2022 in the Netherlands, along with the patient and procedure characteristics associated with these trajectories.

Lastly, **Chapter 10** presents a general discussion on the aforementioned chapters, and **Chapters 11** and **12** provide a summary of the thesis.

References

[1] Ferguson RJ, Palmer AJ, Taylor A, Porter ML, Malchau H, Glyn-Jones S. Hip replacement. Lancet 2018;392(10158):1662-71. https://doi.org/10.1016/S0140-6736(18)31777-X.

[2] Price AJ, Alvand A, Troelsen A, Katz JN, Hooper G, Gray A, Carr A, Beard D. Knee replacement. Lancet 2018;392(10158):1672-82. https://doi.org/10.1016/S0140-6736(18)32344-4.

[3] LROI. Annual report 2024. Landelijke Registratie Orthopedische Interventies; 2024. Available from: https://www.lroi.nl/media/prqogokg/pdf-lroi-report-2024.pdf.

[4] Padegimas EM, Maltenfort M, Lazarus MD, Ramsey ML, Williams GR, Namdari S. Future patient demand for shoulder arthroplasty by younger patients: national projections. Clin Orthop Relat Res 2015;473(6):1860-7. https://doi.org/10.1007/s11999-015-4231-z.

[5] Matharu GS, Culliford DJ, Blom AW, Judge A. Projections for primary hip and knee replacement surgery up to the year 2060: an analysis based on data from The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. Ann R Coll Surg Engl 2022;104(6):443-8. https://doi.org/10.1308/rcsann.2021.0206.

[6] Ackerman IN, Bohensky MA, Zomer E, Tacey M, Gorelik A, Brand CA, de Steiger R. The projected burden of primary total knee and hip replacement for osteoarthritis in Australia to the year 2030. BMC Musculoskelet Disord 2019;20(1):90. https://doi.org/10.1186/s12891-019-2411-9.

[7] Knight SR, Aujla R, Biswas SP. Total Hip Arthroplasty - over 100 years of operative history. Orthop Rev (Pavia) 2011;3(2):e16. https://doi.org/10.4081/or.2011.e16.

[8] Hernigou P. Earliest times before hip arthroplasty: from John Rhea Barton to Themistocles Gluck. Int Orthop 2013;37(11):2313-8. https://doi.org/10.1007/s00264-013-2004-4.

[9] Bota NC, Nistor DV, Caterev S, Todor A. Historical overview of hip arthroplasty: From humble beginnings to a high-tech future. Orthop Rev (Pavia) 2021;13(1):8773. https://doi.org/10.4081/or.2021.8773.

[10] Zilber S. Shoulder Arthroplasty: Historical Considerations. Open Orthop J 2017;11:1100-7. https://doi.org/10.2174/1874325001711011100.

[11] Malchau H, Garellick G, Berry D, Harris WH, Robertson O, Karrlholm J, Lewallen D, Bragdon CR, Lidgren L, Herberts P. Arthroplasty implant registries over the past five decades: Development, current, and future impact. J Orthop Res 2018;36(9):2319-30. https://doi.org/10.1002/jor.24014.

[12] Robertsson O, Lewold S, Knutson K, Lidgren L. The Swedish Knee Arthroplasty Project. Acta Orthop Scand 2000;71(1):7-18. https://doi.org/10.1080/00016470052943829.

[13] Karrholm J. The Swedish Hip Arthroplasty Register (www.shpr.se). Acta Orthop 2010;81(1):3-4. https://doi.org/10.3109/17453671003635918.

[14] Lubbeke A, Silman AJ, Barea C, Prieto-Alhambra D, Carr AJ. Mapping existing hip and knee replacement registries in Europe. Health Policy 2018;122(5):548-57. https://doi.org/10.1016/j.healthpol.2018.03.010.

[15] Prentice HA, Harris JE, Sucher K, Fasig BH, Navarro RA, Okike KM, Maletis GB, Guppy KH, Chang RW, Kelly MP, Hinman AD, Paxton EW. Improvements in Quality, Safety and Costs Associated with Use of Implant Registries Within a Health System. Jt Comm J Qual Patient Saf 2024. https://doi.org/10.1016/j.jcjq.2024.01.011.

[16] Baker PN, Jeyapalan R, Jameson SS. The value of national arthroplasty registry data in 2023. Bone Joint J 2023;105-B(4):356-60. https://doi.org/10.1302/0301-620X.105B4.BJJ-2022-1190.R2.

[17] Pijls BG. The value of hip and knee arthroplasty registries. Expert Rev Med Devices 2023;20(12):1005-8. https://doi.org/10.1080/17434440.2023.2282747.

[18] Havelin LI, Espehaug B, Vollset SE, Engesaeter LB. The effect of the type of cement on early revision of Charnley total hip prostheses. A review of eight thousand five hundred and seventy-nine primary arthroplasties from the Norwegian Arthroplasty Register. J Bone Joint Surg Am 1995;77(10):1543-50. https://doi.org/10.2106/00004623-199510000-00009.

[19] Havelin LI, Engesaeter LB, Espehaug B, Furnes O, Lie SA, Vollset SE. The Norwegian Arthroplasty Register: 11 years and 73,000 arthroplasties. Acta Orthop Scand 2000;71(4):337-53. https://doi.org/10.1080/000164700317393321.

[20] de Steiger RN, Graves SE. Orthopaedic registries: the Australian experience. EFORT Open Rev 2019;4(6):409-15. https://doi.org/10.1302/2058-5241.4.180071.

[21] Verheyen CC, Verhaar JA. Failure rates of stemmed metal-on-metal hip replacements. Lancet 2012;380(9837):105; author reply 6. https://doi.org/10.1016/S0140-6736(12)61169-6.
[22] Makela KT, Furnes O, Hallan G, Fenstad AM, Rolfson O, Karrholm J, Rogmark C, Pedersen AB, Robertsson O, A WD, Eskelinen A, Schroder HM, Aarimaa V, Rasmussen JV, Salomonsson B, Hole R, Overgaard S. The benefits of collaboration: the Nordic Arthroplasty Register Association. EFORT Open Rev 2019;4(6):391-400. https://doi.org/10.1302/2058-5241.4.180058.
[23] Delaunay C. Registries in orthopaedics. Orthop Traumatol Surg Res 2015;101(1 Suppl):S69-75. https://doi.org/10.1016/j.otsr.2014.06.029.
[24] LROI. LROI brengt de orthopedie in beeld: Strategisch plan 2023-2027. Landelijke Registratie Orthopedische Interventies; n.d. Available from: https://nov.foleon.com/strategisch-plan-lroi-2023-2027/lroi-strategisch-plan-2023-2027/.
[25] van Steenbergen LN, Denissen GA, Spooren A, van Rooden SM, van Oosterhout FJ, Morrenhof JW, Nelissen RG. More than 95% completeness of reported procedures in the population-based Dutch Arthroplasty Register. Acta Orthop 2015;86(4):498-505. https://doi.org/10.3109/17453674.2015.1028307.
[26] LROI. Methodologie voor verzameling van LROI-data. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/jzpet12v/methodologie-voor-verzameling-van-lroi-data.pdf.
[27] NOV. NOV PROMs-advies orthopedie 2020: Focus op patiënten met een heup- of knieprothese. Nederlandse Orthopaedische Vereniging; 2020. Available from: https://www.orthopeden.org/media/efjffe05/nov-proms-advies.pdf.
[28] AOANJRR. Hip, Knee & Shoulder Arthroplasty: 2023 Annual report. Australian Orthopaedic Association National Joint Replacement Registry; 2023. Available from: https://aoanjrr.sahmri.com/documents/10180/1579982/AOA_NJRR_AR23.pdf/c3bcc83b-5590-e034-4ad8-802e4ad8bf5b?t=1695887126627.
[29] Steinbruck A, Grimberg AW, Elliott J, Melsheimer O, Jansson V. Short versus conventional stem in cementless total hip arthroplasty : An evidence-based approach with registry data of mid-term survival. Orthopade 2021;50(4):296-305. https://doi.org/10.1007/s00132-021-04083-y.
[30] Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J 2019;101-B(5):502-11. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018-1199.R1.
[31] van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. Acta Orthop 2014;85(3):250-8. https://doi.org/10.3109/17453674.2014.908343.
[32] Lindgren JV, Gordon M, Wretenberg P, Karrholm J, Garellick G. Validation of reoperations due to infection in the Swedish Hip Arthroplasty Register. BMC Musculoskelet Disord 2014;15. https://doi.org/10.1186/1471-2474-15-384.
[33] Jamsen E, Huotari K, Huhtala H, Nevalainen J, Konttinen YT. Low rate of infected knee replacements in a nationwide series--is it an underestimate? Acta Orthop 2009;80(2):205-12. https://doi.org/10.3109/17453670902947432.
[34] Gundtoft PH, Pedersen AB, Schonheyder HC, Overgaard S. Validation of the diagnosis 'prosthetic joint infection' in the Danish Hip Arthroplasty Register. Bone Joint J 2016;98-B(3):320-5. https://doi.org/10.1302/0301-620X.98B3.36705.
[35] Sinagra ZP, Davis JS, Lorimer M, de Steiger RN, Graves SE, Yates P, Manning L. The accuracy of reporting of periprosthetic joint infection to the Australian Orthopaedic Association National Joint Replacement Registry. Bone Jt Open 2022;3(5):367-73. https://doi.org/10.1302/2633-1462.35.BJO-2022-0011.R1.
[36] Kamp MC, Liu WY, Goosen JHM, Rijnen WHC, van Steenbergen LN, van der Weegen W, Regional Prosthetic Joint Infection Working G. Mismatch in Capture of Periprosthetic Joint Infections Between the Dutch Arthroplasty Register (LROI) and a Detailed Regional Periprosthetic Joint Infection Registry. J Arthroplasty 2022;37(1):126-31. https://doi.org/10.1016/j.arth.2021.09.001.
[37] Zmistowski B, Karam JA, Durinka JB, Casper DS, Parvizi J. Periprosthetic joint infection increases the risk of one-year mortality. J Bone Joint Surg Am 2013;95(24):2177-84. https://doi.org/10.2106/JBJS.L.00789.

[38] Argenson JN, Arndt M, Babis G, Battenberg A, Budhiparama N, Catani F, Chen F, de Beaubien B, Ebied A, Esposito S, Ferry C, Flores H, Giorgini A, Hansen E, Hernugrahanto KD, Hyonmin C, Kim TK, Koh IJ, Komnos G, Lausmann C, Loloi J, Lora-Tamayo J, Lumban-Gaol I, Mahyudin F, Mancheno-Losa M, Marculescu C, Marei S, Martin KE, Meshram P, Paprosky WG, Poultsides L, Saxena A, Schwechter E, Shah J, Shohat N, Sierra RJ, Soriano A, Stefansdottir A, Suleiman LI, Taylor A, Triantafyllopoulos GK, Utomo DN, Warren D, Whiteside L, Wouthuyzen-Bakker M, Yombi J, Zmistowski B. Hip and Knee Section, Treatment, Debridement and Retention of Implant: Proceedings of International Consensus on Orthopedic Infections. J Arthroplasty 2019;34(2S):S399-S419. https://doi.org/10.1016/j.arth.2018.09.025.

[39] Gundtoft PH, Pedersen AB, Varnum C, Overgaard S. Increased Mortality After Prosthetic Joint Infection in Primary THA. Clin Orthop Relat Res 2017;475(11):2623-31. https://doi.org/10.1007/s11999-017-5289-6.

[40] Manning L, Davis JS, Robinson O, Clark B, Lorimer M, de Steiger R, Graves SE. High prevalence of older Australians with one or more joint replacements: estimating the population at risk for late complications of arthroplasty. ANZ J Surg 2020;90(5):846-50. https://doi.org/10.1111/ans.15774.

[41] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89(4):780-5. https://doi.org/10.2106/JBJS.F.00222.

[42] Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res 2009;467(10):2606-12. https://doi.org/10.1007/s11999-009-0834-6.

[43] Maradit Kremers H, Larson DR, Crowson CS, Kremers WK, Washington RE, Steiner CA, Jiranek WA, Berry DJ. Prevalence of Total Hip and Knee Replacement in the United States. J Bone Joint Surg Am 2015;97(17):1386-97. https://doi.org/10.2106/JBJS.N.01141.

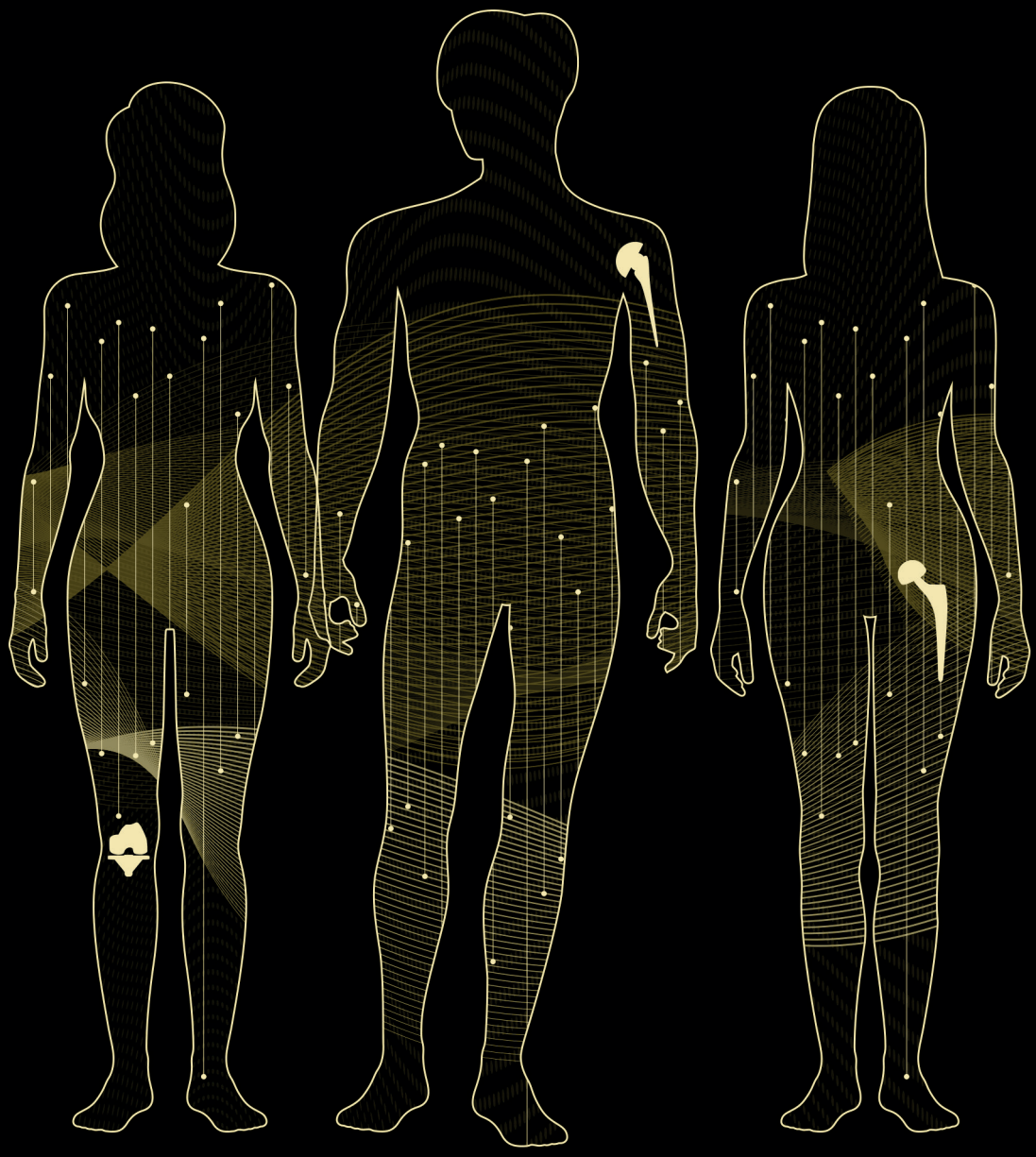
[44] Hesseling B, Mathijssen NMC, van Steenbergen LN, Melles M, Vehmeijer SBW, Porsius JT. Fast Starters, Slow Starters, and Late Dippers: Trajectories of Patient-Reported Outcomes After Total Hip Arthroplasty: Results from a Dutch Nationwide Database. J Bone Joint Surg Am 2019;101(24):2175-86. https://doi.org/10.2106/JBJS.19.00234.

[45] van Egmond JC, Hesseling B, Melles M, Vehmeijer SBW, van Steenbergen LN, Mathijssen NMC, Porsius JT. Three distinct recovery patterns following primary total knee arthroplasty: dutch arthroplasty register study of 809 patients. Knee Surg Sports Traumatol Arthrosc 2021;29(2):529-39. https://doi.org/10.1007/s00167-020-05969-8.

[46] Carter MJ, Mikuls TR, Nayak S, Fehringer EV, Michaud K. Impact of total shoulder arthroplasty on generic and shoulder-specific health-related quality-of-life measures: a systematic literature review and meta-analysis. J Bone Joint Surg Am 2012;94(17):e127. https://doi.org/10.2106/JBJS.K.00204.

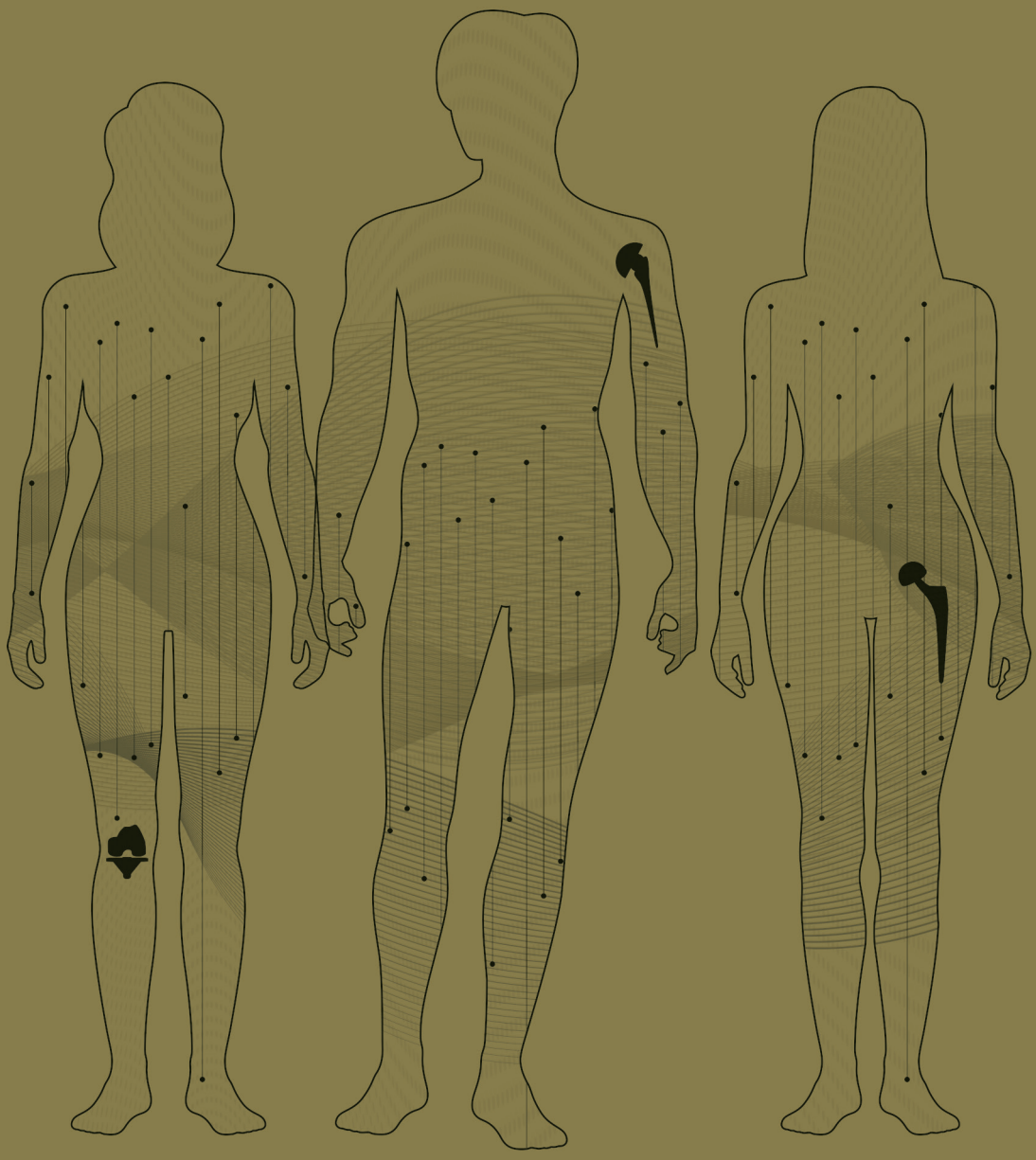
[47] Roberson TA, Bentley JC, Griscom JT, Kissenberth MJ, Tolan SJ, Hawkins RJ, Tokish JM. Outcomes of total shoulder arthroplasty in patients younger than 65 years: a systematic review. J Shoulder Elbow Surg 2017;26(7):1298-306. https://doi.org/10.1016/j.jse.2016.12.069.

[48] Bjornholdt KT, Brandsborg B, Soballe K, Nikolajsen L. Persistent pain is common 1-2 years after shoulder replacement. Acta Orthop 2015;86(1):71-7. https://doi.org/10.3109/17453674.2014.987065.



Part 1

Collaboration & comparison between national arthroplasty registries



2

A comparison of uncemented short versus standard stem length in total hip arthroplasty: results from the Dutch Arthroplasty Register

MHW van Veghel
G Hannink
J van Oldenrijk
LN van Steenbergen
BW Schreurs

Acta Orthopaedica 2023; 94: 330–335

Abstract

Background and purpose: We aimed to compare revision rates between uncemented short and standard stems in total hip arthroplasties (THAs) and the corresponding patient-reported outcome measures (PROMs).

Patients and methods: We included all short (C.F.P., Fitmore, GTS, Metha, Nanos, Optimys, Pulchra, and Taperloc Microplasty) and standard stems in uncemented THAs registered between 2009 and 2021 in the Dutch Arthroplasty Register. Kaplan–Meier survival and multivariable Cox regression analyses were performed with overall and femoral stem revision as endpoints.

Results: Short stems were used in 3,352 and standard stems in 228,917 hips. 10-year overall revision rates (4.8%, 95% confidence interval [CI] 3.7–6.3 vs. 4.5%, CI 4.4–4.6) and femoral stem revision rates (3.0%, CI 2.2–4.2 vs. 2.3%, CI 2.2–2.4) were comparable for short- and standard-stem THAs. Today's predominant short stems (Fitmore and Optimys) showed short-term revision rates similar to that of standard-stem THAs. Other, less frequently used short stems had higher 10-year overall (6.3%, CI 4.7–8.5) and femoral stem (4.5%, CI 3.1–6.3) revision rates. Multivariable Cox regression also showed a higher risk for overall (HR 1.7, CI 1.0–2.9) and femoral stem revision (HR 2.0, CI 1.1–3.5) using the latter short stems compared with standard stems. An exploratory analysis of PROMs showed no difference.

Conclusion: There was no overall difference in revision rates but a tendency toward increased revision of short stems both for the whole THA and for the stem itself. The less frequently used short stems had increased revision risk. No difference in PROMs was shown.

Introduction

In recent decades, there has been an increase in total hip arthroplasties (THAs), particularly in young patients [1,2]. Bone-saving implants such as short femoral components may be important in these patients to facilitate future revisions, although little evidence for this exists [3].

Uncemented short-stem THAs have become more prevalent in recent years in some countries [4]. Although a clear definition is lacking, these short stems are characterized as small cementless femoral components that preserve more femoral neck and achieve metaphyseal fixation [5,6]. 3 main advantages of short stems may be preservation of proximal bone stock for future revisions, improvement of biomechanical reconstruction, and the possibility for less invasive approaches [4,7-9].

Short stems have shown revision rates and improvements in functional outcome similar to standard stems at short- and mid-term follow-up [4,8,10]. However, only limited population-based registry studies on short-stem THAs are available [8,10,11]. Due to their increased popularity, particularly in younger and fitter patient groups, more population-based registry studies on incidence of short-stem THAs, revision rates, and patient-reported outcome measures (PROMs) are needed to show the average results in contrast to randomized controlled trials.

Also, the bone-preserving features of short stems during future revisions have yet to be confirmed. Bone preservation may allow for the use of standard-length stems during component exchange, rather than larger revision stems to compensate for proximal bone loss. It may be valuable to know more about the types of femoral implants used during revision of these short stems.

Therefore, we aimed to compare patients, procedure and prosthesis characteristics, revision rates, patient-reported quality of life, pain, and physical functioning in patients with primary uncemented short-stem THAs and standard-stem THAs, using data from the Dutch Arthroplasty Register (LROI).

Patients and methods

Data was obtained from the LROI. The LROI is a national population-based arthroplasty register, established by the Netherlands Orthopaedic Association (NOV) in 2007. In 2012, 100% coverage of Dutch hospitals was achieved with a completeness of more than 95% of primary THAs [12]. Nowadays, 99% completeness of primary THAs and 98% of revision arthroplasties have been reached [13]. The LROI contains data on patient, prosthesis, and procedure characteristics of primary and revision arthroplasties and PROMs. Prosthesis characteristics are obtained from an implant library, which is based on article numbers of prosthesis components, and consists among others of data on type, brand, name, and material of the prosthesis component provided by the manufacturer. Revision arthroplasty is defined as a replacement, removal or addition of 1 or more components of the implant [12]. PROMs registered in the LROI are the EuroQol 5 Dimensions index score (EQ-5D), the EuroQol Visual Analog Scale (EQ VAS), the Hip disability and Osteoarthritis Outcome Score – Physical function Short form (HOOS-PS), the Oxford Hip Score (OHS), and the Numeric Rating Scale during activity (NRS activity) and at rest (NRS rest). PROMs are measured preoperative and at 3 months and 12 months postoperatively.

We included all primary THAs with an uncemented short or standard femoral component in the period 2009–2021 (Figure 1). THAs with a metal-on-metal articulation (n = 3,619) and procedures with the diagnosis tumor (n = 20) were excluded. Short-stem THAs were defined based on the definition of the LROI and previous literature [4-6,8,14-16]. The LROI defines a short stem as a small cementless femoral component with special design features where fixation is intended to be metaphyseal [17]. Short stems identified in the LROI were C.F.P. (Waldemar Link, Hamburg, Germany), Fitmore (Zimmer Biomet, Warsaw, IN, USA), GTS (Zimmer Biomet, Warsaw, IN, USA), Metha (B. Braun Aesculap, Tuttlingen, Germany), Nanos (Smith & Nephew, London, UK), Optimys (Mathys, Bettlach, Switzerland), Pulchra (Adler Orthro, Cormano, Italy) and Taperloc Microplasty (Zimmer Biomet, Warsaw, IN, USA) (Figure 1).

Statistics

Descriptive statistics were used to present patients, prosthesis, and procedure characteristics as well as the incidence of short-stem THAs by type of hospital (i.e., general hospital, private clinic, or academic medical center). Crude Kaplan–Meier survival analyses were performed to determine 10-year overall and femoral stem revision rates including 95% confidence intervals (CI) according to type of stem. Survival was defined as the time between primary THA to first revision, death of the

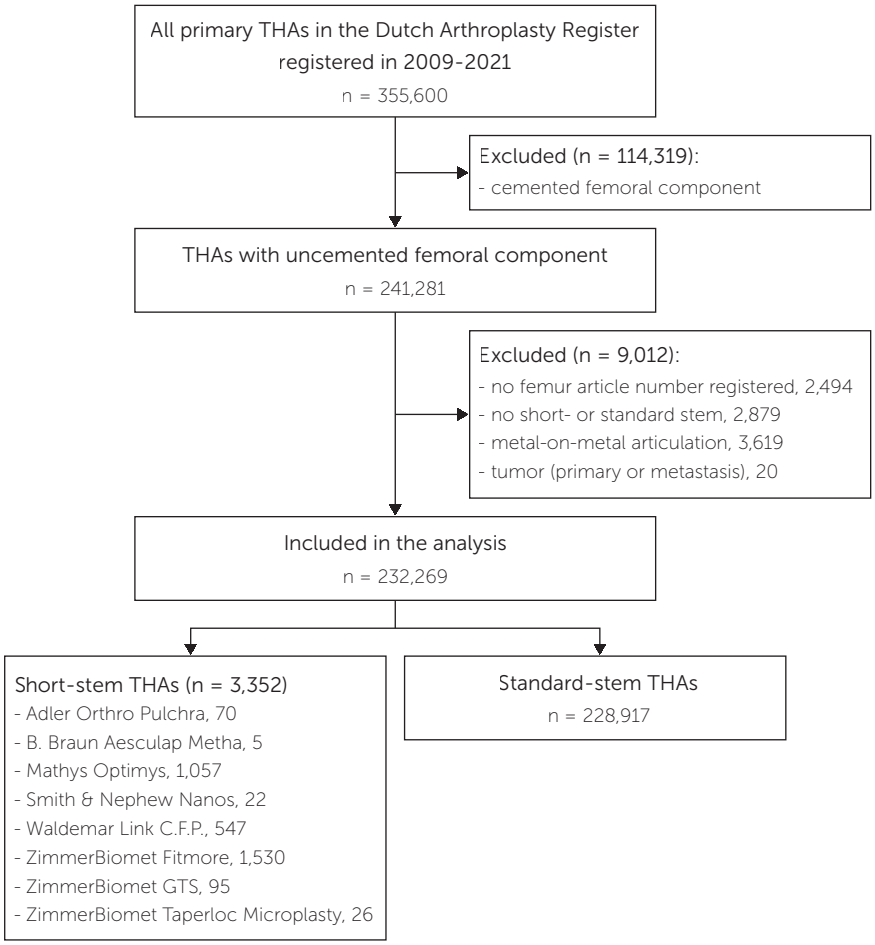


Figure 1. Flowchart of included hips.

patient, or end of follow-up (January 1, 2022). Multivariable Cox regression analyses were used to account for differences in confounders between the short-stem and standard-stem groups. We used log–log plots and testing of scaled Schoenfeld residuals to assess the proportional hazards assumption, which appeared to be violated. Therefore, Schemper's weighted Cox models were used [18]. Age, sex, American Society of Anesthesiologists (ASA) score, diagnosis (osteoarthritis [OA] vs. non-OA), and surgical approach were considered confounders. Body mass index (BMI) and smoking status were not included as confounders, as these variables have been registered in the LROI since 2014. Missing data in confounders was

imputed, using multiple imputation by chained equations using predictive mean matching in which 15 datasets were created. Less than 1% was missing for each confounder. There was no missing data in outcome variables. Effect estimates were pooled according to Rubin's Rules. For CIs, we assumed that the number of observed cases followed a Poisson distribution. Reasons for overall and femoral stem revision were described according to stem type. Linear mixed models were performed to analyze PROM scores. Time (i.e., preoperative, 3 months, and 12 months postoperatively) and group (i.e., short stem vs. standard stem) were included as fixed factors, and patient as a random factor. Possible interaction between time and group was included as fixed factor if model fit improved. Residual plots as well as Q–Q plots were used to visually examine the distributions of both random effects and residuals, which were approximately normally distributed. PROM analyses were performed on patients with a short-stem or standard-stem THA for primary OA since 2014, as PROM scores are available for these patients since 2014 in the LROI. PROM data were not imputed, as a complete PROM score (preoperative as well as 3-month and 12-month postoperative response) was available in less than 30%. Only patients with complete PROM scores were included in the PROM analyses. Therefore, the PROM analyses should be considered an exploratory analysis.

Incidence analyses, Kaplan–Meier survival analyses, and multivariable Schemper's weighted Cox regression analyses were also performed separately for short-stem THAs with Fitmore, and Optimys versus other short stems, as Fitmore and Optimys are currently widely used in the Netherlands, while the other short stems have mainly been used in the past.

This study was reported in accordance with the STROBE guidelines. R (version 4.0.4, R Foundation for Statistical Computing, Vienna, Austria) was used to perform all analyses.

Ethics, data sharing, funding, and disclosures

Data was received completely anonymously. Data was available from the LROI, but restrictions apply to the availability of this data, which was used under license for the current study. This study is funded by the Dutch Arthroplasty Register. No conflicts of interest were declared. Completed disclosure forms for this article following the ICMJE template are available on the article page, doi: 10.2340/17453674.2023.13652

Results

232,269 THAs were included in the period 2009–2021, of which 3,352 (1.4%) were short-stem THAs. Fitmore (n = 1,530) and Optimys (n = 1,057) were the 2 most implanted short stems (Figure 1). Median follow-up was 5.1 (interquartile range [IQR] 2.5–8.1) years. Short-stem THA patients were younger (63, SD 10 vs. 67, SD 10 years) and had a lower ASA score (ASA-I 36% vs. 22%) than standard-stem THA patients. More short-stem THA patients were of normal weight than standard-stem THA patients (36% vs. 23%). The anterior approach was most often used in short-stem THAs (67%), while the posterolateral approach was commonly used in standard-stem THAs (53%). In both groups, a ceramic-on-polyethylene articulation and a 32 mm femoral head were most frequently used. Short-stem THAs were more often performed in a private clinic than standard-stem THAs (59% vs. 9.0%) (Table 1).

In general hospitals, the annual number of short-stem THAs varied between 40 and 180 in the period 2009–2021, whereas in private clinics it increased from 1 in 2015 to 1,124 in 2021. In both general hospitals and private clinics, the Fitmore and Optimys stem were used most often in recent years, while the use of the other short stems decreased in this period. In academic medical centers, the annual number of short-stem THAs ranged between 0 and 10 in the period 2009–2021.

Revision

Crude 10-year overall and femoral stem revision rates were comparable for short-stem and standard-stem THAs (Figure 2). The crude 10-year overall revision rate was 4.8% (CI 3.7–6.3) for short-stem THAs and 4.5% (CI 4.4–4.6) for standard-stem THAs. The crude 10-year femoral stem revision rate was 3.0% (CI 2.2–4.2) for short-stem THAs and 2.3% (CI 2.2–2.4) for standard-stem THAs. Short-stem THAs with a Fitmore or Optimys stem showed comparable short-term overall and femoral stem revision rates to standard-stem THAs. THAs with other short stems had higher 10-year overall (6.3%, CI 4.7–8.5) and femoral stem (4.5%, CI 3.1–6.3) revision rates than standard-stem THAs.

Multivariable Schemper's weighted Cox regression analyses adjusted for age, sex, ASA score, diagnosis, and surgical approach showed a comparable risk of overall revision (HR 1.4, CI 0.9–2.1), but a higher risk of femoral stem revision (HR 1.5, CI 1.0–2.4) for short-stem THAs compared with standard-stem THAs (Table 2). No statistically significant differences in risk of overall and femoral stem revision were found between THAs with a Fitmore, Optimys, or standard stem, adjusted for age, sex, ASA score, diagnosis, and surgical approach. The other short-stem group was associated with a higher adjusted risk for overall (HR 1.7, CI 1.0–2.9) and femoral stem (HR 2.0, CI 1.1–3.5) revision compared with the standard stem.

Table 1. Patient, prosthesis, and procedure characteristics of primary THAs according to type of stem. Values are count (%) unless otherwise specified

	Standard stem	Short stem
Factor	n = 228,917	n = 3,352
Age, mean (SD)	67 (10)	63 (10)
Missing	169 (0.1)	1 (0.0)
Male sex	85,633 (37)	1,323 (40)
Missing	300 (0.1)	1 (0.0)
Diagnosis		
Osteoarthritis	202,126 (88)	3,059 (91)
Dysplasia	4,785 (2.1)	117 (3.5)
Fracture	7,654 (3.3)	1 (0.0)
Other	13,339 (5.8)	163 (4.9)
Missing	1,013 (0.4)	12 (0.4)
ASA score		
I	51,070 (22)	1,198 (36)
II	143,788 (63)	2,000 (60)
III-IV	32,516 (14)	125 (3.7)
Missing	1,543 (0.7)	29 (0.9)
Charnley [a]		
A	72,261 (32)	1,342 (40)
B1	47,381 (21)	858 (26)
B2	33,962 (15)	539 (16)
C	3,844 (1.7)	59 (1.8)
Missing	71,469 (31)	554 (17)
Smoking [a]	18,365 (8.0)	243 (7.2)
Missing	72,065 (32)	550 (16)
Body mass index [a]		
Underweight (≤18.5)	1,171 (0.5)	11 (0.3)
Normal weight (>18.5–25)	53,265 (23)	1,195 (36)
Overweight (>25–30)	68,739 (30)	1,141 (34)
Obesity (>30–40)	37,379 (16)	449 (13)
Morbid obesity (>40)	1,849 (0.8)	5 (0.1)
Missing	66,514 (29)	551 (16)
Previous surgery at affected hip	9,157 (4.0)	139 (4.1)
Missing	6,008 (2.6)	31 (0.9)
Fixation		
Cementless	215,573 (94)	3,252 (97)
Acetabulum cemented	13,158 (5.7)	99 (3.0)
Missing	186 (0.1)	1 (0.0)

Table 1. Continued

Factor	Standard stem n = 228,917	Short stem n = 3,352
Surgical approach		
Anterior	58,654 (26)	2,249 (67)
Anterolateral	12,795 (5.6)	89 (2.7)
Posterolateral	121,353 (53)	368 (11)
Straight lateral	33,350 (15)	601 (18)
Other	2,040 (0.9)	38 (1.1)
Missing	725 (0.3)	7 (0.2)
Articulation		
Ceramic-on-ceramic	20,081 (8.8)	145 (4.3)
Ceramic-on-metal	66 (0.0)	0 (0.0)
Ceramic-on-polyethylene	137,586 (60)	2,878 (86)
Metal-on-ceramic	5 (0.0)	0 (0.0)
Metal-on-polyethylene	44,699 (20)	193 (5.8)
Oxidized zirconium-on-polyethylene	18,707 (8.2)	19 (0.6)
Missing	7,773 (3.4)	117 (3.5)
Femoral head size		
22–28 mm	38,854 (17)	231 (6.9)
32 mm	126,521 (55)	2,388 (71)
36 mm	60,242 (26)	662 (20)
≥38 mm	1,253 (0.5)	13 (0.4)
Missing	2,047 (0.9)	58 (1.7)
Type of hospital		
General hospital	204,420 (89)	1,322 (39)
Private clinic	20,664 (9.0)	1,982 (59)
Academic medical center	3,832 (1.7)	48 (1.4)
Missing	1 (0.1)	0 (0.0)

[a] Registered since 2014.

Reasons for revision

The most common reason for overall and femoral stem revision of short-stem THAs was aseptic femoral loosening (27% and 42% respectively), followed by infection (25% and 20% respectively) (Table 3). In short-stem THAs, dislocation was less frequently registered as reason for overall revision compared with standard-stem THAs (8.2% vs. 22%). Femoral stem revisions due to periprosthetic fractures were less prevalent in short-stem THAs compared with standard-stem THAs (13% vs. 24%).

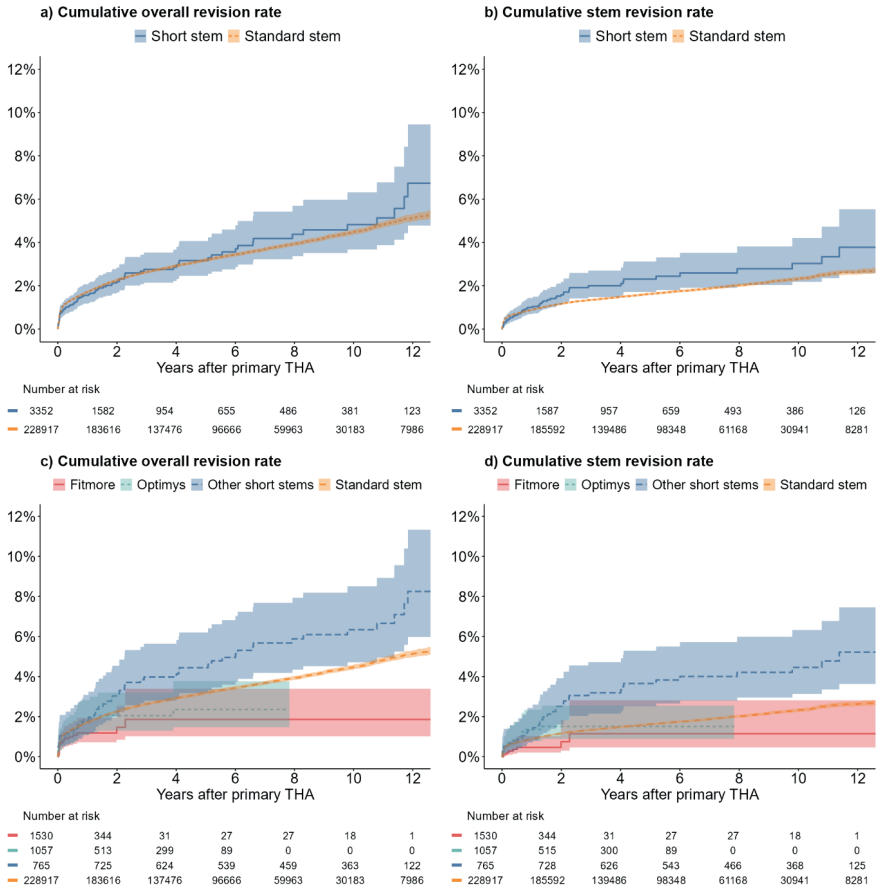


Figure 2. Cumulative overall (a) and femoral stem (b) revision rates of primary THAs according to type of stem and according to type of short stem (c and d respectively).

Table 2. Cox regression analyses of risk for overall and femoral stem revision of primary THAs according to type of stem and type of short stem

	Overall revision		Femoral stem revision	
Type of stem	Crude HR (CI)	Adjusted [a] HR (CI)	Crude HR (CI)	Adjusted [a] HR (CI)
Standard stems	1.0 (ref.)	1.0 (ref.)	1.0 (ref.)	1.0 (ref.)
All short stems	1.3 (0.9–2.0)	1.4 (0.9–2.1)	1.4 (0.9–2.2)	1.5 (1.0–2.4)
Fitmore	0.6 (0.4–1.0)	0.9 (0.5–1.4)	0.6 (0.3–1.1)	0.7 (0.4–1.5)
Optimys	0.8 (0.5–1.2)	0.9 (0.6–1.4)	1.0 (0.6–1.8)	1.1 (0.7–1.9)
Other short stems	1.8 (1.0–3.0)	1.7 (1.0–2.9)	1.9 (1.1–3.4)	2.0 (1.1–3.5)

[a] Adjusted for age, sex, ASA score, diagnosis, and surgical approach.

Table 3. Reasons for overall and femoral stem revision of primary THAs registered in the LROI according to type of stem. Values are count (%)

	Overall revision		Femoral stem revision	
	Standard stem	Short stem	Standard stem	Short stem
Reason	n = 7,423	n = 85	n = 3,813	n = 55
Infection	1,409 (19)	21 (25)	638 (17)	11 (20)
Aseptic loosening				
acetabulum	707 (9.5)	12 (14)	146 (3.8)	0 (0.0)
femur	1,449 (20)	23 (27)	1,428 (38)	23 (42)
Periprosthetic fracture	986 (13)	7 (8.2)	918 (24)	7 (13)
Dislocation	1,608 (22)	7 (8.2)	272 (7.1)	3 (5.5)
Wear	102 (1.4)	3 (3.5)	8 (0.2)	1 (1.8)
Periarticular ossification	53 (0.7)	0 (0.0)	7 (0.2)	0 (0.0)
Girdlestone	54 (0.7)	0 (0.0)	53 (1.4)	0 (0.0)
Other	906 (12)	8 (9.4)	301 (7.9)	7 (13)
No reason registered	149 (2.0)	4 (4.7)	42 (1.1)	3 (5.5)

PROMs

There were 142,314 THAs for primary OA since 2014, of which 2,589 (1.8%) had a short stem. Depending on the type of PROM, 8–11% of short-stem THA patients and 22–24% of standard-stem THA patients completed the preoperative as well as the 3-months and 12-months postoperative PROMs. All PROM scores improved at 3 months and 12 months postoperatively in both the short-stem and standard-stem groups (Figure 3). No clinically relevant differences were found between short-stem

and standard-stem patients in EQ-5D (0.0, CI 0.0–0.0), EQ VAS (0.8, CI –0.8 to 2.4), HOOS-PS (0.8, CI –0.5 to 2.2), OHS (0.0, CI –0.8 to 0.7), NRS during activity (0.2, CI 0.0–0.4), and NRS at rest (0.1, CI 0.0–0.3) scores.

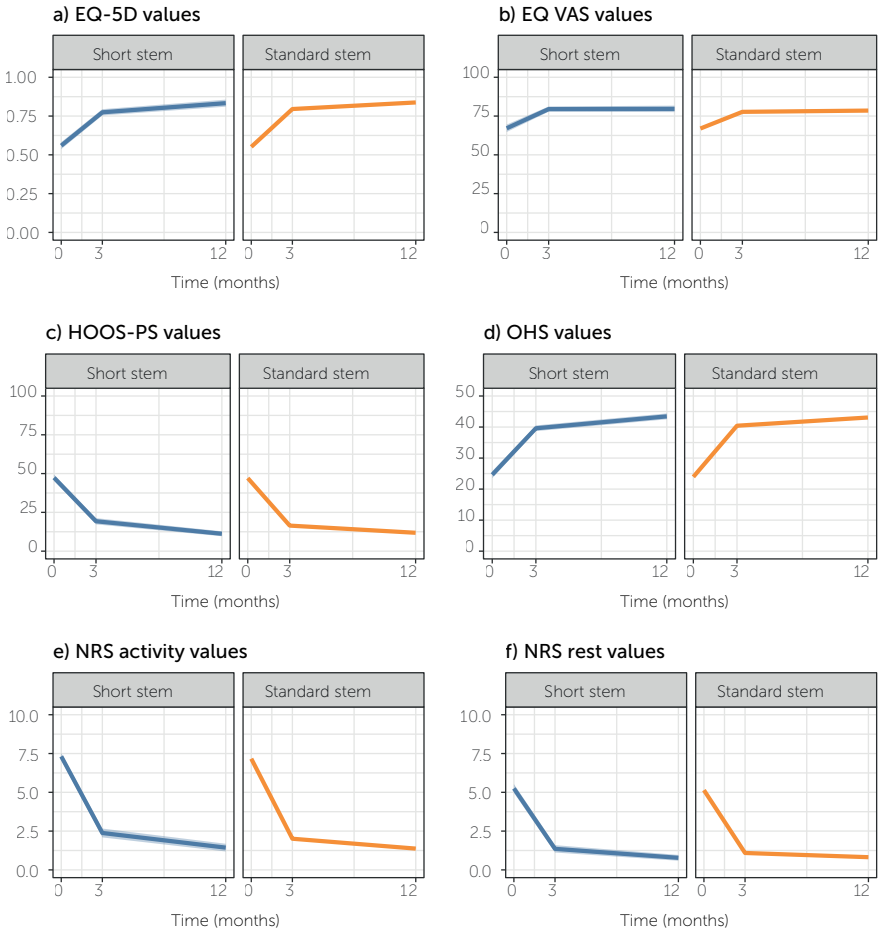


Figure 3. (a) EQ-5D (n = 33,642), (b) EQ VAS (n = 34,214), (c) HOOS-PS (n = 30,485), (d) OHS (n = 30,654), (e) NRS during activity (n = 34,453), and (f) NRS at rest (n = 34,460) mean scores with 95%CI of primary THAs for OA since 2014 according to type of stem.

Discussion

We aimed to compare patients, procedure and prosthesis characteristics, revision rates, patient-reported quality of life, pain, and physical functioning in patients with primary uncemented short versus standard stems in THA. We showed no difference in overall or femoral stem revision rates of THAs with a Fitmore, Optimys, or standard stem, whereas less frequent short stems had higher revision rates. However, it is uncertain whether Fitmore, Optimys, and standard stems have comparable short-term overall and femoral stem revision rates in the general patient population as the number of short stems was small and thus the confidence intervals were wide in our study.

Comparing our study with other registry studies on short-stem THAs is complex, as each study included different short stems. A recent study from Steinbrück et al. [19] demonstrated similar 5-year overall revision rates between matched cohorts of short-stem THAs (2.9%, CI 2.4–3.5, including Optimys, Metha, A2-Kurzschaft, and Nanos) and standard-stem THAs (3.1%, CI 2.7–3.4), using data from the German Arthroplasty Registry (EPRD [Endoprothesenregister Deutschland]). The 5-year overall revision rate for THAs with an Optimys stem was 1.8% (CI 1.5–2.2), which is comparable to our results. The Registry of Prosthetic Orthopedic Implants (RIPO, Italy) found somewhat higher 10-year overall revision rates of 6.1–6.6% for both short-stem THAs (including C.F.P., Nanos, Parva, Fitmore, MiniMax, and Amistem-H) and standard-stem THAs [11]. No prosthesis-specific results for short stems were described. None of these registries have reported results on femoral stem revision or PROMs of short-stem THAs.

The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) reported a 10-year overall revision rate of 2.9% (CI 2.4–3.6) for short-stem THAs in their annual report [20]. This revision rate is lower than for standard-stem THAs performed in Australia (4.4%, CI 4.3– 4.5) and our 10-year overall revision rate of short-stem THAs. However, the AOANJRR restricted its analyses to prostheses currently in use, including Collo-Mis, Metha, MiniHip, MiniMax, Nanos, Optimys, and Taperloc Microplasty, whereas we included all commercially available short stems. THAs with an Optimys stem had a 5-year overall revision rate of 1.6% (CI 0.8–3.2), which is in line with our results.

In our study, patients with short stems may have a higher risk for femoral stem revision compared with standard-stem THA patients. However, this higher risk can be explained by short stems that are hardly used in the Netherlands anymore, including Pulchra, Metha, Nanos, C.F.P., GTS, and Taperloc Microplasty. Our study

showed a comparable risk for femoral stem revision for Fitmore, Optimys, and standard stems.

Dislocation is less frequently reported as the reason for overall revision of short-stem THAs compared with standard-stem THAs in our study. This may be explained by the more frequent use of the anterior approach in short-stem THAs [21]. In short-stem THAs, periprosthetic fractures are less frequently registered as reason for femoral stem revision than in standard-stem THAs. Advanced age is associated with an increased risk of periprosthetic fractures. In our study, short-stem THA patients were younger than standard-stem THA patients, which may explain the smaller proportion of femoral stem revisions due to periprosthetic fractures in the short-stem THA group. An alternative explanation is that these short stems have their fixation mainly in the metaphyseal area and hence generate less stress in the diaphyseal area.

No differences are found in patient-reported quality of life, pain, and physical functioning between short-stem and standard-stem THA patients. However, PROM response was low in both groups. Hutchings et al. [22] found a pattern of lower postoperative PROM response in patients with worse preoperative EQ-5D and OHS scores. Consequently, PROM scores could be overestimated in this study. In addition, floor and ceiling effects as well as regression to the mean may have played a role in the PROM scores. The proportion of PROMs of patients with a Fitmore stem was relatively low in this study. More than half of the Fitmore stems were implanted in 2021. Therefore, 12 months of follow-up is not yet available for these stems. As a result, there were relatively fewer PROM scores from private clinics. There were no differences in age and sex between PROM responders and non-responders.

This study has some limitations. Confounding may occur by indication as short-stem THA patients are younger and may have better health. Short stems may have been used in few hospitals or by few surgeons, resulting in less generalizable results. Multivariable Cox regression analyses were restricted to patient and procedure characteristics recorded in the LROI. Therefore, possible confounders such as physical activity could not be included. Furthermore, BMI and smoking status could not be included as covariates, as these variables have been registered only since 2014 in the LROI. However, sensitivity analyses with data from the period 2014–2021 showed our results to be robust. Lastly, in the absence of a clear definition of short stem, we based our definition on that of the LROI and previous literature. However, other national arthroplasty registers such as the AOANJRR and the EPRD use a similar definition of a short stem [20,23].

In conclusion, there was no overall difference in revision rates but a tendency toward increased revision of short stems both for the whole THA and for the stem itself. The less frequently used short stems had increased revision risk. No difference in PROMs was shown. As the follow-up of patients with short stems is still limited in the Netherlands, it is recommended to continue following these patients.

References

[1] Mei XY, Gong YJ, Safir O, Gross A, Kuzyk P. Long-term outcomes of total hip arthroplasty in patients younger than 55 years: a systematic review of the contemporary literature. Can J Surg 2019;62(4):249-58. https://doi.org/10.1503/cjs.013118.

[2] Pivec R, Johnson AJ, Mears SC, Mont MA. Hip arthroplasty. Lancet 2012;380(9855):1768-77. https://doi.org/10.1016/S0140-6736(12)60607-2.

[3] Bayliss LE, Culliford D, Monk AP, Glyn-Jones S, Prieto-Alhambra D, Judge A, Cooper C, Carr AJ, Arden NK, Beard DJ, Price AJ. The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study. Lancet 2017;389(10077):1424-30. https://doi.org/10.1016/S0140-6736(17)30059-4.

[4] Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J 2019;101-B(5):502-11. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018-1199.R1.

[5] Falez F, Casella F, Papalia M. Current concepts, classification, and results in short stem hip arthroplasty. Orthopedics 2015;38(3 Suppl):S6-13. https://doi.org/10.3928/01477447-20150215-50.

[6] Khanuja HS, Banerjee S, Jain D, Pivec R, Mont MA. Short bone-conserving stems in cementless hip arthroplasty. J Bone Joint Surg Am 2014;96(20):1742-52. https://doi.org/10.2106/JBJS.M.00780.

[7] Gustke K. Short stems for total hip arthroplasty: initial experience with the Fitmore stem. J Bone Joint Surg Br 2012;94(11 Suppl A):47-51. https://doi.org/10.1302/0301-620X.94B11.30677.

[8] van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. Acta Orthop 2014;85(3):250-8. https://doi.org/10.3109/17453674.2014.908343.

[9] Patel RM, Stulberg SD. The rationale for short uncemented stems in total hip arthroplasty. Orthop Clin North Am 2014;45(1):19-31. https://doi.org/10.1016/j.ocl.2013.08.007.

[10] Hauer G, Vielgut I, Amerstorfer F, Maurer-Ertl W, Leithner A, Sadoghi P. Survival Rate of Short-Stem Hip Prostheses: A Comparative Analysis of Clinical Studies and National Arthroplasty Registers. J Arthroplasty 2018;33(6):1800-5. https://doi.org/10.1016/j.arth.2018.01.017.

[11] Giardina F, Castagnini F, Stea S, Bordini B, Montalti M, Toni A. Short Stems Versus Conventional Stems in Cementless Total Hip Arthroplasty: A Long-Term Registry Study. J Arthroplasty 2018;33(6):1794-9. https://doi.org/10.1016/j.arth.2018.01.005.

[12] van Steenbergen LN, Denissen GA, Spooren A, van Rooden SM, van Oosterhout FJ, Morrenhof JW, Nelissen RG. More than 95% completeness of reported procedures in the population-based Dutch Arthroplasty Register. Acta Orthop 2015;86(4):498-505. https://doi.org/10.3109/17453674.2015.1028307.

[13] LROI. Annual report 2022. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/3j2o5wjg/pdf-lroi-annual-report-2022.pdf.

[14] Feyen H, Shimmin AJ. Is the length of the femoral component important in primary total hip replacement? Bone Joint J 2014;96-B(4):442-8. https://doi.org/10.1302/0301-620X.96B4.33036.

[15] Pardo F, Bordini B, Castagnini F, Giardina F, Faldini C, Traina F. Are powder-technology-built stems safe? A midterm follow-up registry study. J Mater Sci Mater Med 2021;32(1):10. https://doi.org/10.1007/s10856-020-06481-8.

[16] Erivan R, Villatte G, Dartus J, Mertl P, Piriou P, Tracol P, Vernizeau M, Mulliez A, Puch JM, Girard J, Descamps S, Boisgard S, French H, Knee S. French Hip & Knee Society classification of short-stem hip prostheses: Inter- and intra-observer reproducibility. Orthop Traumatol Surg Res 2022;108(1):103126. https://doi.org/10.1016/j.otsr.2021.103126.

[17] LROI. LROI Implant Library - Hip. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/byym2eyc/625522c726f17lroi-implant-library-hip.pdf.

[18] Schemper M, Wakounig S, Heinze G. The estimation of average hazard ratios by weighted Cox regression. Stat Med 2009;28(19):2473-89. https://doi.org/10.1002/sim.3623.

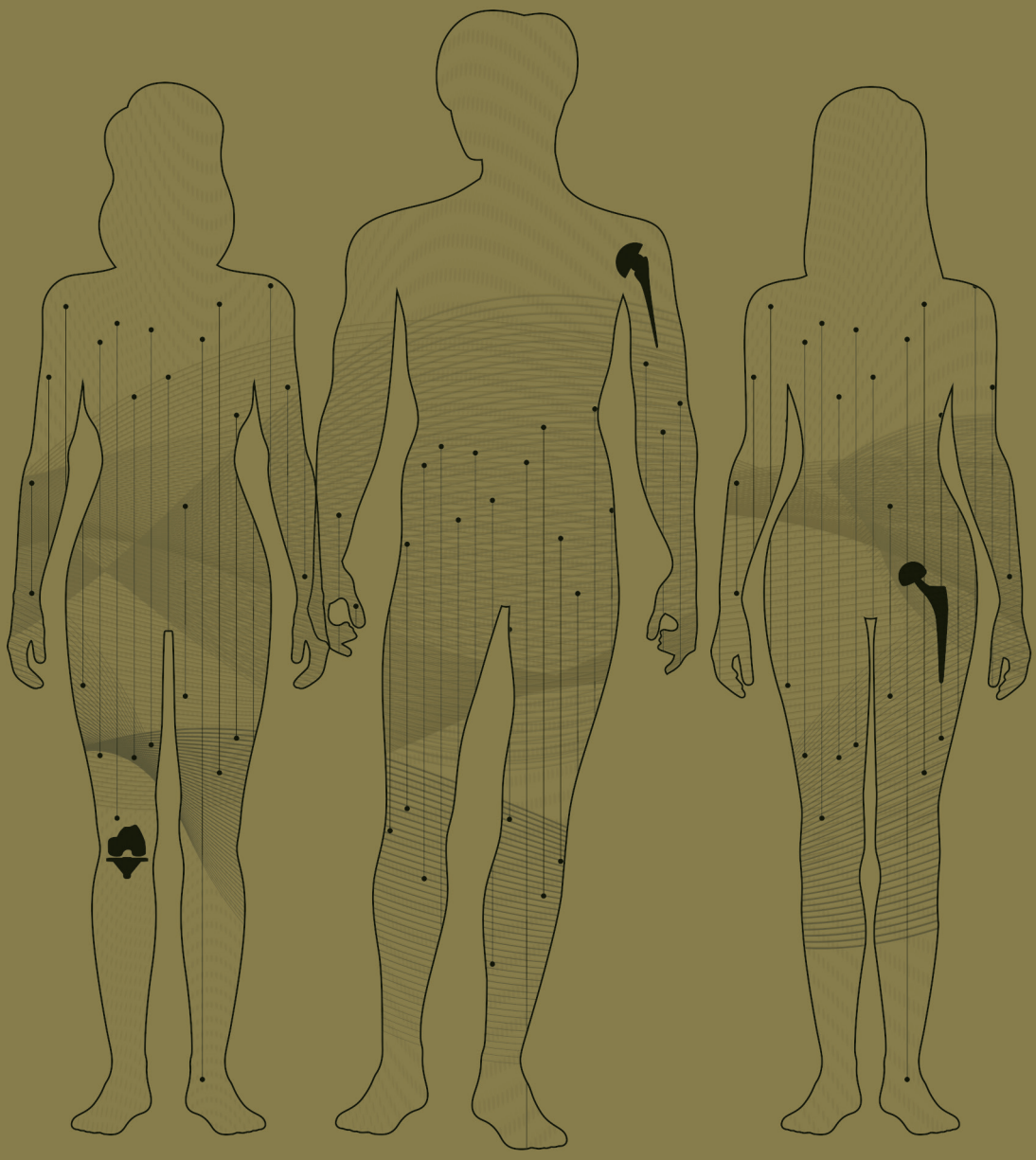
[19] Steinbruck A, Grimberg AW, Elliott J, Melsheimer O, Jansson V. Short versus conventional stem in cementless total hip arthroplasty : An evidence-based approach with registry data of mid-term survival. Orthopade 2021;50(4):296-305. https://doi.org/10.1007/s00132-021-04083-y.

[20] AOANJRR. Hip, Knee & Shoulder Arthroplasty: 2021 Annual Report. Australian Orthopaedic Association National Joint Replacement Registry; 2021. Available from: https://aoanjrr.sahmri.com/annual-reports-2021.

[21] Zijlstra WP, De Hartog B, Van Steenbergen LN, Scheurs BW, Nelissen R. Effect of femoral head size and surgical approach on risk of revision for dislocation after total hip arthroplasty. Acta Orthop 2017;88(4):395-401. https://doi.org/10.1080/17453674.2017.1317515.

[22] Hutchings A, Neuburger J, Grosse Frie K, Black N, van der Meulen J. Factors associated with non-response in routine use of patient reported outcome measures after elective surgery in England. Health Qual Life Outcomes 2012;10:34. https://doi.org/10.1186/1477-7525-10-34.

[23] EPRD. Annual Report 2021. The German Arthoplasty Registry (EPRD); 2021. Available from: https://www.eprd.de/fileadmin/user_upload/Dateien/Publikationen/Berichte/AnnualReport2021-Web_2022-05-19_F.pdf.



3

Short-stem hip arthroplasty in Australia and the Netherlands: a comparison of 12,680 cases between the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the Dutch Arthroplasty Register (LROI)

MHW van Veghel
G Hannink
PL Lewis
C Holder
LN van Steenbergen
BW Schreurs

Acta Orthopaedica 2023; 94: 453–459

Abstract

Background and purpose: We compared the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the Dutch Arthroplasty Register (LROI) regarding patient, prosthesis, and procedure characteristics as well as revision rates for uncemented short-stem total hip arthroplasties (THAs).

Patients and methods: All THAs with an uncemented short-stemmed femoral component performed between 2009 and 2021 were included from the AOANJRR (n = 9,328) and the LROI (n = 3,352). Kaplan–Meier survival analyses and multivariable Schemper's weighted Cox regression analyses with data from 2009–2021 and 2015–2021 were performed with overall revision as endpoint.

Results: In Australia, the proportion of male patients (51% vs. 40%), patients with ASA III–IV score (30% vs. 3.7%), BMI ≥ 30.0 (39% vs. 19%), and femoral heads of 36 mm (58% vs. 20%) were higher than in the Netherlands. Short-stem THAs in Australia and the Netherlands had comparable 10-year revision rates (3.4%, 95% confidence interval [CI] 2.9–4.0 vs. 4.8%, CI 3.7–6.3). Multivariable Cox regression analyses with data from 2009–2021 showed a higher risk for revision of short-stem THAs performed in the Netherlands (HR 1.8, CI 1.1–2.8), whereas the risk for revision was comparable (HR 0.9, CI 0.5–1.7) when adjusted for more potential confounders using data from 2015–2021.

Conclusion: Short-stem THAs in Australia and the Netherlands have similar crude and adjusted revision rates, which are acceptable at 10 years of follow-up.

Introduction

In recent years, short-stem THAs have been increasingly performed in both Australia and the Netherlands, although currently representing less than 2% of all THAs in both countries [1,2]. Short-stemmed femoral components are designed to achieve metaphyseal fixation and to preserve proximal femoral bone stock to facilitate future revisions [3-6]. This may be advantageous in younger patients, who have a relatively high lifetime risk of revision, making bone preservation in these patients beneficial [7].

Due to the relatively small numbers of short-stem THAs in Australia and the Netherlands, it may be useful to compare both sets of data to advise on the efficacy of these devices, particularly in light of their increasing use. Therefore, we aimed to compare the incidence, patient, prosthesis, and procedure characteristics as well as the revision rates of all short-stem THAs registered in the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the Dutch Arthroplasty Register (LROI).

Patients and methods

Data was obtained from the AOANJRR and the LROI. The AOANJRR is the national population-based arthroplasty register of Australia, and contains information on primary and revision arthroplasties performed in Australia. The AOANJRR was initiated in 1999 by the Australian Orthopaedic Association. Full implementation was completed in 2003 with a minimal dataset [8]. In 2012, the AOANJRR was expanded to include the American Society of Anesthesiologists (ASA) score, and in 2015, body mass index (BMI) and surgical approach were added. At present, all Australian hospitals submit their data to the AOANJRR and completeness is reported to be 99% [1].

The LROI is the national population-based arthroplasty register of the Netherlands, established by the Netherlands Orthopaedic Association (NOV) in 2007. In 2012, 100% coverage of Dutch hospitals was achieved with a completeness of more than 95% of primary THAs [9]. Currently, 99% completeness of primary THAs and 98% of revision arthroplasties have been reached [10]. The LROI contains data on patient, prosthesis, and procedure characteristics of primary and revision arthroplasties. In 2014, BMI, smoking, and Charnley score were added to the LROI database.

In this study, we included all primary THAs with an uncemented short-stemmed femoral component registered in the AOANJRR (n = 9,328) and the LROI (n = 3,352) between 2009 and 2021. Short-stem THAs were identified based on the AOANJRR and the LROI definitions, and previous literature [3,5,11]. Both the AOANJRR and the LROI define a short stem as a small cementless femoral stem where fixation is intended to be metaphyseal [1,12]. Short-stem THAs with a metal-on-metal articulation (AOANJRR: n = 0; LROI: n = 1) or with a diagnosis of tumor (AOANJRR: n = 5; LROI: n = 0) were excluded (Figure 1).

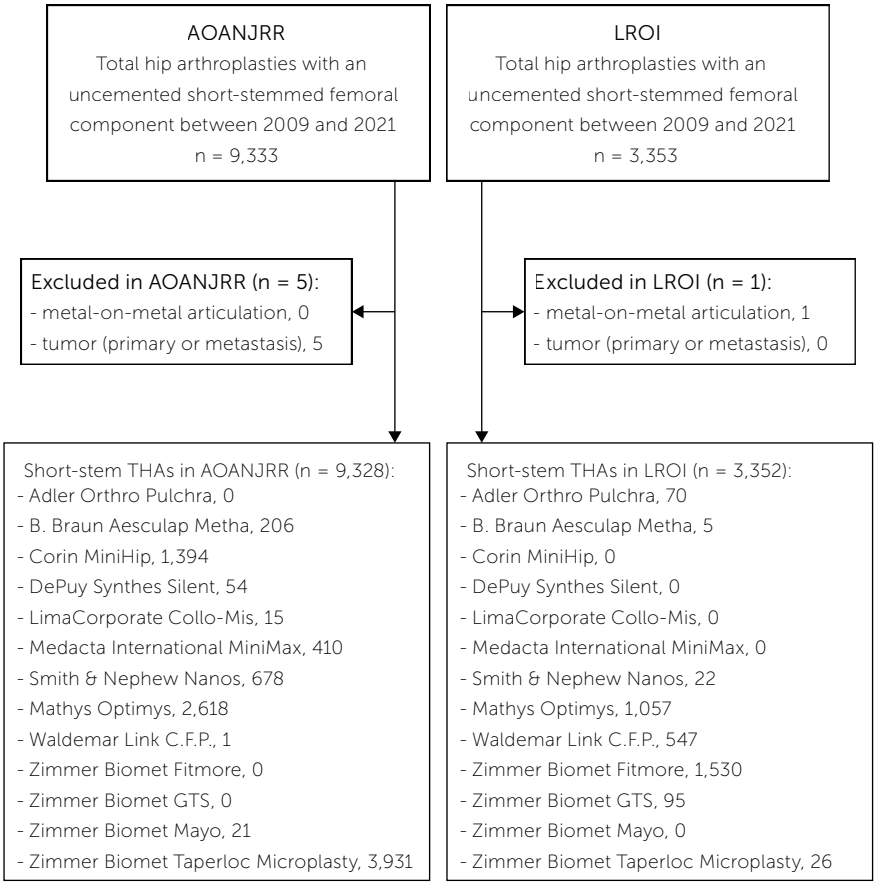


Figure 1. Inclusions and exclusions.

Diagnosis and surgical approach were harmonized between the AOANJRR and the LROI. Diagnosis was classified as osteoarthritis, osteonecrosis, dysplasia, inflammatory arthritis, and other diagnoses after harmonization. In both registries, rheumatoid arthritis and inflammatory arthritis were combined, as numbers were small (< 1.0%). Post-Perthes was merged with dysplasia in the LROI. Other diagnoses included acute and late post-traumatic fractures in the LROI, and failed internal fixations and fractures in the AOANJRR. Surgical approach was divided into anterior, lateral, posterior, and other approaches.

Multiple reasons for revision can be registered in the LROI, whereas the AOANJRR database contains only 1 reason. Therefore, a hierarchal structure was applied to the LROI data: infection, aseptic loosening, peri-prosthetic fracture, dislocation, wear, other, and no reason registered [13]. In the LROI, aseptic acetabular loosening and aseptic femoral loosening were combined into aseptic loosening. In the AOANJRR, lysis was merged with loosening, and implant breakage, incorrect sizing, leg length discrepancy, malposition, and pain were combined in the category other.

Statistics

Descriptive statistics were used to summarize patient, prosthesis, and procedure characteristics as well as short-stem THA incidence per year according to country. Kaplan–Meier survival analyses were performed to determine 1-, 5-, and 10-year revision rates for any component and reason including CIs per country. Survival was defined as the time between primary THA to first revision, death of the patient, or end of follow-up (January 1, 2022). A log-rank test was used to compare the survival distributions between Australia and the Netherlands. Multivariable Cox regression analyses were used to account for differences in confounders between short-stem THAs performed in Australia and the Netherlands. Sex, age, diagnosis (osteoarthritis vs. non-osteoarthritis), BMI, ASA score, and surgical approach were considered confounders. BMI, ASA score, and surgical approach have only been recorded in 1 or both registries since 2012, 2014, or 2015. Therefore, multivariable Cox regression analyses were performed with data from 2009–2021, including sex, age, and diagnosis, and with data from 2015–2021 with additional adjustments for BMI, ASA score, and surgical approach. Schemper's weighted Cox models were used, as the hazards were non-proportional [14]. Kaplan–Meier survival analyses and multivariable Cox regression analyses were performed separately for short-stem THAs with an Optimys (Mathys, Bettlach, Switzerland) stem, as Optimys was the only short stem widely used in both Australia and the Netherlands. Revision according to reason for revision within 1 and 5 years was compared between the 2 countries, using competing risk analyses in which other reasons for revision were considered competing risks. R version 4.2.0 (R Foundation for Statistical Computing,

Vienna, Austria) was used to perform all analyses. This study was reported in accordance with the STROBE guidelines.

Ethics, funding, and disclosures

Data was available from the AOANJRR and the LROI; however, restrictions apply to the availability of this data, which was used under license for the current study. All data was received completely de-identified. Both the AOANJRR and the LROI use the opt-out system to require informed consent from patients. This study is funded by the Dutch Arthroplasty Register. No conflicts of interest were declared. Completed disclosure forms for this article following the ICMJE template are available on the article page, doi: 10.2340/17453674.2023.18491

Results

12,680 short-stem THAs were included, of which 9,328 (74%) were registered in the AOANJRR and 3,352 (26%) in the LROI. Short stems identified in the AOANJRR were C.F.P. (Waldemar Link, Hamburg, Germany), Collo-Mis (LimaCorporate, Udine, Italy), Mayo (Zimmer Biomet, Warsaw, IN, USA), Metha (B. Braun Aesculap, Tuttlingen, Germany), MiniHip (Corin, Cirencester, UK), MiniMax (Medacta International, Castel San Pietro, Switzerland), Nanos (Smith & Nephew, London, UK), Optimys, Silent (DePuy Synthes, Raynham, MA, USA), and Taperloc Microplasty (Zimmer Biomet, Warsaw, IN, USA). From the LROI, C.F.P., Fitmore (Zimmer Biomet, Warsaw, IN, USA), GTS (Zimmer Biomet, Warsaw, IN, USA), Metha, Nanos, Optimys, Pulchra (Adler Orthro, Cormano, Italy), and Taperloc Microplasty were included. Median follow-up was 3.1 years (interquartile range [IQR] 1.3–5.4) for short-stem THAs performed in Australia and 1.8 years (IQR 0.7–4.5) for those performed in the Netherlands. The most frequently used short stem in Australia was Taperloc Microplasty (n = 3,931), followed by Optimys (n = 2,618) and MiniHip (n = 1,394). In the Netherlands, Fitmore (n = 1,530) and Optimys (n = 1,057) were most frequently used (Figure 1).

Patient, procedure, and prosthesis characteristics

The proportion of male patients was 51% in Australia, which was higher than in the Netherlands (40%). In both countries, the mean age was 63 years. Osteoarthritis was the most common diagnosis in both Australia (94%) and the Netherlands (91%). The proportion of patients with an ASA I score was lower in Australia (12% vs. 36%), whereas more patients in Australia had an ASA III–IV score than in the Netherlands (30% vs. 3.7%). Fewer patients in Australia were of normal weight (21% vs. 36%) or were pre-obese (36% vs. 43%), while patients with obese class 1 (24% vs. 17%), class

2 (10% vs. 2.2%), or class 3 (4.7% vs. 0.2%) were more prevalent in Australia than in the Netherlands. In both countries, the anterior approach was most frequently used (Australia: 64%, the Netherlands: 67%) followed by the posterior approach in Australia (30%) and the lateral approach in the Netherlands (21%). The most frequently used femoral head size was 36 mm in Australia (58%), whereas a femoral head of 32 mm was more common in the Netherlands (71%). In Australia, a ceramic-on-polyethylene articulation was used in 53% of the procedures, which was less often than in the Netherlands (86%). A ceramic-on-ceramic articulation was more frequently used in Australia than in the Netherlands (26% vs. 4.3%) (Table 1).

Incidence

The annual incidence rate of short-stem THAs increased almost each year in Australia during the study period, reaching 377 per 10,000 THAs in 2021. In the Netherlands, this ranged between 15 and 77 per 10,000 THAs in the period 2009–2018. The annual incidence rate increased from 128 per 10,000 THAs in 2019 to 389 per 10,000 THAs in 2021 in the Netherlands (Figure 2).

Revision

1-year and 5-year revision rates were comparable in Australia and the Netherlands (Figure 3). The 1-year revision rate was 1.9% (CI 1.6–2.2) for short-stem THAs in Australia and 1.6% (CI 1.2–2.1) for those in the Netherlands. The 5-year revision rate was 2.8% (CI 2.4–3.2) in Australia compared with 3.2% (CI 2.5–4.1) in the Netherlands. The 10-year revision rate was 3.4% (CI 2.9–4.0) in Australia and 4.8% (CI 3.7–6.3) in the Netherlands, which did not differ statistically significantly (P = 0.3). A prosthesis specific analysis using the Optimys stem showed similar revision rates in both Australia and the Netherlands (P = 0.8). At 5-year follow-up, the revision rate was 2.8% (CI 2.0–3.9) in Australia and 2.4% (CI 1.5–3.8) in the Netherlands (Figure 4).

Multivariable Schemper's weighted Cox regression analysis with data from 2009–2021 adjusted for sex, age, and diagnosis revealed a higher risk of revision for short-stem THAs performed in the Netherlands than those performed in Australia (HR 1.8, CI 1.1–2.8). For the period 2015–2021, the risk of revision was similar for both countries (HR 0.9, CI 0.5–1.7), adjusted for age, sex, diagnosis, ASA score, BMI, and surgical approach. No differences were found in the adjusted risks for revision of short-stem THAs with an Optimys stem between Australia and the Netherlands in the period 2009–2021 (HR 0.8, CI 0.4–1.5) and 2015–2021 (HR 0.9, CI 0.5–1.9) (Table 2).

Table 1. Patient, prosthesis, and procedure characteristics of short-stem THAs per country. Values are count (%) unless otherwise specified

Factor	AOANJRR n = 9,328	LROI n = 3,352	Standardized differences
Male sex	4,799 (51)	1,323 (40)	0.24
Missing	0 (0.0)	1 (0.0)	
Mean age (SD)	63 (12)	63 (10)	0.02
Missing	0 (0.0)	1 (0.0)	
Diagnosis			0.16
Osteoarthritis	8,728 (94)	3,059 (91)	
Osteonecrosis	258 (2.8)	75 (2.2)	
Dysplasia	172 (1.8)	133 (4.0)	
Inflammatory arthritis	69 (0.7)	28 (0.8)	
Other	101 (1.1)	45 (1.3)	
Missing	0 (0.0)	12 (0.4)	
ASA score			1.02
ASA I	1,074 (12)	1,198 (36)	
ASA II	4,594 (52)	2,000 (59)	
ASA III-IV	2,661 (30)	125 (3.7)	
Missing	493 (5.9)	29 (0.9)	
Not registered in the AOANJRR [a]	506	-	
Body mass index			0.54
Underweight (< 18.5)	49 (0.6)	11 (0.4)	
Normal (18.5–24.9)	1,624 (21)	1,022 (36)	
Pre-obese (25.0–29.9)	2,728 (36)	1,220 (43)	
Obese class 1 (30.0–34.9)	1,849 (24)	481 (17)	
Obese class 2 (35.0–39.9)	764 (10)	62 (2.2)	
Obese class 3 (≥ 40.0)	359 (4.7)	5 (0.2)	
Missing	238 (3.1)	32 (1.1)	
Not registered in the AOANJRR [b]/LROI [c]	1,717	519	
Surgical approach			0.97
Anterior	4,862 (64)	2,249 (67)	
Lateral	372 (4.9)	690 (21)	
Posterior	2,311 (30)	368 (11)	
Other	0 (0)	38 (1.1)	
Missing	87 (1.1)	7 (0.2)	
Not registered in the AOANJRR [b]	1,696	-	
Acetabulum cemented	9 (0.1)	99 (3.0)	0.24
Missing	0 (0.0)	1 (0.0)	

Table 1. Continued

Factor	AOANJRR n = 9,328	LROI n = 3,352	Standardized differences
Femoral head size			1.38
22–28 mm	1,470 (16)	231 (6.9)	
32 mm	1,615 (17)	2,388 (71)	
36 mm	5,424 (58)	662 (20)	
≥ 38 mm	817 (8.8)	13 (0.4)	
Missing	2 (0.0)	58 (1.7)	
Articulation			0.92
Ceramic-on-ceramic	2,425 (26)	145 (4.3)	
Ceramic-on-metal	2 (0.0)	0 (0.0)	
Ceramic-on-polyethylene	4,977 (53)	2,878 (86)	
Ceramicised metal-on-polyethylene	545 (5.8)	19 (0.6)	
Metal-on-polyethylene	1,377 (15)	193 (5.8)	
Missing	2 (0.0)	117 (3.5)	

AOANJRR: Australian Orthopaedic Association National Joint Replacement Registry; LROI: Dutch Arthroplasty Register.

[a] Registered since 2012 in the AOANJRR.

[b] Registered since 2015 in the AOANJRR.

[c] Registered since 2014 in the LROI.

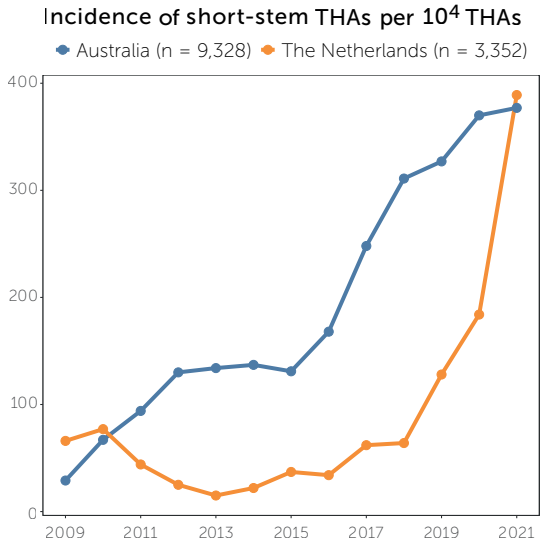


Figure 2. Annual incidence of short-stem THAs per 10,000 THAs by country.

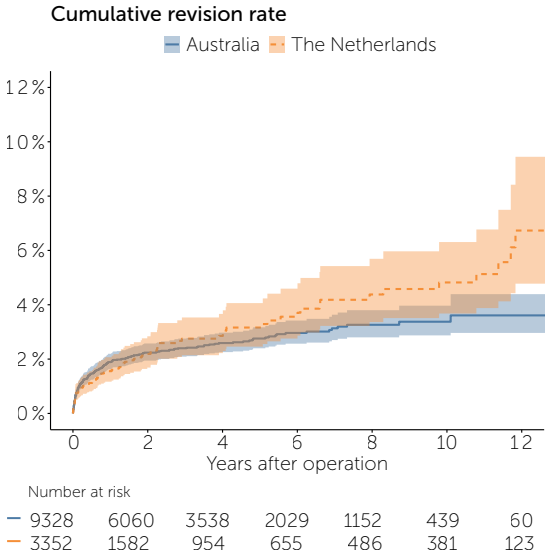


Figure 3. Cumulative revision rates of all short-stem THAs registered in the AOANJRR (n = 9,328) and the LROI (n = 3,352).

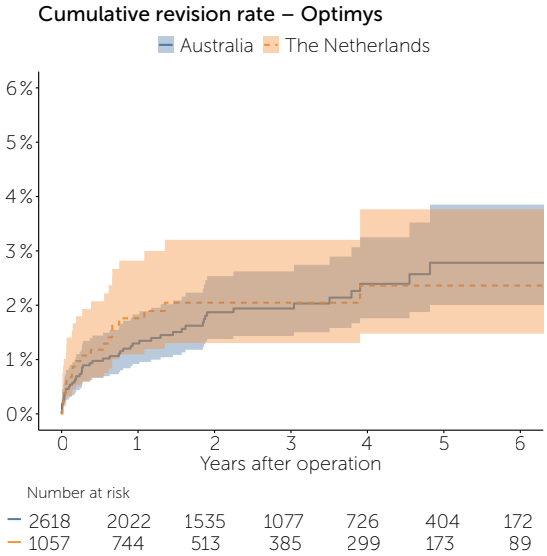


Figure 4. Cumulative revision rates of short-stem THAs with an Optimys stem registered in the AOANJRR (n = 2,618) and the LROI (n = 1,057).

Table 2. Cox regression analyses for risk of revision of all short-stem THAs and short-stem THAs with an Optimys stem per country

	Data from 2009–2021		Data from 2015–2021		
Factor	Crude HR (CI)	Adjusted [a] HR (CI)	Crude HR (CI)	Adjusted [a] HR (CI)	Adjusted [b] HR (CI)
All short stems					
AOANJRR	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)
LROI	1.7 (1.1–2.7)	1.8 (1.1–2.8)	0.8 (0.5–1.3)	0.8 (0.5–1.3)	0.9 (0.5–1.7)
Optimys					
AOANJRR	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)
LROI	0.8 (0.4–1.5)	0.8 (0.4–1.5)	0.7 (0.4–1.4)	0.7 (0.4–1.5)	0.9 (0.5–1.9)

For abbreviations, see Table 1.

[a] Adjusted for sex, age, and diagnosis.

[b] Adjusted for a + BMI, ASA score, and surgical approach.

Reasons for revision

The most common reasons for revision within 1 and 5 years were aseptic loosening and peri-prosthetic fracture in Australia, and infection and aseptic loosening in the Netherlands. Revision within 1 and 5 years due to peri-prosthetic fracture was more prevalent in Australia (1-year: 0.6%, CI 0.5–0.8; 5-year: 0.7%, CI 0.5–0.9) than in the Netherlands (1-year: 0.1%, CI 0.0–0.3; 5-year: 0.1%, CI 0.0–0.3). In Australia, the 5-year revision rate for infection was lower (0.3%, CI 0.2–0.5) compared with the Netherlands (0.8%, CI 0.5–1.2). Revision within 5 years for aseptic loosening was less common in Australia (0.9%, CI 0.7–1.1) than in the Netherlands (1.5%, CI 1.0–2.2) (Table 3).

Table 3. Revision within 1 and 5 years according to reason for revision of short-stem THAs registered per country

	AOANJRR			LROI		
Factor	Events ≤ 5 year	1-year revision rate	5-year revision rate	Events ≤ 5 year	1-year revision rate	5-year revision rate
Infection	26	0.3 (0.2–0.4)	0.3 (0.2–0.5)	19	0.4 (0.2–0.7)	0.8 (0.5–1.2)
Aseptic loosening	67	0.6 (0.5–0.8)	0.9 (0.7–1.1)	30	0.6 (0.3–0.9)	1.5 (1.0–2.2)
Peri-prosthetic fracture	60	0.6 (0.5–0.8)	0.7 (0.5–0.9)	4	0.1 (0.0–0.3)	0.1 (0.0–0.3)
Dislocation/instability	26	0.2 (0.1–0.3)	0.3 (0.2–0.5)	7	0.2 (0.1–0.5)	0.2 (0.1–0.5)
Wear	1	0.0 (0.0–0.0)	0.0 (0.0–0.1)	0	-	-
Other	34	0.2 (0.1–0.3)	0.5 (0.4–0.8)	7	0.1 (0.0–0.3)	0.3 (0.1–0.7)
No reason registered	0	-	-	4	0.1 (0.0–0.2)	0.2 (0.1–0.5)

For abbreviations, see Table 1.

Discussion

Our collaborative registry study shows that patient, prosthesis, and procedure characteristics as well as revision rates of short-stem THAs can be compared between the AOANJRR and the LROI, which increases our understanding of the differences in short stems used and the differences in patient population receiving short stems, but also shows similar revision rates between the two countries, although reasons for revision were different. However, difficulties were encountered when merging data from the two registers, such as differences in variable classifications, the addition of variables to the registers in different years and potential misclassification. These difficulties were largely overcome by harmonizing the diagnosis and surgical approach, by applying a hierarchical structure to the reason for revision and by limiting the time interval for the multivariable Cox regression analyses. Short-stem THA patients in Australia were more often male, had a higher ASA score and BMI, were more likely to receive a 36 mm femoral head, and received a ceramic-on-polyethylene articulation less often than short-stem THA patients in the Netherlands.

The differences in sex and BMI between Australian and Dutch short-stem THA patients in this study appear more to reflect the differences in THA patients between the two countries than differences in short-stem THA patients. In Australia, 45% of all THA patients are male, compared with 35% in the Netherlands [1,10]. However, the number of short-stem THA male patients was slightly higher in both countries compared with all THAs performed in Australia and the Netherlands. Australian THA patients are more likely to be obese than Dutch THA patients [1,10]. For both Australia and the Netherlands, the BMI of short-stem THA patients was comparable to that of all THA patients.

In our study, there is a discrepancy in ASA score between Australia and the Netherlands. Comparing ASA score between countries can be complicated as there may be differences in the application of the scoring system. An explanation can be that orthopedic surgeons or anesthesiologists may experience advantages or disadvantages of over- or underestimating the ASA score, leading to between-country variations in ASA score [15]. Furthermore, the higher BMI of Australian short-stem THA patients may explain the higher ASA scores in Australia, as ASA and BMI are linked.

Revision within 1 and 5 years according to reason for revision differed slightly between short-stem THAs performed in Australia and in the Netherlands in this study. In Australia, peri-prosthetic fractures were a more common reason for

revision within 1 and 5 years. Revisions within 5 years due to infection and aseptic loosening were registered more often in the Netherlands. This may be partly explained by the majority of the short-stem THAs being placed using the anterior approach. In Australia, the anterior approach is associated with a higher rate of revision for early fracture, but a lower rate for infection in THAs for osteoarthritis [1]. Another reason may be that the higher BMI in Australia is associated with a higher fracture risk. However, using revisions to monitor specific outcomes after THA may underestimate the true incidence of that specific outcome. Multiple registry studies have found an underreporting of up to 53% of peri-prosthetic joint infections (PJIs), as most national arthroplasty registers record revisions when at least 1 of the components has been replaced, removed, or added [16,17]. PJIs treated with reoperation without component exchange or treated nonoperatively are therefore not included in those registers. The same applies to peri-prosthetic fractures, as reoperations for internal fixation without component exchange are not included either. The number of complications after primary short-stem THAs treated with reoperation without component exchange or treated nonoperatively may differ between Australia and the Netherlands.

Short-stem THAs performed in Australia and the Netherlands had comparable revision rates in our study. However, after 10 years of follow-up, the revision rates of short-stem THAs in Australia seem to be slightly better than those in the Netherlands. The 10-year revision rate of short-stem THAs in Australia is also lower than that of all uncemented THAs performed in Australia. At 10-year follow-up, the revision rate of all Australian uncemented THAs for primary osteoarthritis is 4.4% (CI 4.3–4.5) [1]. In the Netherlands, the performance of short-stem THAs is comparable to that of conventional-stem THAs, as the 10-year revision rate of conventional-stem THAs is 4.5% (CI 4.4–4.6) [2].

In contrast, short-stem THAs in Australia had a lower risk of revision than those in the Netherlands between 2009 and 2021. This can be explained by the types of short stems used in the Netherlands. In the Netherlands, the short stems used in the early years of the study performed less optimally, whereas today's predominant short stems, including Fitmore and Optimys, have a similar risk of revision to conventional stems [2]. This is reflected by the comparable risks for revision of all short-stem THAs performed between 2015 and 2021 in Australia and the Netherlands.

The mid-term revision rates of short-stem THAs performed in Australia and the Netherlands are in line with those performed in Germany. The German Arthroplasty Register examined overall revision rates of 17,526 short-stem THAs and found a

5-year revision rate of 2.9% (CI 2.4–3.5). Stratified analyses by short stem type showed a revision rate of 1.8% (CI 1.5–2.2) for Optimys at 5-year follow-up [18].

Limitations

The adjusted revision rates may be biased due to harmonization and possible misclassification of, for example, the ASA score. Consequently, the differences in revision rates between Australia and the Netherlands may be over- or underestimated [19]. Moreover, the use of registry data, which is collected as part of the usual care process to increase quality of care, is limited by the number of variables collected. Therefore, there is residual confounding in this study, as the multivariable Cox regression analyses were limited to sex, age, diagnosis, BMI, ASA score, and surgical approach. Potential confounders, such as physical activity, type of hospital, or hospital volume, could not be included in the analyses. Although perceived quality of life, pain, and physical functioning are as important as revision rates to measure the success of a THA, this study did not include data on patient-reported outcome measures (PROMs), as PROM data collection started in 2018 in the AOANJRR and in 2014 in the LROI [10,20,21]. Finally, the follow-up of the study was relatively short, especially in the Netherlands where the median follow-up was 1.8 years.

Conclusion

Despite differences in short stems used and patient population, short-stem THAs in Australia and the Netherlands appear to have comparable crude and adjusted revision rates, which are acceptable at 10 years of follow-up. Although it is feasible to compare short-stem THAs between the AOANJRR and the LROI, difficulties in merging data from the two registries should be considered, which can be largely overcome by harmonization of terminology.

References

[1] AOANJRR. Hip, Knee & Shoulder Arthroplasty: 2022 Annual report. Australian Orthopaedic Association National Joint Replacement Registry; 2022. Available from: https://aoanjrr.sahmri.com/annual-reports-2022.

[2] Van Veghel MHW, Hannink G, Van Oldenrijk J, Van Steenbergen LN, Schreurs BW. A comparison of uncemented short versus standard stem length in total hip arthroplasty: results from the Dutch Arthroplasty Register. Acta Orthop 2023;94:330-5. https://doi.org/10.2340/17453674.2023.13652.

[3] Falez F, Casella F, Papalia M. Current concepts, classification, and results in short stem hip arthroplasty. Orthopedics 2015;38(3 Suppl):S6-13. https://doi.org/10.3928/01477447-20150215-50.

[4] Patel RM, Stulberg SD. The rationale for short uncemented stems in total hip arthroplasty. Orthop Clin North Am 2014;45(1):19-31. https://doi.org/10.1016/j.ocl.2013.08.007.

[5] van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. Acta Orthop 2014;85(3):250-8. https://doi.org/10.3109/17453674.2014.908343.

[6] Khanuja HS, Banerjee S, Jain D, Pivec R, Mont MA. Short bone-conserving stems in cementless hip arthroplasty. J Bone Joint Surg Am 2014;96(20):1742-52. https://doi.org/10.2106/JBJS.M.00780.

[7] Bayliss LE, Culliford D, Monk AP, Glyn-Jones S, Prieto-Alhambra D, Judge A, Cooper C, Carr AJ, Arden NK, Beard DJ, Price AJ. The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study. Lancet 2017;389(10077):1424-30. https://doi.org/10.1016/S0140-6736(17)30059-4.

[8] de Steiger RN, Graves SE. Orthopaedic registries: the Australian experience. EFORT Open Rev 2019;4(6):409-15. https://doi.org/10.1302/2058-5241.4.180071.

[9] van Steenbergen LN, Denissen GA, Spooren A, van Rooden SM, van Oosterhout FJ, Morrenhof JW, Nelissen RG. More than 95% completeness of reported procedures in the population-based Dutch Arthroplasty Register. Acta Orthop 2015;86(4):498-505. https://doi.org/10.3109/17453674.2015.1028307.

[10] LROI. Annual report 2022. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/3j2o5wjg/pdf-lroi-annual-report-2022.pdf.

[11] Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J 2019;101-B(5):502-11. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018-1199.R1.

[12] LROI. LROI Implant Library - Hip. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/byym2eyc/625522c726f17lroi-implant-library-hip.pdf.

[13] van Steenbergen LN, Makela KT, Karrholm J, Rolfson O, Overgaard S, Furnes O, Pedersen AB, Eskelinen A, Hallan G, Schreurs BW, Nelissen R. Total hip arthroplasties in the Dutch Arthroplasty Register (LROI) and the Nordic Arthroplasty Register Association (NARA): comparison of patient and procedure characteristics in 475,685 cases. Acta Orthop 2021;92(1):15-22. https://doi.org/10.1080/17453674.2020.1843875.

[14] Schemper M, Wakounig S, Heinze G. The estimation of average hazard ratios by weighted Cox regression. Stat Med 2009;28(19):2473-89. https://doi.org/10.1002/sim.3623.

[15] Silman AJ, Combescure C, Ferguson RJ, Graves SE, Paxton EW, Frampton C, Furnes O, Fenstad AM, Hooper G, Garland A, Spekenbrink-Spooren A, Wilkinson JM, Makela K, Lubbeke A, Rolfson O. International variation in distribution of ASA class in patients undergoing total hip arthroplasty and its influence on mortality: data from an international consortium of arthroplasty registries. Acta Orthop 2021;92(3):304-10. https://doi.org/10.1080/17453674.2021.1892267.

[16] Kamp MC, Liu WY, Goosen JHM, Rijnen WHC, van Steenbergen LN, van der Weegen W, Regional Prosthetic Joint Infection Working G. Mismatch in Capture of Periprosthetic Joint Infections Between the Dutch Arthroplasty Register (LROI) and a Detailed Regional Periprosthetic Joint Infection Registry. J Arthroplasty 2022;37(1):126-31. https://doi.org/10.1016/j.arth.2021.09.001.

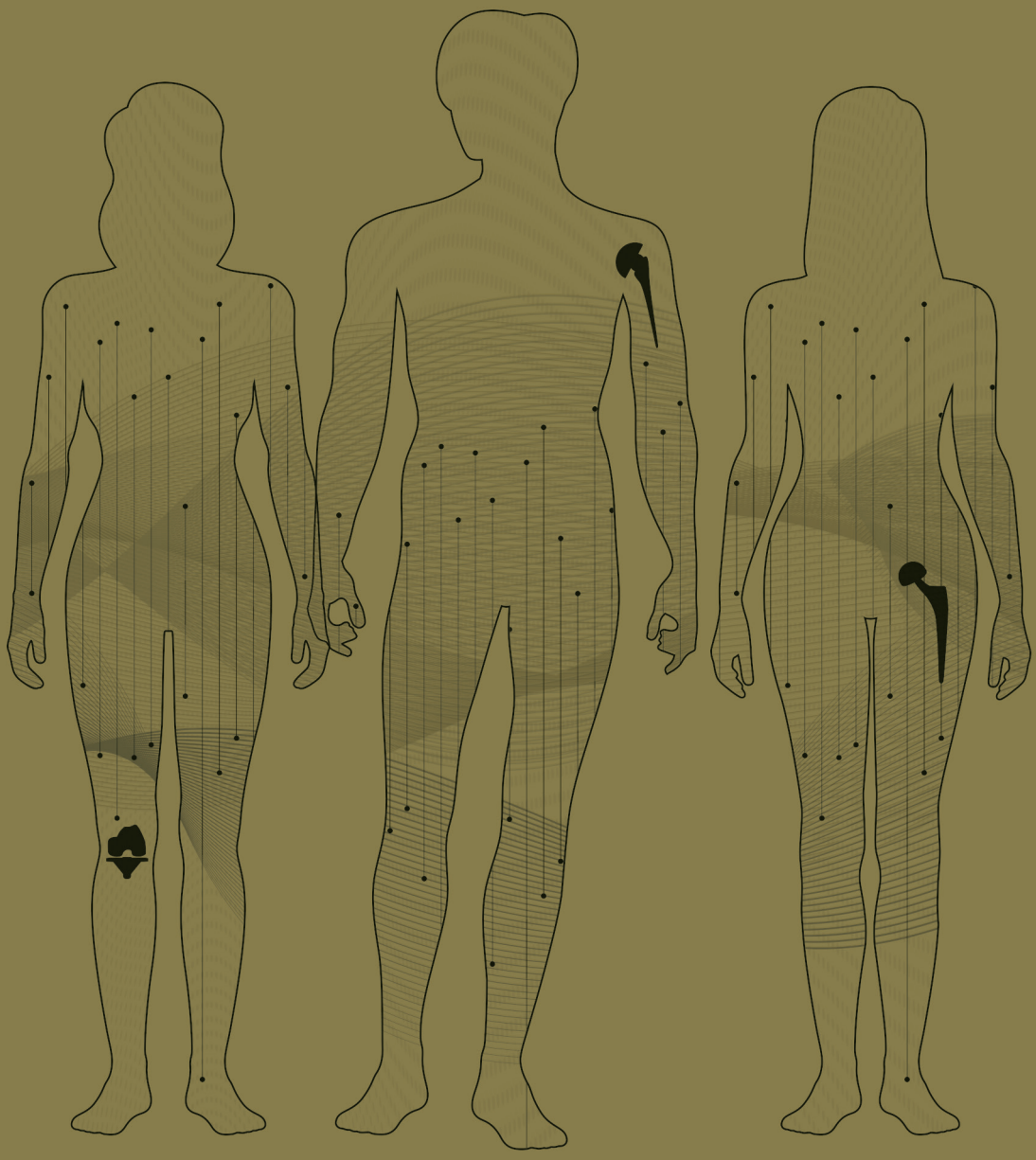
[17] Sinagra ZP, Davis JS, Lorimer M, de Steiger RN, Graves SE, Yates P, Manning L. The accuracy of reporting of periprosthetic joint infection to the Australian Orthopaedic Association National Joint Replacement Registry. Bone Jt Open 2022;3(5):367-73. https://doi.org/10.1302/2633-1462.35.BJO-2022-0011.R1.

[18] Steinbruck A, Grimberg AW, Elliott J, Melsheimer O, Jansson V. Short versus conventional stem in cementless total hip arthroplasty : An evidence-based approach with registry data of mid-term survival. Orthopade 2021;50(4):296-305. https://doi.org/10.1007/s00132-021-04083-y.

[19] van Smeden M, Lash TL, Groenwold RHH. Reflection on modern methods: five myths about measurement error in epidemiological research. Int J Epidemiol 2020;49(1):338-47. https://doi.org/10.1093/ije/dyz251.

[20] AOANJRR. AOA PROMs Pilot Project: Final Report. Australian Orthopaedic Association National Joint Replacement Registry; 2020. Available from: https://aoanjrr.sahmri.com/documents/10180/681914/AOANJRR+PROMs+Pilot+Final+Report.

[21] Labek G, Janda W, Agreiter M, Schuh R, Bohler N. Organisation, data evaluation, interpretation and effect of arthroplasty register data on the outcome in terms of revision rate in total hip arthroplasty. Int Orthop 2011;35(2):157-63. https://doi.org/10.1007/s00264-010-1131-4.



4

Do cumulative revision rate and first-time re-revision rate vary between short and standard femoral stem lengths? A multinational registry study

K Rilby
MHW van Veghel
M Mohaddes
LN van Steenbergen
PL Lewis
J Kärrholm
BW Schreurs
G Hannink

The first two authors contributed equally to this manuscript.

Clinical Orthopaedics and Related Research 2025; 483(6): 1010–1019

Abstract

Background: Advocates of short-stem THA suggest that these devices preserve proximal femoral bone for future revisions. This contention is as yet unsupported by robust evidence, and ultimately, it will be irrelevant if short-stem THA increases the overall risk of premature revision. To our knowledge, large, registry-based efforts have yet to explore the types of stems used in first-time stem revision as well as the survivorship of short versus standard-length femoral stems in THA.

Questions/purposes: (1) Which stems are used in the first stem revision of primary short-stem and standard-stem THAs? (2) What is the overall cumulative revision rate (CRR) of primary short-stem THAs compared with primary standard-stem THAs? (3) What is the overall cumulative re-revision rate of primary short-stem THAs compared with primary standard-stem THAs?

Methods: Patients with short-stem THAs, defined as a short stem with mainly metaphyseal fixation, registered in the Australian Orthopaedic Association National Joint Replacement Register (AOANJRR), the Dutch Arthroplasty Register (Landelijke Registratie Orthopedische Interventies [LROI]), or the Swedish Arthroplasty Register (SAR) between January 2007 and December 2022 were included (n = 15,771), as well as a propensity score–matched cohort (1:2) with standard-stem THAs, defined as a stem with a standard length (n = 31,542). Groups were matched on sex, age, year of procedure, diagnosis, bearing material, and surgical approach. After matching, the groups did not differ in terms of age (mean ± SD 63 ± 11 versus 64 ± 11 years), sex (48% [7546 of 15,771] male versus 48% [15,093 of 31,542] male), and diagnosis (93% [14,655 of 15,771] osteoarthritis [OA] versus 94% [29,585 of 31,542] OA). We used those three registries because all are high-quality national arthroplasty registries with high levels of completeness. Also, the AOANJRR is the only registry globally that reports on short-stem THA as its own entity. The type of stem used in revision surgery was classified as standard stem (< 160 mm) or long stem (≥ 160 mm). Overall CRR of primary THAs at 12 years of follow-up and overall CRR of all first-time revisions at 5 years were calculated using Kaplan-Meier survival analyses. Any type of revision was used as endpoint.

Results: In first-time stem revisions of the short-stem THAs, a standard stem was used more often (58% [116 of 201]) than in the revision of standard-stem THAs (46% [149 of 322]; p = 0.01). The 12-year overall CRRs between primary short-stem and standard-stem THAs did not differ (4.7% [95% confidence interval (CI) 4.0% to 5.5%] versus 5.1% [95% CI 4.5% to 5.7%], respectively; p = 0.20). The overall CRR for a second revision at 5 years also did not differ when primary short-stem THAs were

compared with standard-stem THAs (20.9% [95% CI 16.8% to 25.8%]) versus 20.4% [95% CI 17.3% to 23.9%]; p = 0.80).

Conclusion: In light of these findings, there may be a perceived benefit of using short stems in primary THA if a revision is later required, as the short stems included in this study were to a higher degree revised using a standard (more bone-sparing) stem. Further, the first and second overall CRR of the studied short-stem THAs did not differ from that of standard-stem THAs, also supporting use of short-stem THA. Further research, preferably multinational registry-based studies, should be performed to confirm our findings.

Introduction

Short cementless femoral components (a small cementless stem that is designed to be entirely metaphyseal) for THA have been available since the late 1980s. Although these designs make up only a small proportion of all THAs, their use is steadily increasing [1]. National registers report use of short-stem THAs that ranges from 3.7% of all THAs in Australia to 10% in Germany [2,3]. A meta-analysis and systematic reviews have shown that short-stem THAs have midterm cumulative revision rates (CRRs) comparable to those of standard-stem THAs [4-7]. Multiple studies from several different arthroplasty registries also confirm these results [3,8,9].

The theoretical benefit of the short-stem THA design is to preserve proximal femoral bone, which may be valuable if a revision is required [6,7]. Consequently, some may argue that a standard-length stem could be considered for revision of short-stem THAs, whereas longer revision stems more frequently are considered at revision of standard-stem THAs. To the best of our knowledge, large registry-based studies have yet to explore the types of stems used during the first stem revision, which could serve as a proxy for bone-saving properties. However, the types of stems used during the first stem revision will ultimately be irrelevant if short-stem THAs increase the risk of overall revision and re-revision.

We therefore pooled data from three large, national registries to increase our sample size and asked: (1) Which stems are used in the first stem revision of primary short-stem and standard-stem THAs? (2) What is the overall CRR of primary short-stem THAs compared with primary standard-stem THAs? (3) What is the overall cumulative re-revision rate of primary short-stem THAs compared with primary standard-stem THAs?

Patients and Methods

Study Design and Setting

This population-based registry study used data from three national arthroplasty registries: the Australian Orthopaedic Association National Joint Replacement Register (AOANJRR), the Dutch Arthroplasty Register (Landelijke Registratie Orthopedische Interventies [LROI]), and the Swedish Arthroplasty Register (SAR). These three registries are all high-quality national arthroplasty registries with high levels of completeness. The AOANJRR is also the only registry globally that reports on short-stem THA as its own entity.

The AOANJRR

The AOANJRR is a publicly funded, population-based arthroplasty register established in 1999 and run by the Australian Orthopaedic Association. In 2021, the completeness for primary THAs reached approximately 99%. It is validated through a multistep process in which the reported data are compared with the state and territory health department data. Both private- and government-funded hospitals report to the register. Patient and implant characteristics are recorded. Through December 31, 2022, a total of 642,704 primary THAs had been reported to the register. In the AOANJRR data set, the endpoint is overall revision, defined as a new surgical intervention in which any part of the implant is removed or exchanged. Therefore, for the Australian data, only overall revision rates could be calculated using any type of revision as the endpoint rather than specifically calculating revision and re-revision rates for stem revisions alone. However, other arthroplasty registry studies also use overall revision rates as the endpoint in the comparison of short-stem and standard-stem THAs [3,8].

The LROI

The LROI includes data on arthroplasties since 2007. It is a population-based register established by the Netherlands Orthopaedic Association. The completeness for primary THA is approximately 99%; for revision, the corresponding figure is 97%. The register is validated in multiple steps comparing the reported data with the data in the hospital information system. Data on patients and implant characteristics are collected. Implant characteristics are derived from an implant library with information provided from the manufacturers. A total of 550,227 primary THAs have been reported to this register between 2007 and 2022.

The SAR

Since 2021, the SAR has been the result of a merger of the former Swedish Hip Arthroplasty Register (SHAR) and the Swedish Knee Arthroplasty Register. The SHAR was founded in 1979, making it one of the oldest hip arthroplasty registries globally. The completeness of primary and revision procedures in the register is about 99% and 92% to 94%, respectively. The data are validated through a multistep process in which the reported data are compared with data in the patient register administered by the Swedish National Board of Health and Welfare. The register contains data on patients and implant characteristics. Information on implants is derived from information given by the manufacturers. Between 1979 and 2022, a total of 541,078 primary THAs have been reported to the register.

Participants

Data on primary short-stem THAs inserted between January 2007 and December 2022 were extracted from the registries, as data on short-stem THAs from all three registries were available within that period. In the AOANJRR, a short stem is defined as a short cementless femoral stem in which fixation is designed to be entirely metaphyseal, which is comparable to the LROI definition, which describes a short stem as a small cementless femoral stem with special design features, in which fixation is entirely metaphyseal [2,10]. These definitions were also used to identify short stems in the SAR. In this study population, we did not include THAs with metal-on-metal articulations, THAs performed because of tumor diagnosis, or rarely utilized short-stem THA designs that were used in < 1% of all short-stem THAs. We identified 15,771 primary short-stem THAs with seven different short-stem THA designs.

We selected a propensity score–matched (1:2) cohort of patients who had undergone primary standard-stem THAs from the three most commonly used uncemented standard stems in each country (Figure 1). We performed propensity score matching using the nearest neighbor method within each registry to account for differences between the short-stem and standard-stem THA groups. Groups were matched 1:2 on sex, age, year of procedure, diagnosis, bearing material, and surgical approach. In the AOANJRR, information on surgical approach was first recorded in 2015, hence the AOANJRR data were not matched for that variable.

After matching, all standardized mean differences (SMDs) were < 0.10 in the AOANJRR and the LROI data, indicating a well-balanced matching process [11]. In the SAR data, an SMD of > 0.10 was observed for age (SMD 0.12), diagnosis other than osteoarthritis (OA) (SMD 0.11), ceramic cups (SMD 0.31), direct lateral approach in supine position (SMD 0.24), and other approach (SMD 0.11). The remaining variables in the SAR had an SMD of < 0.10.

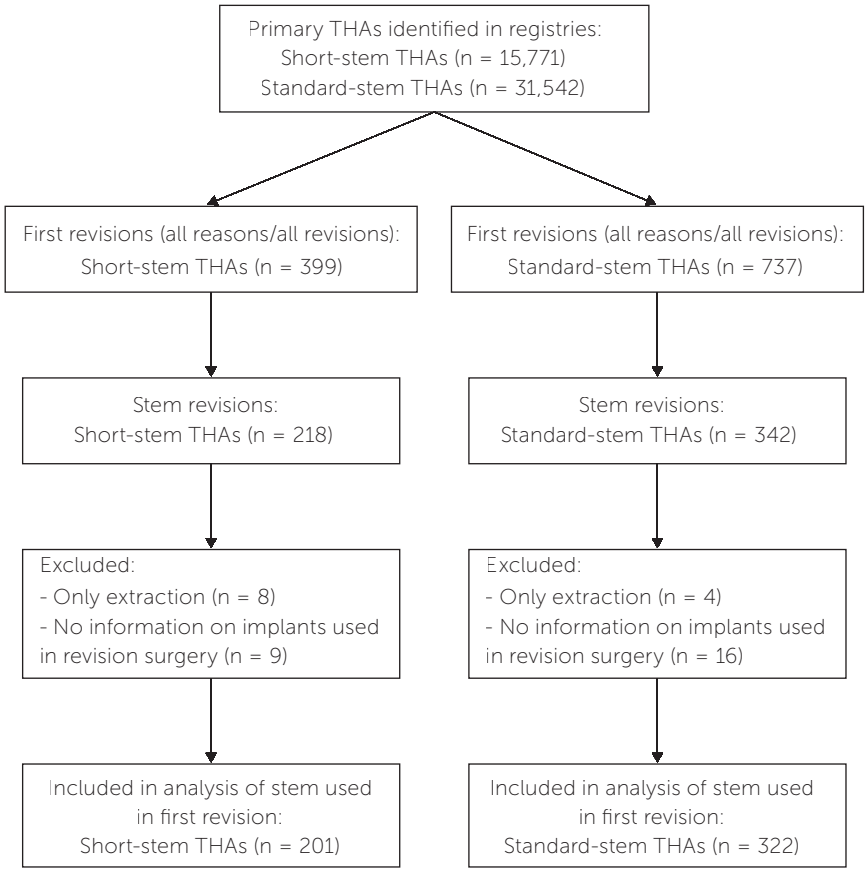


Figure 1. The flow chart of our study.

Descriptive Data

The matched cohort included 31,542 patients who had undergone primary standard-stem THAs with seven different standard-stem THA designs, all of which had similar fixation modes. In the AOANJRR, the MiniHip (Corin Group), Optimys (Mathys), and Taperloc Microplasty (Zimmer Biomet) constituted almost 90% (9416 of 10,515) of the short-stem THAs. In the LROI, CFP (Waldemar Link), Fitmore (Zimmer Biomet), and Optimys were the three most commonly used short-stem THAs, contributing to 99% (4453 of 4502) of the hips. And in the SAR, the CFP and Fitmore stems comprised almost 93% (701 of 754) of short-stem THAs (Table 1).

Table 1. Implants used per register

	AOANJRR[a]	LROI[b]	SAR[c]	Total[d]
Short stems				
CFP (Waldemar Link)	< 1 (3)	13 (592)	51 (381)	6 (976)
Fitmore (Zimmer Biomet)		55 (2480)	42 (320)	18 (2800)
MiniHip (Corin Group)	14 (1457)			9 (1457)
MiniMax (Medacta International)	4 (415)			3 (415)
Nanos (Smith+Nephew)	7 (681)	< 1 (23)		5 (704)
Optimys (Mathys)	30 (3168)	31 (1381)		29 (4549)
Taperloc Microplasty (Zimmer Biomet)	46 (4791)	< 1 (26)	7 (53)	31 (4870)
Standard stems				
Corail (DePuy Synthes)	55 (11,570)	35 (3105)	46 (686)	49 (15,361)
Polarstem (Smith+Nephew)	25 (5185)			16 (5185)
Quadra-H (Medacta)	20 (4275)			14 (4275)
Alloclassic Zweymuller (Zimmer Biomet)		14 (1212)		4 (1212)
Taperloc Complete (Zimmer Biomet)		52 (4687)		15 (4687)
CLS (Zimmer Biomet)			37 (553)	2 (553)
Bi-Metric (Zimmer Biomet)			18 (269)	1 (269)

Data presented as % (n). A cell without data indicates that a specific stem was not used in that country.
[a]Short stems n = 10,515. Standard stems n = 21,030.
[b]Short stems n = 4502. Standard stems n = 9004.
[c]Short stems n = 754. Standard stems n = 1508.
[d]Short stems n = 15,771. Standard stems n = 31,542.

After matching, the groups did not differ in terms of age (mean ± SD 63 ± 11 versus 64 ± 11 years), sex (48% [7546 of 15,771] male versus 48% [15,093 of 31,542] male), BMI (28 ± 5.5 versus 29 ± 5.6 kg/m^2), American Society of Anesthesiologists (ASA) class (54% [8460 of 15,771] ASA II versus 53% [16,837 of 31,542] ASA II), and diagnosis (93% [14,655 of 15,771] OA versus 94% [29,585 of 31,542] OA) (Table 2). There are some differences in patient and procedure characteristics between the registries. In Sweden, patients tended to be younger. In Australia and Sweden, there were slightly larger proportions of male patients, whereas in the Netherlands, female patients more frequently received short-stem THAs. Diagnoses other than OA were more frequent in Sweden. In Sweden, the direct anterior approach was not used, whereas this approach was the most common or second most common in the Netherlands and Australia. In Australia, patients were more frequently classified with ASA classes

Table 2. Baseline demographic characteristics after matching

	AOANJRR		LROI	
	Short stem	Standard stem	Short stem	Standard stem
Number of primary THAs	10,515	21,030	4502	9004
Age in years	63 ± 12	64 ± 11	63 ± 10	64 ± 10
Sex				
Male	51 (5363)	51 (10,786)	40 (1787)	39 (3522)
Female	49 (5152)	49 (10,244)	60 (2715)	61 (5482)
BMI in kg/m^2[a]	29 ± 5.9	30 ± 5.9	26 ± 3.9	27 ± 4.4
ASA[b]				
ASA I	11 (1194)	10 (2029)	34 (1527)	24 (2182)
ASA II	51 (5358)	51 (10,756)	61 (2766)	60 (5403)
ASA III[c]	29 (3022)	31 (6465)	4 (170)	15 (1380)
ASA IV	2 (161)	1 (211)		
Missing	7 (780)	8 (1569)	1 (39)	< 1 (39)
Diagnosis				
OA	94 (9833)	94 (19,819)	93 (4169)	94 (8415)
Non-OA	6 (682)	6 (1211)	7 (333)	6 (589)
Surgical approach[d]				
Direct anterior	54 (5648)	38 (7904)	74 (3341)	76 (6833)
Direct lateral, lateral	4 (438)	9 (1829)	2 (90)	2 (207)
Posterior, lateral	28 (2918)	39 (8250)	9 (402)	8 (723)
Other			15 (669)	14 (1241)
Missing	14 (1511)	14 (3047)		

Data presented as mean ± SD or % (n).
[a]Since 2014 in LROI and since 2015 in AOANJRR.
[b]Since 2012 in the AOANJRR.
[c]ASA III and ASA IV are merged in the LROI.
[d]Since 2015 in AOANJRR.

III or IV and also tended to have a higher BMI. Because matching was performed separately within each registry, these differences applied to both short-stem and standard-stem THAs in the countries. Therefore, we believed that these differences across countries would not affect our results. Baseline demographic characteristics for the entire group of patients with revisions did not differ in terms of age (mean ± SD 63 ± 12 versus 63 ± 12 years), sex (49% [196 of 399] male versus 50% [368 of 737] male), and BMI (29 ± 6.1 versus 30 ± 6.4 kg/m^2).

	SAR		Total	
	Short stem	Standard stem	Short stem	Standard stem
Number of primary THAs	754	1508	15,771	31,542
Age in years	56 ± 10	57 ± 9.0	63 ± 11	64 ± 11
Sex				
Male	53 (396)	52 (785)	48 (7546)	48 (15,093)
Female	47 (358)	48 (723)	52 (8225)	52 (16,449)
BMI in kg/m^2[a]	27 ± 4.3	28 ± 4.4	28 ± 5.5	29 ± 5.6
ASA[b]				
ASA I	45 (341)	39 (586)	19 (3062)	15 (4797)
ASA II	45 (336)	45 (678)	54 (8460)	53 (16,837)
ASA III[c]	6 (44)	7 (112)	21 (3236)	6 (7957)
ASA IV		< 1 (4)	1 (161)	6 (215)
Missing	4 (33)	9 (128)	5 (852)	6 (1736)
Diagnosis				
OA	87 (653)	90 (1351)	93 (14,655)	94 (29,585)
Non-OA	13 (101)	10 (157)	7 (1116)	6 (1957)
Surgical approach[d]				
Direct anterior			57 (8989)	47 (14,737)
Direct lateral, lateral	62 (463)	57 (860)	6 (991)	9 (2896)
Posterior, lateral	36 (273)	36 (545)	23 (3593)	30 (9518)
Other	2 (18)	7 (103)	4 (687)	4 (1344)
Missing			10 (1511)	10 (3047)

Variables and Outcome Measures

Revision was defined as a new surgical intervention in which any part of the implant is removed or exchanged. This definition is also used in other arthroplasty registry studies comparing short-stem and standard-stem THAs [3,8]. A total of 399 first revisions were identified among short-stem THAs, of which 218 were revisions of the femoral component (Figure 1). For the standard-stem THAs, there were 737 first revisions, with 342 revisions of the femoral component. In 92% (201 of 218) of short-stem THA revisions, we could identify the femoral stem inserted at the

revision procedure. In the standard-stem THA group, we could identify 94% (322 of 342). Furthermore, we identified all re-revisions or second revisions (all revisions, all reasons) (primary short-stem THA n = 78, primary standard-stem THA n = 137). In research question 1, femoral stem revisions (regardless of reasons) were analyzed. In research questions 2 and 3, all revisions, regardless of the component being revised or reasons, were included because of the registration process in the AOANJRR.

Definition of Stems Used for Revision Surgery

The implants used for the revision surgery were classified as standard stems (< 160 mm) or as long stems (≥ 160 mm). In modular stems, we could identify the proximal part, whereas information on the length of the distal part was lacking. Because these stems are mainly used in cases of revision with need for distal fixation, they were all classified as long stems.

Reasons for Revision

In all three registries, multiple reasons for revision can be recorded. Therefore, in all registries, a hierarchical structure is used to harmonize the reason for revision between the registries, which was periprosthetic infection, aseptic loosening, periprosthetic fracture, dislocation, other reasons, and "missing." Thus, for example, THA revised because of loosening and dislocation was classified as revised due to loosening. In the "other" group, reasons such as leg length discrepancies, implant failure or breakage, and pain with no other reason were included.

Ethical Approval

We obtained ethical approval for this study from the National Ethical Board of Sweden to share anonymous data from the SAR (Nr: 2022-06130-02). For the LROI and the AOANJRR, no ethical approval was required, as both registers use the opt-out system to obtain informed consent from patients. All data included in the study were de-identified.

Statistical Analysis

We used descriptive statistics to summarize patient, implant, and procedure characteristics. To evaluate the choice of revision stem (< 160 mm or ≥ 160 mm), we used the chi-square test. In addition, we performed stratified analyses of choice of standard or long stems based on age and sex. We studied two age groups: 63 years or younger and older than 63 years (median age in the study population).

To calculate the all-cause CRRs of primary THAs, we used Kaplan-Meier survival analyses; we performed similar analyses for first-time overall revisions. Kaplan-Meier survival analyses were performed as we were interested in the net failure (that is, failure of an implant) of the short-stem and standard-stem THAs rather than the crude failure (that is, accounting for patient survival for health economics or resource planning) [12,13]. We used the log-rank test for a comparison of revision rates. Reasons for both overall and femoral stem revision were presented. Significance level was set at 5%. SPSS (IBM group) and R version 4.3.2 (The R Foundation for Statistical Computing) were used to perform all analyses.

Results

Stem Usage in First-time Revision of Short and Standard Stems

When short-stem THAs were revised, a stem with standard length (< 160 mm) was used in 58% (116 of 201) of patients (Table 3). In the standard-stem THA group, a stem with standard length was used in 46% (149 of 322) of patients (p = 0.01). In the female population, distribution of standard and long revision stems was not associated with the design of the primary stem being revised. In male patients, 63% (70 of 111) of the short-stem THAs were revised with a standard stem, whereas this occurred in only 47% (75 of 160) of those in which a primary standard-stem THA was revised (p = 0.01). Stratification by age revealed a difference only in the older (> 63 years) group. In the older age group, it was more common to use a long stem (60% [107 of 177]) when a standard-stem THA was revised compared with the short-stem THAs (p = 0.02).

Overall CRR of Primary Short-stem and Standard stem THAs

The 12-year overall CRR in the total cohort between primary short-stem and standard-stem THAs did not differ (4.7% [95% confidence interval (CI) 4.0% to 5.5%] versus 5.1% [95% CI 4.5% to 5.7%], respectively; p = 0.20). The CRR differed between countries (Figure 2). In Australia, the 12-year overall CRR was lower for primary short-stem THAs than for standard-stem THAs (3.1% [95% CI 2.6% to 3.8%] versus 5.4% [95% CI 4.5% to 6.3%], respectively; p = 0.03). In both the Netherlands (5.4% [95% CI 4.1% to 7.2%] versus 2.7% [95% CI 2.0% to 37%], respectively; p < 0.001) and Sweden (7.8% [95% CI 5.9% to 10.1%] versus 6.2% [95% CI 4.9% to 7.8%], respectively; p = 0.04), the 12-year overall CRR was higher for primary short-stem THAs than for standard-stem THAs. Reasons for femoral revisions did not differ between the two groups of primary stems (Supplemental Table 1).

Table 3. Choice of stem used in first revision

	AOANJRR		LROI		SAR		Total		P value
Stem extracted	< 160 mm	≥ 160 mm	< 160 mm	≥ 160 mm	< 160 mm	≥ 160 mm	< 160 mm	≥ 160 mm	
Short[a]	53 (66 of 124)	47 (58 of 124)	73 (33 of 45)	27 (12 of 45)	53 (17 of 32)	47 (15 of 32)	58 (116 of 201)	42 (85 of 201)	
Standard[b]	45 (111 of 247)	55 (136 of 247)	52 (21 of 40)	48 (19 of 40)	49 (17 of 35)	51 (18 of 35)	46 (149 of 322)	54 (173 of 322)	0.01

Data presented as % (n).

[a]Primary short-stem THA.

[b]Primary standard-stem THA.

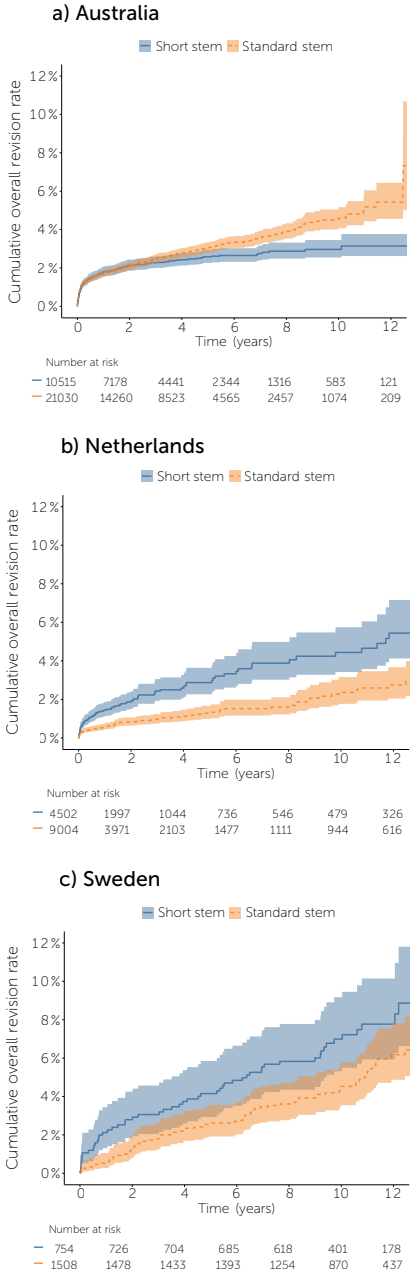


Figure 2. Overall revision rate (all revision, all reasons) of all short-stem and standard-stem THAs, stratified by (**a**) Australia, (**b**) the Netherlands, and (**c**) Sweden.

Re-revisions of Primary Short-stem THAs and Primary Standard-stem THAs

At 5 years, overall CRR for a second revision also did not differ when primary short-stem THAs were compared with standard-stem THAs (20.9% [95% CI 16.8% to 25.8%] versus 20.4% [95% CI 17.3% to 23.9%]; p = 0.80) (Figure 3). Reasons for second overall revision did not differ between groups (Supplemental Table 2).

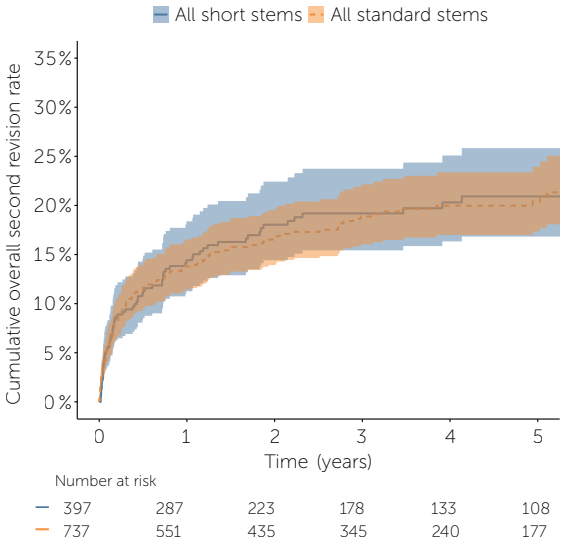


Figure 3. Overall re-revision rate (all revisions, all reasons) of all short-stem and standard-stem THAs.

Discussion

One primary rationale for the use of short stems in hip arthroplasty is the anticipation that there will be more bone stock remaining for any future revision surgery. Therefore, some may anticipate that a standard-length stem could be more often used for revision of short-stem THAs instead of longer revision stems compared with standard-stem THAs. This contention is as yet unsupported by robust evidence, and ultimately, it will not be important if short-stem THA increases the overall risk of revision. We merged data on short stems from three national registries and found that during a revision procedure of a short-stem THA, a standard stem (< 160 mm) was used more often than in revision of standard-stem THAs. There were no differences in overall revision rates of first and second revisions for short-stem and

standard-stem THAs. Therefore, uncemented short stems used in primary THA in this study are not associated with a higher risk of a first or second revision compared with standard-length stems in the primary surgery even though short-stem THAs were more frequently revised using a standard-length stem than were standard-stem THAs. If this finding as well as the bone-sparing properties can be supported by future studies, it may advocate for the wider use of short stems.

Limitations

Our study has a number of limitations. There is no universally accepted definition of a short-stem THA. However, the definitions provided by the AOANJRR and LROI are comparable, as both registries define a short stem as a short cementless femoral stem designed for entirely metaphyseal fixation [2,10]. This suggests that the definition of a short stem is more focused on design rather than stem length, which aligns with previous reports [14]. Standard-stem THAs were selected based on the three most commonly used stems within the registries, and the findings of this study only apply to the short and standard stems used in this study.

In the AOANJRR data set, only overall revision rates could be analyzed, as time-to-revision for stem revision alone was not included. Because the AOANJRR makes up the greater part of the total data set, separate analysis with use of stem revision as the endpoint was not performed based on the remaining data from the LROI and SAR. We believe this is justified, as other arthroplasty registry studies have also reported overall revision rates rather than stem revision rates when comparing short-stem and standard-stem THAs [3,8]. However, we acknowledge that as a result, numerous revisions may be included that have no association with stem length or, in fact, any failure of the stem.

In the SAR, the matching was not balanced for age, diagnosis, bearing material, and surgical approach. The imbalance for age, diagnoses other than OA, and other approaches appears limited, with SMDs of 0.11 or 0.12, which is just above the commonly used threshold of 0.10 [11]. However, the imbalance was greater for ceramic cups and the direct lateral approach in the supine position. We did not use additional strategies to minimize confounding, such as stratification or adjustment for unbalanced covariates, because of the relatively small Swedish sample size and the inability to perform adjusted analyses in Kaplan-Meier analysis. This might affect the results because the reference group does not exactly match the studied group, and residual confounding may be still present. Consequently, the differences in revision rates between short-stem and standard-stem THAs in Sweden may be either overestimated or underestimated. Therefore, these revision rates should be interpreted with caution.

The categorization of stems used in first revisions is also crude because it was based only on length or whether or not the stem was modular. Analysis of radiographic changes that might have affected the choice of stem used in the revision surgery has not been performed. Also, other patient-related factors such as comorbidities or osteoporosis have not been considered, nor have surgeon factors, which could have influenced the choice of revision stem. Our findings need to be interpreted with respect to this, and they are only an indication that short stems in fact are often revised using a stem of standard length.

We used the median age of the cohorts as a cutoff for younger versus older patients. A more finely granulated separation into age classes would have been preferable. Because of the comparatively small sample size, and in an effort to analyze by age, we were only able to dichotomize into "younger" and "older" groups. Stem revision is an uncommon event, and to increase numbers, we pooled data from three different national registries. Despite this, we were only able to identify 399 revised short-stem THAs over a 15-year period that could be included. Thus, a prospective clinical study would be difficult to perform even if multiple centers were involved. We encourage cooperation between registers and continued updates of our data. Short-stem THAs as a group are heterogeneous, and further studies should be conducted to identify individual implant designs with better or worse outcomes.

Stem Usage in First-time Revision of Short and Standard Stems

The findings in this study indicate that when compared with a standard-stem THA, a higher proportion of short-stem THAs were revised using a standard-length stem. The stem used in the first revision was also associated with sex, as male patients in the short-stem THA group underwent revision more often with a standard stem than in the standard-stem THA group. When we stratified our results by age, it was more common to use a longer implant during the revision of standard stems in patients > 63 years of age than during the revision of short stems. These findings may reflect the presence of poorer bone stock in elderly or female patients. The absence of a difference in stem length during the first stem revision in patients younger than 63 years also suggests that the bone-sparing effect of a short stem may have limited applicability in the younger population. Although we had small numbers for this analysis, this does nonetheless challenge the use of short-stem designs for the younger population.

Overall CRR of Primary Short-stem and Standard-stem THAs

Although the overall revision rates of primary short stem and standard stems did not differ in our study, the revision rates did differ among the registries. In Australia,

short-stem THAs had lower overall first revision rates than standard-stem THAs, while in the Netherlands and Sweden, the overall first revision rates were higher for short-stem THAs. Other registry-based studies of revision rates of short-stem THAs suggest that revision risk depends on short-stem design [8,9]. The neck-sparing implants, such as the CFP stem from Waldemar Link, show higher revision rates than stems that do not spare the neck, such as the Fitmore or the Optimys stem. The CFP stem was more frequently used in the Netherlands and Sweden than in Australia. Because stem selection and usage vary between the registries, this might be one explanation for the differences in revision rates between countries in our study. Another observation is the difference in revision rate of standard-stem THAs between the three countries. In the Netherlands, the revision rate for standard-stem THAs was less than half that observed in the other two countries. The reason for this is unknown, but it could in part be a function of implant selection (both acetabular and femoral) and the matching procedure, which may have selected standard-stem THAs with fewer revisions than all standard-stem THAs in the Netherlands.

Re-revisions of Primary Short-stem THAs and Primary Standard-stem THAs

The revision rates of first revisions did not differ between groups, nor did the reasons for a second revision; the share of aseptic revisions was not higher in the short-stem THA group. Although the numbers are small, and it is difficult to draw any firm conclusion, our findings suggest that the risk of a second revision is not associated with the implant used in primary THA. If a short stem can be revised using a stem of standard length without a higher risk of a second revision, the bone-sparing aspects of the procedure might prove beneficial, but this remains speculative.

Conclusion

Our findings suggest that surgeons choose to revise a primary short-stem THA with a stem < 160 mm more frequently than a primary standard-stem THA, which more often are revised using a stem ≥ 160 mm or a modular stem. These circumstances might suggest that short stems may have a bone-sparing effect if the primary stem fails, although this conclusion is speculative. In addition, no differences could be seen in overall revision rates between selected short-stem THA and standard-stem THA both for first and second revisions. These findings suggest that short-stem THAs perform as well as standard-stem THAs. Future studies, including multinational registry-based evaluation of revision rates, as well as studies examining the bone-sparing properties of short stems, must be conducted to verify and extend our results. Registries need to seek further harmonization of various study endpoints to make such analyses more feasible in the future.

References

[1] Van Veghel MHW, Hannink G, Lewis PL, Holder C, Van Steenbergen LN, Schreurs BW. Short-stem hip arthroplasty in Australia and the Netherlands: a comparison of 12,680 cases between the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the Dutch Arthroplasty Register (LROI). Acta Orthop 2023;94:453-9. https://doi.org/10.2340/17453674.2023.18491.

[2] AOANJRR. Hip, Knee & Shoulder Arthroplasty: 2023 Annual report. Australian Orthopaedic Association National Joint Replacement Registry; 2023. Available from: https://aoanjrr.sahmri.com/documents/10180/1579982/AOA_NJRR_AR23.pdf/c3bcc83b-5590-e034-4ad8-802e4ad8bf5b?t=1695887126627.

[3] Steinbruck A, Grimberg AW, Elliott J, Melsheimer O, Jansson V. Short versus conventional stem in cementless total hip arthroplasty : An evidence-based approach with registry data of mid-term survival. Orthopade 2021;50(4):296-305. https://doi.org/10.1007/s00132-021-04083-y.

[4] Hauer G, Vielgut I, Amerstorfer F, Maurer-Ertl W, Leithner A, Sadoghi P. Survival Rate of Short-Stem Hip Prostheses: A Comparative Analysis of Clinical Studies and National Arthroplasty Registers. J Arthroplasty 2018;33(6):1800-5. https://doi.org/10.1016/j.arth.2018.01.017.

[5] Huo SC, Wang F, Dong LJ, Wei W, Zeng JQ, Huang HX, Han QM, Duan RQ. Short-stem prostheses in primary total hip arthroplasty: A meta-analysis of randomized controlled trials. Medicine (Baltimore) 2016;95(43):e5215. https://doi.org/10.1097/MD.0000000000005215.

[6] Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J 2019;101-B(5):502-11. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018-1199.R1.

[7] van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. Acta Orthop 2014;85(3):250-8. https://doi.org/10.3109/17453674.2014.908343.

[8] Giardina F, Castagnini F, Stea S, Bordini B, Montalti M, Toni A. Short Stems Versus Conventional Stems in Cementless Total Hip Arthroplasty: A Long-Term Registry Study. J Arthroplasty 2018;33(6):1794-9. https://doi.org/10.1016/j.arth.2018.01.005.

[9] Van Veghel MHW, Hannink G, Van Oldenrijk J, Van Steenbergen LN, Schreurs BW. A comparison of uncemented short versus standard stem length in total hip arthroplasty: results from the Dutch Arthroplasty Register. Acta Orthop 2023;94:330-5. https://doi.org/10.2340/17453674.2023.13652.

[10] LROI. LROI Implant Library - Hip. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/byym2eyc/625522c726f17lroi-implant-library-hip.pdf.

[11] Nguyen TL, Collins GS, Spence J, Daures JP, Devereaux PJ, Landais P, Le Manach Y. Double-adjustment in propensity score matching analysis: choosing a threshold for considering residual imbalance. BMC Med Res Methodol 2017;17(1):1-8. https://doi.org/10.1186/s12874-017-0338-0.

[12] Ranstam J. Are competing risks models appropriate to describe implant failure? Acta Orthop 2018;89(3):253. https://doi.org/10.1080/17453674.2018.1452470.

[13] Sayers A, Evans JT, Whitehouse MR, Blom AW. Are competing risks models appropriate to describe implant failure? Acta Orthop 2018;89(3):256-8. https://doi.org/10.1080/17453674.2018.1444876.

[14] Falez F, Casella F, Papalia M. Current concepts, classification, and results in short stem hip arthroplasty. Orthopedics 2015;38(3 Suppl):S6-13. https://doi.org/10.3928/01477447-20150215-50.

Supplemental material

Supplemental Table 1. Reasons for revision

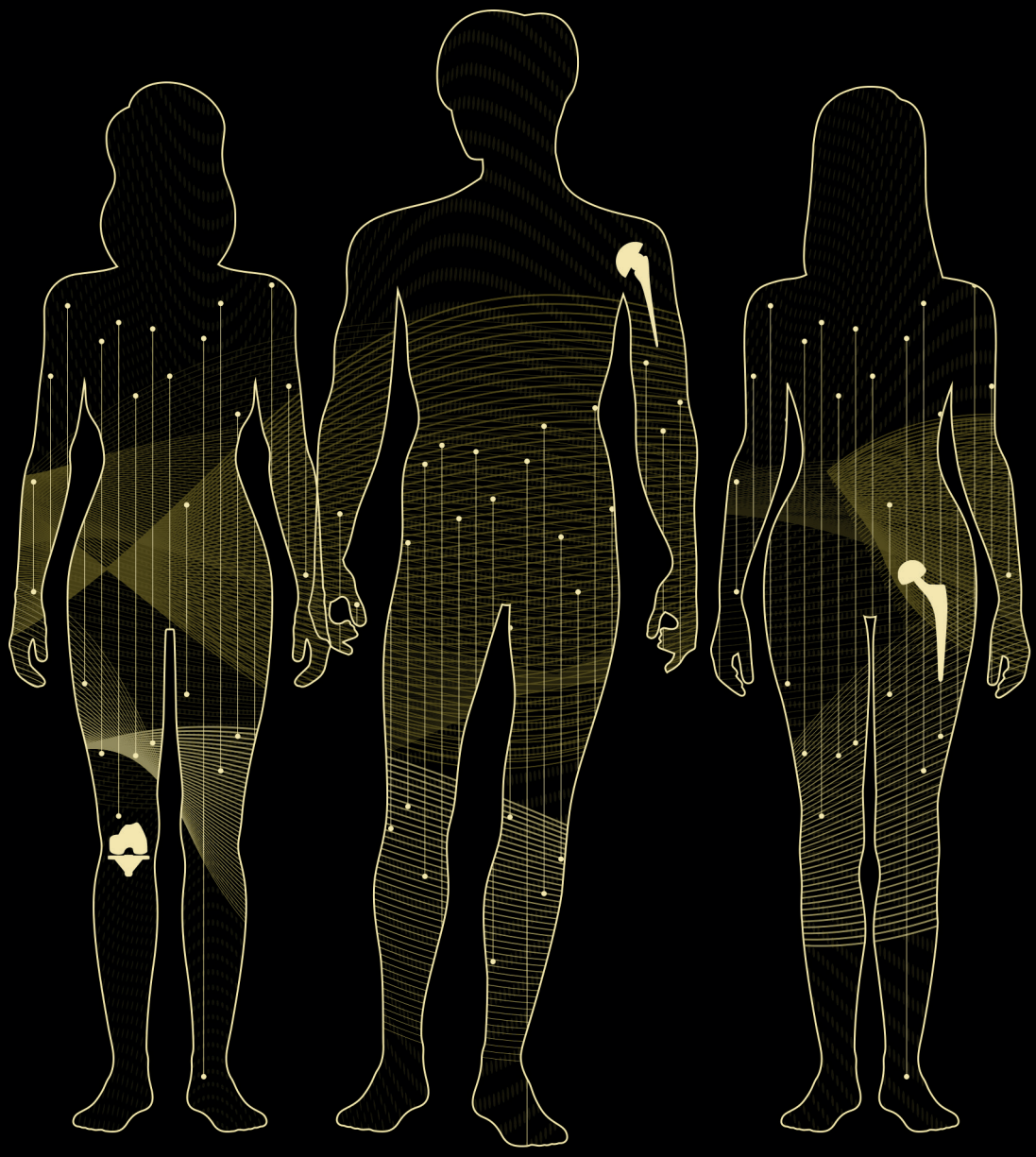
	All revisions		Femoral revisions	
	Short stem[a]	Standard stem[b]	Short stem[a]	Standard stem[b]
Number of revision THAs	399	737	218	342
Periprosthetic infections	18 (73)	24 (179)	13 (29)	14 (47)
Aseptic loosening	32 (127)	27 (200)	35 (76)	40 (138)
Periprosthetic fracture	20 (81)	14 (106)	33 (72)	28 (94)
Dislocation	13 (50)	21 (154)	4 (8)	8 (28)
Other	16 (62)	12 (91)	14 (31)	9 (32)
Missing	2 (6)	1 (7)	1 (2)	1 (3)

Data presented as % (n).
[a]Primary short-stem THA.
[b]Primary standard-stem THA.

Supplemental Table 2. Reasons for second revision (all revisions)

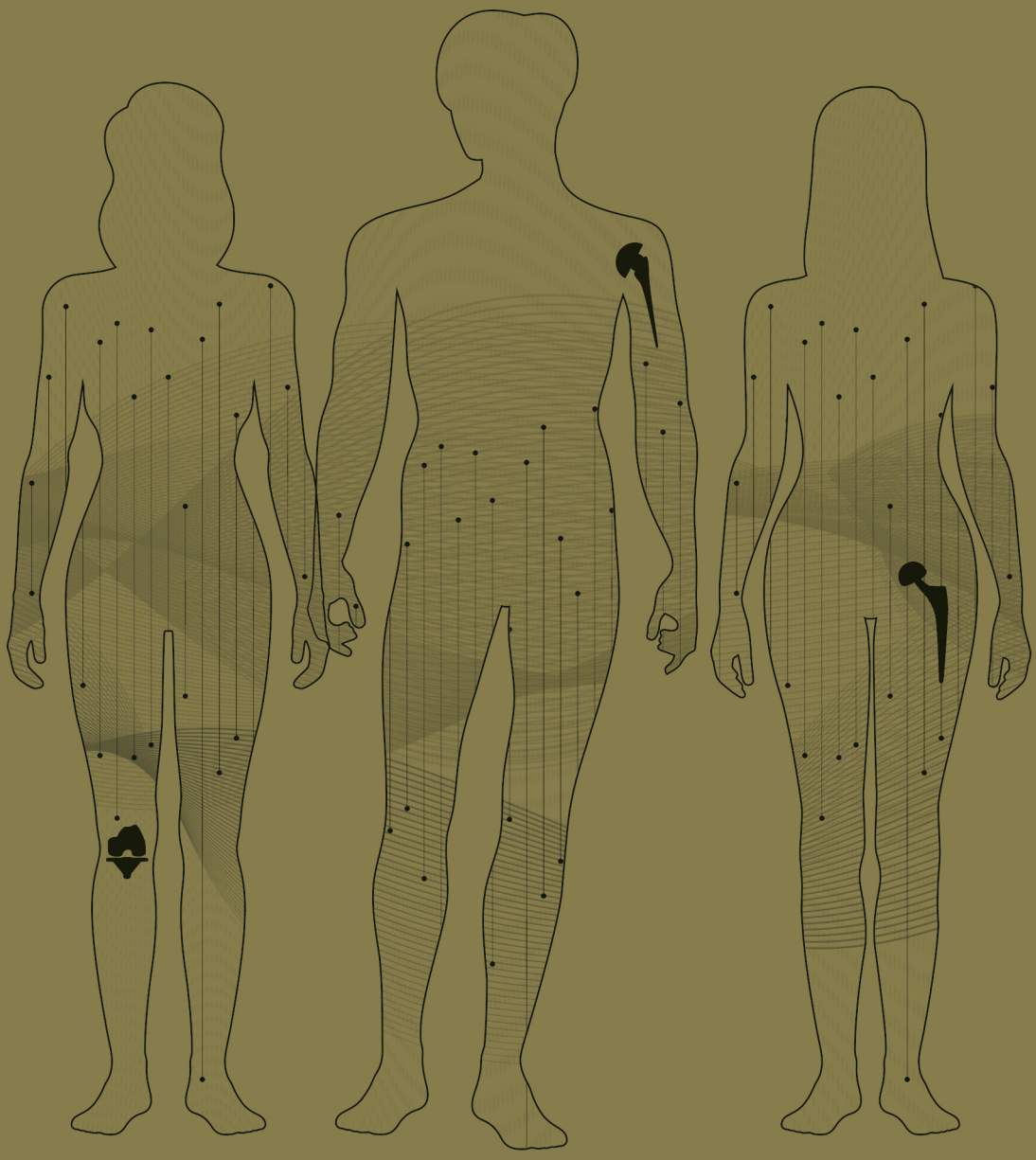
	All revisions	
	Short stem[a]	Standard stem[b]
Number of second revision	78	137
Periprosthetic infection	51 (40)	54 (74)
Aseptic loosening	19 (15)	15 (21)
Periprosthetic fracture	5 (4)	6 (8)
Dislocation	14 (11)	18 (25)
Other	9 (7)	7 (9)
Missing	1 (1)	0 (0)

Data presented as % (n).
[a]Primary short-stem THA.
[b]Primary standard-stem THA.



Part 2

Enrichment & linking with other (non-)arthroplasty registries



5

Validation of the incidence of reported periprosthetic joint infections in total hip and knee arthroplasty in the Dutch Arthroplasty Register

MHW van Veghel
M Belt
A Spekenbrink-Spooren
MFL Kuijpers
TII van der Kooi
BW Schreurs
G Hannink

The Journal of Arthroplasty 2024; 39(4): 1054–1059

Abstract

Background: Arthroplasty registers underreport the incidence of periprosthetic joint infections (PJIs). We validated the incidence of reported PJIs in total hip arthroplasties (THAs) and total knee arthroplasties (TKAs) in the Dutch Arthroplasty Register (LROI) using data from the Dutch National Nosocomial Surveillance Network (PREZIES).

Methods: All primary THAs and TKAs from the LROI and all primary THAs and TKAs performed in consenting hospitals from PREZIES between 2012 and 2018 were matched on date of birth, date of surgery, sex, hospital, and type of procedure (THA n = 91,208; TKA n = 80,304). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for PJIs registered in the LROI, using PREZIES as a reference.

Results: The incidence of registered PJIs in THAs was 1.2% in PREZIES and 0.5% in the LROI. For TKAs, this was 0.7 and 0.4%, respectively. The PJIs in THAs in the LROI had a sensitivity of 0.32 (confidence interval [CI]: 0.29 to 0.35), specificity of 1.00 (CI: 1.00 to 1.00), PPV of 0.74 (CI: 0.70 to 0.78), and NPV of 0.99 (CI: 0.99 to 0.99). In TKAs, the sensitivity, specificity, PPV, and NPV were 0.38 (CI: 0.34 to 0.42), 1.00 (CI: 1.00 to 1.00), 0.65 (CI: 0.59 to 0.70), and 1.00 (CI: 1.00 to 1.00), respectively.

Conclusions: The LROI captures approximately one-third of the PJIs as revision within one year for infection or resection arthroplasty. The capture rate of PJIs can be improved by including all reoperations without component exchange and nonsurgical treatments with antibiotics only.

Introduction

Revisions due to periprosthetic joint infections (PJIs) remain a major problem in both total hip arthroplasty (THA) and total knee arthroplasty (TKA) and are associated with high morbidity, poor postoperative outcomes such as higher re-revision rates, and even higher mortality rates [1,2]. Population-based registry studies have shown that approximately 1% of all total joint arthroplasties are revised due to PJIs [3-5]. However, concerns have been raised regarding the validity of reported PJIs in national arthroplasty registers [6-9].

Multiple population-based registry studies have found an underreporting of PJIs of up to 40% [6-9]. Several reasons have been suggested for the underreporting of PJIs in these registers. Most national arthroplasty registers record revisions, which are defined as a replacement, removal, or addition of one or more components of the prosthesis. However, a PJI can also be treated with a debridement, antibiotics, and implant retention (DAIR) procedure without component exchange or nonoperatively with antibiotics, and these PJIs are therefore not included in those registers. Also, the reason for revision is usually reported immediately after surgery, whereas diagnosing a PJI based on cultures usually takes several days. It is unlikely that a reason for revision other than a PJI reported at the time of surgery will be updated after a proven PJI [6-9].

Since 2007, the Dutch Arthroplasty Register (LROI) has been registering THAs and TKAs on a nationwide basis. A recent study found that only 47% of the PJIs were captured in the LROI [10]. However, in that study, the LROI data were benchmarked against a Regional Infection Cohort, including only 8 hospitals located in the South-East of the Netherlands.

Based on the previous registry studies, the LROI is expected to underreport the incidence of PJIs in the Netherlands. It is important to quantify the possible underreporting of PJIs in the LROI to obtain reliable data of PJIs that can guide future optimalization steps in the Netherlands. The Dutch National Nosocomial Surveillance Network (PREZIES) is a health care-associated infection (HAI) surveillance network. One of the PREZIES modules focuses on the surveillance of surgical site infections (SSIs), such as PJIs in THAs and TKAs. The PREZIES collects these surveillance data in a national registration system for infectious diseases [11,12]. Therefore, this study aims to validate the incidence of reported PJIs in THAs and TKAs in the LROI using data from PREZIES.

Material and Methods

Data were obtained from the LROI and PREZIES. The LROI is the national population-based arthroplasty register of the Netherlands, established by the Netherlands Orthopaedic Association (NOV) in 2007. In 2012, 100% coverage of Dutch hospitals was achieved with a completeness of more than 95% of primary THAs and TKAs [13]. Nowadays, completeness of primary and revision hip and knee arthroplasties is reported to be higher than 97%, and the validity is higher than 94% for hip arthroplasties and 97% for knee arthroplasties [14]. The LROI contains data on patient, prosthesis, and procedure characteristics of primary and revision arthroplasties.

The PREZIES is the national surveillance system for the incidence of HAIs in the Netherlands, founded in 1996 and coordinated by the National Institute for Public Health and the Environment (RIVM). The goal of this network is to gain insight into the incidence and prevalence of HAIs using standardized surveillance methods, which result in national reference values. Participation is voluntary and almost all Dutch hospitals take part in one or more modules of the PREZIES program. In the SSI module, hospitals can choose each year to send their data on several surgical procedures, including THAs and TKAs, toward PREZIES to keep track of their infections [11,12]. The PREZIES data are owned by the hospital where the procedure was performed. Therefore, approval to use their data was needed from all hospitals delivering data to PREZIES. In total, 52 hospitals (52% of all Dutch hospitals) gave approval to use their data in this study. Of these 52 hospitals, 85% were general hospitals, 13% were private clinics, and 2% were university medical centers.

In this study, we included all primary THAs (n = 197,924) and TKAs (n = 168,712) performed between 2012 and 2018 from the LROI and all primary THAs (n = 105,006) and TKAs (n = 95,264) performed between 2012 and 2018 in consenting hospitals from PREZIES. Data from the LROI and PREZIES were matched on case level using a pseudonym created by a Trusted Third Party (ZorgTTP, Houten, the Netherlands) on the variables: date of birth, date of surgery, sex, hospital of primary procedure, and type of procedure (THA or TKA). Sensitivity analyses were performed to determine the number of variables required for the matching procedure, showing that those 5 variables were needed to achieve the optimal number of matched cases with a limited number of multiple cases with the same pseudonyms. Our matched data set did not include the variables date of birth, date of surgery, and hospital of primary procedure. Therefore, patient privacy was ensured in this study. Patients in the LROI were excluded before matching if they were diagnosed with a tumor (THA n = 402, TKA n = 98) or had a missing date of birth (THA n = 155, TKA n = 134). After matching, several cases had the same pseudonyms based on the 5 matching variables; these cases (THA n = 682, TKA n = 488) were excluded (Figure 1).

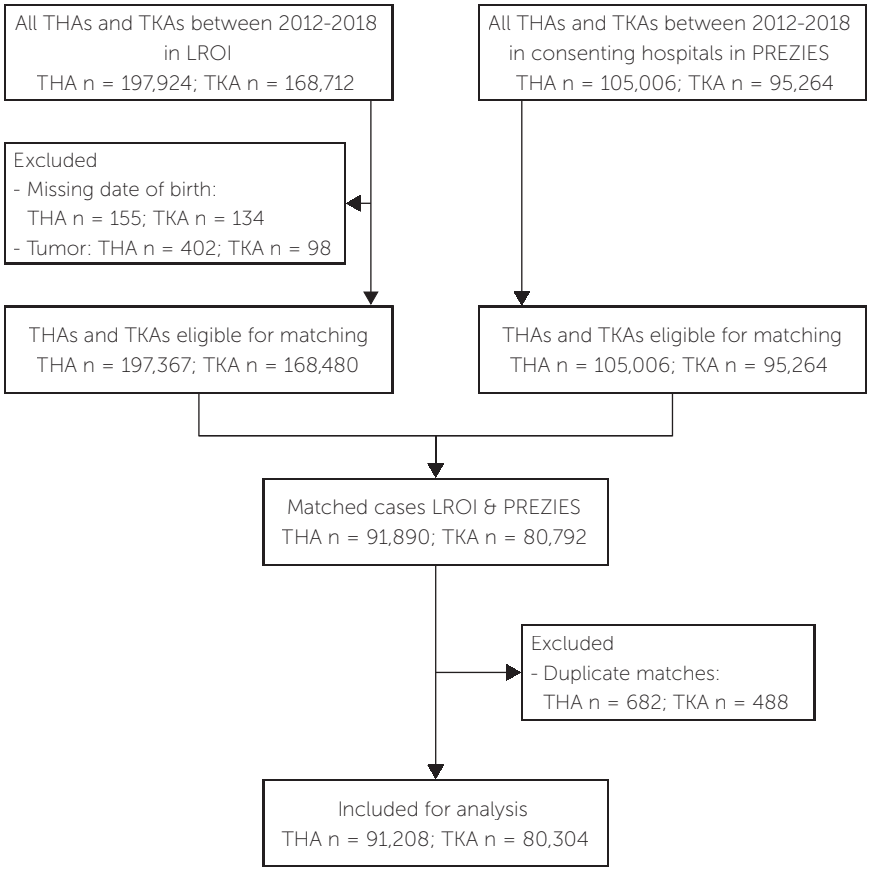


Figure 1. Flowchart.

LROI, Dutch Arthroplasty Register; PREZIES, Dutch National Nosocomial Surveillance Network; THA, total hip arthroplasty; TKA, total knee arthroplasty.

In total, 171,512 matches could be made between the LROI and PREZIES, of which 91,208 (53%) THAs and 80,304 (47%) TKAs (Table 1). Most THA and TKA patients were women (THA 66%; TKA 65%), were diagnosed with osteoarthritis (THA 90%; TKA 97%), and had an American Society of Anesthesiologists II score (THA 65%; TKA 68%). Most THA patients were preobese (36%) or had a normal (26%) body mass index (BMI). In TKA patients, preobese (34%) and obese class 1 (24%) were the most common BMI classes. The most commonly used type of fixation in THAs was cementless (62%), whereas TKAs were more often cemented (94%).

Table 1. Characteristics of Matched Total Hip Arthroplasties and Total Knee Arthroplasties Between the Dutch Arthroplasty Register and the Dutch National Nosocomial Surveillance Network.

	Total	THAs	TKAs
Characteristic	n = 171,512	n = 91,208	n = 80,304
Sex, women (%)	112,183 (65)	60,133 (66)	52,050 (65)
Diagnosis (%)			
Osteoarthritis	159,564 (93)	81,809 (90)	77,755 (97)
Fracture	3,104 (1.8)	3,104 (3.4)	n.a.
Osteonecrosis	2,413 (1.4)	2,062 (2.3)	351 (0.4)
Late post-traumatic	1,844 (1.1)	999 (1.1)	845 (1.1)
Dysplasia	1,770 (1.0)	1,770 (1.9)	n.a.
Inflammatory arthritis	1,596 (0.9)	636 (0.7)	960 (1.2)
Other	457 (0.3)	377 (0.4)	80 (0.1)
Missing	764 (0.4)	451 (0.5)	313 (0.4)
ASA score (%)			
ASA I	26,925 (16)	16,108 (18)	10,817 (14)
ASA II	114,153 (67)	59,306 (65)	54,847 (68)
ASA III-IV	29,525 (17)	15,211 (17)	14,314 (18)
Missing	909 (0.5)	583 (0.6)	326 (0.4)
Body mass index[a] (kg/m^2) (%)			
Underweight (<18.5)	725 (0.4)	614 (0.7)	111 (0.1)
Normal (18.5 to 24.9)	34,964 (20)	24,016 (26)	10,948 (14)
Preobese (25.0 to 29.9)	60,032 (35)	32,407 (36)	27,625 (34)
Obese class 1 (30.0 to 34.9)	33,003 (19)	13,923 (15)	19,080 (24)
Obese class 2 (35.0 to 39.9)	10,758 (6.3)	3,717 (4.1)	7,041 (8.8)
Obese class 3 (≥40.0)	3,586 (2.1)	1,008 (1.1)	2,578 (3.2)
Missing	28,444 (17)	15,523 (17)	12,921 (16)
Type of fixation (%)			
Cemented	99,442 (58)	24,223 (27)	75,219 (94)
Cementless	59,469 (35)	56,212 (62)	3,257 (4.1)
Hybrid	12,155 (7.1)	10,503 (12)	1,652 (2.1)
Missing	446 (0.3)	270 (0.3)	176 (0.2)

THA, total hip arthroplasty; TKA, total knee arthroplasty; n.a., not applicable; ASA, American Society of Anesthesiologists.

[a] Registered in the Dutch Arthroplasty Register since 2014.

Both the definition of a PJI and the follow-up of THAs and TKAs differed between the LROI and PREZIES. Participation in PREZIES required a mandatory follow-up of one year in 2012 to 2014, and of 90 days in 2015 to 2018. In the LROI, follow-up for

primary THAs and TKAs ends at the time of first revision, death of the patient, or end of follow-up (January 1, 2022). A PJI is defined as a revision with reason 'infection' within the LROI. In this study, revisions with reason 'Girdlestone' were also considered a PJI. A Girdlestone is defined as a hip revision procedure in which the prosthesis is removed and no new prosthesis is implanted (ie, resection arthroplasty), often due to a bacterial infection [14]. Therefore, in the LROI data, we defined a PJI as a revision within one year with reason 'infection' or 'Girdlestone.' The definition of a PJI in PREZIES is based on that of the European Center of Disease Prevention and Control (ECDC) and has been described elsewhere [15,16]. This ECDC definition includes both superficial and deep SSIs. In this study, only deep SSIs in the PREZIES data were considered a PJI, as superficial SSIs are more likely to be wound complications than PJIs. These PJIs cover PJIs treated with revision surgery, treated with reoperation without component exchange, or nonsurgical treatment. This study was reported in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines.

Data Analyses

Descriptive statistics were used to summarize the patient and procedure characteristics as well as the incidence of PJIs in the LROI and the PREZIES databases. BMI was classified as underweight (<18.5), normal (18.5 to 24.9), preobese (25.0 to 29.9), obese class 1 (30.0 to 34.9), obese class 2 (35.0 to 39.9), or obese class 3 (≥40.0). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) including 95% confidence intervals (CIs) were calculated for PJIs registered in the LROI, using PREZIES as a reference standard. Only PJIs that have been treated with a revision procedure can be captured by the LROI. Therefore, patient status (ie, alive without revision, deceased, or revision) was described for PJIs with no revision for infection or resection arthroplasty within one year in the LROI to assess the proportion of PJIs that were rightly not reported to the LROI. Results were stratified by type of procedure. R (version 4.2.0, R Foundation for Statistical Computing, Vienna, Austria) was used to perform all analyses.

Results

Among THAs, 1,101 (1.2%) PJIs were registered in PREZIES and 476 (0.5%) in the LROI, of which 353 PJIs were reported in both the LROI and PREZIES (Table 2). For TKAs, there were 547 (0.7%) PJIs registered in PREZIES and 322 (0.4%) in the LROI, of which 209 PJIs were reported in both the LROI and PREZIES. The PJIs in THAs in the LROI had a sensitivity of 0.32 (CI: 0.29 to 0.35), a specificity of 1.00 (CI: 1.00-1.00), a PPV of 0.74 (CI: 0.70 to 0.78), and an NPV of 0.99 (CI: 0.99 to 0.99). In

Table 2. Sensitivity, Specificity, Positive Predictive Value, and Negative Predictive Value of Periprosthetic Joint Infections Registered in the Dutch Arthroplasty Register and the Dutch National Nosocomial Surveillance Network According to Type of Procedure.

Outcome	PREZIES: PJI								
	Total n = 171,512			THAs n = 91,208			TKAs n = 80,304		
	Yes	No	Total	Yes	No	Total	Yes	No	Total
LROI: PJI									
Yes	562	236	798	353	123	476	209	113	322
No	1,086	169,628	170,714	748	89,984	90,732	338	79,644	79,982
Total	1,648	169,864	171,512	1,101	90,107	91,208	547	79,757	80,304
Sensitivity	0.34	(CI: 0.32 to 0.36)		0.32	(CI: 0.29 to 0.35)		0.38	(CI: 0.34 to 0.42)	
Specificity	1.00	(CI: 1.00 to 1.00)		1.00	(CI: 1.00 to 1.00)		1.00	(CI: 1.00 to 1.00)	
PPV	0.70	(CI: 0.67 to 0.74)		0.74	(CI: 0.70 to 0.78)		0.65	(CI: 0.59 to 0.70)	
NPV	0.99	(CI: 0.99 to 0.99)		0.99	(CI: 0.99 to 0.99)		1.00	(CI: 1.00 to 1.00)	

LROI, Dutch Arthroplasty Register; PREZIES, Dutch National Nosocomial Surveillance Network; THA, total hip arthroplasty; TKA, total knee arthroplasty; CI, 95% confidence interval. PPV, positive predictive value; NPV, negative predictive value; PJIs, periprosthetic joint infections.

TKAs, the sensitivity, specificity, PPV, and NPV were 0.38 (CI: 0.34 to 0.42), 1.00 (CI: 1.00 to 1.00), 0.65 (CI: 0.59 to 0.70), and 1.00 (CI: 1.00 to 1.00), respectively.

A total of 748 (68%) THA patients and 338 (62%) TKA patients with a PJI in PREZIES were not captured by the LROI as revision for infection or resection arthroplasty within one year. Of these, 87% of the THA patients and 89% of the TKA patients were alive without a revision one year after primary THA or TKA, 9% of the THA patients and 7% of the TKA patients had a revision procedure within one year that was registered for reasons other than infection or resection arthroplasty, and 4% of the THA and TKA patients were deceased within one year (Table 3).

Table 3. Status Within One Year of Patients With Nonregistered Periprosthetic Joint Infections in the Dutch Arthroplasty Register According to the Dutch National Nosocomial Surveillance Network by Type of Procedure.

	Total	THAs	TKAs
Patient Status	n = 1,086	n = 748	n = 338
Alive without revision within one year	953 (88)	653 (87)	300 (89)
Revision within one year	92 (8)	68 (9)	24 (7)
Deceased within one year	41 (4)	27 (4)	14 (4)

THA, total hip arthroplasty; TKA, total knee arthroplasty.

Discussion

This study shows that only approximately one-third of the PJIs in THAs and TKAs, according to the international definition used by PREZIES, are registered in the LROI as revision for infection or resection arthroplasty within one year. The proportion of PJIs registered in the LROI that were correctly classified compared to the PREZIES database was 74% in THAs and 65% in TKAs.

The capture rate of PJIs reported in the LROI in this study is substantially lower than in other national arthroplasty registers, which report a minimum of 60% of the PJIs as revision or reoperation for infection [6-9]. This can partly be explained by the limitations in the documentation system of the LROI. After the primary procedures, the LROI registers only revisions where at least one of the components has been replaced, removed, or added. The Finnish and Swedish arthroplasty registers include these revisions as well as reoperations without component exchange [6,7]. In the Danish arthroplasty register, debridement without component exchange is

also considered a revision procedure, whereas in the LROI only a DAIR procedure with exchange of the femoral head and/or inlay is considered a revision [8]. These factors likely contribute to a higher capture rate of PJIs.

A previous study showed that the LROI captured 47% of the PJIs, which is higher than in the current study [10]. However, this previous study only included revision surgeries and DAIR procedures from the Regional Infection Cohort, which was used as a benchmark, while PREZIES also included PJIs treated nonoperatively. A study using data from the Swedish arthroplasty register has shown that 9% of the deep PJIs in THAs were treated nonoperatively with antibiotics [17]. Moreover, the definition of a PJI was stricter in the Regional Infection Cohort than in PREZIES. In the Regional Infection Cohort, a PJI was diagnosed when there were at least 2 phenotypically identical pathogens, isolated in cultures from at least 2 separate tissues obtained from the affected prosthesis [10]. In PREZIES, the presence of microorganisms is not required, as other evidence of infection, such as an abscess, is sufficient to diagnose a PJI [15].

The majority of patients who have a nonregistered PJI in the LROI were alive without a revision procedure one year after the primary THA or TKA. These patients likely underwent reoperation without component exchange, nonsurgical treatment with antibiotics, or no treatment was required, suggesting that they were rightly not reported in the LROI. This stresses the importance of a more extensive registration system. The LROI, in collaboration with the Netherlands Orthopaedic Association (NOV), has recently started a complication registration system to improve orthopedic care and patient safety in which complications related to a joint arthroplasty are reported [18]. This complication registration system could make it possible to capture PJIs in the LROI that do not require revision arthroplasty. Unfortunately, LROI data on complications without revision procedures are not yet available for research purposes, as registration has started in 2022.

A total of 68 (9%) and 24 (7%) of the nonregistered PJIs in THAs and TKAs in the LROI, respectively, involved patients undergoing revision procedures. These revision procedures are likely registered as revision due to, for example, aseptic loosening, dislocation, wear, or periprosthetic fractures in THAs, and instability, aseptic loosening, patellar pain, or malalignment in TKAs [14]. Registration of the revision procedure, including the reason for revision, will usually take place during or immediately after surgery. However, an assessment of any microorganism present from cultures taken during the procedure will probably become available after the revision procedure is reported in the LROI. An already reported reason for revision is unlikely to be modified when pathogens are found to be present in those

cultures. However, delaying reporting of the revision procedure to improve the capture rate of PJIs is likely to negatively impact the completeness of revision arthroplasties [8]. A small proportion of the patients who have a nonregistered PJI had died within one year after the primary THA or TKA. It is unclear if these deaths were related to the PJIs.

More than 25% of the PJIs in THAs and TKAs in the LROI could not be confirmed by PREZIES. This may include revisions for infection or resection arthroplasty between 90 days and one year after primary procedures performed in 2015 to 2018, as PREZIES changed the mandatory follow-up from one year to 90 days in 2015. Therefore, the PJIs registered in PREZIES between 2015 and 2018 reflect only the acute PJIs rather than the acute and delayed PJIs [19]. It was not possible to differentiate between primary procedures performed in 2012 to 2014 and 2015 to 2018, as the matched data set did not contain information on procedure year. Another explanation may be that the orthopedic surgeon suspects a PJI as the indication for revision, but this suspicion is ultimately not confirmed by the PREZIES criteria for deep SSIs.

A strength of this study is the large number of matched cases between the LROI and PREZIES, showing that combining the LROI and PREZIES databases is feasible. This offers new possibilities for future registry studies on PJIs in the Netherlands, as the LROI collects data on patient, prosthesis, and procedure characteristics as well as the survival of prostheses, whereas PREZIES collects data on associated micro-organisms. Microorganisms that cause PJIs can be identified per patient, prosthesis, or procedure characteristic to investigate whether the most common antibiotic treatments for PJIs are still suitable for these microorganisms.

The findings of the study should be interpreted carefully. Participation in the PREZIES program is voluntary and not all Dutch hospitals gave approval to use their data in this study. Consequently, PREZIES data were missing in a minority of hospitals. However, we assume that the participating hospitals in this study are representative of the Netherlands. Another potential limitation may be the different definitions of a PJI in the LROI and PREZIES. The PREZIES uses the ECDC criteria for SSIs instead of the Musculoskeletal Infection Society criteria for diagnosing a PJI, where we considered the deep SSIs as PJIs [15,16,20]. Within the LROI, it is unclear whether orthopedic surgeons use criteria to diagnose a PJI. This may result in false positive or false negative PJIs in the LROI or PREZIES data, leading to an overestimation or underestimation of the capture rate of PJIs in the LROI. Also, due to privacy regulations, it was impossible to validate the LROI database to the PREZIES database on hospital level. The Swedish arthroplasty register has shown that the capture rate of PJIs varies between hospitals [6].

In conclusion, the LROI captures approximately one-third of the PJIs in THAs and TKAs, according to PREZIES, as revision for infection or resection arthroplasty within one year. The capture rate of PJIs can be improved by including reoperations without component exchange, such as DAIR procedures, and nonsurgical treatments with antibiotics. Combining the LROI and PREZIES databases is feasible, enabling new research opportunities to improve outcomes of PJIs in primary THAs and TKAs in the Netherlands.

References

[1] Zmistowski B, Karam JA, Durinka JB, Casper DS, Parvizi J. Periprosthetic joint infection increases the risk of one-year mortality. J Bone Joint Surg Am 2013;95(24):2177-84. https://doi.org/10.2106/JBJS.L.00789.

[2] Kuijpers MFL, Hannink G, van Steenbergen LN, Schreurs BW. Outcome of revision hip arthroplasty in patients younger than 55 years: an analysis of 1,037 revisions in the Dutch Arthroplasty Register. Acta Orthop 2020;91(2):165-70. https://doi.org/10.1080/17453674.2019.1708655.

[3] Pedersen AB, Svendsson JE, Johnsen SP, Riis A, Overgaard S. Risk factors for revision due to infection after primary total hip arthroplasty. A population-based study of 80,756 primary procedures in the Danish Hip Arthroplasty Registry. Acta Orthop 2010;81(5):542-7. https://doi.org/10.3109/17453674.2010.519908.

[4] Dale H, Fenstad AM, Hallan G, Havelin LI, Furnes O, Overgaard S, Pedersen AB, Karrholm J, Garellick G, Pulkkinen P, Eskelinen A, Makela K, Engesaeter LB. Increasing risk of prosthetic joint infection after total hip arthroplasty. Acta Orthop 2012;83(5):449-58. https://doi.org/10.3109/17453674.2012.733918.

[5] Springer BD, Cahue S, Etkin CD, Lewallen DG, McGrory BJ. Infection burden in total hip and knee arthroplasties: an international registry-based perspective. Arthroplast Today 2017;3(2):137-40. https://doi.org/10.1016/j.artd.2017.05.003.

[6] Lindgren JV, Gordon M, Wretenberg P, Karrholm J, Garellick G. Validation of reoperations due to infection in the Swedish Hip Arthroplasty Register. BMC Musculoskelet Disord 2014;15. https://doi.org/10.1186/1471-2474-15-384.

[7] Jamsen E, Huotari K, Huhtala H, Nevalainen J, Konttinen YT. Low rate of infected knee replacements in a nationwide series--is it an underestimate? Acta Orthop 2009;80(2):205-12. https://doi.org/10.3109/17453670902947432.

[8] Gundtoft PH, Pedersen AB, Schonheyder HC, Overgaard S. Validation of the diagnosis 'prosthetic joint infection' in the Danish Hip Arthroplasty Register. Bone Joint J 2016;98-B(3):320-5. https://doi.org/10.1302/0301-620X.98B3.36705.

[9] Sinagra ZP, Davis JS, Lorimer M, de Steiger RN, Graves SE, Yates P, Manning L. The accuracy of reporting of periprosthetic joint infection to the Australian Orthopaedic Association National Joint Replacement Registry. Bone Jt Open 2022;3(5):367-73. https://doi.org/10.1302/2633-1462.35.BJO-2022-0011.R1.

[10] Kamp MC, Liu WY, Goosen JHM, Rijnen WHC, van Steenbergen LN, van der Weegen W, Regional Prosthetic Joint Infection Working G. Mismatch in Capture of Periprosthetic Joint Infections Between the Dutch Arthroplasty Register (LROI) and a Detailed Regional Periprosthetic Joint Infection Registry. J Arthroplasty 2022;37(1):126-31. https://doi.org/10.1016/j.arth.2021.09.001.

[11] Koek MB, Wille JC, Isken MR, Voss A, van Benthem BH. Post-discharge surveillance (PDS) for surgical site infections: a good method is more important than a long duration. Euro Surveill 2015;20(8). https://doi.org/10.2807/1560-7917.es2015.20.8.21042.

[12] Mannien J, Wille JC, Snoeren RL, van den Hof S. Impact of postdischarge surveillance on surgical site infection rates for several surgical procedures: results from the nosocomial surveillance network in The Netherlands. Infect Control Hosp Epidemiol 2006;27(8):809-16. https://doi.org/10.1086/506403.

[13] van Steenbergen LN, Denissen GA, Spooren A, van Rooden SM, van Oosterhout FJ, Morrenhof JW, Nelissen RG. More than 95% completeness of reported procedures in the population-based Dutch Arthroplasty Register. Acta Orthop 2015;86(4):498-505. https://doi.org/10.3109/17453674.2015.1028307.

[14] LROI. Annual report 2022. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/3j2o5wjg/pdf-lroi-annual-report-2022.pdf.

[15] PREZIES. Case definitions of Surgical Site Infections (SSIs) in the PREZIES Surveillance. National Institute for Public Health and the Environment; 2020. Available from: https://www.rivm.nl/documenten/case-definitions-ssis.

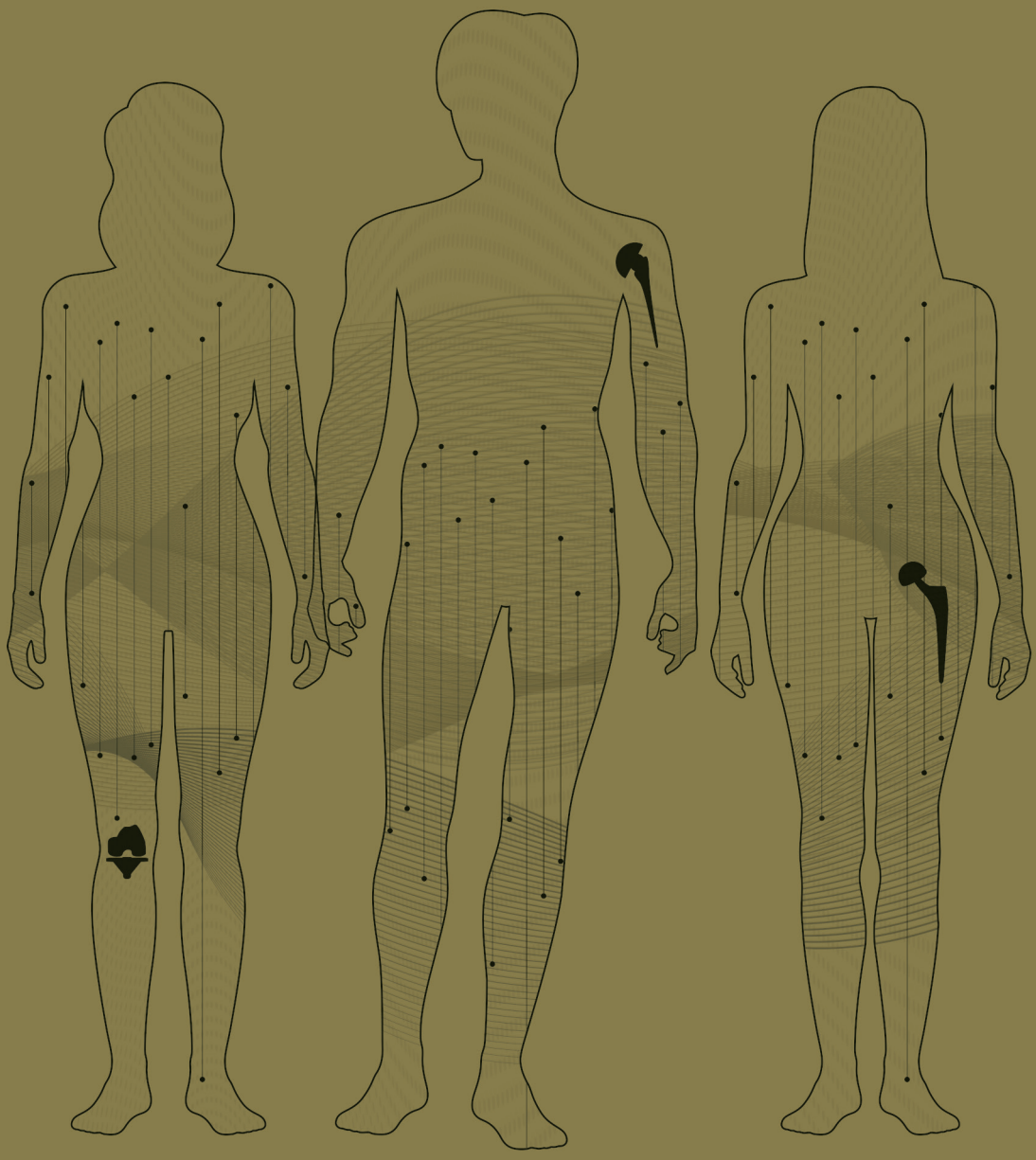
[16] ECDC. Surveillance of surgical site infections and prevention indicators in European hospitals - HAI-Net SSI protocol, version 2.2. European Centre for Disease Prevention and Control; 2017. Available from: https://www.ecdc.europa.eu/sites/default/files/documents/HAI-Net-SSI-protocol-v2.2.pdf.

[17] Lindgren JV, Gordon M, Wretenberg P, Karrholm J, Garellick G. Deep infection after total hip replacement: a method for national incidence surveillance. Infect Control Hosp Epidemiol 2014;35(12):1491-6. https://doi.org/10.1086/678600.

[18] de Reus I. Implementatie uitbreiden LROI met complicaties. Nederlandse Orthopaedische Vereniging; 2021. Available from: https://www.orthopeden.org/media/sc3pfujh/rapport-implementatie-uit-breiden-lroi-met-complicaties.pdf.

[19] Kapadia BH, Berg RA, Daley JA, Fritz J, Bhave A, Mont MA. Periprosthetic joint infection. Lancet 2016;387(10016):386-94. https://doi.org/10.1016/S0140-6736(14)61798-0.

[20] Parvizi J, Tan TL, Goswami K, Higuera C, Della Valle C, Chen AF, Shohat N. The 2018 Definition of Periprosthetic Hip and Knee Infection: An Evidence-Based and Validated Criteria. J Arthroplasty 2018;33(5):1309-14 e2. https://doi.org/10.1016/j.arth.2018.02.078.



6

Early periprosthetic joint infections in total hip and knee arthroplasty: microorganisms, mortality, and implant survival using a combined dataset from the Dutch Arthroplasty Register and the Dutch National Nosocomial Surveillance Network

MHW van Veghel
LN van Steenbergen
HFL Wertheim
TII van der Kooi
BW Schreurs
G Hannink

The Journal of Arthroplasty 2025; 40(1): 208–213

Abstract

Background: Periprosthetic joint infections (PJIs) can lead to higher re-revision rates and even higher mortality rates that may be associated with the responsible microorganism. We evaluated microorganisms that cause early PJIs in primary total hip and knee arthroplasty (THA and TKA) and examined mortality as well as PJI re-revision rates after these PJIs, using a combined dataset from the Dutch Arthroplasty Register and the Dutch National Nosocomial Surveillance Network (PREZIES). Secondly, the most common microorganisms that cause PJIs were described according to patient and implant survival.

Methods: We included all PREZIES-confirmed PJIs (n = 1,648) from the combined dataset in which primary THAs and TKAs (2012 to 2018) from the Dutch Arthroplasty Register and PREZIES were case-level matched. Kaplan-Meier survival analyses were performed to determine mortality and PJI re-revision rates following PJI revision.

Results: The most prevalent microorganism in THAs and TKAs was *Staphylococcus aureus* (THA 34%; TKA 39%), followed by Coagulase-negative *staphylococci* (THA 20%; TKA 19%), with *Staphylococcus epidermidis* (THA 12%; TKA 11%) as the most common subtype, and *Enterococcus* species (THA 8.6%; TKA 5.9%). The 5-year mortality was 15% (95% confidence interval [CI]: 13 to 18) and 18% (CI: 14 to 21) for THA and TKA patients, respectively. The 5-year PJI re-revision rate was 28% (CI: 24 to 34) for THAs and 30% (CI: 24 to 38) for TKAs. In deceased THA patients who had a PJI, *Enterococcus* species (14%) were more often registered as microorganisms responsible for the PJI than *S. epidermidis* (8.5%).

Conclusions: Over half of the early PJIs in THAs and TKAs in the Netherlands were caused by *Staphylococcus aureus* and Coagulase-negative *staphylococci* including *Staphylococcus epidermidis*. Both 5-year mortality and PJI re-revision rates following PJI were relatively high.

Introduction

Although periprosthetic joint infections (PJIs) after primary total hip and knee arthroplasty (THA and TKA) are uncommon, they can cause major complications. Associated with high morbidity, PJIs have poor postoperative outcomes, such as higher re-revision rates and even higher mortality rates [1,2]. Moreover, PJI is the second most common cause of THA revisions and the fourth most common cause of TKA revisions in the Netherlands [3].

In a previous study, we combined data from the Dutch Arthroplasty Register (LROI) and the Dutch National Nosocomial Surveillance Network (PREZIES) to identify the incidence of reported PJIs in THAs and TKAs in the Netherlands [4]. The LROI collects data on patient, prosthesis, and procedure characteristics of primary and revision arthroplasties, while PREZIES collects data on early PJIs and the associated microorganisms [3,5,6]. Combining the LROI and PREZIES databases also allows the evaluation of more than 1,600 early PJIs with responsible microorganisms in THAs and TKAs in the Netherlands. Microorganisms that cause PJIs can be identified to investigate whether the most common preventive antibiotic treatments for PJIs are still suitable for these microorganisms. Commonly reported microorganisms in PJIs are *Staphylococcus aureus*, Coagulase-negative *Staphylococci* (CoNS), *streptococci*, and *enterococci* [7]. The identification of microorganisms may also be important when choosing treatment strategies for PJI. *S. aureus* and *enterococci* are associated with an increased risk of failure after debridement, antibiotics, and implant retention (DAIR) procedures with or without modular component exchange, contributing to higher PJI revision and re-revision rates [8]. Moreover, *enterococci* are associated with a higher mortality risk than PJIs caused by other microorganisms [9].

Since PJIs can lead to higher re-revision rates and even higher mortality rates that may be associated with the responsible microorganism, it may be valuable to evaluate mortality and PJI re-revision rates and their associated microorganisms. Therefore, this study aimed to evaluate the microorganisms that cause early PJIs in primary THAs and TKAs in the Netherlands, and to examine mortality rates as well as PJI re-revision rates after a PJI. Secondly, we categorized the most common microorganisms that cause PJIs based on patient and implant survival.

Material and Methods

Data were obtained from the LROI and PREZIES. The LROI is the national population-based arthroplasty register of the Netherlands, established by the Netherlands Orthopaedic Association in 2007. In 2012, 100% coverage of Dutch hospitals was achieved, with the completeness of more than 95% of primary THAs and TKAs [10]. Nowadays, completeness of primary and revision hip and knee arthroplasties is reported to be higher than 97% [3]. The LROI contains data on patient, prosthesis, and procedure characteristics, as well as on patient and implant survival.

The PREZIES is the national surveillance system for the incidence of health care-associated infections in the Netherlands, founded in 1996 and coordinated by the National Institute for Public Health and the Environment. The goal of this network is to gain insight into the incidence and prevalence of health care-associated infections using standardized surveillance methods, which result in national reference values. Almost all Dutch hospitals take part in one or more modules of the PREZIES program. In the surgical site infection (SSI) module, hospitals can choose each year to send their data on several surgical procedures, including primary THAs and TKAs, toward PREZIES to keep track of their infections [5,6]. The PREZIES data are owned by the hospital where the procedure was performed. Therefore, approval to use their data was needed from all hospitals delivering data to PREZIES. In total, 52 hospitals (52% of all Dutch hospitals) approved the use of their data in this study. Of these, 85% were general hospitals, 13% were private clinics, and 2% were university medical centers, reflecting the total hospital composition in the Netherlands [3].

In this study, we included all PJIs according to PREZIES (n = 1,648), identified in the combined dataset between the LROI and PREZIES from our previous study [4]. Briefly, in this combined dataset, all primary THAs and TKAs registered in the LROI between January 1, 2012, and December 31, 2018, were case-level matched to all primary THAs and TKAs performed between January 1, 2012, and December 31, 2018, in consenting hospitals in the PREZIES database (n = 171,512). Matching was performed using a unique record-identification created by a Trusted Third Party (ZorgTTP, Houten, the Netherlands) on date of birth, date of surgery, sex, hospital of the primary procedure, and type of procedure (THA or TKA). Patient privacy was ensured, as the combined dataset did not include the date of birth, the date of surgery, or the hospital of the primary procedure. In the combined dataset, the PJI definition of PREZIES was based on the European Center of Disease Prevention and Control criteria for deep SSIs, which have been previously described in detail [11,12]. The incidence of PJIs was 1.2% in THAs and 0.7% in TKAs in the combined dataset

[4]. Detailed information regarding the matching procedure and the dataset has been described previously [4].

Of the 1,648 PJIs, 1,101 occurred in primary THAs and 547 in primary TKAs (Figure 1). The proportion of women was 53% in THA patients and 48% in TKA patients (Table 1). Most THA and TKA patients were diagnosed with osteoarthritis (THA 89%; TKA 94%), were American Society of Anesthesiologists (ASA) class II (THA 60%; TKA 56%), were preobese (THA 34%; TKA 33%), or had obese class 1 (THA 22%; TKA 22%). A total of 353 (32%) THAs and 209 (38%) TKAs were revised within 1 year due to PJI, which is defined as a replacement, removal, or addition of one or more components of the prosthesis (Figure 1).

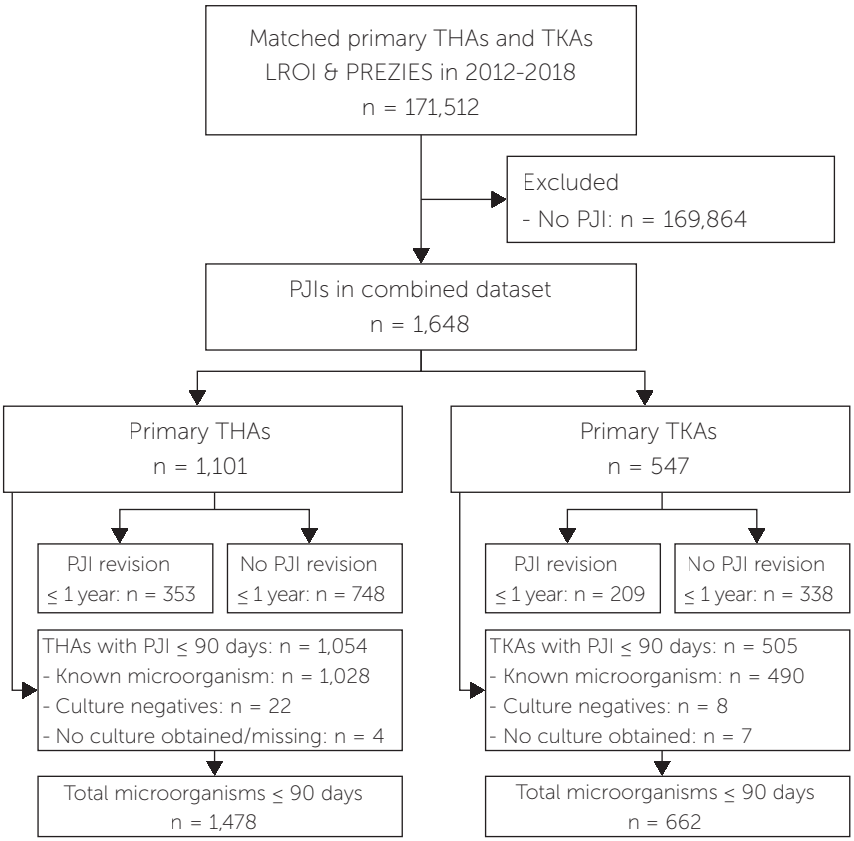


Figure 1. Flowchart.

THA, total hip arthroplasty; TKA, total knee arthroplasty; LROI, Dutch Arthroplasty Register; PREZIES, Dutch National Nosocomial Surveillance Network; PJI, periprosthetic joint infection.

Table 1. Characteristics of Total Hip and Knee Arthroplasties With a Periprosthetic Joint Infection in The Matched Dataset Between the Dutch Arthroplasty Register (LROI) and the Dutch National Nosocomial Surveillance Network (PREZIES).

	Total	THAs	TKAs
Characteristics	n = 1,648	n = 1,101	n = 547
Sex, women (%)	840 (51)	579 (53)	261 (48)
Diagnosis (%)			
Osteoarthritis	1,494 (90)	977 (89)	517 (94)
Fracture	41 (2.5)	41 (3.7)	-
Other	102 (6.2)	74 (6.7)	28 (5.1)
Missing	11 (0.7)	9 (0.8)	2 (0.4)
ASA class (%)			
I	180 (11)	119 (11)	61 (11)
II	971 (59)	665 (60)	306 (56)
III-IV	482 (29)	308 (28)	174 (32)
Missing	15 (0.9)	9 (0.8)	6 (1.1)
Body mass index[a] (kg/m^2) (%)			
Underweight (<18.5)	5 (0.3)	5 (0.5)	0 (0.0)
Normal (18.5 to 24.9)	207 (13)	151 (14)	56 (10)
Preobese (25.0 to 29.9)	555 (34)	375 (34)	180 (33)
Obese class 1 (30.0 to 34.9)	358 (22)	237 (22)	121 (22)
Obese class 2 (35.0 to 39.9)	174 (11)	116 (11)	58 (11)
Obese class 3 (≥40.0)	79 (4.8)	41 (3.7)	38 (6.9)
Missing	270 (16)	176 (16)	94 (17)
Previous surgery at affected joint (%)	165 (10)	19 (1.7)	146 (27)
Missing	57 (3.5)	38 (3.5)	19 (3.5)
Type of fixation (%)			
Cemented	884 (54)	356 (32)	528 (97)
Cementless	611 (37)	597 (54)	14 (2.6)
Hybrid	141 (8.6)	139 (13)	2 (0.4)
Missing	12 (0.7)	9 (0.8)	3 (0.5)

THA, total hip arthroplasty; TKA, total knee arthroplasty; ASA, American Society of Anesthesiologists.
[a] Registered in the Dutch Arthroplasty Register since 2014.

Data on microorganisms in PREZIES originates from the reporting hospitals, which isolated microorganisms from aseptically obtained cultures from deep soft tissues [12]. Microorganisms were assessed in early PJIs (≤90 days), as participation in PREZIES required a mandatory follow-up of one year in 2012 to 2014 and of 90 days in 2015 to 2018. Of the 1,101 PJIs in THAs and 547 PJIs in TKAs, there were 1,054

(96%) THAs and 505 (92%) TKAs with a PJI within 90 days (Figure 1). In these cases, the microorganism responsible for the PJI was known in 1,028 (97%) THAs and 490 (97%) TKAs. Cultures were negative in 22 (2.1%) THAs and 8 (1.6%) TKAs, and no cultures were obtained in 3 (0.3%) THAs and 7 (1.4%) TKAs. In one (0.1%) THA, information about cultures was missing. This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

Data Analyses

Descriptive statistics were used to summarize patient and procedure characteristics, as well as the 10 most frequently registered microorganisms of the first PJI occurring after primary THA and/or TKA. Kaplan-Meier survival analyses were performed to determine cumulative mortality rates, including 95% confidence intervals (CIs), and cumulative PJI re-revision rates following revision for PJI, including CIs. Mortality was defined as the time between primary THA (n = 1,101) or TKA (n = 547) and the death of the patient or the end of follow-up (January 1, 2021). Implant survival was defined as the time between the first revision (ie, replacement, removal, or addition of at least one component) of the THA (n = 353) or TKA (n = 209) within one year for PJI and the first subsequent revision (ie, re-revision) for PJI, death of the patient, or end of follow-up. Re-revisions for reasons other than PJI were censored. The Kaplan-Meier survival analyses included culture-positive PJIs, culture-negative PJIs, as well as PJIs where no cultures were obtained or with missing data about cultures, corresponding with the PREZIES definition of a PJI. A total of 16 cases (THA n = 7; TKA n = 9) were excluded from the Kaplan-Meier survival analyses for PJI re-revision rates, as implant survival time was missing. The 5 most frequently registered microorganisms according to patient and implant survival were presented. All results were stratified by type of procedure. R (version 4.3.1, R Foundation for Statistical Computing, Vienna, Austria) was used to perform all analyses.

Results

Microorganisms

A total of 2,140 microorganisms were registered, of which 1,478 microorganisms were in 1,028 THAs and 662 were in 490 TKAs (Figure 1). One microorganism was found in 700 (68%) THAs and 357 (73%) TKAs, 2 different microorganisms in 206 (20%) THAs and 94 (19%) TKAs, and a maximum of 3 different microorganisms in 122 (12%) THAs and 39 (8.0%) TKAs. The most prevalent microorganism in both THAs and TKAs was *S. aureus* (THA n = 509, 34%; TKA n = 260, 39%), followed by CoNS (THA n = 297, 20%; TKA n = 125, 19%) with *Staphylococcus epidermidis* (THA n = 183, 12%; TKA n = 75,11%) being the most common within the CoNS group, and

Enterococcus species (THA n = 127, 8.6%; TKA n = 39, 5.9%), including *Enterococcus faecium* (THA n = 13; TKA n = 5; Table 2). The full list of registered microorganisms is shown in Appendix Table S1.

Table 2. The 10 Most Frequently Registered Microorganisms in Periprosthetic Joint Infections Within 90 Days in Total Hip and Knee Arthroplasties.

Total hip arthroplasty		Total knee arthroplasty	
Microorganism	n = 1,478	Microorganism	n = 662
Staphylococcus aureus	509 (34)	*Staphylococcus aureus*	260 (39)
Coagulase-negative *staphylococci*	297 (20)	Coagulase-negative *staphylococci*	125 (19)
Of which *Staphylococcus epidermidis*	183 (12)	Of which *Staphylococcus epidermidis*	75 (11)
Enterococcus species	127 (8.6)	*Enterococcus* species	39 (5.9)
Enterobacter cloacae	61 (4.1)	*Streptococcus* species	29 (4.4)
Corynebacterium species	59 (4.0)	*Corynebacterium* species	27 (4.1)
Escherichia coli	50 (3.4)	*Escherichia coli*	18 (2.7)
Proteus mirabilis	39 (2.6)	Group G *streptococci*	16 (2.4)
Pseudomonas aeruginosa	34 (2.3)	*Enterobacter cloacae*	15 (2.3)
Streptococcus species	34 (2.3)	*Pseudomonas aeruginosa*	15 (2.3)
Other	268	Other	118

Values are count (%).

Mortality

The 1-year mortality was 3.2% (CI: 2.3 to 4.4) for THA patients who had a PJI and 3.7% (CI: 2.4 to 5.6) for TKA patients who had a PJI (Figure 2). The 5-year mortality was 15% (CI: 13 to 18) and 18% (CI: 14 to 21) for THA and TKA patients who had a PJI, respectively. In deceased THA patients who had a PJI, *Enterococcus* species (n = 34, 14%) were more often registered as microorganisms responsible for the PJI than *S. epidermidis* (n = 21, 8.5%; Table 3).

Re-revision

In total, 76% of the PJI revisions in THAs and 79% of the PJI revisions in TKAs were partial revisions in which only the modular components (ie, femoral head and/or insert in THAs; polyethylene insert in TKAs) were replaced or removed. The 1-year PJI re-revision rate following PJI revision was 20% (CI: 17 to 25) for THAs and 19% (CI: 14 to 25) for TKAs (Figure 3). The 5-year PJI re-revision rate following PJI revision was 28% (CI: 24 to 34) for THAs and 30% (CI: 24 to 38) for TKAs. No differences appear to be found between microorganisms from revised PJIs with and without PJI re-revision (Table 4).

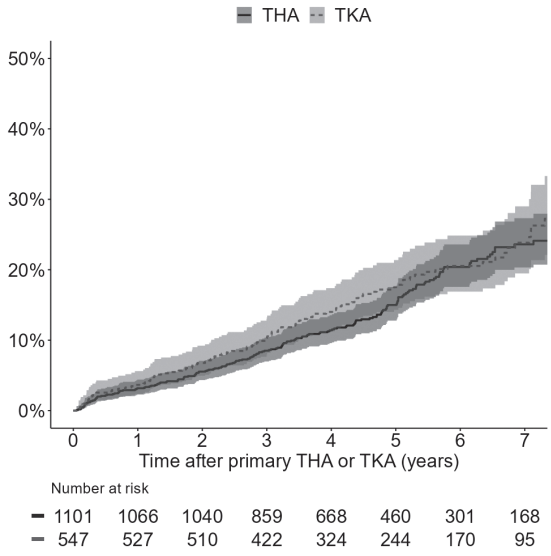


Figure 2. Cumulative mortality rates of patients who have a periprosthetic joint infection in primary total hip (n = 1,101) and knee arthroplasties (n = 547).

THA, total hip arthroplasty; TKA, total knee arthroplasty.

Table 3. The 5 Most Frequently Registered Microorganisms in Periprosthetic Joint Infections in Total Hip and Knee Arthroplasties According to Patient Survival.

Total hip arthroplasty			Total knee arthroplasty		
Microorganism	Alive patients	Deceased patients	Microorganism	Alive patients	Deceased patients
Staphylococcus aureus	431 (35)	78 (32)	*Staphylococcus aureus*	207 (39)	53 (41)
Coagulase-negative *staphylococci*	261 (21)	36 (15)	Coagulase-negative *staphylococci*	107 (20)	18 (14)
Of which *Staphylococcus epidermidis*	162 (13)	21 (8.5)	Of which *Staphylococcus epidermidis*	62 (12)	13 (10)
Enterococcus species	93 (7.6)	34 (14)	*Enterococcus* species	31 (5.8)	8 (6.2)
Enterobacter cloacae	47 (3.8)	14 (5.6)	*Streptococcus* species	26 (4.9)	3 (2.3)

Values are count (%).

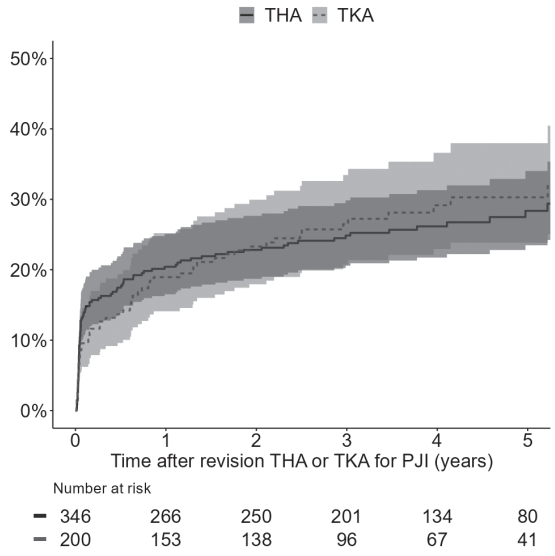


Figure 3. Cumulative re-revision rates due to periprosthetic joint infection following revision due to periprosthetic joint infection of primary total hip (n = 346) and knee (n = 200) arthroplasties.

THA, total hip arthroplasty; TKA, total knee arthroplasty; PJI, periprosthetic joint infection.

Table 4. The 5 Most Frequently Registered Microorganisms in Revised Periprosthetic Joint Infections in Total Hip and Knee Arthroplasties According to Implant Survival.

Total hip arthroplasty			Total knee arthroplasty		
Microorganism	PJI re-revision	No PJI re-revision	Microorganism	PJI re-revision	No PJI re-revision
Staphylococcus aureus	49 (34)	118 (36)	*Staphylococcus aureus*	35 (50)	84 (46)
Coagulase-negative *staphylococci*	32 (22)	56 (17)	Coagulase-negative *staphylococci*	9 (13)	23 (13)
Of which *Staphylococcus epidermidis*	19 (13)	37 (11)	Of which *Staphylococcus epidermidis*	5 (7.1)	13 (7.2)
Enterococcus species	10 (7.0)	26 (7.9)	*Streptococcus* species	5 (7.1)	9 (5.0)
Escherichia coli	3 (2.1)	20 (6.1)	*Enterococcus* species	3 (4.3)	9 (5.0)

Values are count (%). PJI, periprosthetic joint infection.

Discussion

Our study showed that *S. aureus* and CoNS, including *S. epidermidis*, are the most common microorganisms of early PJIs in THAs and TKAs in the Netherlands. In addition, we showed that 15 and 18% of the THA and TKA patients who had a PJI had died within 5 years after the primary THA or TKA, respectively, and more than a quarter of the THA and TKA patients who had a revision due to PJI underwent a second revision due to PJI within 5 years.

Previous studies have shown that early PJIs in THAs and TKAs are mainly caused by *S. aureus* and *S. epidermidis*, which is in accordance with the results of this study [7,13,14]. The microbiological findings in this study are also comparable to those from the Danish Hip Arthroplasty Register [9]. The Danish Hip Arthroplasty Register linked their data to data from the national Danish Microbiology Database and to data from the local electronic laboratory information systems of all clinical microbiological departments in Denmark. They found that *S. aureus* and CoNS are the most common microorganisms in revisions for PJI within one year after primary THA [9].

In contrast, a study from the Norwegian Arthroplasty Register revealed that CoNS caused more revisions for PJI in THAs than *S. aureus* [15]. However, most PJIs were delayed or late-onset, occurring between 3 months and 2 years and more than 2 years after primary THA, respectively. Delayed and late-onset PJIs are more commonly attributed to CoNS [7]. The Australian Orthopaedic Association National Joint Replacement Registry showed that *S. aureus* and β-hemolytic *Streptococci* are the most frequently documented microorganisms of PJIs in primary and revision arthroplasties in Australia [16]. The Australian Orthopaedic Association National Joint Replacement Registry data were combined with data from a prospective cohort study of PJI patients from 22 Australian centers. However, patients who had a chronic PJI as well as patients who had a PJI in the shoulder, elbow, or ankle were also included [16].

In the Netherlands, preoperative administration of cefazolin intravenously is recommended as antibiotic prophylaxis to reduce the risk of SSIs, such as PJIs [17]. Methicillin-susceptible *S. aureus* and *S. epidermidis* are sensitive to cefazolin. However, cefazolin is ineffective against *Enterococcus* species, *Proteus mirabilis*, *Pseudomonas aeruginosa*, and several *Enterobacteriaceae* species, and has limited effectiveness against *Escherichia coli*. Consequently, over 20 and 10% of the PJIs in THAs and TKAs in our study, respectively, were caused by microorganisms with limited or no susceptibility to cefazolin. Further research is warranted to determine

whether the recommended antibiotic prophylaxis is still suitable for reducing the risk of PJIs in the Netherlands.

Mortality was relatively high in this study, as 15 and 18% of the THA and TKA patients who had a PJI, respectively, had died within 5 years after the primary THA or TKA. This is in accordance with a study from the Swedish Arthroplasty Register (SAR), which reported a 5-year mortality rate of 16% after primary TKAs with a PJI within 90 days, but slightly lower than another SAR study, which found a 5-year mortality rate of 21% after primary THAs with a PJI within 2 years [18,19]. Furthermore, the SAR showed an even higher mortality rate of 33% (CI: 32 to 35) after revision of the THA for PJI [20]. However, they concluded that the increased mortality after a PJI is more likely caused by the patient's comorbidity and age than by the PJI itself. In comparison, another study using LROI data found a 5-year mortality rate of 5.8% (CI: 5.6 to 5.9) for primary TKAs performed between 2007 and 2014 [21]. Moreover, the 5-year mortality rates for THA and TKA patients who do not have a PJI in the Netherlands between 2012 and 2018 were 8.2% (CI: 8.0 to 8.4) and 6.6% (CI: 6.4 to 6.8), respectively.

In this study, PJI re-revision rates after PJI revision were 28% for THAs and 30% for TKAs at 5 years of follow-up. This is substantially higher than the 5-year re-revision rates after THA and TKA revisions within one year for any reason, which are 17% (CI: 16 to 18) and 21% (CI: 19 to 22), respectively [3]. The majority of PJI revisions were partial revisions with modular component exchange only, indicating a DAIR procedure. The timing of these procedures may be important, as DAIR procedures performed within 6 weeks after the primary THA or TKA are more likely to be successful [22]. In this study, a small proportion of the DAIR procedures were performed more than 6 weeks after the primary THA (15%) or TKA (21%). Moreover, the effectiveness of a DAIR procedure for *S. aureus* and *enterococci* appears to be less favorable compared to other microorganisms [7,8]. Failed DAIR treatment will result in a second DAIR treatment or in one- or two-stage revision arthroplasty, contributing to higher PJI re-revision rates.

Enterococcus species were more common in deceased THA patients who had a PJI than *S. epidermidis*. Previous studies have shown that PJIs caused by *enterococci* are associated with a higher risk of mortality than PJIs caused by other microorganisms [9,23]. These studies suggest that the higher mortality risk of *enterococci* may be due to their intrinsic antimicrobial resistance to β-lactams. Although *enterococci* may contribute to higher PJI re-revision rates due to the increased risk of DAIR failures [8], there appear to be no differences in the proportions of PJIs caused by *enterococci* treated with re-revision and those

treated without re-revision in the current study. However, the number of PJIs caused by *enterococci* was small.

This study has some potential limitations. In our previous study, approximately 28,000 THAs and TKAs in PREZIES could not be matched to the LROI data, resulting in approximately 300 PJIs that could not be included in the current study [4]. A PJI was defined based on the European Center of Disease Prevention and Control criteria for deep SSIs. Using these criteria rather than the Musculoskeletal Infection Society criteria may result in false positive or false negative PJIs within the combined dataset [24]. Furthermore, PREZIES changed their mandatory follow-up from one year to 90 days in 2015. It was not possible to distinguish between primary THAs and TKAs performed in 2012 to 2014 and 2015 to 2018, as the procedure year was not available in the combined dataset. Consequently, PJIs occurring between 90 days and one year in 2015 to 2018 were missing. Moreover, antibiotic resistance was not taken into account in this study, as the combined dataset did not contain this data. The SSIs due to methicillin-resistant *S. aureus* are associated with an increased risk of mortality compared to the SSIs due to methicillin susceptible *S. aureus* [25]. However, the number of PJIs due to methicillin-resistant *S. aureus* appears to be low in the Netherlands [26]. In addition, patient age and comorbidity, with the exception of ASA class, were not included in the dataset as well, although higher age and comorbidity scores are associated with increased mortality [20]. More THA (28%) and TKA (32%) patients who had a PJI were ASA class III to IV compared to the entire cohort of THA (17%) and TKA (18%) patients between 2012 and 2018, which may partly explain the relatively high mortality rates [4]. Another limitation may be the registration of PJI revisions. In DAIR procedures, it is recommended to exchange all modular components [8]. According to the LROI, DAIR procedures with modular component exchange should be registered as a revision. However, only 64% of the Dutch hospitals register DAIR procedures, whereas modular component exchange is performed by 75 and 82% of the Dutch hospitals in THAs and TKAs, respectively [27]. Therefore, PJI revisions may be underreported in the LROI, which may impact the PJI re-revision rates. Lastly, 16 cases were excluded from the Kaplan-Meier survival analyses, as implant survival time was missing. Of these, only one THA had a PJI re-revision. Therefore, the impact of the excluded cases on the PJI re-revision rates seems limited.

In conclusion, *Staphylococcus aureus* and CoNS, including *Staphylococcus epidermidis*, are responsible for more than half of the early PJIs in THAs and TKAs in the Netherlands. Both 5-year mortality rates and PJI re-revision rates following PJI revision are relatively high.

References

[1] Zmistowski B, Karam JA, Durinka JB, Casper DS, Parvizi J. Periprosthetic joint infection increases the risk of one-year mortality. J Bone Joint Surg Am 2013;95(24):2177-84. https://doi.org/10.2106/JBJS.L.00789.

[2] Kuijpers MFL, Hannink G, van Steenbergen LN, Schreurs BW. Outcome of revision hip arthroplasty in patients younger than 55 years: an analysis of 1,037 revisions in the Dutch Arthroplasty Register. Acta Orthop 2020;91(2):165-70. https://doi.org/10.1080/17453674.2019.1708655.

[3] LROI. Annual report 2023. Landelijke Registratie Orthopedische Interventies; 2023. Available from: https://www.lroi.nl/media/bjge0yfe/pdf-lroi-annual-report-2023-1-gecomprimeerd.pdf.

[4] van Veghel MHW, Belt M, Spekenbrink-Spooren A, Kuijpers MFL, van der Kooi TII, Schreurs BW, Hannink G. Validation of the Incidence of Reported Periprosthetic Joint Infections in Total Hip and Knee Arthroplasty in the Dutch Arthroplasty Register. J Arthroplasty 2024;39(4):1054-9. https://doi.org/10.1016/j.arth.2023.10.040.

[5] Mannien J, Wille JC, Snoeren RL, van den Hof S. Impact of postdischarge surveillance on surgical site infection rates for several surgical procedures: results from the nosocomial surveillance network in The Netherlands. Infect Control Hosp Epidemiol 2006;27(8):809-16. https://doi.org/10.1086/506403.

[6] Koek MB, Wille JC, Isken MR, Voss A, van Benthem BH. Post-discharge surveillance (PDS) for surgical site infections: a good method is more important than a long duration. Euro Surveill 2015;20(8). https://doi.org/10.2807/1560-7917.es2015.20.8.21042.

[7] Tande AJ, Patel R. Prosthetic joint infection. Clin Microbiol Rev 2014;27(2):302-45. https://doi.org/10.1128/CMR.00111-13.

[8] Argenson JN, Arndt M, Babis G, Battenberg A, Budhiparama N, Catani F, Chen F, de Beaubien B, Ebied A, Esposito S, Ferry C, Flores H, Giorgini A, Hansen E, Hernugrahanto KD, Hyonmin C, Kim TK, Koh IJ, Komnos G, Lausmann C, Loloi J, Lora-Tamayo J, Lumban-Gaol I, Mahyudin F, Mancheno-Losa M, Marculescu C, Marei S, Martin KE, Meshram P, Paprosky WG, Poultsides L, Saxena A, Schwechter E, Shah J, Shohat N, Sierra RJ, Soriano A, Stefansdottir A, Suleiman LI, Taylor A, Triantafyllopoulos GK, Utomo DN, Warren D, Whiteside L, Wouthuyzen-Bakker M, Yombi J, Zmistowski B. Hip and Knee Section, Treatment, Debridement and Retention of Implant: Proceedings of International Consensus on Orthopedic Infections. J Arthroplasty 2019;34(2S):S399-S419. https://doi.org/10.1016/j.arth.2018.09.025.

[9] Gundtoft PH, Pedersen AB, Varnum C, Overgaard S. Increased Mortality After Prosthetic Joint Infection in Primary THA. Clin Orthop Relat Res 2017;475(11):2623-31. https://doi.org/10.1007/s11999-017-5289-6.

[10] van Steenbergen LN, Denissen GA, Spooren A, van Rooden SM, van Oosterhout FJ, Morrenhof JW, Nelissen RG. More than 95% completeness of reported procedures in the population-based Dutch Arthroplasty Register. Acta Orthop 2015;86(4):498-505. https://doi.org/10.3109/17453674.2015.1028307.

[11] ECDC. Surveillance of surgical site infections and prevention indicators in European hospitals - HAI-Net SSI protocol, version 2.2. European Centre for Disease Prevention and Control; 2017. Available from: https://www.ecdc.europa.eu/sites/default/files/documents/HAI-Net-SSI-protocol-v2.2.pdf.

[12] PREZIES. Case definitions of Surgical Site Infections (SSIs) in the PREZIES Surveillance. National Institute for Public Health and the Environment; 2020. Available from: https://www.rivm.nl/documenten/case-definitions-ssis.

[13] Lima AL, Oliveira PR, Carvalho VC, Saconi ES, Cabrita HB, Rodrigues MB. Periprosthetic joint infections. Interdiscip Perspect Infect Dis 2013;2013:542796. https://doi.org/10.1155/2013/542796.

[14] Villa JM, Pannu TS, Theeb I, Buttaro MA, Onativia JI, Carbo L, Rienzi DH, Fregeiro JI, Kornilov NN, Bozhkova SA, Sandiford NA, Piuzzi NS, Higuera CA, Kendoff DO. International Organism Profile of Periprosthetic Total Hip and Knee Infections. J Arthroplasty 2021;36(1):274-8. https://doi.org/10.1016/j.arth.2020.07.020.

[15] Langvatn H, Lutro O, Dale H, Schrama JC, Hallan G, Espehaug B, Sjursen H, Engesaeter LB. Bacterial and Hematological Findings in Infected Total Hip Arthroplasties in Norway Assessment of 278 Revisions Due to Infection in the Norwegian Arthroplasty Register. Open Orthop J 2015;9:445-9. https://doi.org/10.2174/1874325001509010445.

[16] Sinagra ZP, Davis JS, Lorimer M, de Steiger RN, Graves SE, Yates P, Manning L. The accuracy of reporting of periprosthetic joint infection to the Australian Orthopaedic Association National Joint Replacement Registry. Bone Jt Open 2022;3(5):367-73. https://doi.org/10.1302/2633-1462.35.BJO-2022-0011.R1.

[17] van Kasteren ME, Gyssens IC, Kullberg BJ, Bruining HA, Stobberingh EE, Goris RJ. Optimizing antibiotics policy in the Netherlands. V. SWAB guidelines for perioperative antibiotic prophylaxis. Foundation Antibiotics Policy Team. Ned Tijdschr Geneeskd 2000;144(43):2049-55.

[18] Thompson O, A WD, Stefansdottir A. Increased short- and long-term mortality amongst patients with early periprosthetic knee joint infection. BMC Musculoskelet Disord 2022;23(1):1069. https://doi.org/10.1186/s12891-022-06024-y.

[19] Wildeman P, Rolfson O, Soderquist B, Wretenberg P, Lindgren V. What Are the Long-term Outcomes of Mortality, Quality of Life, and Hip Function after Prosthetic Joint Infection of the Hip? A 10-year Follow-up from Sweden. Clin Orthop Relat Res 2021;479(10):2203-13. https://doi.org/10.1097/CORR.0000000000001838.

[20] Persson A, Skoldenberg O, Mohaddes M, Eisler T, Gordon M. Increased mortality after total hip prosthetic joint infection is mainly caused by the comorbidities rather than the infection itself. Acta Orthop 2023;94:484-9. https://doi.org/10.2340/17453674.2023.18619.

[21] Quispel CR, van Egmond JC, Bruin MM, Spekenbrink-Spooren A, Verburg H, Pasma JH. No effect of fixation type on early and late mortality after total knee arthroplasty: a Dutch arthroplasty register study. Knee Surg Sports Traumatol Arthrosc 2022;30(4):1231-8. https://doi.org/10.1007/s00167-021-06552-5.

[22] Zijlstra WP, Ploegmakers JJW, Kampinga GA, Toren-Wielema ML, Ettema HB, Knobben BAS, Jutte PC, Wouthuyzen-Bakker M, Northern Infection Network for Joint A. A protocol for periprosthetic joint infections from the Northern Infection Network for Joint Arthroplasty (NINJA) in the Netherlands. Arthroplasty 2022;4(1):19. https://doi.org/10.1186/s42836-022-00116-9.

[23] Fischbacher A, Borens O. Prosthetic-joint Infections: Mortality Over The Last 10 Years. J Bone Jt Infect 2019;4(4):198-202. https://doi.org/10.7150/jbji.35428.

[24] Parvizi J, Tan TL, Goswami K, Higuera C, Della Valle C, Chen AF, Shohat N. The 2018 Definition of Periprosthetic Hip and Knee Infection: An Evidence-Based and Validated Criteria. J Arthroplasty 2018;33(5):1309-14 e2. https://doi.org/10.1016/j.arth.2018.02.078.

[25] Engemann JJ, Carmeli Y, Cosgrove SE, Fowler VG, Bronstein MZ, Trivette SL, Briggs JP, Sexton DJ, Kaye KS. Adverse clinical and economic outcomes attributable to methicillin resistance among patients with Staphylococcus aureus surgical site infection. Clin Infect Dis 2003;36(5):592-8. https://doi.org/10.1086/367653.

[26] Espindola R, Vella V, Benito N, Mur I, Tedeschi S, Zamparini E, Hendriks JGE, Sorli L, Murillo O, Soldevila L, Scarborough M, Scarborough C, Kluytmans J, Ferrari MC, Pletz MW, McNamara I, Escudero-Sanchez R, Arvieux C, Batailler C, Dauchy FA, Liu WY, Lora-Tamayo J, Praena J, Ustianowski A, Cinconze E, Pellegrini M, Bagnoli F, Rodriguez-Bano J, Del-Toro-Lopez MD, Group A-I. Incidence, associated disease burden and healthcare utilization due to Staphylococcus aureus prosthetic joint infection in European hospitals: the COMBACTE-NET ARTHR-IS multi-centre study. J Hosp Infect 2023;142:9-17. https://doi.org/10.1016/j.jhin.2023.09.012.

[27] Veltman ES, Moojen DJF, Nelissen RG, Poolman RW. Antibiotic Prophylaxis and DAIR Treatment in Primary Total Hip and Knee Arthroplasty, A National Survey in The Netherlands. J Bone Jt Infect 2018;3(1):5-9. https://doi.org/10.7150/jbji.20259.

Appendix

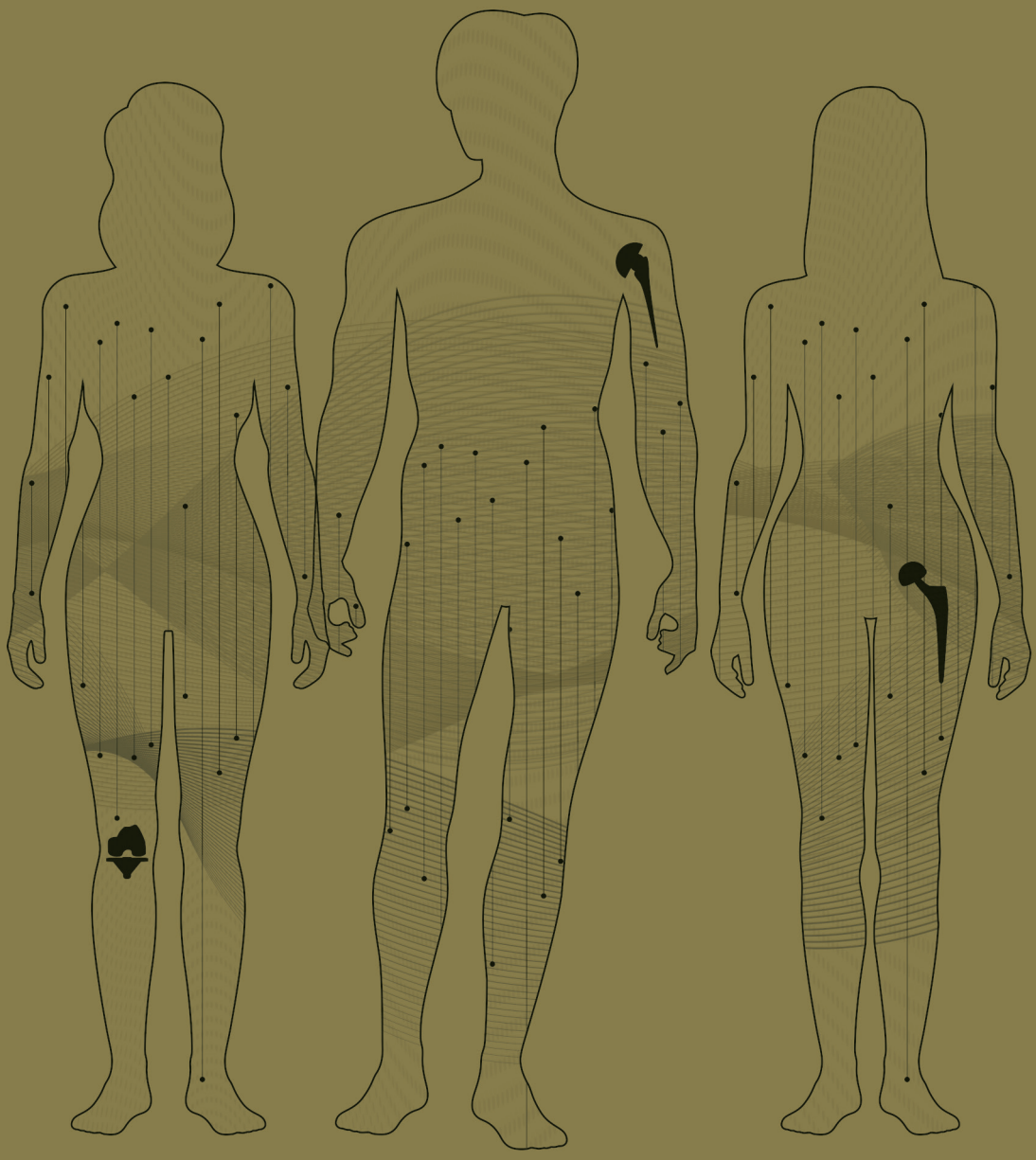
Appendix Table S1. All Registered Microorganisms in Periprosthetic Joint Infections Within 90 Days in Total Hip and Knee Arthroplasties.

	Total	THA	TKA
Microorganism	n = 2,140	n = 1,478	n = 662
Staphylococcus aureus	769 (36)	509 (34)	260 (39)
Coagulase-negative *staphylococci*	422 (20)	297 (20)	125 (19)
Of which *Staphylococcus epidermidis*	258 (12)	183 (12)	75 (11)
Enterococcus species	166 (7.8)	127 (8.6)	39 (5.9)
Corynebacterium species	86 (4.0)	59 (4.0)	27 (4.1)
Enterobacter cloacae	76 (3.6)	61 (4.1)	15 (2.3)
Escherichia coli	68 (3.2)	50 (3.4)	18 (2.7)
Streptococcus species	63 (2.9)	34 (2.3)	29 (4.4)
Proteus mirabilis	52 (2.4)	39 (2.6)	13 (2.0)
Pseudomonas aeruginosa	49 (2.3)	34 (2.3)	15 (2.3)
Group B *streptococci (S. agalactiae*)	43 (2.0)	33 (2.2)	10 (1.5)
Group G *streptococci*	39 (1.8)	23 (1.6)	16 (2.4)
Group B *streptococci*	32 (1.5)	20 (1.4)	12 (1.8)
Group C *streptococci*	28 (1.3)	22 (1.5)	6 (0.9)
Serratia marcescens	27 (1.3)	22 (1.5)	5 (0.8)
Klebsiella pneumoniae	20 (0.9)	18 (1.2)	2 (0.3)
Propioni species (*Cutibacterium*)	19 (0.9)	16 (1.1)	3 (0.5)
Polymicrobial	18 (0.8)	11 (0.7)	7 (1.1)
Streptococcus equisimilis (Group C G)	16 (0.7)	12 (0.8)	4 (0.6)
Klebsiella oxytoca	14 (0.7)	11 (0.7)	3 (0.5)
Group A *streptococci*	10 (0.5)	3 (0.2)	7 (1.1)
Morganella species	10 (0.5)	8 (0.5)	2 (0.3)
Group A *streptococci* (*S. pyogenes*)	8 (0.4)	6 (0.4)	2 (0.3)
Enterobacter species	7 (0.3)	5 (0.3)	2 (0.3)
Propioni species	7 (0.3)	3 (0.2)	4 (0.6)
Aerococcus species	6 (0.3)	2 (0.1)	4 (0.6)
Clostridium perfringens	6 (0.3)	3 (0.2)	3 (0.5)
Enterobacter aerogenes	6 (0.3)	4 (0.3)	2 (0.3)
Micrococcus species	6 (0.3)	4 (0.3)	2 (0.3)
Peptostreptococcus species	6 (0.3)	2 (0.1)	4 (0.6)
Citrobacter koseri	5 (0.2)	3 (0.2)	2 (0.3)
Bacillus species	4 (0.2)	3 (0.2)	1 (0.2)

Appendix Table S1. Continued.

	Total	THA	TKA
Microorganism	n = 2,140	n = 1,478	n = 662
Bacteroides species	4 (0.2)	1 (0.1)	3 (0.5)
Mycoplasma hominis	4 (0.2)	4 (0.3)	0 (0.0)
Acinetobacter baumannii	3 (0.1)	3 (0.2)	0 (0.0)
Acinetobacter species	3 (0.1)	3 (0.2)	0 (0.0)
Actinomyces species	3 (0.1)	2 (0.1)	1 (0.2)
Lactobacillus species	3 (0.1)	2 (0.1)	1 (0.2)
Proteus vulgaris	3 (0.1)	3 (0.2)	0 (0.0)
Prevotella species	3 (0.1)	1 (0.1)	2 (0.3)
Actinobaculum schaalii	2 (0.1)	2 (0.1)	0 (0.0)
Candida albicans	2 (0.1)	2 (0.1)	0 (0.0)
Rothia species	2 (0.1)	1 (0.1)	1 (0.2)
Stenotrophomonas species	2 (0.1)	1 (0.1)	1 (0.2)
Dermabacter hominis	2 (0.1)	1 (0.1)	1 (0.2)
Arthrobacter species	1 (0.0)	1 (0.1)	0 (0.0)
Brevibacterium species	1 (0.0)	1 (0.1)	0 (0.0)
Citrobacter species	1 (0.0)	1 (0.1)	0 (0.0)
Eikenella species	1 (0.0)	0 (0.0)	1 (0.2)
Haemophilus influenzae	1 (0.0)	1 (0.1)	0 (0.0)
Listeria monocytogenes	1 (0.0)	0 (0.0)	1 (0.2)
Streptobacillus	1 (0.0)	1 (0.1)	0 (0.0)
Streptococcus equi	1 (0.0)	0 (0.0)	1 (0.2)
Arcanobacterium haemolyticum	1 (0.0)	0 (0.0)	1 (0.2)
Mycobacterium flavescens	1 (0.0)	0 (0.0)	1 (0.2)
Neisseria species	1 (0.0)	1 (0.1)	0 (0.0)
Pasteurella species	1 (0.0)	0 (0.0)	1 (0.2)
Pseudomonas species	1 (0.0)	0 (0.0)	1 (0.2)
Rhodococcus species	1 (0.0)	1 (0.1)	0 (0.0)
Haemophilus species	1 (0.0)	0 (0.0)	1 (0.2)
Microbacterium species	1 (0.0)	1 (0.1)	0 (0.0)

Values are count (%). THA, total hip arthroplasty; TKA, total knee arthroplasty.



7

Survival of cemented short Exeter femoral components in primary total hip arthroplasty: an analysis of 394 femoral components in total hip arthroplasties undertaken between 1993 and 2021

MHW van Veghel
RE van der Koelen
G Hannink
BW Schreurs
WHC Rijnen

The Bone & Joint Journal 2024; 106-B(3 Supple A): 137–142

Abstract

Aims: The aim of this study was to report the long-term follow-up of cemented short Exeter femoral components when used in primary total hip arthroplasty (THA).

Methods: We included all primary 394 THAs with a cemented short Exeter femoral component (≤ 125 mm) used in our tertiary referral centre between October 1993 and December 2021. A total of 83 patients (21%) were male. The median age of the patients at the time of surgery was 42 years (interquartile range (IQR) 30 to 55). The main indication for THA was a childhood hip disease (202; 51%). The median follow-up was 6.7 years (IQR 3.1 to 11.0). Kaplan-Meier survival analyses were performed to determine the rates of survival with femoral revision for any indication, for septic loosening, for fracture of the femoral component and for aseptic loosening as endpoints. The indications for revision were evaluated. Fractures of the femoral component were described in detail.

Results: The 20-year rate of survival was 85.4% (95% confidence interval (CI) 73.9 to 92.0) with revision for any indication, 96.2% (95% CI 90.5 to 98.5) with revision for septic loosening and 92.7% (95% CI 78.5 to 97.6) with revision for fracture of the femoral component. No femoral components were revised for aseptic loosening. There were 21 revisions of the femoral component; most (seven) as part of a two-stage management of infection. Fracture of the femoral component occurred in four THAs (1.0%) at 6.6, 11.6, 16.5, and 18.2 years of follow-up, respectively. Three of these were transverse fractures and occurred at the level of the lesser trochanter. In one THA, there was a fracture of the neck of the component.

Conclusion: THAs using cemented short Exeter femoral components showed acceptable rates of survival of the femoral component at long-term follow-up, in this young cohort of patients. Although fracture is a rare complication of these components, surgeons should be aware of their incidence and possible risk factors.

Introduction

The Exeter femoral component (Stryker, UK) is a commonly used cemented femoral component [1-3]. It was designed in 1969 by Robin Ling and Clive Lee [4]. The current standard Exeter Universal V40 femoral component is made of Orthinox stainless steel, polished and double-tapered, is 150 mm long, and available in different-sized offsets, ranging from 37.5 mm to 56 mm.

Shorter Exeter femoral components also became available to reconstruct leg length and offset independently in smaller femora or in patients with abnormal anatomy of the hip as in those with developmental dysplasia of the hip (DDH). The number of available short Exeter femoral components was later extended, with some designed for the Asian market in which patients are considerably smaller [5]. In 2006, the so-called 'Short Revision Stem' (SRS) was introduced for cement-in-cement revisions, fitting the original cement mantles better. However, it is also known for its off-label use in primary total hip arthroplasty (THA) for patients with a narrow femoral canal and a relatively large offset [6]. In 2014, an additional range of short femoral components became available, with different offsets for Dorr type A femora with a narrow intramedullary canal and larger offsets, intended to be used in primary THA [7]. Currently, there are seven cemented short Exeter femoral components on the market with a length of between 95 mm and 125 mm and in different offsets, ranging from 30 mm to 50 mm.

The use of short femoral components has recently become more prevalent in uncemented THAs, with revision rates and improvements in functional outcome similar to those of conventional femoral components at short- and mid-term follow-up [8-11]. However, studies reporting on the outcome of cemented short femoral components often have limited sample size or follow-up [6,7,12,13]. There are some concerns that these components may have inferior long-term outcomes and higher rates of fracture, especially in obese patients [14-18]. The aim of this study, therefore, was to evaluate the long-term outcome of the seven types of cemented short Exeter femoral components used in primary THA.

Methods

In this retrospective cohort study, we included all 333 patients who underwent 394 primary THAs with one of these types of components, whose length was ≤ 125 mm, in our tertiary referral centre between October 1993 and December 2021. In approximately 7% (394) of our primary THAs performed between 1993 and 2021,

we used a cemented short Exeter femoral component. These components are mainly used in small patients, and often in younger patients with a narrow femoral canal and a relatively large offset, or in those with anatomical abnormalities. Two THAs undertaken for tumour were excluded. Data were retrieved from our electronic patient records, obtained during routine care and follow-up. Data from the Dutch Arthroplasty Register (LROI) were used to complete and cross-check our data. The study had institutional ethical approval (NL2022-15846).

A total of 83 patients (21%) were male and the median age of the patients at the time of surgery was 42 years (interquartile range (IQR) 30 to 55) (Table 1). The main indication for THA was a childhood hip disease (202; 51%), followed by primary osteoarthritis (OA) (100; 25%) and avascular necrosis (27; 6.9%). Almost half of the patients had an American Society of Anesthesiologists (ASA) [19] grade of II (186; 47%). Most patients had a normal (18.5 kg/m^2 to 24.9 kg/m^2; 102; 26%) or pre-obese (25.0 kg/m^2 to 29.9 kg/m^2; 58; 15%) BMI. The most commonly used offsets were 35.5 mm (178; 45%) and 44 mm (90; 23%) SRS. The femoral head was 28 mm in diameter in most patients (217; 55%). In 154 THAs (39%), previous hip surgery had been performed. The median follow-up after THA was 6.7 years (IQR 3.1 to 11.0).

All THAs were performed by senior surgeons, using the posterolateral approach and a cemented acetabular component with a third-generation cementing technique using vacuum-mixed Simplex cement. The acetabular components included the Contemporary Flanged (Stryker; 186, 47%), X3 RimFit (Stryker; 140, 36%), Contemporary Hooded (Stryker; 24, 6.1%), Avantage Dual-mobility (Zimmer Biomet, USA; 16, 4.1%), Elite Plus LPW (DePuy Synthes, USA; 10, 2.6%), Mueller polyethylene cup (Centerpulse, Switzerland; 7, 1.8%), Exeter RSA (Stryker; 4, 1.0%), Howmedica CDH (Stryker; 4, 1.0%), and Trident Crossfire constrained cup (Stryker; 1, 0.3%). This information was missing for two THAs. All had a metal-on-polyethylene bearing. All patients received cefazoline antibiotics preoperatively and DVT prophylaxis with low-molecular weight heparin for six weeks. A non-steroidal anti-inflammatory drug was given for seven days to prevent heterotopic ossification.

Statistical analysis

Descriptive statistics were used to summarize the characteristics of the patients, prostheses, and procedures. Kaplan-Meier survival analyses were performed to determine one-, ten-, and 20-year survival rates, including 95% confidence intervals (CIs). Endpoints were femoral revision for any indication, femoral revision for septic loosening, femoral revision for fracture of the femoral component, and femoral revision for aseptic loosening. Revision was defined as the replacement or removal of the femoral component. Survival was calculated as the time from THA to the first

Table 1. The characteristics of the patients and prostheses for 394 total hip arthroplasties using a cemented short Exeter femoral component.

Variable	Value
Sex, n (%)	
Male	83 (21)
Female	311 (79)
Median age, yrs (IQR)	42 (30 to 55)
Diagnosis, n (%)	
Primary osteoarthritis	100 (25)
Secondary osteoarthritis	
Childhood hip diseases	202 (51)
Avascular necrosis	27 (6.9)
Inflammatory	20 (5.1)
Congenital	12 (3.0)
Trauma	12 (3.0)
Infection	7 (1.8)
Other	14 (3.6)
ASA grade, n (%)	
I	144 (37)
II	186 (47)
III or IV	50 (13)
Missing	14 (3.6)
BMI, n (%)	
< 18.5 kg/m^2	10 (2.5)
18.5 to 24.9 kg/m^2	102 (26)
25.0 to 29.9 kg/m^2	58 (15)
30.0 to 34.9 kg/m^2	33 (8.4)
35.0 to 39.9 kg/m^2	10 (2.5)
≥ 40.0 kg/m^2	2 (0.5)
Missing	179 (45)
Offset and length, n (%)	
30 and 95 mm	18 (4.6)
33 and 115 mm	36 (9.1)
35.5 and 125 mm	178 (45)
37.5 and 125 mm	30 (7.6)
44 and 125 mm (Short Revision Stem)	90 (23)
44 and 125 mm	23 (5.8)
50 and 125 mm	19 (4.8)
Femoral head size, n (%)	
22 mm	52 (13)
28 mm	217 (55)
32 mm	125 (32)
Previous hip surgery, n (%)	154 (39)
Missing	1 (0.3)

ASA, American Society of Anesthesiologists; IQR, interquartile range.

revision, the death of the patient, or to the final follow-up. Final follow-up was defined as the patient's most recent outpatient visit up to 1 January 2022. Patients were considered lost to follow-up if their most recent outpatient visit was > five years ago (27; 6.9%). In these cases, the last outpatient visit was used as the end of follow-up at which time patients were censored in the Kaplan-Meier survival analyses. The indications for any revision occurring before the end of the study period on 1 January 2022 were evaluated. These included revisions of at least the femoral and/or acetabular component. The indications for revision were obtained from the hospital's electronic records. Fractures of the femoral component were described in detail. Analyses were performed using R v. 4.2.0 (R Foundation for Statistical Computing, Austria).

Results

The rate of survival with femoral revision for any indication as the endpoint was 98.7% (95% CI 96.9 to 99.5) at one-year follow-up, 93.4% (95% CI 89.2 to 96.0) at ten-year follow-up, and 85.4% (95% CI 73.9 to 92.0) at 20-year follow-up (Figure 1a). The one-, ten-, and 20-year rates of survival for septic loosening were 99.5% (95% CI 97.9 to 99.9), 97.8% (95% CI 94.9 to 99.0), and 96.2% (95% CI 90.5 to 98.5), respectively (Figure 1b). The rates of survival for fracture of the femoral component were 100% (95% CI 100 to 100) at one-year follow-up, 99.5% (95% CI 96.4 to 99.9) at ten-year follow-up, and 92.7% (95% CI 78.5 to 97.6) at 20-year follow-up (Figure 1c). No femoral components were revised for aseptic loosening. There were 21 femoral revisions (5.3%), most as part of two-stage surgery for infection (n = 7; 1.8%) (Table 2).

A fracture of the femoral component occurred in four THAs (1.0%) at 6.6, 11.6, 16.5, and 18.2 years of follow-up. In three of these THAs, a 35.5 mm offset was used and in one THA a 44 mm offset SRS was used. The BMI of three of the patients was 21.1 kg/m^2, 25.3 kg/m^2, and 34.7 kg/m^2 at the time of surgery, and in one the BMI was missing. Three fractures of the femoral component were transverse fractures at the level of the lesser trochanter, all in those with a 35.5 mm offset (Figure 2). At revision, in two of these patients another short femoral component with the same offset was used in view of the narrow femoral canal. None of these two revised femoral components fractured again, with a maximum follow-up of 11 years after revision. The other fractured femoral component with a 35.5 mm offset occurred 18.2 years after surgery. The patient had undergone conversion of a previously fused hip following septic arthritis and remained poorly mobile after the initial procedure. Progressive proximal femoral osteolysis developed with the passage of time,

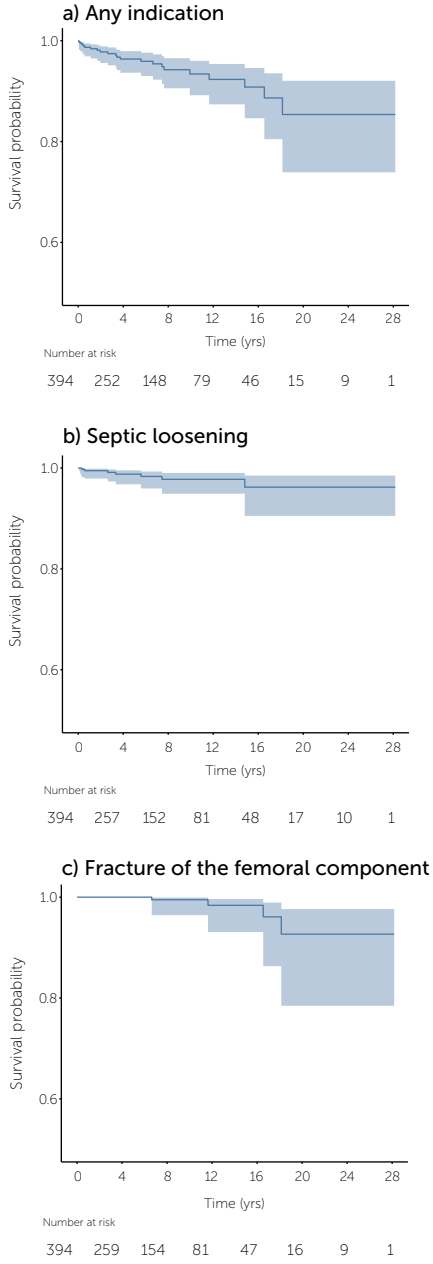


Figure 1. Rates of survival for femoral revision (**a**) for any indication, (**b**) for septic loosening, and (**c**) for fracture of the femoral component in 394 total hip arthroplasties with a cemented short Exeter femoral component.

Table 2. The indication for revision for 31 of 394 total hip arthroplasties with a cemented short Exeter femoral component, stratified by component.

Indication	Total	Acetabular component	Femoral component	Acetabular and femoral component
Total, n	31	10	8	13
Aseptic acetabular loosening	10	8	0	2
Deep infection	7	0	0	7
Dislocation	5	2	2	1
Fracture of the femoral component	4	0	3	1
Periprosthetic fracture	3	0	2	1
Ischiofemoral impingement	1	0	1	0
Unknown	1	0	0	1

resulting in a high load on the distally still fixed component leading to its fracture. As the patient still had a stiff hip after the THA, he preferred to undergo a resection arthroplasty. In one THA, there was a fracture of the neck of a 44 mm Exeter SRS after 11.6 years. In retrospect, the component was undersized in the primary THA, as it was used in a patient with a BMI of 34.7 kg/m^2. A standard-length component was used at the revision procedure.

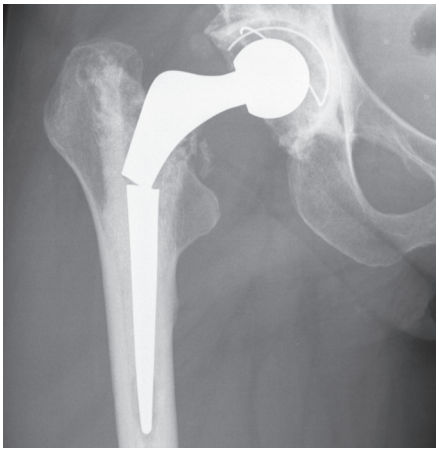


Figure 2. Typical example in anteroposterior view of a transverse fracture of a femoral component in a 47-year-old female patient, 6.6 years postoperatively. The distal part of the component is still stable and well fixed.

Discussion

We found that cemented short Exeter femoral components used in primary THA have acceptable survival rates for revision for any reason, revision for septic loosening and revision for aseptic loosening at long-term follow-up, in a relatively young cohort of patients. Although rare, fractures of the femoral component occur in these short femoral components; the rate of these fractures was 1.0%.

There have been case reports describing fractures of short Exeter femoral components [20,21]. However, favourable rates of survival have been reported with revision for any indication and for aseptic loosening as the endpoint of THAs using these components at mid-term follow-up. In 2009, a study including 47 cemented short Exeter femoral components in Malaysian patients reported a ten-year rate of survival with revision for any indication of 96% (95% CI 82 to 99). There were no revisions for aseptic loosening [12]. Both outcomes were similar to those of the current study. Another study examined the off-label use of the Exeter SRS in 33 primary THAs [6]. Overall survival at five-year follow-up was 96.7% with revision for any indication as the endpoint, and 100% for aseptic femoral loosening. Compared with our findings, however, there were no fractures of the femoral component in either of these previous studies. This may be explained by their limited sample size and short follow-up, as fractures of the femoral component are a rare complication occurring at mid- to long-term follow-up, as we found.

Registry studies dealing with THAs that use cemented short Exeter femoral components have shown contrasting results. A study from the Australian Orthopaedic Association National Joint Replacement Registry showed similar seven-year rates of survival between 1,898 cemented short Exeter femoral components with offsets of ≤ 35.5 mm (96.6%, 95% CI 95.2 to 97.6) and nearly 40,000 standard length Exeter femoral components (96.5%, 95% CI 96.2 to 96.7) [13]. A study from the New Zealand National Joint Registry examined the survival of 1,501 short Exeter femoral components with offsets of ≤ 35.5 mm, 657 short Exeter femoral components with offsets of ≥ 37.5 mm, and 41,260 standard length Exeter femoral components [16]. There was a higher risk for revision for aseptic femoral loosening with short Exeter femoral components with offsets of ≤ 35.5 mm compared with those of a standard length (hazard ratio (HR) 2.7 (95% CI 2.0 to 3.6)). Short Exeter femoral components with offsets of ≥ 37.5 mm and standard length Exeter femoral components had a comparable risk of revision for aseptic femoral loosening (HR 0.7 (95% CI 0.3 to 1.6)). It is not possible to compare the results of the registry studies with our findings, as the registries used revision of any component as the endpoint.

Although fracture of the femoral component is a rare complication of these components, it has been reported that fractures of the femoral component were more common with the shorter Exeter components than with other Exeter components [15,17]. The combination of patient-, prothesis-, and procedure-related characteristics may contribute to these fractures [15]. Orthopaedic surgeons should bear in mind the fact that BMI has the largest effect on the peak stress of the proximal cement mantle [22]. Thus, Harrington et al [22] advised not to use cemented short femoral components in overweight patients with narrow medullary canals. Unfortunately, from a practical point of view, in some overweight patients with a narrow canal these short femoral components are the only ones that fit. In our institution, we try to avoid using shorter femoral components in overweight patients. The femoral canal is sometimes also narrow in younger patients, and a combination of a short femoral component in an active young patient is theoretically unattractive. It was recently reported in a randomized control trial that short Exeter femoral components were associated with an increased rate of varus malalignment [23]. Whether this will affect future implant survival remains unclear. However, we found an acceptable 20-year rate of femoral survival of 85.4% for any indication and no aseptic loosening. Furthermore, alternatives are limited, as uncemented femoral components are also often difficult to insert in these patients.

As in most series involving primary THAs, the most common indication for revision was aseptic acetabular loosening. Ten of 394 THAs (2.5%) were revised for this indication. As more than half of the patients who underwent THA in this study had a childhood hip disease, which affects the acetabular bone stock, as the initial indication for surgery, we believe that this number of aseptic acetabular loosenings is acceptable.

The study has limitations. Firstly, the median follow-up was 6.7 years, and thus a limited number of at-risk THAs were available at follow-up of 20 years. Consequently, some uncertainty surrounds our findings as the CIs were wide. The generalizability of our findings may also be limited as all THAs were performed in one centre, which is a tertiary referral centre in which more complicated THAs are performed than in many general hospitals or private clinics. This may adversely affect the survival of the cemented short Exeter femoral components in our study. Most of our patients (79%) were female, which may be explained by the fact that nearly half of the patients had DDH as the initial indication for surgery [24]. In addition, the patients were relatively young. Therefore, these results cannot be generalized to most patients with OA. Another limitation may be the missing data on BMI (45%), as an increased BMI is a risk factor for fracture of the femoral component [14-17]. BMI was not reported in the patients' records in the early years of the study. However, recent

studies suggest that short Exeter femoral components can be used in patients with Dorr type A femora, and in overweight patients [18,25]. It is, nevertheless, important to note that the use of the 44 mm SRS is contraindicated in overweight patients, as this component is narrower as it was originally designed for revision cement-in-cement procedures. Lastly, it was not possible to stratify the outcomes by the type of cemented short Exeter femoral component, as the subgroups were too small to perform meaningful analyses.

To our knowledge, this is the first study reporting the long-term follow-up of cemented short Exeter femoral components in primary THA in a relatively young cohort of patients. Although follow-up was longer than 20 years, less than 7% of the patients were lost to follow-up.

In conclusion, this series of 394 THAs with a cemented short Exeter femoral component in 333 patients showed acceptable survival rates with femoral revision for any indication, and for fracture of the femoral component, at ten and 20 years of follow-up, despite the relatively young age of the patients. This indicates that these components are acceptable for use in primary THA. Although fractures of the femoral component are a rare complication, surgeons should be aware of their incidence and possible risk factors.

References

[1] AOANJRR. Hip, Knee & Shoulder Arthroplasty: 2022 Annual report. Australian Orthopaedic Association National Joint Replacement Registry; 2022. Available from: https://aoanjrr.sahmri.com/annual-reports-2022.

[2] NJR. National Joint Registry 19th Annual Report 2022. National Joint Registry; 2022. Available from: https://reports.njrcentre.org.uk/Portals/0/PDFdownloads/NJR%2019th%20Annual%20Report%202022.pdf.

[3] LROI. Annual report 2023. Landelijke Registratie Orthopedische Interventies; 2023. Available from: https://www.lroi.nl/media/bjge0yfe/pdf-lroi-annual-report-2023-1-gecomprimeerd.pdf.

[4] Hubble MJW, Timperley AJ, Ling RSM. Long-Term Success with a Double Tapered Polished Straight Stem. In: The Well-Cemented Total Hip Arthroplasty. Berlin, Heidelberg: Springer; 2005, p. 228-34.

[5] Chiu KH, Shen WY, Tsui HF, Chan KM. Experience with primary exeter total hip arthroplasty in patients with small femurs. Review at average follow-up period of 6 years. J Arthroplasty 1997;12(3):267-72. https://doi.org/10.1016/s0883-5403(97)90022-x.

[6] Desy NM, Johnson JD, Sierra RJ. Satisfactory Results of the Exeter Revision Femoral Stem Used for Primary Total Hip Arthroplasty. J Arthroplasty 2017;32(2):494-8. https://doi.org/10.1016/j.arth.2016.07.051.

[7] Martin R, Clark N, James J, Baker P. Clinical evaluation of the cemented Exeter Short 125 mm stem at a minimum of 3 years: A prospective cohort study. J Orthop 2022;30:18-24. https://doi.org/10.1016/j.jor.2022.02.005.

[8] Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J 2019;101-B(5):502-11. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018-1199.R1.

[9] Hauer G, Vielgut I, Amerstorfer F, Maurer-Ertl W, Leithner A, Sadoghi P. Survival Rate of Short-Stem Hip Prostheses: A Comparative Analysis of Clinical Studies and National Arthroplasty Registers. J Arthroplasty 2018;33(6):1800-5. https://doi.org/10.1016/j.arth.2018.01.017.

[10] van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. Acta Orthop 2014;85(3):250-8. https://doi.org/10.3109/17453674.2014.908343.

[11] Van Veghel MHW, Hannink G, Van Oldenrijk J, Van Steenbergen LN, Schreurs BW. A comparison of uncemented short versus standard stem length in total hip arthroplasty: results from the Dutch Arthroplasty Register. Acta Orthop 2023;94:330-5. https://doi.org/10.2340/17453674.2023.13652.

[12] Tai CC, Nam HY, Abbas AA, Merican AM, Choon SK. First series of Exeter small stem primary total hip arthroplasty minimum 5 years of follow-up. J Arthroplasty 2009;24(8):1200-4. https://doi.org/10.1016/j.arth.2009.07.001.

[13] Choy GG, Roe JA, Whitehouse SL, Cashman KS, Crawford RW. Exeter short stems compared with standard length Exeter stems: experience from the Australian Orthopaedic Association National Joint Replacement Registry. J Arthroplasty 2013;28(1):103-9 e1. https://doi.org/10.1016/j.arth.2012.06.016.

[14] Davies BM, Branford White HA, Temple A. A series of four fractured Exeter stems in hip arthroplasty. Ann R Coll Surg Engl 2013;95(8):e130-2. https://doi.org/10.1308/003588413X13629960047993.

[15] Bolland BJ, Wilson MJ, Howell JR, Hubble MJ, Timperley AJ, Gie GA. An Analysis of Reported Cases of Fracture of the Universal Exeter Femoral Stem Prosthesis. J Arthroplasty 2017;32(4):1318-22. https://doi.org/10.1016/j.arth.2016.09.032.

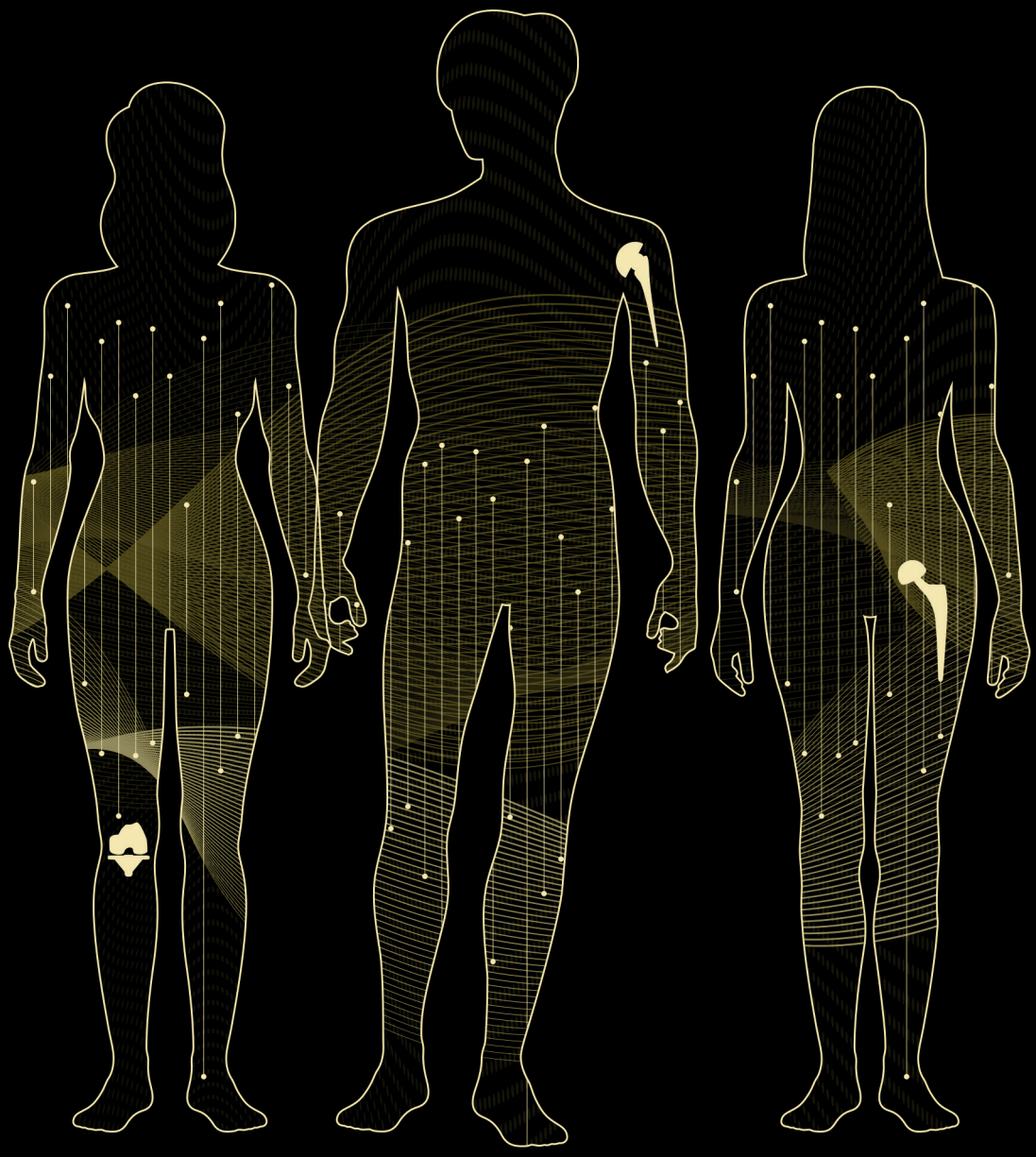
[16] Wyatt MC, Poutawera V, Kieser DC, Frampton CMA, Hooper GJ. How do cemented short Exeter stems perform compared with standard-length Exeter stems? The experience of the New Zealand National Joint Registry. Arthroplast Today 2020;6(1):104-11. https://doi.org/10.1016/j.artd.2020.01.003.

[17] Thompson JW, Corbett J, Bye D, Jones A, Tissingh EK, Nolan J. Analysis of the Exeter V40 femoral stem prosthesis fracture : systematic review and single centre case series. Bone Jt Open 2021;2(6):443-56. https://doi.org/10.1302/2633-1462.26.BJO-2021-0025.R1.

[18] Evans JT, Salar O, Whitehouse SL, Sayers A, Whitehouse MR, Wilton T, Hubble MJW, Exeter Hip Research G. Survival of the Exeter V40 short revision (44/00/125) stem when used in primary total hip arthroplasty. Bone Joint J 2023;105-B(5):504-10. https://doi.org/10.1302/0301-620X.105B5.BJJ-2022-1124.R1.

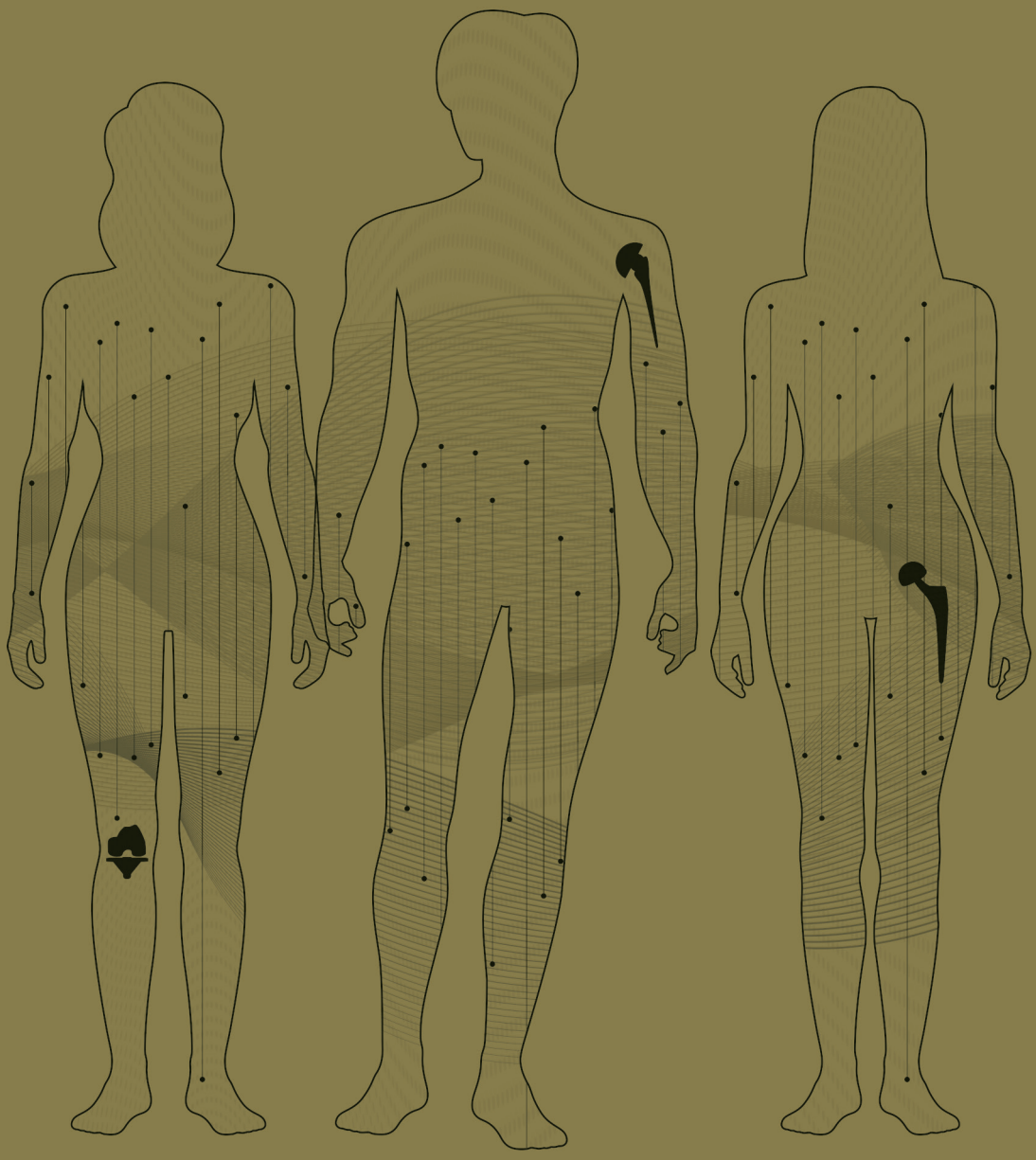
[19] Saklad M. Grading of patients for surgical procedures. Anesthesiol 1941;2(3):281-4. https://doi.org/ https://doi.org/10.1097/00000542-194105000-00004.

[20] Chung KY, Cheung KW, Chiu KH, Shen WY. The Asian size Exeter femoral stem fracture. J Orthop Sci 2016;21(4):562-5. https://doi.org/10.1016/j.jos.2015.06.016.
[21] Woodbridge AB, Hubble MJ, Whitehouse SL, Wilson MJ, Howell JR, Timperley AJ. The Exeter Short Revision Stem for Cement-in-Cement Femoral Revision: A Five to Twelve Year Review. J Arthroplasty 2019;34(7S):S297-S301. https://doi.org/10.1016/j.arth.2019.03.035.
[22] Harrington MA, Jr., O'Connor DO, Lozynsky AJ, Kovach I, Harris WH. Effects of femoral neck length, stem size, and body weight on strains in the proximal cement mantle. J Bone Joint Surg Am 2002;84(4):573-9. https://doi.org/10.2106/00004623-200204000-00010.
[23] Gaston P, Clement ND, Ohly NE, Macpherson GJ, Hamilton DF. Can Arthroplasty Stem Influence Outcome: A Randomized Controlled Trial of Stem Length in Cemented Total Hip Arthroplasty. J Arthroplasty 2023;38(9):1793-801. https://doi.org/10.1016/j.arth.2023.02.045.
[24] de Hundt M, Vlemmix F, Bais JM, Hutton EK, de Groot CJ, Mol BW, Kok M. Risk factors for developmental dysplasia of the hip: a meta-analysis. Eur J Obstet Gynecol Reprod Biol 2012;165(1):8-17. https://doi.org/10.1016/j.ejogrb.2012.06.030.
[25] Jorgensen PB, Jakobsen SS, Vainorius D, Homilius M, Hansen TB, Stilling M. Less early subsidence of cemented Exeter short stems compared with cemented Exeter standard stems in Dorr type A femurs. Bone Jt Open 2023;4(7):507-15. https://doi.org/10.1302/2633-1462.47.BJO-2023-0008.R1.



Part 3

Prevalence & patterns



8

How many people in the Netherlands live with a hip, knee, or shoulder replacement? Prevalence estimates using data from the Dutch Arthroplasty Register (LROI) and Statistics Netherlands

MHW van Veghel
LN van Steenbergen
MGJ Gademan
WB van den Hout
BW Schreurs
G Hannink

Bone & Joint Open 2025; 6(1): 74–81

Abstract

Aims: We estimated the prevalence of people living with at least one hip, knee, or shoulder arthroplasty in the Netherlands.

Methods: We included the first hip (n = 416,333), knee (n = 314,569), or shoulder (n = 23,751) arthroplasty of each patient aged ≥ 40 years between 2007 and 2022 (hip/knee) or 2014 and 2022 (shoulder) from the Dutch Arthroplasty Register (LROI). Data on the size of the Dutch population were obtained from Statistics Netherlands. Annual incidences and deaths from hip and knee arthroplasty since 2010, and shoulder arthroplasty since 2015, were observed from the LROI. Annual incidences and deaths before those years were estimated using Poisson regression analyses and parametric survival models based on a Gompertz distribution. Non-parametric percentile bootstrapping with resampling was used to estimate 95% CIs.

Results: Annual incidences per 100,000 Dutch inhabitants aged ≥ 40 years increased for hip arthroplasties from 221 (95% CI 214 to 229) in 1990 to 360 in 2022, for knee arthroplasties from 181 (95% CI 174 to 188) to 272, and for shoulder arthroplasties from 11 (95% CI 8.0 to 16) to 34. In 2022, 791,000 (95% CI 787,000 to 794,000) people in the Netherlands were living with at least one joint replacement, representing 8.4% (95% CI 8.4 to 8.5) of the Dutch population aged ≥ 40 years. For hip, knee, and shoulder arthroplasties, these were 436,000 (95% CI 433,000 to 438,000), 383,000 (95% CI 380,000 to 386,000), and 34,000 (95% CI 33,000 to 36,000) people, corresponding to 4.7% (95% CI 4.6 to 4.7), 4.1% (95% CI 4.1 to 4.1), and 0.4% (95% CI 0.3 to 0.4) of the Dutch population, respectively. The most common age group living with at least one joint replacement was the ≥ 80-year age group, representing 38% (95% CI 37 to 38) of the Dutch population aged ≥ 80 years.

Conclusion: Approximately 800,000 people in the Netherlands were living with at least one hip, knee, or shoulder replacement in 2022, representing one in 12 Dutch inhabitants aged ≥ 40 years.

Introduction

In recent decades, there has been an increase in the number of arthroplasties in the Netherlands and worldwide [1]. There, the annual number of hip and knee arthroplasties increased from 50,000 in 2010 to 80,000 in 2022. For shoulder arthroplasties, this doubled from 2,000 in 2014 to 4,000 in 2022. Due to the ageing population and the increasing use of arthroplasties in younger patients and vulnerable elderly patients, annual procedure volumes could increase even further in the coming years [2-4].

Since 2007, the Dutch Arthroplasty Register (LROI) has been registering hip and knee arthroplasties in the Netherlands [5]. In 2014, shoulder arthroplasties were added to the LROI database. Registry data can be used to estimate the prevalence of people living with a joint replacement. This provides insight into the number of individuals at risk for associated complications, such as periprosthetic joint infections (PJIs) or periprosthetic fractures, which may lead to higher mortality and higher revision rates [6-9]. In addition, the prevalence of people living with a joint replacement can be used to project future demand for primary and revision arthroplasty, which is crucial for policy-makers in government, education, and industry [10-12].

To our knowledge, the prevalence of people with a joint replacement in the Netherlands has not been estimated before. Therefore, this study aimed to estimate the prevalence of people living with at least one joint replacement in the Netherlands stratified by joint, age, and sex, using data from the LROI and Statistics Netherlands (Centraal Bureau voor de Statistiek (CBS)).

Methods

Patient-level data were obtained from the LROI, which is the national population-based arthroplasty register of the Netherlands, established by the Netherlands Orthopaedic Association (NOV). In 2012, 100% coverage of Dutch hospitals was achieved with a completeness of more than 95% of primary hip and knee arthroplasties [5]. Nowadays, completeness of primary hip, knee, and shoulder arthroplasties is reported to be higher than 97% [1]. The LROI contains data on patient, prosthesis, and procedure characteristics of primary and revision arthroplasties. The vital status of all patients is obtained at regular time intervals from Vektis (Zeist, the Netherlands), which is the national insurance database on healthcare in the Netherlands, recording all deaths of Dutch inhabitants.

In this study, we included all patients aged ≥ 40 years with their first primary hip, knee, or shoulder arthroplasty (n = 706,931) registered in the LROI between 2007 and 2022 (Figure 1). In addition to the entire cohort, separate cohorts were identified for each joint to present joint-specific results (i.e. first primary hip (n = 416,333) or first primary knee (n = 314,569) arthroplasty registered in the LROI between 2007 and 2022, and first primary shoulder (n = 23,751) arthroplasty registered between 2014 and 2022). Patients aged ≥ 40 years comprise more than 98% of all first primary hip, knee, and shoulder arthroplasties in the Netherlands. Patients with missing sex data (no female/male) were excluded (all joints n = 923; hip n = 587; knee n = 354; shoulder n = 3). The sum of the joint-specific cohorts included more patients than the entire cohort, as the entire cohort included only the first primary hip, knee, or shoulder arthroplasty for each patient. Patients with primary arthroplasties in multiple joints could be included in multiple joint-specific cohorts. Publicly available data on the size of the Dutch population were obtained from CBS for the period 1990 to 2022, categorized by calendar year, age (years), and sex (female/male). Dutch people aged ≥ 99 years were classified as 99-year-olds, as CBS grouped all individuals aged ≥ 99 years into a single age category until 1995. This study was reported in accordance with the STROBE guidelines.

Ethics

Data were available from the LROI, however restrictions apply to the availability of these data, which were used under licence for the current study. All data were received completely de-identified. The LROI uses the opt-out system to require informed consent from patients.

Statistical analysis

The annual incidences of primary hip and knee arthroplasties since 2010, and of primary shoulder arthroplasties since 2015, were observed from the LROI, as the LROI has been nearly complete for these arthroplasties since 2010 and 2015, respectively [1]. Incidence was calculated as the number of new primary hip, knee, or shoulder arthroplasties per year divided by the total number of Dutch inhabitants aged ≥ 40 years. Since there are patients alive with a primary hip, knee, or shoulder replacement before those years, the annual incidences of primary hip and knee arthroplasties before 2010 and of primary shoulder arthroplasties before 2015 were estimated using Poisson regression analyses. Data from 2010 to 2019 (hip and knee) or from 2015 to 2019 (shoulder) were used to exclude the first incomplete LROI years and the COVID-19 pandemic, where the annual number of arthroplasties was considerably lower than expected [1,13]. The annual incidences of primary hip, knee, and shoulder arthroplasties were estimated back to 1990. Calendar year (1990 to 2022), sex (female/male), and age (≥ 40 years, continuous) were included

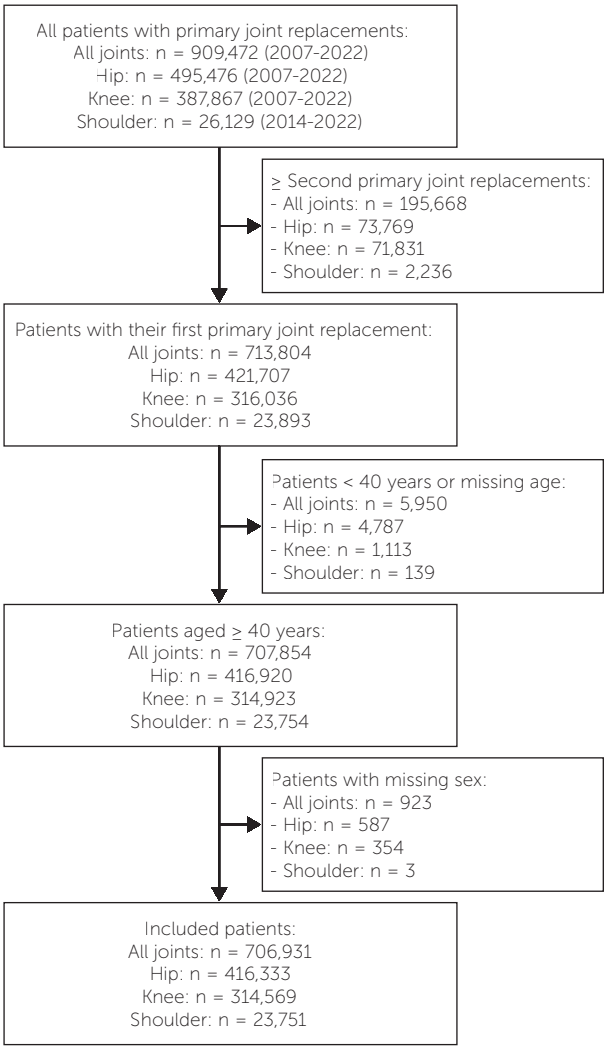


Figure 1. Flowchart.

as covariates in the Poisson regression models to account for differences in incidence between subgroups and in the general population as well as the changes over time.

The annual number of deaths of patients who had their joint replacement since 2010 (hip and knee) or since 2015 (shoulder) was observed from the LROI to obtain the number of living patients since 2010 or 2015, respectively. Parametric survival models based on a Gompertz distribution were used to estimate the survival probability of patients who had their joint replacement before those years, using LROI data from 2007 to 2022 (hip and knee) and from 2014 to 2022 (shoulder). As individuals are observed only if their event of interest takes place after some specified age (i.e. age at LROI entry), both right and left truncation occurs and was taken into account. The reference age was taken as the age at LROI entry, and survival was calculated from that reference age on. Therefore, conditional survival was used, which was defined as the time from the patient's age at surgery to the patient's age at death or end of follow-up (1 January 2023). Survival curves were stratified by an interaction term between sex and procedure year (first five procedure years/later years). The first five procedure years were used for predicting the survival of patients who had their arthroplasty before 2010 (hip and knee) or 2015 (shoulder), as both healthier, younger patients and more vulnerable elderly patients now undergo arthroplasties, whereas they may not have been eligible for these procedures in the past.

Subsequently, the estimated arthroplasties from before the start of the LROI were combined with the observed (i.e. registered) arthroplasties. The combined dataset included all registered cases with a weight of 1. In addition, all unique combinations of pre-registration calendar year, sex, and age were added to the dataset, with a weight equal to the number of arthroplasties as predicted by the Poisson regression. Patient survival status of these pre-registration cases was set to the probability to survive until the specific calendar year, as predicted by the survival analysis. Prevalence was then estimated by the weighted sum of the survival status. Non-parametric percentile bootstrapping of the combined Poisson regression and survival analysis were used to calculate 95% CIs for the prevalence [14]. A total of 500 bootstrap samples were generated.

All analyses were performed for the entire cohort, as well as for the joint-specific cohorts. Reported numbers greater than or equal to 10,000 were rounded to the nearest thousand, numbers between 1,000 and 9,999 were rounded to the nearest hundred, and numbers less than 1,000 were rounded to the nearest ten. R v. 4.3.2 (R Foundation for Statistical Computing, Austria) was used to perform all analyses.

Results

The annual incidences per 100,000 Dutch inhabitants aged ≥ 40 years increased for primary hip arthroplasty from 221 (95% CI 214 to 229) in 1990 to 360 in 2022, for primary knee arthroplasty from 181 (95% CI 174 to 188) in 1990 to 272 in 2022, and for primary shoulder arthroplasty from 11 (95% CI 8.0 to 16) in 1990 to 34 in 2022 (Figure 2). At the start of the LROI in 2007, the incidence per 100,000 Dutch inhabitants of hip and knee arthroplasties was estimated at 264 (95% CI 260 to 267) and 208 (95% CI 205 to 211), respectively. The estimated incidence of primary shoulder arthroplasties was 25 (95% CI 24 to 26) per 100,000 Dutch inhabitants when shoulder arthroplasties were added to the LROI in 2014.

In 2022, 791,000 (95% CI 787,000 to 794,000) people in the Netherlands were living with at least one joint replacement, representing 8.4% (95% CI 8.4 to 8.5) of the Dutch population aged ≥ 40 years (Figure 3; Supplementary Table i). Of these, 516,000 (65%) people were observed in the LROI. A total of 436,000 (95% CI 433,000 to 438,000) people were living with at least one hip replacement (Figure 4a),

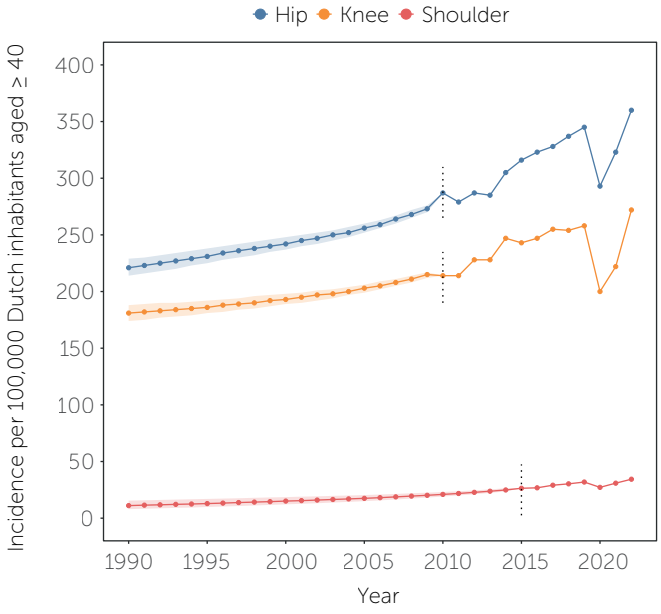


Figure 2. Annual incidence of primary arthroplasties per 100,000 Dutch inhabitants aged ≥ 40 years, stratified by joint. Annual incidences before 2010 (hip and knee) and before 2015 (shoulder) are estimated.

383,000 (95% CI 380,000 to 386,000) people with at least one knee replacement (Figure 4b), and 34,000 (95% CI 33,000 to 36,000) people with at least one shoulder replacement (Figure 4c). This corresponds to 4.7% (95% CI 4.6 to 4.7), 4.1% (95% CI 4.1 to 4.1), and 0.4% (95% CI 0.3 to 0.4) of the Dutch population aged ≥ 40 years, respectively (Supplementary Table i). Among them, 289,000 (66%) people with at least one hip replacement, 246,000 (64%) people with at least one knee replacement, and 19,000 (57%) people with at least one shoulder replacement were observed from the LROI. The prevalence of people living with at least one joint replacement was 4.5% (95% CI 4.5 to 4.5) when considering the entire Dutch population of 17.6 million people. For hip, knee, and shoulder replacements, these were 2.5% (95% CI 2.5 to 2.5), 2.2% (95% CI 2.2 to 2.2), and 0.2% (95% CI 0.2 to 0.2), respectively.

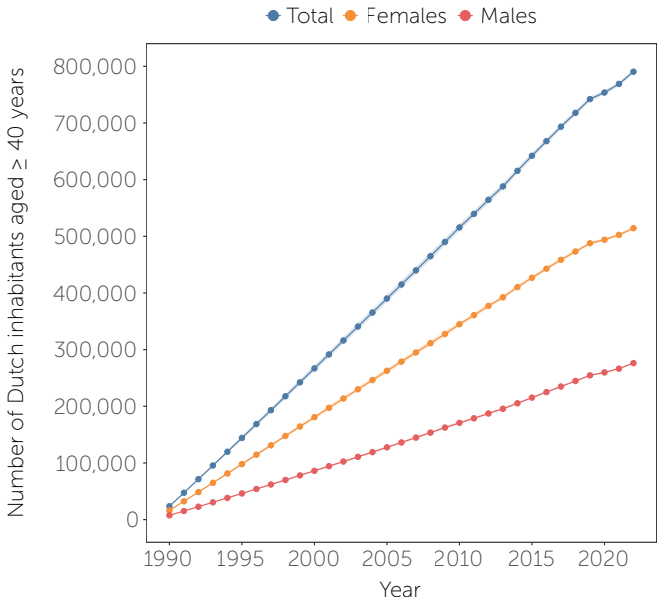


Figure 3. Total number of Dutch inhabitants aged ≥ 40 years living with at least one joint replacement over time, stratified by sex. The 95% CIs are small and therefore may not be visible.

The number of females having at least one hip (n = 290,000, 95% CI 288,000 to 292,000), knee (n = 246,000, 95% CI 244,000 to 248,000), or shoulder replacement (n = 26,000, 95% CI 25,000 to 27,000) in 2022 was 2.0, 1.8 and 3.1 times higher than the number of males with at least one hip (n = 146,000, 95% CI 145,000 to 147,000; Figure 4a), knee (n = 137,000, 95% CI 136,000 to 138,000; Figure 4b),

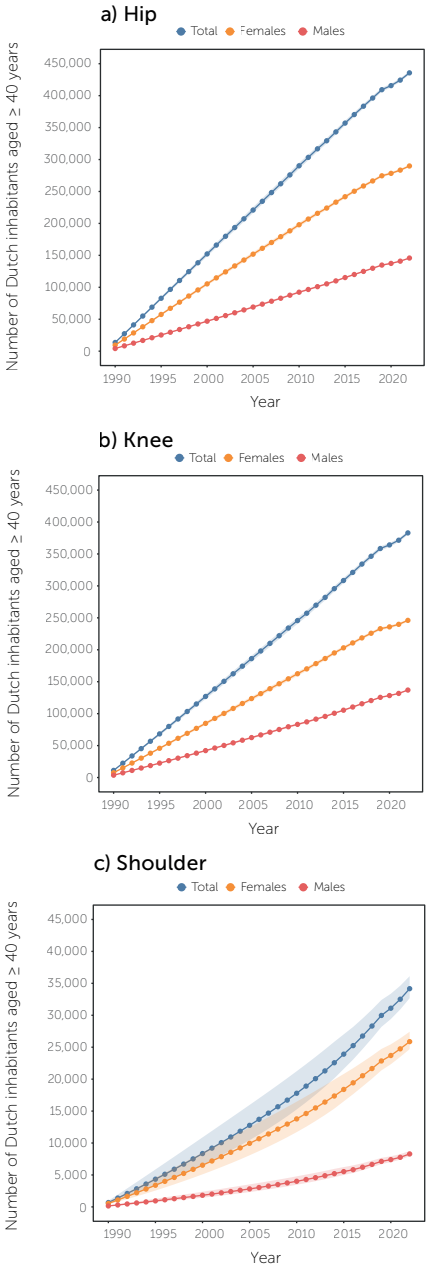


Figure 4. Total number of Dutch inhabitants aged ≥ 40 years living with at least one joint replacement over time, stratified by a) hip, b) knee, or c) shoulder replacement, and sex. The 95% CIs are small and therefore may not be visible.

or shoulder replacement (n = 8,300, 95% CI 7,900 to 8,800; Figure 4c), respectively. Females with at least one hip, knee, or shoulder replacement represent 6.0% (95% CI 6.0 to 6.1), 5.1% (95% CI 5.1 to 5.2), and 0.5% (95% CI 0.5 to 0.6) of the Dutch female population, respectively (Supplementary Table i). For males, this is 3.2% (95% CI 3.2 to 3.2), 3.0% (95% CI 3.0 to 3.0), and 0.2% (95% CI 0.2 to 0.2) of the Dutch male population, respectively.

The most common age groups living with at least one joint replacement were the 70- to 79-year and ≥ 80-year age groups, representing 17% (95% CI 16 to 17) and 38% (95% CI 37 to 38) of the Dutch population aged 70 to 79 years and ≥ 80 years in 2022, respectively (Supplementary Table i). Among females, the highest number of women who had at least one hip, knee, or shoulder replacement was found in the ≥ 80-year age group, accounting for 27% (95% CI 27 to 27), 20% (95% CI 19 to 20), and 2.3% (95% CI 2.2 to 2.5) of the Dutch population aged ≥ 80 years, respectively (Figure 5; Supplementary Table i). In males, the highest number of men with at least one hip replacement was observed in the ≥ 80-year age group, while the highest number with at least one knee or shoulder replacement was observed in the 70- to 79-year age group (Figure 5). The highest prevalence for males was found in the ≥ 80-year age group for hip (16%, 95% CI 16 to 16), knee (13%, 95% CI 12 to 13), and shoulder (0.8%, 95% CI 0.7 to 0.8) replacements (Supplementary Table i). The number of people with at least one hip, knee, or shoulder replacement over time, stratified by age, is shown in Supplementary Figure a.

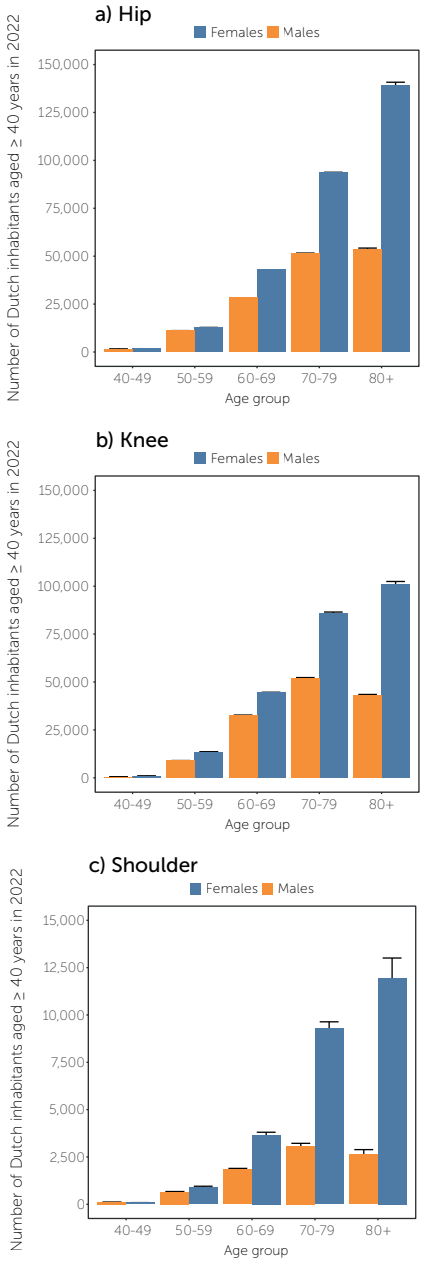


Figure 5. Total number of Dutch inhabitants aged ≥ 40 years living with at least one joint replacement in 2022, stratified by a) hip, b) knee, or c) shoulder replacement, age, and sex. The 95% CI are small and therefore may not be visible.

Discussion

At the end of 2022, there were approximately 800,000 people living with a least one hip, knee, or shoulder replacement in the Netherlands. This corresponds to one in 12 Dutch inhabitants aged ≥ 40 years having at least one joint replacement. Among the ≥ 80-year-olds, approximately one in three Dutch inhabitants were living with at least one joint replacement. Females were more often living with at least one hip, knee, or shoulder arthroplasty compared to males due to the predominance of females in joint replacements, as well as their higher life expectancy [15].

Both the estimated and observed incidences of hip and knee arthroplasties in this study are comparable to those reported by the Swedish Hip Arthroplasty Register and the Swedish Knee Arthroplasty Register, which have a long history of data collection [16,17]. The annual incidence per 100,000 Swedish inhabitants aged ≥ 40 years was 225 in 1990 and 332 in 2010 for total hip arthroplasties, and 203 in 2005 and 268 in 2013 for total knee arthroplasties [16,17].

Although comparing our findings with other countries may be complex due to differences in modelling methodologies, patient populations, and surgical indications, our findings appear to be in line with published prevalences estimated for all ages using data from Australia, Sweden, and the USA [6,18,19]. In our study, 2.5%, 2.2%, and 0.2% of the entire Dutch population had at least one hip, knee, or shoulder replacement in 2022, respectively. In Australia, the prevalence of people with at least one hip, knee, or shoulder replacement was 3.4% in 2016 [6]. No distinction in the prevalences of different joints was reported. In Sweden, 3.3% of citizens were living with a hip or knee replacement at the end of 2022, of which 2.1% had at least one hip replacement and 1.5% had at least one knee replacement [18]. In the USA, approximately 0.3% of the population had a shoulder replacement in 2017 [19].

The sum of the joint-specific proportions of Dutch people aged ≥ 40 years living with at least one hip, knee, or shoulder replacement was 9.2%, while 8.4% were living with at least one hip, knee, or shoulder replacement. This indicates that 9.5% of the proportion of people with at least one joint replacement have multiple primary joint replacements in different joints, either ipsilateral or cross-lateral. A previous LROI study on multiple primary hip and knee arthroplasties in osteo-arthritic patients in the Netherlands found that 43% of the people underwent a second primary arthroplasty during their lifetime [20]. The majority of these patients (83%) underwent a contralateral primary arthroplasty. Contralateral primary arthroplasties were not part of our study, as we used only the first hip, knee,

or shoulder arthroplasty from patients to estimate the prevalence of people with at least one joint replacement.

Traditionally, hip arthroplasties have been more common than knee arthroplasties, as shown by both our and previous studies [6,16,17]. This may be due to the earlier introduction of modern hip arthroplasty, earlier innovations in effective hip implants, and variations in the complexity of hip and knee arthroplasty procedures [17,21,22]. However, previous studies also suggest that the number of primary knee arthroplasties will exceed the number of primary hip arthroplasties in the future as a result of a higher BMI, as well as increasing future incidences and prevalences of knee osteoarthritis [6,16,17]. It remains unclear whether this trend also applies to the Dutch population.

Prevalence estimates of people living with at least one joint replacement may be important, as these estimates provide knowledge about the number of people who are at risk of complications following arthroplasty [6]. These complications include PJIs, periprosthetic fractures, aseptic loosening, and dislocation, all of which may require reoperation or revision. Understanding the number of people living with a primary joint replacement can help project future healthcare procedures for these complications. Moreover, people with joint replacements require lifelong healthcare, including clinical and radiological follow-up. Therefore, the findings of this study may guide future research and assist healthcare providers, policy-makers, and researchers in understanding the impact of arthroplasty on the healthcare system, as well as in planning and allocating resources in both education and industry to meet the growing demand for arthroplasties, and to improve orthopaedic patient care and outcomes.

The findings of the present study should be interpreted carefully. No LROI data were available for hip and knee arthroplasties before 2007 and for shoulder arthroplasties before 2014. Additionally, completeness rates were suboptimal for hip and knee arthroplasties between 2007 and 2009 and for shoulder arthroplasties in 2014. Modelling historical incidences prior to LROI registration was essential, as there are still a considerable number of patients with non-registered hip, knee, or shoulder replacements. Of the current 800,000 people living with at least one joint replacement in the Netherlands, approximately 35% underwent their joint arthroplasty before the start of the LROI. Previous studies suggest the use of asymptotic regression models for predicting (future) incidences, which assume the incidence has an upper limit, rather than Poisson regression models, in which the modelled incidences could theoretically increase to infinity [16,17]. However, we used Poisson regression models to estimate the incidences due to failures of the

asymptotic regression models. We modelled historical incidences rather than predicting future incidences, making the theoretically unlimited incidence less relevant in our study.

Historical incidences were estimated since 1990. However, there may also still be patients alive in 2022 who received their joint replacement before 1990. While estimating historical incidences back to 1985 or 1980 increases the likelihood that patients who received their joint replacement before these years will not be alive in 2022, there is a risk of overestimating the historical incidences, as arthroplasties were performed only in small numbers in the Netherlands during the 1980s. Sensitivity analyses with the starting years 1985 and 1980 showed that by 2022, an estimated 805,000 and 812,000 people were living with at least one joint replacement, respectively. Published prevalence estimates from other countries were calculated from 1994 in Australia for hip, knee, and shoulder arthroplasties, from 1992 for hip arthroplasties and 1979 for knee arthroplasties in Sweden, and from 1988 in the USA for shoulder arthroplasties [6,18,19].

Another limitation related to the estimated historical incidences may be changes in patient population and surgical indications over time. Nowadays, healthier and younger patients as well as more vulnerable elderly patients undergo hip, knee, or shoulder arthroplasties who may not have been eligible for these procedures in the past. Consequently, we may have slightly overestimated the number of people with at least one joint replacement in the Netherlands. Furthermore, all individuals aged ≥ 99 years were classified as 99-year-olds in this study, as CBS combined all Dutch people aged ≥ 99 years into one age category until 1995. Therefore, the survival of people aged > 99 years may be overestimated.

In contrast, while the LROI has achieved a relatively high completeness rate of over 90% for registered primary hip, knee, and shoulder arthroplasties in recent years, there have been cases of patients with non-registered hip, knee, or shoulder replacements [1]. Therefore, this study may underestimate the number of people with at least one joint replacement in the Netherlands. Moreover, patients aged < 40 years were not included in this study, as the number of patients was too small to reliably estimate the prevalence for this group. In addition, we have not taken into account replacements of other joints, such as ankles, elbows, wrists, and fingers. However, the number of these arthroplasties is relatively low in the Netherlands [1]. Nonetheless, LROI data, which offer a nationally representative sample of the Dutch population, are the best available data to estimate the number of people living with at least one joint replacement in the Netherlands.

In conclusion, by the end of 2022, approximately 800,000 people in the Netherlands were living with a least one hip, knee, or shoulder replacement, corresponding to one in 12 Dutch inhabitants aged 40 years or older. More females than males were living with at least one joint replacement. The proportion of the population with at least one joint replacement was highest among individuals aged 80 years or older. These findings may provide a better understanding of the burden of arthroplasty in the Netherlands.

References

[1] LROI. Annual report 2023. Landelijke Registratie Orthopedische Interventies; 2023. Available from: https://www.lroi.nl/media/bjge0yfe/pdf-lroi-annual-report-2023-1-gecomprimeerd.pdf.

[2] Padegimas EM, Maltenfort M, Lazarus MD, Ramsey ML, Williams GR, Namdari S. Future patient demand for shoulder arthroplasty by younger patients: national projections. Clin Orthop Relat Res 2015;473(6):1860-7. https://doi.org/10.1007/s11999-015-4231-z.

[3] Matharu GS, Culliford DJ, Blom AW, Judge A. Projections for primary hip and knee replacement surgery up to the year 2060: an analysis based on data from The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. Ann R Coll Surg Engl 2022;104(6):443-8. https://doi.org/10.1308/rcsann.2021.0206.

[4] Ackerman IN, Bohensky MA, Zomer E, Tacey M, Gorelik A, Brand CA, de Steiger R. The projected burden of primary total knee and hip replacement for osteoarthritis in Australia to the year 2030. BMC Musculoskelet Disord 2019;20(1):90. https://doi.org/10.1186/s12891-019-2411-9.

[5] van Steenbergen LN, Denissen GA, Spooren A, van Rooden SM, van Oosterhout FJ, Morrenhof JW, Nelissen RG. More than 95% completeness of reported procedures in the population-based Dutch Arthroplasty Register. Acta Orthop 2015;86(4):498-505. https://doi.org/10.3109/17453674.2015.1028307.

[6] Manning L, Davis JS, Robinson O, Clark B, Lorimer M, de Steiger R, Graves SE. High prevalence of older Australians with one or more joint replacements: estimating the population at risk for late complications of arthroplasty. ANZ J Surg 2020;90(5):846-50. https://doi.org/10.1111/ans.15774.

[7] van Veghel MHW, van Steenbergen LN, Wertheim HFL, van der Kooi TII, Schreurs BW, Hannink G. Early Periprosthetic Joint Infections in Total Hip and Knee Arthroplasty: Microorganisms, Mortality, and Implant Survival Using a Combined Dataset From the Dutch Arthroplasty Register and the Dutch National Nosocomial Surveillance Network. J Arthroplasty 2025;40(1):208-13 e1. https://doi.org/10.1016/j.arth.2024.07.019.

[8] Cnudde P, Bulow E, Nemes S, Tyson Y, Mohaddes M, Rolfson O. Association between patient survival following reoperation after total hip replacement and the reason for reoperation: an analysis of 9,926 patients in the Swedish Hip Arthroplasty Register. Acta Orthop 2019;90(3):226-30. https://doi.org/10.1080/17453674.2019.1597062.

[9] Lenguerrand E, Whitehouse MR, Beswick AD, Kunutsor SK, Webb JCJ, Mehendale S, Porter M, Blom AW, National Joint Registry for England WNItIoM, the States of G. Mortality and re-revision following single-stage and two-stage revision surgery for the management of infected primary hip arthroplasty in England and Wales. Bone Joint Res 2023;12(5):321-30. https://doi.org/10.1302/2046-3758.125.BJR-2022-0131.R1.

[10] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89(4):780-5. https://doi.org/10.2106/JBJS.F.00222.

[11] Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res 2009;467(10):2606-12. https://doi.org/10.1007/s11999-009-0834-6.

[12] Maradit Kremers H, Larson DR, Crowson CS, Kremers WK, Washington RE, Steiner CA, Jiranek WA, Berry DJ. Prevalence of Total Hip and Knee Replacement in the United States. J Bone Joint Surg Am 2015;97(17):1386-97. https://doi.org/10.2106/JBJS.N.01141.

[13] Latijnhouwers D, Pedersen A, Kristiansen E, Cannegieter S, Schreurs BW, van den Hout W, Nelissen R, Gademan M. No time to waste; the impact of the COVID-19 pandemic on hip, knee, and shoulder arthroplasty surgeries in the Netherlands and Denmark. Bone Jt Open 2022;3(12):977-90. https://doi.org/10.1302/2633-1462.312.BJO-2022-0111.R1.

[14] Efron B, Tibshiranu R. Bootstrap Methods for Standard Errors, Confidence Intervals, and Other Measures of Statistical Accuracy. Statistical Science 1986;1(1):54-75. https://doi.org/10.1214/ss/1177013815.

[15] CBS. Overlijden: Hoe oud worden mensen in Nederland? Available from: https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/levensloop/verweduwen.

[16] Nemes S, Gordon M, Rogmark C, Rolfson O. Projections of total hip replacement in Sweden from 2013 to 2030. Acta Orthop 2014;85(3):238-43. https://doi.org/10.3109/17453674.2014.913224.
[17] Nemes S, Rolfson O, A WD, Garellick G, Sundberg M, Karrholm J, Robertsson O. Historical view and future demand for knee arthroplasty in Sweden. Acta Orthop 2015;86(4):426-31. https://doi.org/10.3109/17453674.2015.1034608.
[18] SAR. Annual report 2023. Swedish Arthroplasty Register; 2023. Available from: https://registercentrum.blob.core.windows.net/sar/r/SAR_Annual-report-2023_EN-DS5gryeOB.pdf.
[19] Farley KX, Wilson JM, Kumar A, Gottschalk MB, Daly C, Sanchez-Sotelo J, Wagner ER. Prevalence of Shoulder Arthroplasty in the United States and the Increasing Burden of Revision Shoulder Arthroplasty. JB JS Open Access 2021;6(3). https://doi.org/10.2106/JBJS.OA.20.00156.
[20] Latijnhouwers D, van Gils JA, Vliet Vlieland TPM, van Steenbergen LN, Marang-van de Mheen PJ, Cannegieter SC, Verdegaal SHM, Nelissen R, Gademan MGJ. Multiple Joint Arthroplasty in Hip and Knee Osteoarthritis Patients: A National Longitudinal Cohort Study. J Arthroplasty 2024. https://doi.org/10.1016/j.arth.2024.05.060.
[21] Knight SR, Aujla R, Biswas SP. Total Hip Arthroplasty - over 100 years of operative history. Orthop Rev (Pavia) 2011;3(2):e16. https://doi.org/10.4081/or.2011.e16.
[22] Causero A, Di Benedetto P, Beltrame A, Gisonni R, Cainero V, Pagano M. Design evolution in total knee replacement: which is the future? Acta Biomed 2014;85 Suppl 2:5-19.

Table i. The proportion of the Dutch population aged ≥ 40 years with at least one joint replacement in 2022, stratified by joint, sex, and age.

Sex/age group	Population aged ≥ 40 years*	All joints				Hip			
		N*	95% CI	% of population	95% CI	N*	95% CI	% of population	95% CI
Total	**9,365,014**	**791,000**	**787,000 to 794,000**	**8.4**	**8.4 to 8.5**	**436,000**	**433,000 to 438,000**	**4.7**	**4.6 to 4.7**
40 to 49	2,132,501	4,700	4,700 to 4,700	0.2	0.2 to 0.2	3,100	3,100 to 3,100	0.1	0,1 to 0,1
50 to 59	2,548,563	47,000	47,000 to 47,000	1.8	1.8 to 1.8	24,000	24,000 to 24,000	0.9	0,9 to 0,9
60 to 69	2,175,813	146,000	146,000 to 146,000	6.7	6.7 to 6.7	71,000	71,000 to 71,000	3.3	3,3 to 3,3
70 to 79	1,655,030	273,000	272,000 to 274,000	17	16 to 17	145,000	144,000 to 145,000	8.8	8,7 to 8,8
≥ 80	853,107	321,000	318,000 to 323,000	38	37 to 38	193,000	191,000 to 195,000	23	22 to 23
Female	**4,808,539**	**514,000**	**512,000 to 517,000**	**11**	**11 to 11**	**290,000**	**288,000 to 292,000**	**6.0**	**6.0 to 6.1**
40 to 49	1,070,268	2,600	2,600 to 2,600	0.2	0.2 to 0.2	1,600	1,600 to 1,600	0.1	0.1 to 0.1
50 to 59	1,271,096	26,000	26,000 to 26,000	2.1	2.1 to 2.1	13,000	13,000 to 13,000	1.0	1.0 to 1.0
60 to 69	1,096,496	86,000	85,000 to 86,000	7.8	7.8 to 7.8	43,000	43,000 to 43,000	3.9	3.9 to 3.9
70 to 79	857,776	172,000	172,000 to 173,000	20	20 to 20	93,000	93,000 to 94,000	11	11 to 11
≥ 80	512,903	228,000	226,000 to 230,000	44	44 to 45	139,000	138,000 to 141,000	27	27 to 27
Male	**4,556,475**	**276,000**	**275,000 to 278,000**	**6.1**	**6.0 to 6.1**	**146,000**	**145,000 to 147,000**	**3.2**	**3.2 to 3.2**
40 to 49	1,062,233	2,100	2,100 to 2,100	0.2	0.2 to 0.2	1,500	1,500 to 1,500	0.1	0.1 to 0.1
50 to 59	1,277,467	20,000	20,000 to 20,000	1.6	1.6 to 1.6	11,000	11,000 to 11,000	0.9	0.9 to 0.9
60 to 69	1,079,317	60,000	60,000 to 60,000	5.6	5.6 to 5.6	28,000	28,000 to 28,000	2.6	2.6 to 2.6
70 to 79	797,254	100,000	100,000 to 101,000	13	13 to 13	51,000	51,000 to 52,000	6.4	6.4 to 6.5
≥ 80	340,204	93,000	92,000 to 94,000	27	27 to 28	54,000	53,000 to 54,000	16	16 to 16

Table i. Continued.

Sex/age group	Population aged ≥ 40 years*	Knee				Shoulder			
		N*	95% CI	% of population	95% CI	N*	95% CI	% of population	95% CI
Total	**9,365,014**	**383,000**	**380,000 to 386,000**	**4.1**	**4.1 to 4.1**	**34,000**	**33,000 to 36,000**	**0.4**	**0.3 to 0.4**
40 to 49	2,132,501	1,400	1,400 to 1,400	0.1	0.1 to 0.1	190	190 to 200	0.0	0.0 to 0.0
50 to 59	2,548,563	23,000	23,000 to 23,000	0.9	0.9 to 0.9	1,500	1,500 to 1,600	0.1	0.1 to 0.1
60 to 69	2,175,813	77,000	77,000 to 77,000	3.5	3.5 to 3.6	5,500	5,400 to 5,700	0.3	0.2 to 0.3
70 to 79	1,655,030	138,000	137,000 to 139,000	8.3	8.3 to 8.4	12,000	12,000 to 13,000	0.7	0.7 to 0.8
≥ 80	853,107	144,000	142,000 to 146,000	17	17 to 17	15,000	14,000 to 16,000	1.7	1.6 to 1.9
Female	**4,808,539**	**246,000**	**244,000 to 248,000**	**5.1**	**5.1 to 5.2**	**26,000**	**25,000 to 27,000**	**0.5**	**0.5 to 0.6**
40 to 49	1,070,268	920	920 to 920	0.1	0.1 to 0.1	90	90 to 90	0.0	0.0 to 0.0
50 to 59	1,271,096	14,000	14,000 to 14,000	1.1	1.1 to 1.1	880	880 to 950	0.1	0.1 to 0.1
60 to 69	1,096,496	45,000	44,000 to 45,000	4.1	4.1 to 4.1	3,700	3,600 to 3,800	0.3	0.3 to 0.3
70 to 79	857,776	86,000	86,000 to 87,000	10	10 to 10	9,300	9,000 to 9,600	1.1	1.1 to 1.1
≥ 80	512,903	101,000	99,000 to 102,000	20	19 to 20	12,000	11,000 to 13,000	2.3	2.2 to 2.5
Male	**4,556,475**	**137,000**	**136,000 to 138,000**	**3.0**	**3.0 to 3.0**	**8,300**	**7,900 to 8,800**	**0.2**	**0.2 to 0.2**
40 to 49	1,062,233	500	500 to 500	0.0	0.0 to 0.0	110	110 to 110	0.0	0.0 to 0.0
50 to 59	1,277,467	9,000	9,000 to 9,000	0.7	0.7 to 0.7	650	650 to 680	0.1	0.1 to 0.1
60 to 69	1,079,317	33,000	33,000 to 33,000	3.0	3.0 to 3.0	1,800	1,800 to 1,900	0.2	0.2 to 0.2
70 to 79	797,254	52,000	52,000 to 52,000	6.5	6.5 to 6.6	3,100	3,000 to 3,200	0.4	0.4 to 0.4
≥ 80	340,204	43,000	42,000 to 44,000	13	12 to 13	2,600	2,400 to 2,900	0.8	0.7 to 0.8

*Numbers may not add up due to rounding.

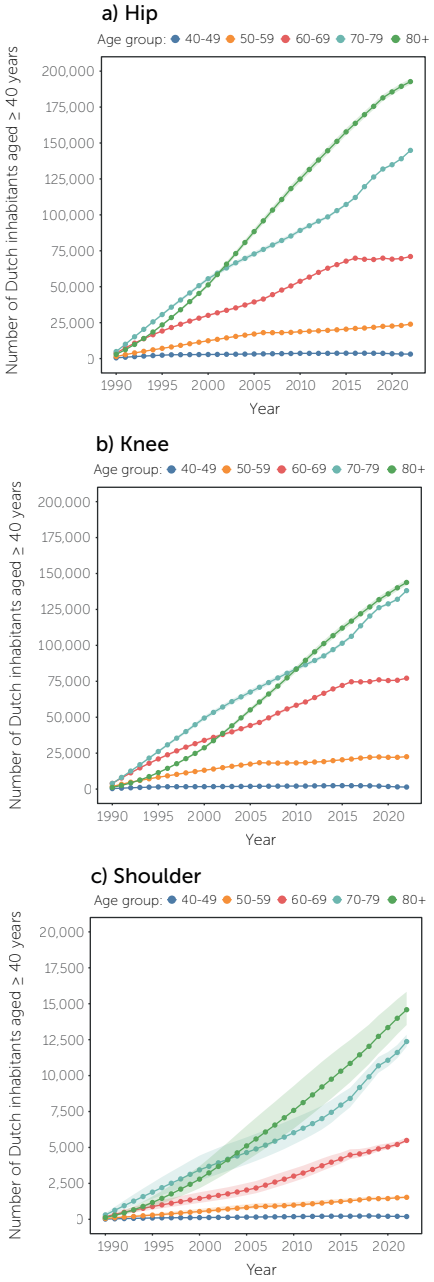
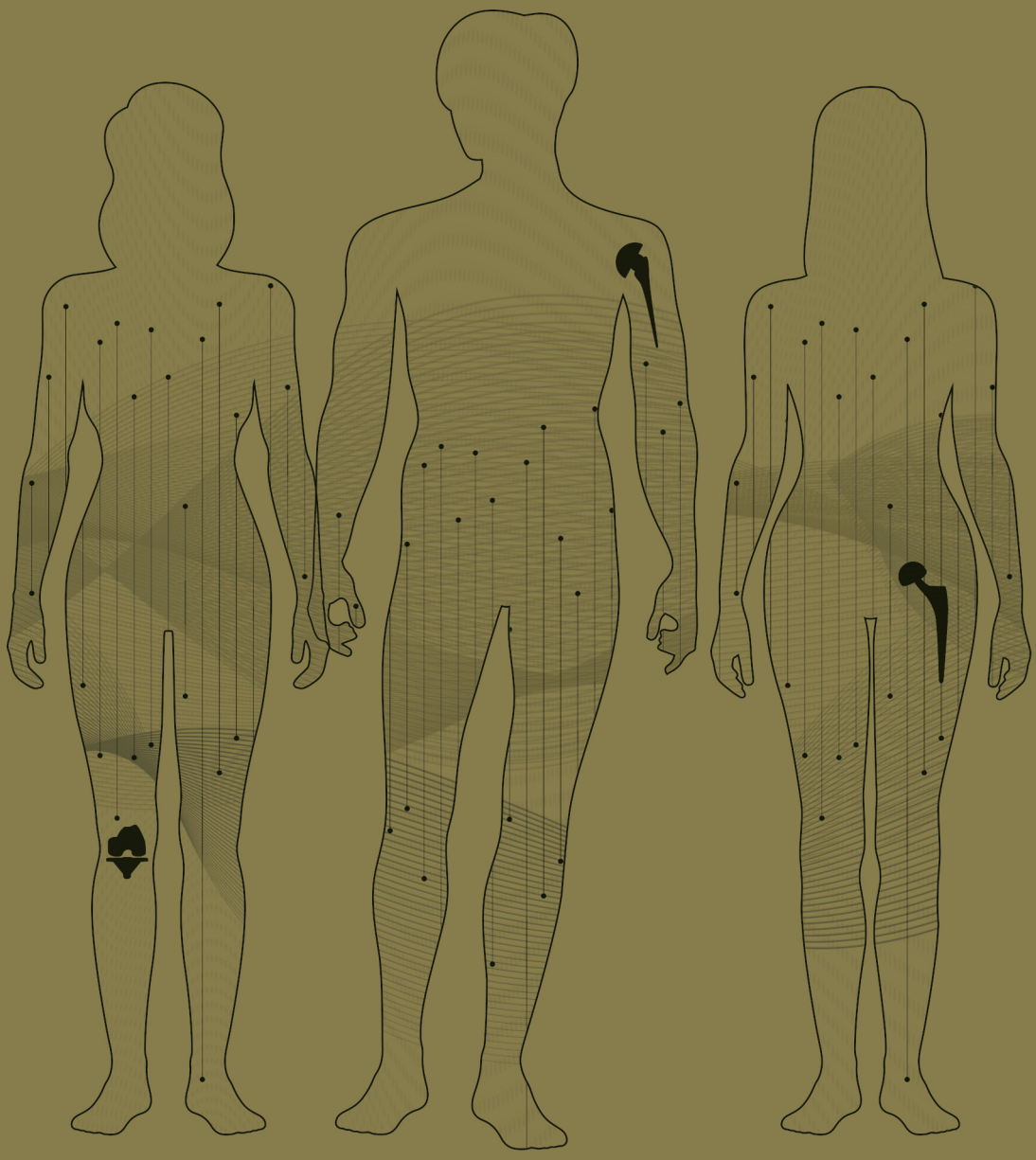


Figure a. The number of Dutch inhabitants aged ≥ 40 years living with at least one joint replacement over time, stratified by a) hip, b) knee, and c) shoulder replacement, and age. The 95% CIs are small and therefore may not be visible.



9

Identifying recovery trajectories following primary total shoulder arthroplasty: a cohort study of 3,358 patients from the Dutch Arthroplasty Register

MHW van Veghel
LN van Steenbergen
CPJ Visser
BW Schreurs
G Hannink

Acta Orthopaedica 2025; 96: 226–234

Abstract

Background and purpose: Some patients do not improve after total shoulder arthroplasty (TSA), indicating different recovery trajectories. We aimed to identify recovery trajectories after TSA based on the Oxford Shoulder Score (OSS). Second, we investigated whether recovery trajectories were associated with patient or procedure characteristics.

Methods: We included primary anatomical and reversed TSAs (ATSAs/RTSAs) for osteoarthritis (OA) or cuff arthropathy/rupture with preoperative, 3-month, and/or 12-month postoperative OSS, registered between 2016 and 2022 in the Dutch Arthroplasty Register (n = 3,358). We used latent class growth modeling (LCGM) to identify recovery patterns, and multinomial logistic regression analyses to investigate associations between potential risk factors and class membership (odds ratio [OR], 95% confidence interval [CI]).

Results: We identified 3 recovery patterns: "Fast responders" (59%), "Steady responders" (27%), and "Poor responders" (14%). Factors associated with "Steady responders" vs "Fast responders" were female vs male sex (OR 2.0, CI 1.5–2.7), ASA III–IV vs ASA I (OR 1.9, CI 1.2–3.1), Walch A1 vs B2 (OR 1.6, CI 1.1–2.5), and most vs medium socioeconomic deprivation (OR 1.4, CI 1.1–1.9). Factors associated with "Poor responders" vs "Fast responders" were ASA II vs ASA I (OR 2.0, CI 1.1–3.6), ASA III–IV vs ASA I (OR 3.0, CI 1.6–5.5), Walch A1 vs B2 (OR 2.1, CI 1.3–3.3), previous shoulder surgeries (OR 1.8, CI 1.3–2.4), most vs medium socioeconomic deprivation (OR 1.5, CI 1.2–2.0), RTSA for OA vs ATSA for OA (OR 1.8, CI 1.2–2.7), and RTSA for cuff arthropathy or rupture vs ATSA for OA (OR 2.3, CI 1.5–3.4).

Conclusion: 3 recovery trajectories were identified following TSA, which we labelled as "Fast responders," "Steady responders," and "Poor responders." "Steady responders" and "Poor responders" were more likely to have higher ASA scores, a Walch A1 vs B2 classification, and greater vs medium socioeconomic deprivation than "Fast responders." Moreover, "Steady responders" were more likely to be female, while "Poor responders" were more likely to have previous shoulder surgeries and RTSA for OA or for cuff arthropathy or rupture than "Fast responders."

Introduction

Although total shoulder arthroplasty (TSA) usually leads to substantial improvements in both pain and physical functioning, certain patients do not experience improvement or continue to report persistent pain 1 year after the procedure [1-3]. This indicates different recovery trajectories after TSA. However, little is known about the recovery trajectories after TSA. Gaining insight into the different recovery trajectories following TSA, as well as the patient and procedure characteristics associated with them, may provide valuable guidance for clinical decision-making [4].

Latent class growth modeling (LCGM) is an effective statistical technique for understanding heterogeneous recovery trajectories, as it enables the identification of different patient groups based on shared recovery patterns, rather than predefined patient categories [5]. While previous studies from the Dutch Arthroplasty Register (LROI) have successfully identified several recovery trajectories of patient-reported outcomes after total hip and knee arthroplasty using LCGM, recovery trajectories after TSA have not previously been identified with LROI data [6-8].

An earlier single-center study including small numbers of TSAs identified 3 recovery trajectories, which were named "High performers," "Steady progressors," and "Resistant responders" [9]. The study may have limited generalizability. Therefore, we aimed to identify recovery trajectories after TSA according to the Oxford Shoulder Score (OSS), using data from the national database, LROI. Second, we aimed to investigate whether recovery trajectories were associated with patient or procedure characteristics.

Methods

Data source

Data was obtained from the LROI, which is the national population-based arthroplasty register of the Netherlands. The completeness of primary shoulder arthroplasties is reported to be higher than 95% [10]. The LROI contains data on patient, prosthesis, and procedure characteristics of primary and revision arthroplasties as well as patient-reported outcome measurements (PROMs). PROMs after TSA have been registered in the LROI since 2016 and include the EuroQol 5 Dimensions index score (EQ-5D index), the EuroQol Visual Analog Scale (EQ VAS), the OSS, and the Numeric Rating Scale during activity (NRS activity) and at rest (NRS rest). These PROMs are measured preoperatively (within 182 days before surgery), and at 3 months (between 63 and 110 days) and 12 months (between 323 and 407 days) post-operatively. This study was reported in accordance with the STROBE guidelines.

Participants

We included all primary anatomical TSAs (ATSAs) and reversed TSAs (RTSAs) due to glenohumeral osteoarthritis (OA), cuff arthropathy, or cuff rupture registered in the LROI between 2016 and 2022, with PROM data available at least at 2 of the 3 time-points (n = 3,358; Figure 1). The LROI defines cuff arthropathy as "osteoarthritis of the shoulder joint as a consequence of the tendons around the shoulder joint being affected," and cuff rupture as "rupture of a tendon of the muscles that are around the shoulder joint" [10]. TSAs that were revised within 1 year (n = 42) were excluded. The number of ATSAs for cuff arthropathy or rupture (n = 2) was small, and these cases were therefore excluded as well.

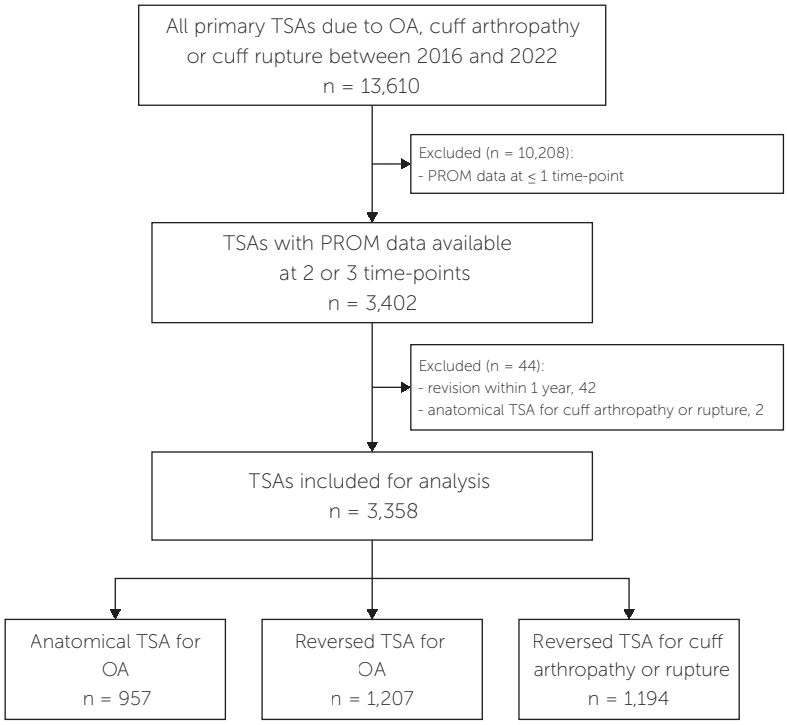


Figure 1. Flowchart.

TSA = total shoulder arthroplasty; OA = osteoarthritis; PROM = patient-reported outcome measurement.

PROM responders and non-responders were similar in terms of sex, age, diagnosis and arthroplasty type, American Society of Anesthesiologists (ASA) class, body mass index (BMI), Walch classification, smoking status, previous surgeries on the affected shoulder, socioeconomic status (SES), surgical approach, and fixation method. Therefore, we considered the missing cases to be missing at random. Non-responders were more frequently treated in the early years of the study (i.e., 2016–2017) and were therefore more often operated on using the anterosuperior or superolateral approach than responders, as this approach was more commonly used in the early years of our study.

Outcome

The primary outcome was the recovery trajectory, based on patient-reported pain and physical function, as measured by OSS. The OSS was chosen as it is the only shoulder-specific PROM available in the LROI. The OSS is a validated PROM designed to evaluate shoulder surgery outcomes. It consists of 12 questions assessing various aspects of shoulder function (e.g., dressing, shopping) and pain (e.g., worst pain, usual pain) experienced over the past 4 weeks. Each question is scored on a scale from 0 to 4, with 4 representing the best outcome. The total score ranges from 0 to 48, with higher values indicating better shoulder function and less pain [11]. Incomplete questionnaires are treated as missing data in the LROI database, accounting for only 1.1% of the missing preoperative OSS in the total population of 13,610 cases in our study. For the 3-month and 12-month postoperative OSS, the proportions were 0.7% and 0.8%, respectively.

Statistics

Descriptive statistics were used to summarize patient and procedure characteristics. Diagnosis and type of shoulder arthroplasty were combined into a single variable with 3 categories: ATSA for OA, RTSA for OA, and RTSA for cuff arthropathy or rupture. Missing data ranged between 0.0% for sex and age, and 17% for 12-month postoperative OSS (Table 1). Missing data was imputed, using multiple imputation by chained equations using predictive mean matching in which 10 datasets were created. All estimates were pooled according to Rubin's Rules. Subsequently, LCGM was performed using R (version 4.4.0, R Foundation for Statistical Computing, Vienna, Austria) with the "lcmm" package to identify possible subgroups of patients based on their recovery trajectories. A 1-class to 4-class latent class growth model was conducted. A model with additional classes was not clinically relevant, since only minor variations in the same recovery trajectories were observed. Model selection was determined by visually examining the plots, taking into account interpretability and clinical relevance, and evaluating the relative fit statistics Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Adjusted BIC

of the model [12]. The final model was selected for having the lowest relative fit statistics, while still offering satisfactory interpretability and clinical relevance. Our method assumes that the response variables within each latent class are normally distributed. Violations of the normality assumption can affect the estimation of the latent classes, potentially leading to biased class assignments or incorrect inferences regarding the number of latent classes. However, the method is generally robust to moderate deviations from normality, particularly when sample sizes are large. Therefore, we performed diagnostic checks such as visual inspection of histograms and Q–Q plots for the residuals of each latent class, and distribution assumptions appeared not to be violated. Posterior probabilities were assessed for estimating the likelihood of each patient belonging to a particular class. Sensitivity analyses were performed to identify recovery trajectories within sub-cohorts based on diagnosis and type of shoulder arthroplasty (ATSA for OA, RTSA for OA vs RTSA for cuff arthropathy or rupture), exploring potential differences in trajectories across diagnosis and arthroplasty types.

Crude and adjusted multinomial logistic regression analyses were used to investigate associations between potential risk factors and class membership, accounting for classification error, as described by Proust-Lima et al. [13]. These factors were chosen based on expert knowledge, relevant literature, and their availability within the LROI database. Potential risk factors considered included sex, age, diagnosis and type of shoulder arthroplasty, ASA class, BMI, Walch classification, smoking status, previous surgeries on the affected shoulder, and SES. SES was determined by the 4-digit postal code of the patient, and categorized (i.e., most deprived, medium deprived, or least deprived) as described by Bonsel et al. [14]. Briefly, the SES score is calculated for each postal code area with at least 100 inhabitants, based on the mean income per household, the percentage of households with low income, the percentage of unemployed inhabitants, and the percentages of households with low education. Subsequently, the SES scores were categorized into quintiles according to the cumulative z-distribution. Quintile 1 was classified as most deprived, quintiles 2 to 4 as medium deprived, and quintile 5 as least deprived. Surgical approach and fixation method were not considered potential risk factors, as these variables were inherently linked to the type of arthroplasty. The majority of ATSAs for OA (98%) were placed using the deltopectoral approach, and the majority of RTSAs for OA (91%) and RTSAs for cuff arthropathy or rupture (93%) had a cementless fixation (Table 1). A directed acyclic graph (DAG) was created to visualize potential causal relationships between the risk factors, confounders and the outcome (Figure 4, see Appendix). The largest recovery trajectory was considered the reference class. Estimates are presented as odds ratios (OR) with corresponding 95% confidence intervals (CI). Sensitivity analyses for each sub-cohort were not

Table 1. Patient and procedure characteristics of 3,358 total shoulder arthroplasties, stratified by diagnosis and type of shoulder arthroplasty. Values are count (%) unless otherwise specified

	All TSAs	ATSA–OA	RTSA–OA	RTSA–Cuff
Characteristic	n = 3,358	n = 957	n = 1,207	n = 1,194
Female sex	2,304 (69)	654 (68)	880 (73)	770 (65)
Age, mean (SD)	72 (8.5)	66 (8.6)	74 (7.1)	73 (7.4)
ASA class				
I	307 (9.1)	141 (15)	88 (7.3)	78 (6.5)
II	2,006 (60)	638 (66)	688 (57)	680 (57)
III–IV	1,008 (30)	167 (18)	423 (35)	418 (35)
Missing	37 (1.1)	11 (1.1)	8 (0.7)	18 (1.5)
BMI, mean (SD)	28.3 (5.0)	28.7 (4.9)	28.3 (5.1)	28.0 (4.9)
Missing, n (%)	43 (1.3)	14 (1.5)	10 (0.8)	19 (1.6)
Walch classification				
A1	1,356 (40)	307 (32)	338 (28)	711 (60)
A2	892 (27)	296 (31)	380 (32)	216 (18)
B1	438 (13)	196 (21)	157 (13)	85 (7.1)
B2	327 (9.7)	95 (9.9)	187 (16)	45 (3.8)
B3	112 (3.3)	18 (1.9)	62 (5.1)	32 (2.7)
C	52 (1.5)	5 (0.5)	40 (3.3)	7 (0.6)
Missing	181 (5.4)	40 (4.2)	43 (3.6)	98 (8.2)
Previous surgery on affected shoulder	567 (17)	122 (13)	139 (12)	306 (26)
Missing	13 (0.4)	4 (0.4)	3 (0.2)	6 (0.5)
Smoking	220 (6.6)	77 (8.0)	63 (5.2)	80 (6.7)
Missing	21 (0.6)	2 (0.2)	8 (0.7)	11 (0.9)
Surgical approach				
Anterosuperior/superolateral	569 (17)	4 (0.4)	218 (18)	347 (29)
Deltopectoral	2,738 (82)	938 (98)	971 (80)	829 (69)
Other approach	31 (0.9)	0 (0.0)	18 (1.5)	13 (1.1)
Missing	20 (0.6)	15 (1.6)	0 (0.0)	5 (0.4)
Fixation method				
Cemented	78 (2.3)	56 (5.9)	15 (1.2)	7 (0.6)
Cementless	2,369 (70)	153 (16)	1,100 (91)	1,116 (93)
Hybrid	898 (27)	736 (77)	91 (7.5)	71 (5.9)
Missing	13 (0.4)	12 (1.3)	1 (0.1)	0 (0.0)

Table 1. Continued

	All TSAs	ATSA–OA	RTSA–OA	RTSA–Cuff
Characteristic	n = 3,358	n = 957	n = 1,207	n = 1,194
Socioeconomic status				
Most deprived	828 (25)	203 (21)	307 (25)	318 (27)
Medium deprived	2,106 (63)	586 (61)	770 (64)	750 (63)
Least deprived	397 (12)	153 (16)	123 (10)	121 (10)
Missing	27 (0.8)	15 (1.6)	7 (0.6)	5 (0.4)
OSS, mean (SD)				
Preoperative	19 (8.0)	21 (7.7)	19 (7.8)	18 (8.2)
Missing, n (%)	343 (10)	113 (12)	89 (7.4)	141 (12)
3-month postoperative	29 (11)	29 (11)	30 (11)	27 (11)
Missing, n (%)	530 (16)	142 (15)	197 (16)	191 (16)
12-month postoperative	35 (11)	38 (10)	35 (12)	33 (11)
Missing, n (%)	566 (17)	166 (17)	213 (18)	187 (16)

TSA = total shoulder arthroplasty; ATSA = anatomical TSA; RTSA = reversed TSA; OA = osteoarthritis; Cuff = cuff arthropathy or rupture; ASA = American Society of Anesthesiologists; BMI = Body mass index; OSS = Oxford Shoulder Score.

performed in the multinomial logistic regression analyses, as sample sizes were considered too small for meaningful analyses, and similar recovery trajectories with only slightly different class sizes for ATSA for OA, RTSA for OA, and RTSA for cuff arthropathy or rupture were observed.

Ethics, data sharing, funding, and disclosures

Data was available from the LROI; however, restrictions apply to the availability of this data, which was used under license for the current study. All data was received completely de-identified. The data used in this study is available upon reasonable request, subject to the approval of the LROI. The LROI uses the opt-out system to require informed consent from patients. This study was funded by the LROI. The authors have the following potential conflicts of interest to declare. GH: payment received for meeting hours as member of the Scientific Advisory Board of the LROI, and member of the Data Safety Monitoring Board of the PERSuaDER trial. Complete disclosure of interest forms according to ICMJE are available on the article page, doi: 10.2340/17453674.2025.43085

Results

Between 2016 and 2022, a total of 13,610 ATSAs and RTSAs for OA, cuff arthropathy, or cuff rupture were registered in the LROI (Figure 1). Of these, 10,208 (75%) cases had PROM data available for only 1 time-point or no PROM data available and were excluded. Among the 3,358 included cases, 1,919 (57%) had PROM data available at all 3 time-points. 343 (10%) cases had a missing preoperative score, 530 (16%) cases had a missing 3-month postoperative score, and 566 (17%) cases had a missing 12-month postoperative score. Of the 3,358 TSAs, 957 were ATSAs for OA, 1,207 were RTSAs for OA, and 1,194 were RTSAs for cuff arthropathy or rupture (Figure 1).

Most TSA patients were female (69%), were ASA II class (60%), had a Walch A1 classification (40%), had not previously undergone surgery on the affected shoulder (83%), were non-smokers (93%), and were operated on with the deltopectoral approach (82%; Table 1). The mean (SD) age was 72 years (8.5), and the mean (SD) BMI was 28.3 (5.0). Table 2 provides an overview of the imputed data.

Model selection

The pooled relative fit statistics showed a decrease from the 1-class to the 4-class model, suggesting that a higher number of classes provided a better fit (Table 3). The 4-class model revealed minor variations in recovery trajectories, and was considered less clinically relevant. Therefore, the model with 3 classes was selected as the final model. The pooled mean (SD) posterior probabilities of class membership in the 3-class model were 0.89 (0.14) for class 1, 0.76 (0.15) for class 2, and 0.84 (0.17) for class 3, indicating satisfactory model performance (Table 4).

Sensitivity analyses showed that the 3-class models were also the most appropriate for ATSA for OA, RTSA for OA, and RTSA for cuff arthropathy or rupture (Table 3). The pooled mean (SD) posterior probabilities of class membership were 0.91 (0.13) for class 1, 0.81 (0.15) for class 2, and 0.86 (0.16) for class 3 among ATSAs for OA; 0.90 (0.13) for class 1, 0.75 (0.16) for class 2, and 0.85 (0.17) for class 3 among RTSAs for OA; and 0.86 (0.15) for class 1, 0.73 (0.15) for class 2, and 0.82 (0.17) for class 3 among RTSAs for cuff arthropathy or rupture (Table 4).

Table 2. Patient and procedure characteristics of all total shoulder arthroplasties, and stratified by class membership

	All TSAs			Fast responders		
Characteristic	n[a] (%)	min.	max.[b]	n[a] (%)	min.	max.[b]
TSAs	3,358			1,999 (59)	1,969	2,041
Sex						
Female	2,304 (69)	2,304	2,304	1,310 (65)	1,282	1,337
Male	1,054 (31)	1,054	1,054	689 (35)	680	704
Age, mean (SD)	71 (8.5)	71	71	72 (8.0)	71	72
ASA class						
I	308 (9.2)	307	310	208 (10)	199	213
II	2,027 (60)	2,020	2,032	1,253 (63)	1,233	1,276
III–IV	1,023 (31)	1,019	1,029	538 (27)	521	558
BMI, mean (SD)	28 (5.0)	28	28	28 (4.8)	28	28
Walch classification						
A1	1,446 (43)	1,434	1,457	806 (40)	792	817
A2	939 (28)	927	947	558 (28)	536	580
B1	460 (14)	453	468	289 (15)	277	300
B2	340 (10)	335	345	229 (11)	222	234
B3	118 (3.5)	116	121	83 (4.1)	80	86
C	54 (1.6)	52	56	35 (1.7)	30	38
Previous surgery on affected shoulder						
Yes	569 (17)	568	570	309 (16)	301	319
No	2,789 (83)	2,788	2,790	1,690 (84)	1,667	1,722
Smoking						
Yes	222 (6.6)	221	223	122 (6.1)	118	130
No	3,136 (93)	3,135	3,137	1,876 (94)	1,850	1,914
Surgical approach						
Anterosuperior/superolateral	570 (17)	569	571	262 (13)	254	268
Deltopectoral	2,757 (82)	2,755	2,758	1,710 (86)	1,680	1,747
Other	32 (0.9)	31	33	27 (1.3)	25	29
Fixation method						
Cemented	79 (2.4)	78	82	61 (3.0)	59	65
Cementless	2,372 (71)	2,370	2,375	1,406 (70)	1,382	1,438
Hybrid	907 (27)	904	910	532 (27)	525	543
Socioeconomic status						
Most deprived	836 (25)	833	839	459 (23)	445	473
Medium deprived	2,122 (63)	2,117	2,125	1,299 (65)	1,282	1,328
Least deprived	400 (12)	397	402	240 (12)	234	247

	Steady responders		Poor responders	
Characteristic	n[a] (%)	min. max.[b]	n[a] (%)	min. max.[b]
TSAs	890 (27)	804 960	469 (14)	427 513
Sex				
Female	667 (75)	607 719	327 (70)	298 360
Male	223 (25)	197 241	142 (30)	129 153
Age, mean (SD)	72 (9.3)	71 72	71 (8.6)	71 72
ASA class				
I	76 (8.6)	72 82	25 (5.2)	22 26
II	504 (56)	460 537	269 (57)	249 296
III–IV	310 (35)	268 342	175 (37)	156 193
BMI, mean (SD)	28 (5.0)	28 28	29 (5.7)	29 29
Walch classification				
A1	408 (46)	376 442	232 (50)	206 248
A2	251 (28)	213 270	130 (28)	120 149
B1	123 (14)	117 132	48 (10)	44 52
B2	77 (8.6)	68 88	35 (7.5)	31 41
B3	22 (2.4)	19 25	14 (3.0)	12 16
C	10 (1.1)	8 13	9 (1.9)	7 12
Previous surgery on affected shoulder				
Yes	153 (17)	138 169	107 (23)	95 115
No	737 (83)	666 791	362 (77)	332 400
Smoking				
Yes	62 (6.9)	54 75	38 (8.2)	30 45
No	828 (93)	750 885	431 (92)	397 472
Surgical approach				
Anterosuperior/superolateral	136 (15)	115 153	172 (37)	163 186
Deltopectoral	751 (84)	686 803	295 (63)	262 324
Other	3 (0.4)	2 4	2 (0.4)	1 3
Fixation method				
Cemented	11 (1.3)	9 15	7 (1.5)	5 8
Cementless	613 (69)	538 671	353 (75)	317 395
Hybrid	266 (30)	252 278	109 (23)	100 115
Socioeconomic status				
Most deprived	240 (27)	213 270	136 (29)	119 150
Medium deprived	551 (62)	500 586	272 (58)	253 297
Least deprived	100 (11)	91 107	61 (13)	55 67

Table 2. Continued

	All TSAs		Fast responders	
Characteristic	n[a] (%)	min. max.[b]	n[a] (%)	min. max.[b]
Diagnosis and type of arthroplasty				
ATSA for OA	957 (28)	957 957	600 (30)	595 609
RTSA for OA	1,207 (36)	1,207 1,207	757 (38)	738 776
RTSA for cuff	1,194 (36)	1,194 1,194	642 (32)	632 656

For Abbreviations, see Table 1.
Estimates are pooled across the 10 imputed datasets.
[a] Pooled cases are rounded to the nearest number.
[b] Lowest and highest values across the 10 imputed datasets.

Table 3. Pooled model fit statistics

Model	Log likelihood	AIC	BIC	Adjusted BIC	Class (%) 1	2	3	4
All TSAs								
1-class	–37,130	74,269	74,300	74,284	100			
2-class	–36,583	73,184	73,240	73,211	80	20		
3-class	–36,373	72,772	72,852	72,811	59	27	14	
4-class	–36,289	72,611	72,715	72,661	55	32	8.9	4.5
ATSA–OA								
1-class	–10,478	20,970	20,993	20,978	100			
2-class	–10,334	20,686	20,729	20,701	82	18		
3-class	–10,236	20,499	20,562	20,521	61	29	10	
4-class	–10,228	20,490	20,573	20,519	52	29	12	7.1
RTSA–OA								
1-class	–13,377	26,763	26,789	26,773	100			
2-class	–13,138	26,295	26,341	26,312	80	20		
3-class	–13,068	26,161	26,228	26,186	63	23	14	
4-class	–13,066	26,165	26,252	26,198	60	25	14	1.6
RTSA–Cuff								
1-class	–13,208	26,425	26,451	26,435	100			
2-class	–13,034	26,086	26,132	26,103	77	23		
3-class	–12,977	25,981	26,047	26,005	55	28	17	
4-class	–12,935	25,904	25,990	25,936	48	35	12	4.7

AIC = Akaike information criterion; BIC = Bayesian information criterion.
For Abbreviations, also see Table 1.

	Steady responders		Poor responders	
Characteristic	n[a] (%)	min. max.[b]	n[a] (%)	min. max.[b]
Diagnosis and type of arthroplasty				
ATSA for OA	259 (29)	249 270	98 (21)	90 102
RTSA for OA	282 (32)	245 319	168 (36)	150 186
RTSA for cuff	349 (39)	310 371	204 (43)	185 228

Table 4. Pooled posterior probabilities of class membership in the 3-class model. Values are mean (standard deviation)

	All TSAs	ATSA–OA	RTSA–OA	RTSA–Cuff
Class	n = 3,358	n = 957	n = 1,207	n = 1,194
Class 1	0.89 (0.14)	0.91 (0.13)	0.90 (0.13)	0.86 (0.15)
Class 2	0.76 (0.15)	0.81 (0.15)	0.75 (0.16)	0.73 (0.15)
Class 3	0.84 (0.17)	0.86 (0.16)	0.85 (0.17)	0.82 (0.17)

For Abbreviations, see Table 1.

Recovery trajectories

The final model showed 3 different recovery trajectories after TSA, which were labelled as "Fast responders," "Steady responders," and "Poor responders" (Figure 2).

The "Fast responders" was the largest class, including 1,999 (59%) TSAs. This class had a pooled estimated preoperative OSS of 20 (CI 20–21). The pooled estimated OSS increased sharply to 35 (CI 35–36) at 3 months postoperatively, followed by a further rise to 41 (CI 40–41) at 12 months postoperatively, which indicates better physical function and reduced pain.

The second class was the "Steady responders," consisting of 890 (27%) TSAs. The pooled estimated preoperative OSS of this class was slightly lower (17, CI 16–17) than that of the "Fast responders." The pooled estimated OSS had a steady increase to 20 (CI 19–20) at 3 months postoperatively, and to 33 (CI 32–34) at 12 months postoperatively, indicating improved physical function and pain.

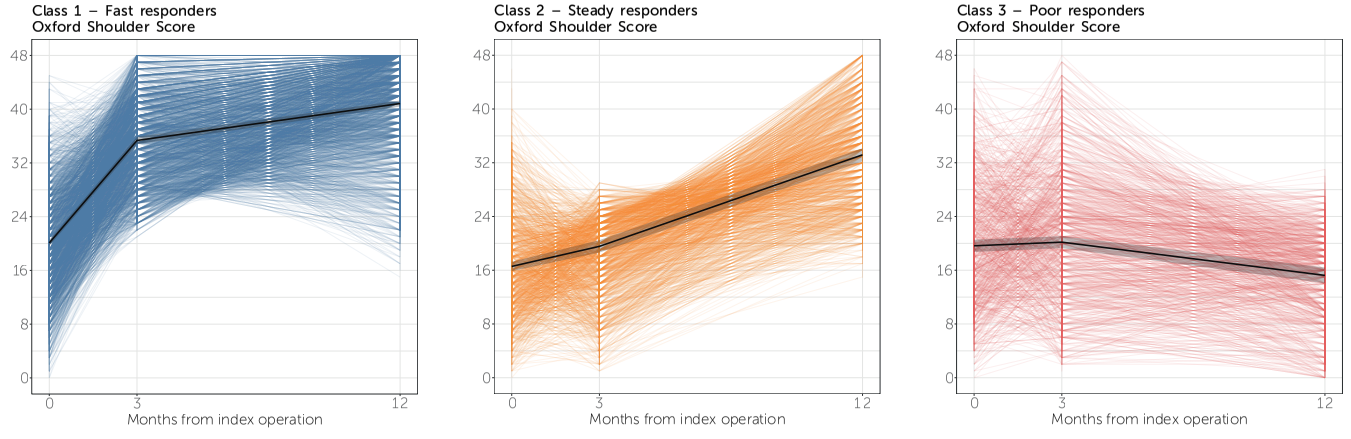


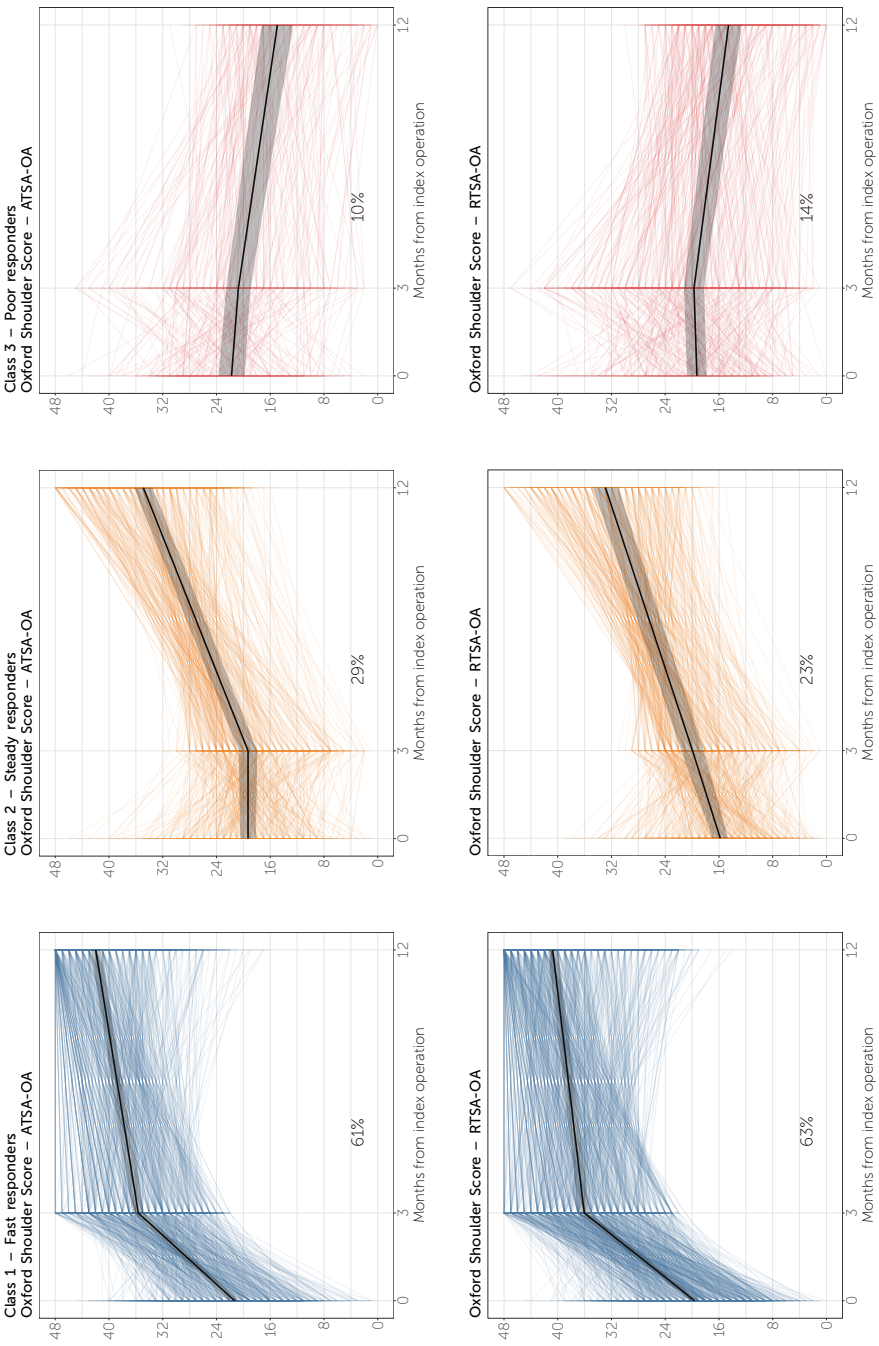
Figure 2. Recovery trajectories based on Oxford Shoulder Scores, stratified by class membership (Class 1: n = 1,999; Class 2: n = 890; Class 3: n = 469). Pooled mean trajectories with corresponding 95% CIs are shown in black, and individual trajectories are displayed in color. Individuals were classified into classes according to their highest probability of class membership.

The smallest class, comprising 469 (14%) TSAs, was labelled "Poor responders." This class had a comparable pooled estimated OSS of 20 (CI 19–21) preoperatively to the "Fast responders." No improvements were observed at 3 months postoperatively (20, CI 19–21). The pooled estimated OSS declined to 15 (CI 14–16) at 12 months postoperatively, indicating worse physical function and increased pain.

Sensitivity analyses revealed similar recovery trajectories with slightly different class sizes for ATSA for OA, RTSA for OA, and RTSA for cuff arthropathy or rupture (Figure 3).

Potential risk factors and class membership

Pooled adjusted multinomial regression analyses showed that factors statistically significantly associated with class membership in the "Steady responders" vs the "Fast responders" were female vs male sex (OR 2.0, CI 1.5–2.7), ASA III–IV vs ASA I (OR 1.9, CI 1.2–3.1), Walch A1 vs B2 (OR 1.6, CI 1.1– 2.5), and most vs medium socioeconomic deprivation (OR 1.4, CI 1.1–1.9). Factors statistically significantly associated with class membership in the "Poor responders" vs the "Fast responders" included ASA II vs ASA I (OR 2.0, CI 1.1–3.6), ASA III–IV vs ASA I (OR 3.0, CI 1.6–5.5), Walch A1 vs B2 (OR 2.1, CI 1.3–3.3), previous shoulder surgeries (OR 1.8, CI 1.3–2.4), most vs medium socioeconomic deprivation (OR 1.5, CI 1.2–2.0), RTSA for OA vs ATSA for OA (OR 1.8, CI 1.2–2.7), and RTSA for cuff arthropathy or rupture vs ATSA for OA (OR 2.3, CI 1.5–3.4; Table 5).


Class 1 – Fast responders
Oxford Shoulder Score – ATSA-OA
61%
Class 2 – Steady responders
Oxford Shoulder Score – ATSA-OA
29%
Class 3 – Poor responders
Oxford Shoulder Score – ATSA-OA
10%
Oxford Shoulder Score – RTSA-OA
63%
Oxford Shoulder Score – RTSA-OA
23%
Oxford Shoulder Score – RTSA-OA
14%
Months from index operation
0
3
12
0
8
16
24
32
40
48

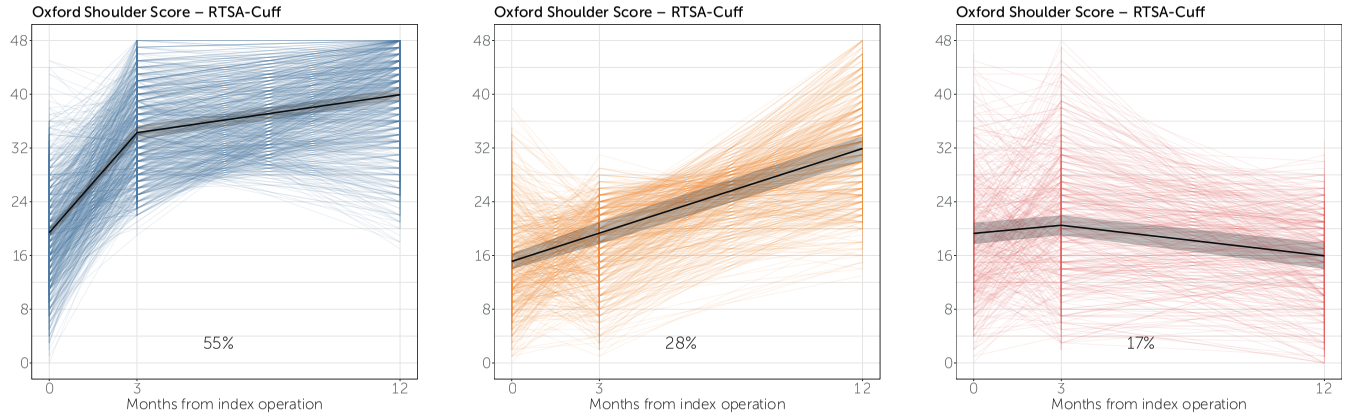


Figure 3. Recovery trajectories based on Oxford Shoulder Scores, stratified by class membership, and diagnosis and arthroplasty type. Pooled mean trajectories with corresponding 95% CIs are shown in black, and individual trajectories are displayed in color. Individuals were classified into classes according to their highest probability of class membership. Class sizes in percentages are shown for each sub-cohort.

ATSA = total anatomical shoulder arthroplasty; RTSA = total reversed shoulder arthroplasty; OA = osteoarthritis; Cuff = cuff arthropathy or rupture.

Table 5. Crude and adjusted multinomial logistic regression analyses of potential risk factors and class membership

	"Steady responders" vs "Fast responders"		"Poor responders" vs "Fast responders"	
	Crude	Adjusted [a]	Crude	Adjusted [a]
Factor	OR (CI)	OR (CI)	OR (CI)	OR (CI)
Females (ref. males)	2.0 (1.5–2.7)	2.0 (1.5–2.7)	1.3 (1.0–1.6)	1.3 (1.0–1.6)
Age	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.0 (1.0–1.0)
ASA class (ref. ASA I)				
II	1.1 (0.7–1.7)	1.1 (0.7–1.7)	2.1 (1.2–3.7)	2.0 (1.1–3.6)
III–IV	1.9 (1.1–3.0)	1.9 (1.2–3.1)	3.2 (1.8–5.8)	3.0 (1.6–5.5)
Body mass index	1.0 (1.0–1.0)	1.0 (1.0–1.0)	1.1 (1.0–1.1)	1.1 (1.0–1.1)
Walch classification (ref. B2)				
A1	1.7 (1.1–2.6)	1.6 (1.1–2.5)	2.1 (1.3–3.3)	2.1 (1.3–3.3)
A2	1.5 (0.9–2.3)	1.4 (0.9–2.1)	1.6 (1.0–2.6)	1.6 (1.0–2.6)
B1	1.3 (0.8–2.2)	1.3 (0.7–2.1)	1.0 (0.6–1.7)	1.0 (0.6–1.8)
B3	0.7 (0.3–1.7)	0.8 (0.3–1.7)	1.1 (0.5–2.5)	1.1 (0.5–2.6)
C	0.9 (0.3–3.0)	0.9 (0.3–3.1)	2.0 (0.7–5.6)	2.0 (0.7–5.7)
Previous surgeries on affected shoulder (ref. no previous surgeries)	1.2 (0.9–1.6)	1.2 (0.9–1.6)	1.8 (1.3–2.4)	1.8 (1.3–2.4)
Smoking (ref. no smoking)	1.3 (0.8–2.0)	1.4 (0.8–2.2)	1.3 (0.8–2.3)	1.3 (0.8–2.3)
Socioeconomic status (ref. medium deprived)				
Most deprived	1.4 (1.1–1.9)	1.4 (1.1–1.9)	1.5 (1.2–2.0)	1.5 (1.2–2.0)
Least deprived	1.1 (0.7–1.7)	1.1 (0.7–1.7)	1.3 (0.9–1.8)	1.3 (0.9–1.8)
Diagnosis and arthroplasty type (ref. ATSA–OA)				
RTSA–OA	0.8 (0.6–1.1)	0.8 (0.6–1.1)	1.5 (1.1–2.2)	1.8 (1.2–2.7)
RTSA–Cuff	1.5 (1.1–2.0)	1.4 (1.0–1.9)	2.3 (1.6–3.3)	2.3 (1.5–3.4)

Estimates are pooled across the 10 imputed datasets.

a Confounders were chosen according to the directed acyclic graph (Figure 4, see Appendix).

OR = odds ratio; CI = 95% confidence interval. For Abbreviations, also see Table 1.

Discussion

We aimed to identify recovery trajectories after TSA based on the Oxford Shoulder Score (OSS) along with their potential risk factors. A total of 3 recovery trajectories were identified after TSA, which we labelled as "Fast responders," "Steady responders," and "Poor responders." Both "Fast responders" and "Steady responders" showed improved physical function and reduced pain 12 months postoperatively, comprising most patients (86%). In contrast, "Poor responders" experienced slightly worsened physical function and increased pain. "Steady responders" and "Poor responders" were more likely to have higher ASA scores, a Walch A1 classification, and greater socioeconomic deprivation than "Fast responders", compared with the reference categories. Moreover, "Steady responders" were more likely to be female, while "Poor responders" were more likely to have previous shoulder surgeries than "Fast responders."

Similar recovery trajectories were observed following ATSA for OA, RTSA for OA, and RTSA for cuff arthropathy or rupture, although the class sizes differed slightly among these groups. Compared with patients with ATSA for OA, patients with RTSA for OA and for cuff arthropathy or rupture were more likely to be "Poor responders" than "Fast responders." These differences may be explained by differences in patient characteristics between the sub-cohorts. In our study, patients with RTSA for OA, cuff arthropathy, or cuff rupture were older and had higher ASA scores than those with ATSA for OA. Moreover, patients with RTSA for cuff arthropathy or rupture had undergone previous shoulder surgeries more often than those with ATSA or RTSA for OA. Although we performed adjusted multinomial logistic regression analyses based on a DAG to minimize confounding, residual confounding is likely still present. The use of registry data, which is collected as part of the usual care process, is limited by the number of variables collected. Possible risk factors for recovery, such as preoperative mental health status and diabetes, could not be included in this study [15-17]. Therefore, the findings regarding diagnosis and arthroplasty type should be interpreted carefully, as unmeasured factors may have influenced the associations between these variables and class membership.

A minority of patients (14%) did not experience improvement after TSA, leading to their classification as "Poor responders." This may include patients with complications and/or revisions occurring more than 1 year postoperatively. This proportion is consistent with other studies, which report that 9% to 16% of patients experience no improvement or continue to suffer from persistent pain 2 years after ATSA or RTSA for OA, cuff arthropathy, or cuff rupture [3,18,19].

Only 1 previous study has identified recovery trajectories after TSA, finding 3 different trajectories: "High performers," "Steady progressors," and "Resistant responders" [9]. The "High performers" and "Steady progressors" seem to be comparable to the "Fast responders" and "Steady responders" in our study. However, while "Resistant responders" showed small improvement, our "Poor responders" experienced slightly worsened physical function and increased pain. This difference may be partly explained by differences in methodological aspects. The previous study was conducted at a single center and included only complete cases, resulting in a smaller sample size compared with our national registry study, covering all Dutch hospitals performing TSA and collecting OSS. Moreover, the previous study used the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment, measured at 5 time-points up to 2 years postoperatively, whereas we used the OSS, measured at 3 time-points up to 1 year postoperatively. In contrast to our results, the study also found differences in the smallest recovery trajectories after ATSA and RTSA, with "Late responders" observed after ATSA and "Late regressors" after RTSA. Their results were stratified by type of shoulder arthroplasty, while we stratified our results by both diagnosis and type of shoulder arthroplasty. Furthermore, 8% of the ATSAs and 13% of the RTSAs were performed for diagnoses other than OA, cuff arthropathy, or cuff rupture [9].

Various studies have explored the relationship between patient and procedure factors and patient-reported outcomes following ATSA or RTSA [15,16,18-22]. Most studies, including ours, found that a history of shoulder surgeries was associated with worse patient-reported outcomes [15,18-21]. Some studies identified comorbidity as a risk factor for worse patient-reported outcomes, which may be reflected by our association of higher ASA scores with suboptimal recovery [16,18,19]. Although both our and another study found an association between sex and patient-reported outcomes [15], other studies did not observe this link [18,19,21,22], potentially due to differences in study design, sample sizes, and methodology. In contrast to our findings, smoking was also identified as risk factor in previous studies [15,20,22]. However, confidence intervals were wide in our study, including for smoking, resulting in uncertainty around the effect estimates.

Limitations

PROM response rate after TSA is relatively low. Of the 13,610 TSAs registered for OA, cuff arthropathy, or cuff rupture between 2016 and 2022, 3,358 (25%) TSA patients had at least 2 out of 3 PROM scores available and were therefore included in this study. This response rate is well below the 60% threshold proposed by the International Society of Arthroplasty Registries as an acceptable response rate, suggesting that our results may be affected by non-responder bias [23]. PROM

non-responders were more frequently treated in the early years of the study (i.e., 2016–2017) and were therefore less often operated on using the deltopectoral approach than responders. No other differences were observed in patient and procedure characteristics between non-responders and responders. Moreover, the response rate of PROMs varies widely among Dutch hospitals, with some hospitals not collecting any PROM data, which may negatively impact the generalizability of this study [10]. However, no associations were found between hospital-level PROM response rates and patient characteristics such as age, sex, BMI, and ASA class in Australia, where PROM response rates range from 4.5% to 82% for preoperative scores and from 3.8% to 69% for 6-month postoperative scores [24]. This may suggest that higher hospital-level PROM response rates may not necessarily result in a more representative sample [24]. Lastly, the OSS may be subject to ceiling effects 6 to 12 months postoperatively [25]. However, 11% of patients across the 10 imputed datasets achieved the maximum OSS score at 12 months postoperatively in our study, which is below the commonly used 15% threshold [26].

Conclusion

3 recovery trajectories were identified following TSA for OA, cuff arthropathy, or cuff rupture, which were labelled as "Fast responders," "Steady responders," and "Poor responders." Both ATSA and RTSA seem to follow similar recovery trajectories, despite the differences in diagnoses and arthroplasty type. "Steady responders" and "Poor responders" were more likely to have higher ASA scores, a Walch A1 vs B2 classification, and greater vs medium socioeconomic deprivation than "Fast responders." Moreover, "Steady responders" were more likely to be female, while "Poor responders" were more likely to have had previous shoulder surgeries than "Fast responders." In perspective, the recovery trajectories and their associated risk factors may provide valuable guidance for orthopedic surgeons in counseling patients undergoing TSA.

References

[1] Carter MJ, Mikuls TR, Nayak S, Fehringer EV, Michaud K. Impact of total shoulder arthroplasty on generic and shoulder-specific health-related quality-of-life measures: a systematic literature review and meta-analysis. J Bone Joint Surg Am 2012;94(17):e127. https://doi.org/10.2106/JBJS.K.00204.

[2] Roberson TA, Bentley JC, Griscom JT, Kissenberth MJ, Tolan SJ, Hawkins RJ, Tokish JM. Outcomes of total shoulder arthroplasty in patients younger than 65 years: a systematic review. J Shoulder Elbow Surg 2017;26(7):1298-306. https://doi.org/10.1016/j.jse.2016.12.069.

[3] Bjornholdt KT, Brandsborg B, Soballe K, Nikolajsen L. Persistent pain is common 1-2 years after shoulder replacement. Acta Orthop 2015;86(1):71-7. https://doi.org/10.3109/17453674.2014.987065.

[4] Auer CJ, Glombiewski JA, Doering BK, Winkler A, Laferton JA, Broadbent E, Rief W. Patients' Expectations Predict Surgery Outcomes: A Meta-Analysis. Int J Behav Med 2016;23(1):49-62. https://doi.org/10.1007/s12529-015-9500-4.

[5] Nagin DS, Odgers CL. Group-based trajectory modeling in clinical research. Annu Rev Clin Psychol 2010;6:109-38. https://doi.org/10.1146/annurev.clinpsy.121208.131413.

[6] Hesseling B, Mathijssen NMC, van Steenbergen LN, Melles M, Vehmeijer SBW, Porsius JT. Fast Starters, Slow Starters, and Late Dippers: Trajectories of Patient-Reported Outcomes After Total Hip Arthroplasty: Results from a Dutch Nationwide Database. J Bone Joint Surg Am 2019;101(24):2175-86. https://doi.org/10.2106/JBJS.19.00234.

[7] van Egmond JC, Hesseling B, Melles M, Vehmeijer SBW, van Steenbergen LN, Mathijssen NMC, Porsius JT. Three distinct recovery patterns following primary total knee arthroplasty: dutch arthroplasty register study of 809 patients. Knee Surg Sports Traumatol Arthrosc 2021;29(2):529-39. https://doi.org/10.1007/s00167-020-05969-8.

[8] Kuijpers MFL, Van Steenbergen LN, Schreurs BW, Hannink G. Patient-reported outcome of 95% of young patients improves after primary total hip arthroplasty: identification of 3 recovery trajectories in 3,207 patients younger than 55 years from the Dutch Arthroplasty Register. Acta Orthop 2022;93:560-7. https://doi.org/10.2340/17453674.2022.3140.

[9] Rubenstein WJ, Warwick HSL, Aung MS, Zhang AL, Feeley BT, Ma CB, Lansdown DA. Defining recovery trajectories after shoulder arthroplasty: a latent class analysis of patient-reported outcomes. J Shoulder Elbow Surg 2021;30(10):2375-85. https://doi.org/10.1016/j.jse.2021.02.024.

[10] LROI. Annual report 2024. Landelijke Registratie Orthopedische Interventies; 2024. Available from: https://www.lroi.nl/media/prqogokg/pdf-lroi-report-2024.pdf.

[11] Resnik L, Borgia M, Silver B, Cancio J. Systematic Review of Measures of Impairment and Activity Limitation for Persons With Upper Limb Trauma and Amputation. Arch Phys Med Rehabil 2017;98(9):1863-92 e14. https://doi.org/10.1016/j.apmr.2017.01.015.

[12] Ram N, Grimm KJ. Growth Mixture Modeling: A Method for Identifying Differences in Longitudinal Change Among Unobserved Groups. Int J Behav Dev 2009;33(6):565-76. https://doi.org/10.1177/0165025409343765.

[13] Proust-Lima C, Saulnier T, Philipps V, Traon AP, Peran P, Rascol O, Meissner WG, Foubert-Samier A. Describing complex disease progression using joint latent class models for multivariate longitudinal markers and clinical endpoints. Stat Med 2023;42(22):3996-4014. https://doi.org/10.1002/sim.9844.

[14] Bonsel JM, Reijman M, Verhaar JAN, van Steenbergen LN, Janssen MF, Bonsel GJ. Socioeconomic inequalities in patient-reported outcome measures of Dutch primary hip and knee arthroplasty patients for osteoarthritis. Osteoarthritis Cartilage 2024;32(2):200-9. https://doi.org/10.1016/j.joca.2023.07.004.

[15] Sahoo S, Entezari V, Ho JC, Jun BJ, Cleveland Clinic Shoulder G, Jin Y, Imrey PB, Derwin KA, Iannotti JP, Ricchetti ET. Disease diagnosis and arthroplasty type are strongly associated with short-term postoperative patient-reported outcomes in patients undergoing primary total shoulder arthroplasty. J Shoulder Elbow Surg 2024;33(6):e308-e21. https://doi.org/10.1016/j.jse.2024.01.028.

[16] Ling DI, Schneider B, Ode G, Lai EY, Gulotta LV. The impact of Charlson and Elixhauser comorbidities on patient outcomes following shoulder arthroplasty. Bone Joint J 2021;103-B(5):964-70. https://doi.org/10.1302/0301-620X.103B5.BJJ-2020-1503.R1.

[17] Broekman MM, Brinkman N, Swanson D, Ring D, van den Bekerom M, Jawa A. Variations in 1-year Trajectories of Levels of Pain and Capability After Shoulder Arthroplasty Are Associated With Baseline Mental Health. Clin Orthop Relat Res 2024;482(3):514-22. https://doi.org/10.1097/CORR.0000000000002821.

[18] Parsons M, Routman HD, Roche CP, Friedman RJ. Patient-reported outcomes of reverse total shoulder arthroplasty: a comparative risk factor analysis of improved versus unimproved cases. JSES Open Access 2019;3(3):174-8. https://doi.org/10.1016/j.jses.2019.07.004.

[19] Mahony GT, Werner BC, Chang B, Grawe BM, Taylor SA, Craig EV, Warren RF, Dines DM, Gulotta LV. Risk factors for failing to achieve improvement after anatomic total shoulder arthroplasty for glenohumeral osteoarthritis. J Shoulder Elbow Surg 2018;27(6):968-75. https://doi.org/10.1016/j.jse.2017.12.018.

[20] Friedman RJ, Eichinger J, Schoch B, Wright T, Zuckerman J, Flurin PH, Bolch C, Roche C. Preoperative parameters that predict postoperative patient-reported outcome measures and range of motion with anatomic and reverse total shoulder arthroplasty. JSES Open Access 2019;3(4):266-72. https://doi.org/10.1016/j.jses.2019.09.010.

[21] Baram A, Ammitzboell M, Brorson S, Olsen BS, Amundsen A, Rasmussen JV. What Factors are Associated with Revision or Worse Patient-reported Outcome after Reverse Shoulder Arthroplasty for Cuff-tear Arthropathy? A Study from the Danish Shoulder Arthroplasty Registry. Clin Orthop Relat Res 2020;478(5):1089-97. https://doi.org/10.1097/CORR.0000000000001114.

[22] Waheed I, Ediripolage F, Alvi I, Haider JM. Preoperative Risk Factors for Pain After Reverse Total Shoulder Arthroplasty: A Systematic Review. Cureus 2024;16(5):e60041. https://doi.org/10.7759/cureus.60041.

[23] Rolfson O, Bohm E, Franklin P, Lyman S, Denissen G, Dawson J, Dunn J, Eresian Chenok K, Dunbar M, Overgaard S, Garellick G, Lubbeke A, Patient-Reported Outcome Measures Working Group of the International Society of Arthroplasty R. Patient-reported outcome measures in arthroplasty registries: Report of the Patient-Reported Outcome Measures Working Group of the International Society of Arthroplasty Registries Part II. Recommendations for selection, administration, and analysis. Acta Orthop 2016;87 Suppl 1(Suppl 1):9-23. https://doi.org/10.1080/17453674.2016.1181816.

[24] Harris IA, Peng Y, Cashman K, Ackerman I, Heath E, Rowden N, Graves SE. Association between patient factors and hospital completeness of a patient-reported outcome measures program in joint arthroplasty, a cohort study. J Patient Rep Outcomes 2022;6(1):32. https://doi.org/10.1186/s41687-022-00441-2.

[25] Pines Y, Gordon D, Alben M, Kwon YW, Zuckerman JD, Virk MS. Performance and responsiveness to change of PROMIS UE in patients undergoing total shoulder arthroplasty. J Orthop Res 2022;40(10):2457-64. https://doi.org/10.1002/jor.25263.

[26] Terwee CB, Bot SD, de Boer MR, van der Windt DA, Knol DL, Dekker J, Bouter LM, de Vet HC. Quality criteria were proposed for measurement properties of health status questionnaires. J Clin Epidemiol 2007;60(1):34-42. https://doi.org/10.1016/j.jclinepi.2006.03.012.

Appendix

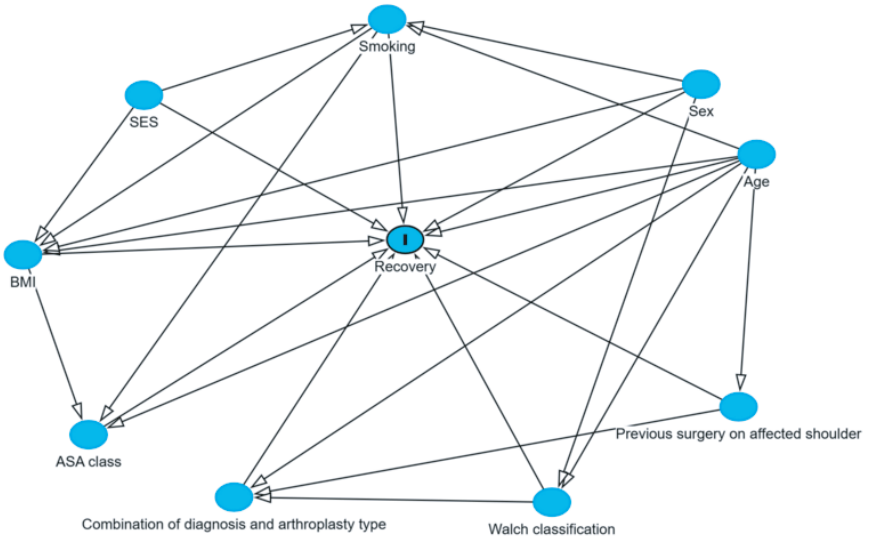
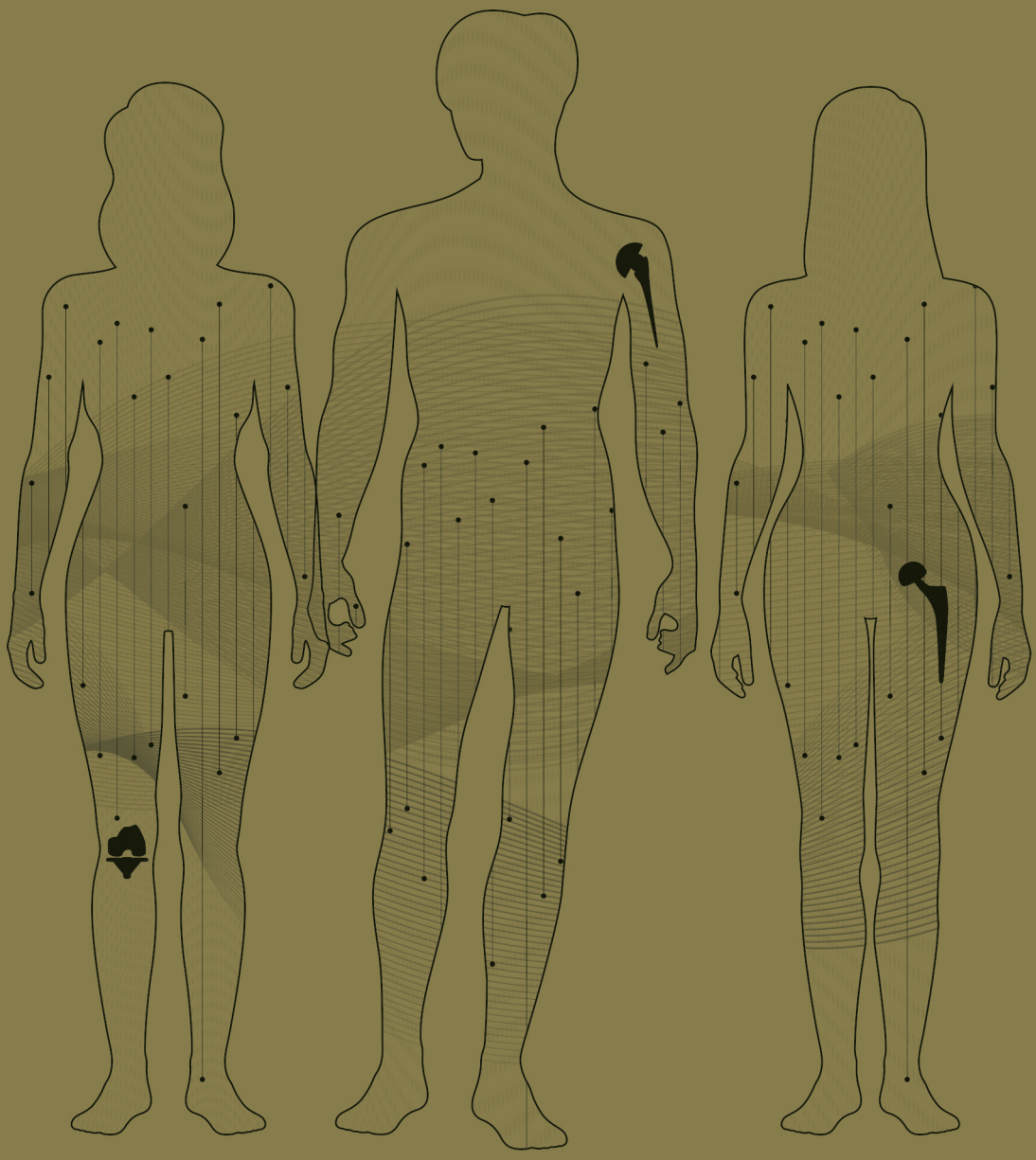


Figure 4. Directed acyclic graph (DAG) illustrating the potential relationships between risk factors and recovery trajectories following total shoulder arthroplasty. Confounders were chosen according to this DAG: ASA class was adjusted for age, BMI, and smoking; BMI was adjusted for sex, age, smoking, and SES; Walch classification was adjusted for sex and age; previous surgeries on affected shoulder was adjusted for age; smoking was adjusted for sex, age, and SES; and diagnosis and arthroplasty type was adjusted for age, previous surgeries on affected shoulder, and Walch classification. No adjustments were made for sex, age, and SES.



10

General discussion and future perspectives

This thesis consists of 3 parts, which include the opportunities and challenges of combining and comparing data from multiple national arthroplasty registries (Part 1), linking Dutch Arthroplasty Register (LROI) data with data from a registry in another medical field and a local database to validate and enrich analyses (Part 2), and conducting epidemiological studies to explore trends, patterns, and associations (Part 3). In this chapter, the main findings of the studies presented in each of the 3 parts of this thesis will be discussed, followed by future research perspectives.

Part 1: Collaboration & comparison between national arthroplasty registries

This first part of the thesis highlights both the opportunities and challenges of combining and comparing data from multiple high-quality national arthroplasty registries. Collaborations between multiple national arthroplasty registries often aim to pool data to increase sample size and improve statistical power. We used uncemented short-stem total hip arthroplasties (THAs) as a case study to explore multinational collaboration between Australia, the Netherlands and Sweden, as uncemented short-stem THAs are a relatively infrequently used type of prosthesis. Some challenges were encountered when combining and comparing data from multiple national arthroplasty registries, including differences in implant selection, country-specific implant use, variable classifications, the addition of variables to registries in different years, and varying degrees of potential confounding. These challenges as well as the opportunities of the multinational collaboration are illustrated using the case study of uncemented short-stem THAs as an example.

There is no clear international definition of an uncemented short stem. However, the definitions used by the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the LROI are comparable, as both registries define a short stem as a cementless femoral stem designed for entirely metaphyseal fixation [1,2]. Since the start of the registry, the LROI has developed an implant library in which the characteristics of prothesis components, based on the article number, are registered in collaboration with the manufacturer [3]. These characteristics include, among others, the type, brand, name, size, coating, and material of the component. By using barcode scanning of article numbers, prothesis components and their characteristics from the implant library are automatically imported into the LROI, reducing the registration burden and increasing accuracy. The implant library includes all prostheses available on the Dutch market and is continuously updated. As a result, the implant library can facilitate the selection of prosthesis types, based on specific characteristics, from the registry (e.g., THAs with a short stem). In our studies, each registry selected its own uncemented

short-stem THAs, with the Swedish Arthroplasty Register (SAR) using the definitions from the AOANJRR and the LROI. In the absence of a clear definition, this may potentially lead to discrepancies in included short stem designs, even though the definitions are overlapping. In 2018, the International Society of Arthroplasty Registries (ISAR) introduced an International Prosthesis Library (IPL), which may be valuable for identifying specific types of prostheses in multinational registry studies, as implant definitions and names can vary across countries [3,4]. In future multinational registry studies on specific prosthesis characteristics, it may be desirable to use the IPL for implant selection from each registry.

The included types of uncemented short stems varied widely across the countries, with no single stem being widely used in all countries, whereas short-stem design may influence revision rates. We found no statistically significant differences in 12-year revision rates or 5-year re-revision rates for the most commonly used primary uncemented short-stem THAs compared to matched cohorts of uncemented standard-stem THAs, based on the combined data from the 3 countries. However, differences were noted between countries. In Australia, uncemented short-stem THAs had lower revision rates than the 3 most commonly used uncemented standard-stem THAs, while revision rates for uncemented short-stem THAs were higher in the Netherlands and Sweden. This may be due to the use of the C.F.P. (Waldemar Link, Germany) stem in the Netherlands and Sweden, whereas this stem was rarely used in Australia. We observed that some mainly older short-stem designs, including the C.F.P. stem, had higher revision rates compared to the Fitmore (Zimmer Biomet, USA) and Optimys (Mathys, Switzerland) stems, as well as uncemented standard stems in the Netherlands.

Other challenges were also recognized, one of which was the variation in variable classifications. For instance, the diagnosis of a bone fracture is recorded in the AOANJRR as 'Fractured neck of femur', in the LROI as 'Fracture' or 'Late posttraumatic', and in the SAR as 'Fracture' or 'Posttraumatic arthritis'. Moreover, we observed discrepancies in the American Society of Anesthesiologists (ASA) scores. In the Netherlands and Sweden, less than 15% of patients had an ASA score of III or IV, compared to more than 30% of patients in Australia. Comparing ASA scores across countries can be challenging, as differences in the application of the scoring system may exist. One possible explanation is that orthopaedic surgeons or anesthesiologists might perceive country-specific advantages or disadvantages in over- or underestimating ASA scores, which could contribute to variations between countries [5]. The higher body mass index (BMI) of Australian patients may also explain the higher ASA scores in Australia, as ASA and BMI are linked. Additionally, some variables were added to the registries in different years. For example, BMI was

added to the LROI in 2014 and to the AOANJRR in 2015, limiting the ability to adjust for this variable across the entire study period. Furthermore, variations in endpoints across the registries were observed. While the AOANJRR dataset included only overall revision as an endpoint, femoral stem revision was also available as an endpoint in the LROI and SAR datasets. Some of these challenges can be overcome by harmonizing variable categories and applying hierarchical structures to variables, resulting in consistent variable categories and structures between registries. The ISAR could play a role in this, as their aims include establishing consistency in terminology and standardizing statistical analyses between arthroplasty registries [6]. Such consistency and standardization could facilitate the process of combining data from multiple national arthroplasty registries. Another important initiative is the Coordinating Research and Evidence for Medical Devices (CORE-MD) project [7]. This initiative focuses on reviewing and improving methods for clinical testing and evaluation of high-risk medical devices in cardiovascular, orthopaedic, and diabetes care. One of its key objectives is to explore ways to combine data from medical device registries and real-world evidence effectively.

Another issue is the potential for confounding, where the degree of confounding may vary by country. Uncemented short-stem THAs are marketed toward younger and fitter patient groups, with the theoretical benefit of preserving proximal bone for future revisions [8,9]. In the Netherlands, uncemented short-stem THAs are predominantly used in private clinics, indicating that these implants are indeed used for younger and fitter patients, introducing confounding by indication in comparisons with uncemented standard-stem THAs. To address this, we used multivariable Cox regression analyses and propensity score matching to account for differences between the short-stem and standard-stem groups, including variables such as age, sex, ASA score, surgical approach, year of procedure, and bearing material. Nonetheless, residual confounding is likely to persist, potentially affecting our findings between the short-stem and standard-stem THA groups, leading to either an overestimation or underestimation of effect estimates. Other relevant confounders may include hospital type, hospital volume, or physical activity level, all of which were not present in the datasets. Furthermore, the previously mentioned challenges, such as differences in variable classifications, potential misclassification, and the addition of variables to the registries in different years, may also affect confounder adjustment, potentially leading to biased effect estimates.

An important aspect of multinational collaborations is establishing data-sharing agreements between countries, as sharing case-level data may be challenging in certain countries due to privacy regulations. A solution is sharing aggregated data

without personally identifiable data through standardized analyses, a method that has already been successfully used in international collaborative studies [10-12]. Leta et al. [11,12] examined the use of antibiotic-loaded bone cement (ALBC) and its association with 1-year revision risk for periprosthetic joint infection (PJI) in over 2 million primary total knee arthroplasties (TKAs) for osteoarthritis, reported across 14 to 16 national and regional arthroplasty registries in Africa, Europe, North America, and Oceania. Using a distributed data network not requiring case-level data, participating registries provided aggregated data on predefined data elements through a data-sharing template, which was subsequently compiled by a single arthroplasty registry. These studies revealed ALBC usage rates ranging from 31% in the USA to 100% in Norway, with similar 1-year revision risks for all causes and for PJI between ALBC and plain bone cement. However, differences between registries were observed, with some reporting a lower revision risk for ALBC and others for plain bone cement. The advantage of sharing aggregated data is that case-level data remain within the registry and country, as only summarized data is shared. This simplifies collaboration across countries, leading to larger research consortia with larger sample sizes and a faster collaboration process, as ethical review is easier for aggregated data than for case-level data. However, the use of aggregated data has a disadvantage as well, as the results depend on how the data is grouped and summarized. Nonetheless, it remains an appropriate alternative when sharing case-level data is not feasible or permitted.

Multinational collaborations can also facilitate comparisons to explore variations across countries. One focus could actually be the evaluation of variation in practice, exploring differences in surgical approaches, fixation methods, implant designs, and revision rates between countries. Such registry-based collaboration has already been established in the Nordic Arthroplasty Register Association (NARA), which is a multinational arthroplasty register including data from Denmark, Finland, Norway, and Sweden [13]. A study by van Steenbergen et al. [14] compared patient and procedure characteristics as well as revision rates of all primary THAs registered between 2010 and 2016 in the LROI to those in the NARA database. The study showed that the majority of THAs in Denmark, Finland, and the Netherlands had an uncemented fixation, whereas a cemented fixation was most commonly used in Sweden and a reverse hybrid fixation in Norway. Moreover, the use of the posterior approach ranged from 39% in Norway to 96% in Denmark. The 5-year overall revision rates were lowest in Sweden and highest in Denmark and Finland. Such international collaborative studies could also be valuable for evaluating implant designs used in different countries and for other types of arthroplasties, including TKA and total shoulder arthroplasty (TSA), which may help identify best practices and improve patient care.

Even though there are challenges in combining and comparing data from multiple national arthroplasty registries, we identified valuable opportunities in the collaboration. To our knowledge, studies on re-revision rates and the bone-sparing properties of short-stem THAs are lacking in the global literature. Revision, particularly revision of a single prosthesis component, is a rare event. Therefore, the sample sizes in each country were too small to perform meaningful analyses of re-revision rates and the types of stems used in the first stem revision. We observed a total of 399 overall revisions and 218 stem revisions of uncemented short-stem THAs across the 3 countries. By combining data from 3 high-quality national arthroplasty registries, we were able to study the re-revision rates and the type of stems used during the first stem revision. We showed that, in first-time stem revisions of short-stem THAs, a standard-length stem was used more often than a longer revision stem compared to revisions of standard-stem THAs. This may suggest bone-saving properties, although this remains speculative. While variations in patient demographics, procedure protocols, prosthesis characteristics, healthcare systems, and surgical indications across countries should be considered in multinational arthroplasty registry studies, our collaboration led to the first large registry-based study on the revision outcomes of short-stem THA. This highlights the value of multinational collaborations for orthopaedic care.

Part 2: Enrichment & linking with other (non-)arthroplasty registries

The linkage between the LROI and the Dutch National Nosocomial Surveillance Network (PREZIES) allowed us to validate the incidence of PJIs in primary THA and TKA registered in the LROI, providing a more accurate and reliable estimate of PJI rates. We found a PJI incidence of 1.2% in THAs and of 0.7% in TKAs in the Netherlands based on the PREZIES data. We showed that only 32% of these PJIs in primary THAs and TKAs are registered in the LROI as revision for infection or resection arthroplasty within 1 year, using the PREZIES database as the gold standard. The rate reported by the LROI is substantially lower than those in the national arthroplasty registries of Denmark, Finland and Sweden, which capture at least 60% of PJIs [15-17]. The low capture rate in the LROI is mainly due to its registration system, which only records revision surgeries where at least one prothesis component has been replaced, removed, or added after the primary procedure. Consequently, patients undergoing reoperations for PJI without component exchange (i.e., debridement, antibiotics, and implant retention (DAIR) procedure) or nonsurgical treatments with antibiotics only are not captured by the LROI, contributing to the underreporting of PJIs. Sweden records these reoperations without component exchange, whereas in Denmark, a debridement without component exchange is also considered a revision procedure [15,16]. In Finland, the data were enriched with hospital discharge data using the patient's Citizen

Service Number [17]. All these factors likely contribute to a higher capture rate of PJIs. Another reason why PJIs are not captured by national arthroplasty registries is that the reason for revision is typically reported immediately after surgery, while diagnosing a PJI based on cultures can take several days. Consequently, a reason for revision recorded at the time of surgery, such as aseptic loosening, is unlikely to be updated if a PJI is confirmed.

Similarly, periprosthetic fractures treated with a reoperation for internal fixation without component exchange, as well as dislocations managed with open reduction without component exchange or closed reduction, are not reported in the LROI. Therefore, the LROI has initiated a complication registration system in which complications related to joint arthroplasty are reported to improve orthopaedic care and patient safety [18]. However, these data are not yet available for research purposes, as the number of reported complications is low and incomplete, indicating that the complication registration system in the LROI is not yet well-established and that adding complications to the registry is complex. Alternatively, hard endpoints, such as reoperation without component exchange, could be used to obtain a more comprehensive outcome of joint arthroplasty, as already used in the Norwegian and Swedish arthroplasty registries [19,20]. Adding reoperations to the LROI database is desirable, and future LROI studies should also focus on this outcome. Therefore, the LROI should explore opportunities to incorporate reoperations without component exchange into the database, ideally based on definitions and processes already used by the Norwegian and Swedish arthroplasty registries. Recently, the LROI introduced a modular registration approach, where new registration initiatives are initially implemented in a limited number of hospitals. This phased approach allows for optimization and adjustments before nationwide implementation. Modular registration may be suitable for incorporating reoperations into the LROI and may contribute to the successful implementation of reoperation data collection.

The linkage between LROI and PREZIES also allowed us to enrich the LROI data with data on microorganisms causing PJIs, which is valuable for evaluating whether the most common preventive antibiotic treatments for PJIs are still effective against these microorganisms in the Netherlands. We found that *Staphylococcus aureus* and coagulase-negative *staphylococci* are the most common microorganisms of early PJIs in primary THAs and TKAs in the Netherlands, which is consistent with the microbiological findings of the Danish Hip Arthroplasty Register [21]. Another important finding was the relatively high 5-year mortality rates of 15% and 18% for THA and TKA patients with a PJI, respectively. In comparison, for all THA patients between 2007 and 2023, the 5-year mortality rates ranged from 2.2% (CI 1.9–2.4)

for patients < 50 years to 8.9% (CI 8.8–9.1) for those aged 70–79 years [22]. The 5-year mortality rate for TKA patients between 2007 and 2014 was 5.8% (CI 5.6–5.9) [23]. Furthermore, the 5-year PJI re-revision rates of 28% for THAs and 30% for TKAs in our study were substantially higher than the 5-year re-revision rates after THA and TKA revisions within 1 year for any reason, which were 18% (CI 17–19) and 21% (CI 19–22), respectively [22]. These high 5-year mortality and re-revision rates emphasize that PJI is a major complication. Moreover, PJI is the most common cause of first and second revisions for both hip and knee arthroplasty in the Netherlands [22]. Therefore, preventing a PJI is of major importance. Our study showed that over 20% and 10% of the microorganisms causing PJIs in THAs and TKAs, respectively, may have limited or no susceptibility to cefazolin, which is the recommended antibiotic prophylaxis for reducing PJIs in the Netherlands. Further research is needed to assess whether this antibiotic prophylaxis remains effective in reducing the risk of PJIs in the Netherlands. Moreover, new Dutch guidelines on the prevention of surgical site infections, including PJIs, were published by the end of 2024 [24]. These guidelines emphasize the importance of antibiotic prophylaxis timing, as well as preoperative skin antiseptic solutions and concentrations. It may be interesting to examine the association between PJI incidence and adherence to the guidelines in the Netherlands.

National arthroplasty registries use a minimal dataset to ensure the completeness of data collection [25,26]. Linkage of national arthroplasty registry data with data from other medical fields can be valuable. It can enrich the data without increasing the registration burden or compromising the completeness rates within each registry. Besides the linkage of PJI data in this thesis, LROI data on THA and TKA have been linked to pharmaceutical data from the Dutch Foundation for Pharmaceutical Statistics to evaluate opioid prescriptions prior to THA and TKA [27]. The linkage was performed using birth year, sex, the 4-digit postal code of the patient or hospital, and the date of surgery or dispense date for thromboprophylaxis medication. Other potential medical datasets for linkage could include rehabilitation data and comorbidity data, such as diabetes mellitus or cardiovascular diseases, which may impact arthroplasty outcomes. However, a main challenge in the Netherlands is the use of patient identifiers to link multiple data registries. In the Nordic countries, the patient's Citizen Service Number allows for the linking of multiple data registries [28-30]. This is not permitted in the Netherlands due to strict privacy regulations. In the PJI studies presented in this thesis, a combination of variables registered in both the LROI and PREZIES was used to create a pseudonym for linkage by a Trusted Third Party (ZorgTTP, Houten, the Netherlands). ZorgTTP is an intermediary that facilitates the linkage of multiple datasets from different registries by creating pseudonyms to replace identifiable data to ensure patient

privacy, all in accordance with Dutch privacy laws. The linking variables included date of birth, date of surgery, sex, hospital of primary procedure, and type of procedure (THA or TKA). However, this method is more prone to errors than using the patient's Citizen Service Number, as a single registration error or missing value in any of these variables results in a failed matching process. Moreover, the number of matching variables is important. Although using more matching variables increases the certainty of the match, it also increases the number of exclusions due to errors or missing values in one of the variables, while using fewer variables increases the likelihood of duplicate pseudonyms. Therefore, it is essential to perform sensitivity analyses to determine the optimal number of matching variables that achieves the highest number of matched cases while minimizing the number of cases with duplicate pseudonyms. In our PJI studies, 0.7% of cases were excluded due to duplicate pseudonyms. Permanent linkage and linkage based on the patient's Citizen Service Number between different registries would be desirable to facilitate future collaborations among various medical fields in the Netherlands. Therefore, adapting the Dutch privacy rules is necessary to promote scientific research in the Netherlands, with a Trusted Third Party potentially playing a role in ensuring patient privacy. Until then, the linkage of LROI data with other medical registries should be based on a combination of variables, with careful selection of linkage variables, and with the assistance of ZorgTTP to ensure patient privacy.

We also used LROI data to complete and cross-check data on the survival of cemented short Exeter (Stryker, UK) stems in primary THA, obtained from electronic patient records at the Radboud university medical center (Radboudumc). The patient cohort was relatively young, with the majority having a childhood hip disease as the underlying diagnosis, leading to complex primary THAs, often accompanied by a narrow femoral canal, which necessitated the use of this short stem. Despite this, the short Exeter stems demonstrated acceptable survival rates up to 20 years of follow-up. Comparing these findings with other studies is complex, as patient populations and indications often differ. Furthermore, many studies use overall revision as the outcome. For instance, the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man (NJR) reported a 10-year overall survival rate for THAs with a short Exeter stem ranging from 95.1% (CI 93.2–96.4) for an offset of 44 mm to 96.9% (CI 96.5–97.3) for an offset of 35 mm, whereas our study showed a 10-year stem survival rate of 93.4% (CI 89.2–96.0) for all offsets [31]. However, their patients were older, and over 75% had osteoarthritis as indication. Our study was conducted at a tertiary referral center where cemented short Exeter stems are mainly used in younger patients with a narrow femoral canal and a relatively large offset, or in those with anatomical abnormalities. A recent LROI study found that younger age and previous pelvic osteotomies were associated

with lower implant survival rates in hip dysplasia patients, which may partly explain our lower stem revision rates compared to the overall revision rates found in the NJR [32].

Extracting specific types of prostheses from the hospital's electronic patient records is challenging due to changes in documentation practices over the past decades in hospitals, including the transition from paper to electronic records. These changes have resulted in variations in where information about prothesis components is stored within electronic patient records. However, it is currently the only way to study long-term outcomes of joint arthroplasties in the Netherlands, as the LROI has been collecting data on joint arthroplasties since 2007. The study on short Exeter stems in primary THA included data starting from 1993. Since the start of the LROI, the registry uses standardized data collection methods. Therefore, LROI data can be used to identify all procedures, including the revisions, that meet specific inclusion and exclusion criteria performed at a given hospital, particularly given the high completeness and validity rates of the LROI. However, if a revision is performed at another Dutch hospital, the LROI is not permitted to share detailed data about that revision due to privacy regulations, potentially leading to an overestimation of the survival rates for procedures conducted at the primary hospital.

Although national arthroplasty registries can identify cases within hospital electronic patient records, hospital records could in turn enrich these registries with information that is typically not included. This allows the LROI database and hospital electronic patient records to complement each other. Relevant data captured in hospital electronic patient records may include information on shared clinical decision-making, medical history, imaging data, including X-rays or CT scans, as well as hospital discharge data, such as length of stay or readmissions. By integrating data from hospital electronic patient records with LROI data, healthcare providers and researchers can gain a more comprehensive view of patients and arthroplasty outcomes. In the near future, a pilot project will begin in which hospital data from 2 Dutch hospitals will be linked to LROI data [33]. In this project, data will be linked by Datapoort (Groningen, the Netherlands), a platform developed by the University Medical Center Groningen that links data from multiple sources. The goal of this project is to incorporate common complications associated with hip arthroplasty, such as PJIs, dislocations, and fractures, into the registry to enhance insights into individual treatment outcomes. The addition of these reoperations and complications might help in predicting patient outcome. In another pilot project, an additional module for patients at a particular Dutch hospital will be developed and integrated into the LROI [33]. This module aims to enrich the LROI data by including additional patient and procedure characteristics of revision procedures to

classify the complexity of hip and knee revisions, ultimately aiming to improve revision care.

Part 3: Prevalence & patterns

We found that approximately 800,000 people were living with at least one hip, knee, or shoulder arthroplasty in the Netherlands in 2022, representing 1 in 12 Dutch inhabitants aged 40 years or older. Additionally, we showed that 2.5%, 2.2%, and 0.2% of the entire Dutch population had at least one hip, knee, or shoulder arthroplasty, respectively, which appears to be in line with prevalences in Australia, Sweden, and the USA [19,34,35]. Prevalence estimates provide knowledge about the number of people who are at risk of complications following joint arthroplasty and who may require reoperation or revision [34]. Moreover, prevalence estimates may guide future research and assist healthcare providers, policymakers, and researchers in understanding the impact of joint arthroplasty on the health care system and the costs generated by these joint diseases, as well as in planning and allocating resources in both education and industry to meet the growing demand for joint arthroplasties and healthcare procedures for related complications.

The success of joint arthroplasty is commonly measured by revision rates, and most studies in this thesis focused on revision as the outcome. However, patient-reported outcomes, such as quality of life, pain, and physical function, are equally important, as they capture the patient's perspective on the procedure, especially given that some patients do not improve after joint arthroplasty [36-38]. We identified recovery trajectories using LROI data on patient-reported outcome measures (PROMs) to better understand variations in recovery following TSA and their associated factors. We identified 3 different recovery trajectories following TSA, which we labelled as 'Fast responders', 'Steady responders' and 'Poor responders'. 'Fast responders' and 'Steady responders', which included the majority of patients, showed improved physical function and reduced pain 12 months post-operatively, whereas 'Poor responders' experienced slightly worsened physical function and increased pain. Sex, ASA score, Walch classification, socioeconomic status, history of shoulder surgeries, and diagnosis and arthroplasty type were associated with these recovery trajectories. This may provide valuable guidance for orthopaedic surgeons in counseling patients undergoing TSA.

National arthroplasty registries provide valuable data for epidemiological studies to explore trends, patterns, and associations [26]. These registries typically include data on all patients, orthopaedic surgeons, and hospitals across a country, rather than focusing on specific patient groups with strict inclusion criteria, or high-volume or specialized hospitals. As a result, the data represent the entire nation and results

are usually generalizable to standard care. Limitations of registry-based studies relate to their observational design and include confounding by indication, residual confounding, and the inability to establish causal associations [39]. Moreover, response rates of PROMs in national arthroplasty registries are often less than the 60% threshold proposed by the ISAR as an acceptable response rate, and vary considerably among hospitals [22,40]. This could affect generalizability and introduce non-responder bias, as PROM responders may be more likely to be either satisfied or unsatisfied with the procedure than non-responders, potentially leading to biased effect estimates. Strategies to increase PROM response rates should be considered by the LROI, and could include collecting only the most valuable PROMs to minimize the patient burden and educating orthopaedic care providers to encourage patient participation [40].

Besides research purposes, data from national arthroplasty registries are valuable for monitoring the quality of implants, hospitals, and surgeons, as well as for educating and informing the public and society, which are both aims of the LROI [41]. The LROI supports quality improvement by providing hospitals and surgeons with automatically updated detailed performance insights through LROI dashboards and quality reports. These tools allow hospitals and surgeons to compare their performance with national data. The LROI quality reports also include factors that may explain any notable performances, such as prosthesis characteristics, the operating surgeon, and the types (e.g., minor or major) and reasons of revision. This can help identify possible improvement strategies to optimize orthopaedic care. In 2018, less than half of the Dutch orthopaedic surgeons were aware of their performance and used the LROI dashboard [42]. Since then, the LROI dashboard and quality reports have been improved. Therefore, it would be interesting to study how these tools are currently used by hospitals and orthopaedic surgeons. Additionally, the LROI, in collaboration with the Netherlands Orthopaedic Association, has initiated an outlier procedure to detect hospitals or prostheses with higher revision rates compared to the national standard [43]. Possible outlier hospitals and manufacturers of possible outlier prostheses are notified and requested to provide possible explanations and, if needed, improvement strategies. If necessary, suitable measures will be taken, such as the withdrawal of an under-performing prosthesis, leading to fewer patients receiving protheses with higher revision rates than expected. For educating and informing the public and society, the LROI publishes publicly available annual reports that highlight trends and outcomes for primary and revision joint arthroplasties, including prosthesis-specific results [22]. Moreover, the LROI has developed initiatives such as the 'Patients-Like-Me' platform to engage the public, which presents patient experiences after joint arthroplasty based on the patient's sex, age, and BMI [33]. This may lead to more

realistic expectations for patients undergoing joint arthroplasty. Other relevant patient characteristics for this platform may include diagnosis, ASA score, and Charnley classification in the case of THA or TKA, or Walch classification in the case of TSA. However, these characteristics may be complex for patients to comprehend.

Randomized controlled trials (RCTs) are generally considered the gold standard in medical research, as causal relationships between interventions and outcomes can be established. Observational studies, such as population-based registry studies, are often ranked lower in the hierarchy of evidence due to their inability to confirm causality [44]. Outcomes in arthroplasty studies, such as revision or mortality, are rare events that typically occur years after the procedure. Such studies require a large number of cases with a relatively long follow-up. This is usually achievable in observational population-based registry studies, but often not feasible in RCTs due to organizational and financial restrictions. By nesting RCTs within a national arthroplasty registry, the strengths of both research designs can be combined [26]. Currently, a registry-nested RCT is being conducted in 10 Dutch hospitals to investigate the incidence of dislocations in primary THA using a dual-mobility cup versus a unipolar cup [45]. The patients are registered in the LROI as usual, allowing the LROI data to be used for the evaluation of long-term revision and mortality. However, this long-term evaluation is limited by the data registered in the LROI. As a result, long-term reoperations without component exchange are not yet captured, leading to the underreporting of dislocations, as mentioned earlier.

Moreover, target trial emulation using real-world data can simulate an RCT, enabling the estimation of causal effects of interventions with observational registry data, provided the emulation is successful [46,47]. In a target trial, a hypothetical RCT is constructed, defining key elements such as the intervention and control groups, inclusion and exclusion criteria, follow-up period, analysis plan, and outcomes. Adjustment for all confounders is essential to ensure comparability between the intervention and control groups to emulate the random assignment at baseline. Statistical methods, including propensity score matching, inverse probability weighting, and multivariable regression, can be used for adjustment. Exploring target trial emulation using LROI data would be interesting. However, the effectiveness of confounder adjustment is limited to the variables available in the registry, which may hinder the successful emulation of random treatment assignment [46,47]. Therefore, the LROI should promote collaborations with registries in other medical fields or local hospital databases to enrich the data without increasing the registration burden in order to apply innovative research methods.

In summary, this thesis explored various aspects of population-based registry studies using data from the LROI. LROI data have been shown to be highly valuable for exploring trends, patterns, and associations at both national and international levels. Future studies could be even more impactful if the LROI: a) further facilitates collaboration with other national arthroplasty registries to ensure consistency in terminology and analyses; b) includes additional endpoints, including reoperations without component exchange; c) facilitates and promotes linkages with registries in other medical fields and local hospital databases to enrich data without increasing registration burden, potentially in consultation with ZorgTTP; and d) facilitates the application of innovative research methods, such as target trial emulation.

References

[1] LROI. LROI Implant Library - Hip. Landelijke Registratie Orthopedische Interventies; 2022. Available from: https://www.lroi.nl/media/byym2eyc/625522c726f17lroi-implant-library-hip.pdf.

[2] AOANJRR. Hip, Knee & Shoulder Arthroplasty: 2024 Annual report. Australian Orthopaedic Association National Joint Replacement Registry; 2024. Available from: https://aoanjrr.sahmri.com/documents/10180/1798900/AOANJRR+2024+Annual+Report.pdf/9d0bfe03-2282-8fc8-a424-b8d9abb82b1f?t=1727666185313.

[3] Denissen GAW, van Steenbergen LN, Lollinga WT, Verdonschot NJJ, Schreurs BW, Nelissen R. Generic implant classification enables comparison across implant designs: the Dutch Arthroplasty Register implant library. EFORT Open Rev 2019;4(6):344-50. https://doi.org/10.1302/2058-5241.4.180063.

[4] Rolfson O. Editorial Comment: 7th International Congress of Arthroplasty Registries. Clin Orthop Relat Res 2019;477(6):1299-300. https://doi.org/10.1097/CORR.0000000000000796.

[5] Silman AJ, Combescure C, Ferguson RJ, Graves SE, Paxton EW, Frampton C, Furnes O, Fenstad AM, Hooper G, Garland A, Spekenbrink-Spooren A, Wilkinson JM, Makela K, Lubbeke A, Rolfson O. International variation in distribution of ASA class in patients undergoing total hip arthroplasty and its influence on mortality: data from an international consortium of arthroplasty registries. Acta Orthop 2021;92(3):304-10. https://doi.org/10.1080/17453674.2021.1892267.

[6] Malchau H, Garellick G, Berry D, Harris WH, Robertson O, Karrlholm J, Lewallen D, Bragdon CR, Lidgren L, Herberts P. Arthroplasty implant registries over the past five decades: Development, current, and future impact. J Orthop Res 2018;36(9):2319-30. https://doi.org/10.1002/jor.24014.

[7] Fraser AG, Nelissen R, Kjaersgaard-Andersen P, Szymanski P, Melvin T, Piscoi P, Investigators C-M. Improved clinical investigation and evaluation of high-risk medical devices: the rationale and objectives of CORE-MD (Coordinating Research and Evidence for Medical Devices). EFORT Open Rev 2021;6(10):839-49. https://doi.org/10.1302/2058-5241.6.210081.

[8] Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J 2019;101-B(5):502-11. https://doi.org/10.1302/0301-620X.101B5.BJJ-2018- 1199.R1.

[9] van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. Acta Orthop 2014;85(3):250-8. https://doi.org/10.3109/17453674.2014.908343.

[10] Paxton EW, Mohaddes M, Laaksonen I, Lorimer M, Graves SE, Malchau H, Namba RS, Karrholm J, Rolfson O, Cafri G. Meta-analysis of individual registry results enhances international registry collaboration. Acta Orthop 2018;89(4):369-73. https://doi.org/10.1080/17453674.2018.1454383.

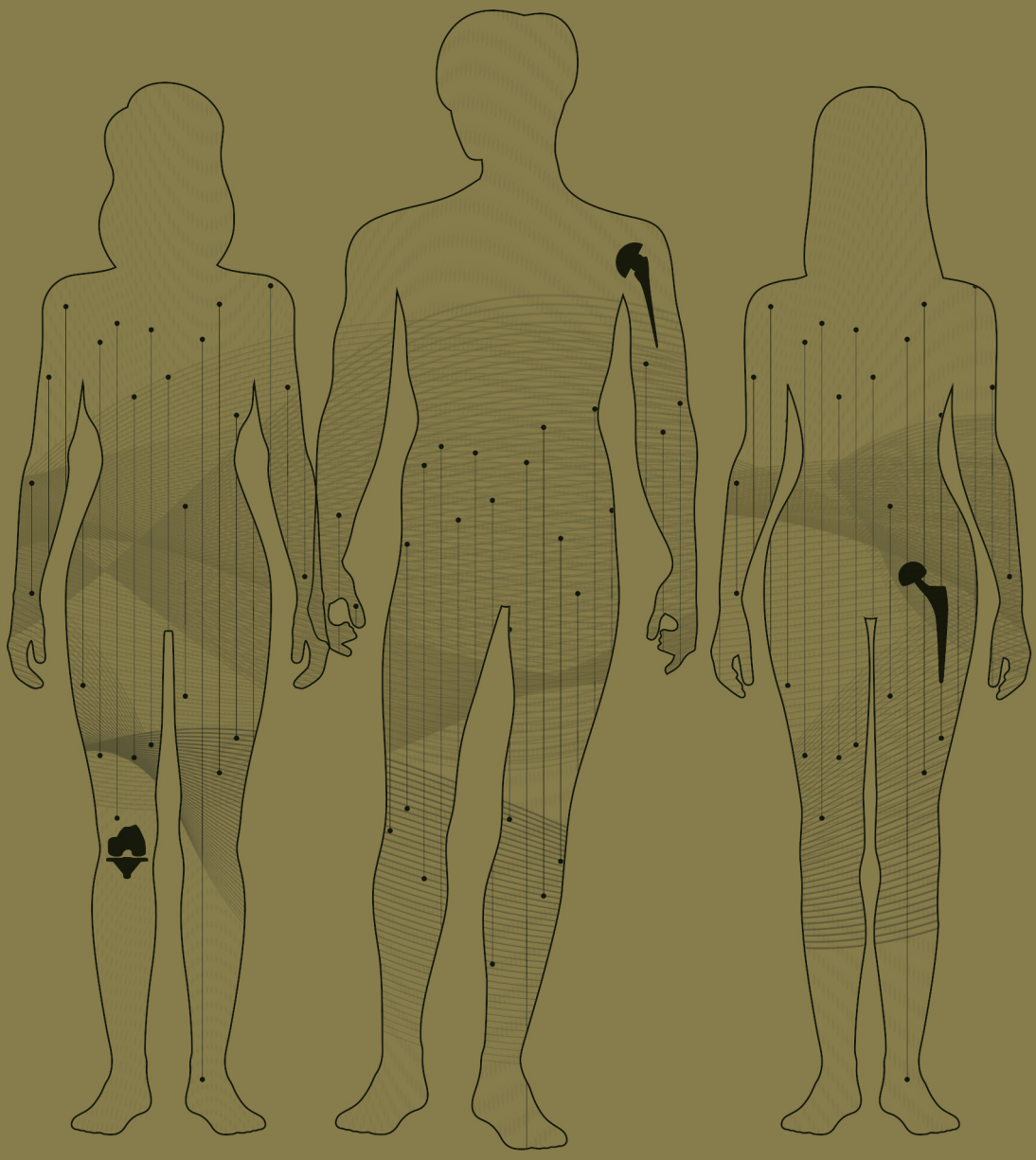
[11] Leta TH, Fenstad AM, Lygre SHL, Lie SA, Lindberg-Larsen M, Pedersen AB, A WD, Rolfson O, Bulow E, Ashforth JA, Van Steenbergen LN, Nelissen R, Harries D, De Steiger R, Lutro O, Hakulinen E, Makela K, Willis J, Wyatt M, Frampton C, Grimberg A, Steinbruck A, Wu Y, Armaroli C, Molinari M, Picus R, Mullen K, Illgen R, Stoica IC, Vorovenci AE, Dragomirescu D, Dale H, Brand C, Christen B, Shapiro J, Wilkinson JM, Armstrong R, Wooster K, Hallan G, Gjertsen JE, Chang RN, Prentice HA, Paxton EW, Furnes O. The use of antibiotic-loaded bone cement and systemic antibiotic prophylactic use in 2,971,357 primary total knee arthroplasties from 2010 to 2020: an international register-based observational study among countries in Africa, Europe, North America, and Oceania. Acta Orthop 2023;94:416-25. https://doi.org/10.2340/17453674.2023.17737.

[12] Leta TH, Lie SA, Fenstad AM, Lygre SHL, Lindberg-Larsen M, Pedersen AB, A WD, Rolfson O, Bulow E, van Steenbergen LN, Nelissen R, Harries D, de Steiger R, Lutro O, Makela K, Venalainen MS, Willis J, Wyatt M, Frampton C, Grimberg A, Steinbruck A, Wu Y, Armaroli C, Gentilini MA, Picus R, Bonetti M, Dragosloveanu S, Vorovenci AE, Dragomirescu D, Dale H, Brand C, Christen B, Shapiro J, Wilkinson JM, Armstrong R, Wooster K, Hallan G, Gjertsen JE, Chang RN, Prentice HA, Sedrakyan A, Paxton EW, Furnes O. Periprosthetic Joint Infection After Total Knee Arthroplasty With or Without Antibiotic Bone Cement. JAMA Netw Open 2024;7(5):e2412898. https://doi.org/10.1001/jamanetworkopen.2024.12898.

[13] Makela KT, Furnes O, Hallan G, Fenstad AM, Rolfson O, Karrholm J, Rogmark C, Pedersen AB, Robertsson O, A WD, Eskelinen A, Schroder HM, Aarimaa V, Rasmussen JV, Salomonsson B, Hole R, Overgaard S. The benefits of collaboration: the Nordic Arthroplasty Register Association. EFORT Open Rev 2019;4(6):391-400. https://doi.org/10.1302/2058-5241.4.180058.

[14] van Steenbergen LN, Makela KT, Karrholm J, Rolfson O, Overgaard S, Furnes O, Pedersen AB, Eskelinen A, Hallan G, Schreurs BW, Nelissen R. Total hip arthroplasties in the Dutch Arthroplasty Register (LROI) and the Nordic Arthroplasty Register Association (NARA): comparison of patient and procedure characteristics in 475,685 cases. Acta Orthop 2021;92(1):15-22. https://doi.org/10.1080/17453674.2020.1843875.
[15] Gundtoft PH, Pedersen AB, Schonheyder HC, Overgaard S. Validation of the diagnosis 'prosthetic joint infection' in the Danish Hip Arthroplasty Register. Bone Joint J 2016;98-B(3):320-5. https://doi.org/10.1302/0301-620X.98B3.36705.
[16] Lindgren JV, Gordon M, Wretenberg P, Karrholm J, Garellick G. Validation of reoperations due to infection in the Swedish Hip Arthroplasty Register. BMC Musculoskelet Disord 2014;15. https://doi.org/10.1186/1471-2474-15-384.
[17] Jamsen E, Huotari K, Huhtala H, Nevalainen J, Konttinen YT. Low rate of infected knee replacements in a nationwide series--is it an underestimate? Acta Orthop 2009;80(2):205-12. https://doi.org/10.3109/17453670902947432.
[18] de Reus I. Implementatie uitbreiden LROI met complicaties. Nederlandse Orthopaedische Vereniging; 2021. Available from: https://www.orthopeden.org/media/sc3pfujh/rapport-implementatie-uitbreiden-lroi-met-complicaties.pdf.
[19] SAR. Annual report 2023. Swedish Arthroplasty Register; 2023. Available from: https://registercentrum.blob.core.windows.net/sar/r/SAR_Annual-report-2023_EN-DS5gryeOB.pdf.
[20] NAR. Report 2023. Norwegian Arthroplasty Register; 2023. Available from: https://www.helse-bergen.no/4ad4ab/contentassets/9f19d57711ee4e60815d6b89e8e8472b/report2023.pdf.
[21] Gundtoft PH, Pedersen AB, Varnum C, Overgaard S. Increased Mortality After Prosthetic Joint Infection in Primary THA. Clin Orthop Relat Res 2017;475(11):2623-31. https://doi.org/10.1007/s11999-017-5289-6.
[22] LROI. Annual report 2024. Landelijke Registratie Orthopedische Interventies; 2024. Available from: https://www.lroi.nl/media/prqogokg/pdf-lroi-report-2024.pdf.
[23] Quispel CR, van Egmond JC, Bruin MM, Spekenbrink-Spooren A, Verburg H, Pasma JH. No effect of fixation type on early and late mortality after total knee arthroplasty: a Dutch arthroplasty register study. Knee Surg Sports Traumatol Arthrosc 2022;30(4):1231-8. https://doi.org/10.1007/s00167-021-06552-5.
[24] Federatie Medisch Specialisten. Preventie van postoperatieve wondinfecties. Federatie Medisch Specialisten; 2024. Available from: https://richtlijnendatabase.nl/richtlijn/preventie_van_postoperatieve_wondinfecties/startpagina_-_preventie_van_postoperatieve_wondinfecties.html.
[25] Porter M, Rolfson O, de Steiger R. International Registries: U.K. National Joint Registry, Nordic Registries, and Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). J Bone Joint Surg Am 2022;104(Suppl 3):23-7. https://doi.org/10.2106/JBJS.22.00561.
[26] Baker PN, Jeyapalan R, Jameson SS. The value of national arthroplasty registry data in 2023. Bone Joint J 2023;105-B(4):356-60. https://doi.org/10.1302/0301-620X.105B4.BJJ-2022-1190.R2.
[27] van Brug HE, Nelissen R, Rosendaal FR, van Dorp ELA, Bouvy ML, Dahan A, Gademan MGJ. What Changes Have Occurred in Opioid Prescriptions and the Prescribers of Opioids Before TKA and THA? A Large National Registry Study. Clin Orthop Relat Res 2023;481(9):1716-28. https://doi.org/10.1097/CORR.0000000000002653.
[28] Schmidt M, Pedersen L, Sorensen HT. The Danish Civil Registration System as a tool in epidemiology. Eur J Epidemiol 2014;29(8):541-9. https://doi.org/10.1007/s10654-014-9930-3.
[29] Meyer AC, Hedstrom M, Modig K. The Swedish Hip Fracture Register and National Patient Register were valuable for research on hip fractures: comparison of two registers. J Clin Epidemiol 2020;125:91-9. https://doi.org/10.1016/j.jclinepi.2020.06.003.
[30] Laugesen K, Ludvigsson JF, Schmidt M, Gissler M, Valdimarsdottir UA, Lunde A, Sorensen HT. Nordic Health Registry-Based Research: A Review of Health Care Systems and Key Registries. Clin Epidemiol 2021;13:533-54. https://doi.org/10.2147/CLEP.S314959.
[31] Evans JT, Salar O, Whitehouse SL, Sayers A, Whitehouse MR, Wilton T, Hubble MJW, Exeter Hip Research G. Survival of the Exeter V40 short revision (44/00/125) stem when used in primary total hip arthroplasty. Bone Joint J 2023;105-B(5):504-10. https://doi.org/10.1302/0301-620X.105B5.BJJ-2022-1124.R1.
[32] Husken MFT, Magre J, Willemsen K, Van Steenbergen LN, Van Veghel MHW, Weinans H, Sakkers RJB, Bekkers JEJ, Van der Wal BCH. Association of osteotomy, age, and component fixation with the

outcomes of total hip arthroplasty in patients with hip dysplasia: a Dutch population-based registry study. Acta Orthop 2024;95:545-52. https://doi.org/10.2340/17453674.2024.41383.
[33] LROI. LROI 2024. Landelijke Registratie Orthopedische Interventies; n.d. Available from: https://nov.foleon.com/nov-lroi/lroi-magazine-2024/.
[34] Manning L, Davis JS, Robinson O, Clark B, Lorimer M, de Steiger R, Graves SE. High prevalence of older Australians with one or more joint replacements: estimating the population at risk for late complications of arthroplasty. ANZ J Surg 2020;90(5):846-50. https://doi.org/10.1111/ans.15774.
[35] Farley KX, Wilson JM, Kumar A, Gottschalk MB, Daly C, Sanchez-Sotelo J, Wagner ER. Prevalence of Shoulder Arthroplasty in the United States and the Increasing Burden of Revision Shoulder Arthroplasty. JB JS Open Access 2021;6(3). https://doi.org/10.2106/JBJS.OA.20.00156.
[36] Labek G, Janda W, Agreiter M, Schuh R, Bohler N. Organisation, data evaluation, interpretation and effect of arthroplasty register data on the outcome in terms of revision rate in total hip arthroplasty. Int Orthop 2011;35(2):157-63. https://doi.org/10.1007/s00264-010-1131-4.
[37] Rolfson O, Eresian Chenok K, Bohm E, Lubbeke A, Denissen G, Dunn J, Lyman S, Franklin P, Dunbar M, Overgaard S, Garellick G, Dawson J, Patient-Reported Outcome Measures Working Group of the International Society of Arthroplasty R. Patient-reported outcome measures in arthroplasty registries. Acta Orthop 2016;87 Suppl 1(Suppl 1):3-8. https://doi.org/10.1080/17453674.2016.1181815.
[38] Bjornholdt KT, Brandsborg B, Soballe K, Nikolajsen L. Persistent pain is common 1-2 years after shoulder replacement. Acta Orthop 2015;86(1):71-7. https://doi.org/10.3109/17453674.2014.987065.
[39] Varnum C, Pedersen AB, Gundtoft PH, Overgaard S. The what, when and how of orthopaedic registers: an introduction into register-based research. EFORT Open Rev 2019;4(6):337-43. https://doi.org/10.1302/2058-5241.4.180097.
[40] Rolfson O, Bohm E, Franklin P, Lyman S, Denissen G, Dawson J, Dunn J, Eresian Chenok K, Dunbar M, Overgaard S, Garellick G, Lubbeke A, Patient-Reported Outcome Measures Working Group of the International Society of Arthroplasty R. Patient-reported outcome measures in arthroplasty registries: Report of the Patient-Reported Outcome Measures Working Group of the International Society of Arthroplasty Registries Part II. Recommendations for selection, administration, and analysis. Acta Orthop 2016;87 Suppl 1(Suppl 1):9-23. https://doi.org/10.1080/17453674.2016.1181816.
[41] LROI. LROI brengt de orthopedie in beeld: Strategisch plan 2023-2027. Landelijke Registratie Orthopedische Interventies; n.d. Available from: https://nov.foleon.com/strategisch-plan-lroi-2023-2027/lroi-strategisch-plan-2023-2027/.
[42] Van Schie P, Van Bodegom-Vos L, Zijdeman TM, Nelissen R, Marang-Van De Mheen PJ. Awareness of performance on outcomes after total hip and knee arthroplasty among Dutch orthopedic surgeons: how to improve feedback from arthroplasty registries. Acta Orthop 2021;92(1):54-61. https://doi.org/10.1080/17453674.2020.1827523.
[43] NOV & LROI. Procedure Uitkomstanalyse. Nederlandse Orthopaedische Vereniging & Landelijke Registratie Orthopedische Interventies; 2020. Available from: https://www.orthopeden.org/media/izapumoz/proces-kwaliteitsinformatie-uitschieters.pdf.
[44] Graves SE. The value of arthroplasty registry data. Acta Orthop 2010;81(1):8-9. https://doi.org/10.3109/17453671003667184.
[45] Van Beers L, Van Der Wal BCH, Van Loon TG, Moojen DJF, Van Wier MF, Klaassen AD, Willigenburg NW, Poolman RW, Collaborator g. Study protocol: Effectiveness of dual-mobility cups compared with uni-polar cups for preventing dislocation after primary total hip arthroplasty in elderly patients - design of a randomized controlled trial nested in the Dutch Arthroplasty Registry. Acta Orthop 2020;91(5):514-9. https://doi.org/10.1080/17453674.2020.1798658.
[46] Hernan MA, Robins JM. Using Big Data to Emulate a Target Trial When a Randomized Trial Is Not Available. Am J Epidemiol 2016;183(8):758-64. https://doi.org/10.1093/aje/kwv254.
[47] Hernan MA, Wang W, Leaf DE. Target Trial Emulation: A Framework for Causal Inference From Observational Data. JAMA 2022;328(24):2446-7. https://doi.org/10.1001/jama.2022.21383.



11

Summary

Data from arthroplasty registries can facilitate research initiatives aimed at improving patient outcomes. In this thesis, various aspects of population-based registry studies were explored, using hip, knee, and shoulder data from the Dutch Arthroplasty Register (LROI). This thesis is divided into 3 parts.

In *Part 1*, data from multiple national arthroplasty registries were combined and compared to study the outcomes of uncemented short-stem total hip arthroplasties (THAs), which is a relatively infrequently used type of prosthesis. Short-stem THAs are marketed to preserve proximal femoral bone stock. This may be valuable if a revision is required, making it especially attractive for use in younger patients. However, the bone-preserving features have yet to be confirmed. Nevertheless, this advantage will become irrelevant if short-stem THAs result in higher revision rates than standard-stem THAs.

In *Part 2*, LROI data were linked with data from the Dutch National Nosocomial Surveillance Network (PREZIES). This was done to validate the incidence of periprosthetic joint infections (PJIs) in primary THAs and total knee arthroplasties (TKAs) in the LROI, as national arthroplasty registries are known to underreport PJIs. This linkage also enriched the LROI data with data on microorganisms causing PJIs in the Netherlands. Additionally, LROI data were used to complete and cross-check a local database from the Radboud university medical center (Radboudumc).

In *Part 3*, studies were conducted to explore trends, patterns, and associations in arthroplasty care. Registry data can be used to estimate the number of people living with a joint arthroplasty. This provides insight into the number of individuals at risk for complications following joint arthroplasty. Furthermore, registry data can be used to identify recovery patterns of patient-reported outcomes after joint arthroplasty and their potential risk factors. This may help guide patient counseling and shared decision-making.

Part 1: Collaboration & comparison between national arthroplasty registries

Chapter 2 provided an overview of the uncemented short stems in THA used in the Netherlands. Patient, procedure and prosthesis characteristics were described. Moreover, we examined overall and femoral stem revision rates, as well as patient-reported outcomes on quality of life, pain and physical function in patients with primary uncemented short-stem and uncemented standard-stem THA. We included primary THAs with uncemented short (n = 3,352) and standard (n = 228,917) stems registered between 2009 and 2021. Kaplan-Meier survival analyses and multivariable Cox regression analyses were performed with overall and femoral stem revision as

endpoints. We performed linear mixed models to analyze patient-reported outcome measures (PROMs). Short-stem THA patients were generally younger, had lower ASA scores, and were more likely to be of normal weight compared to standard-stem THA patients. They also underwent surgery more frequently in private clinics and with the anterior approach compared to standard-stem THA patients. Fitmore (Zimmer Biomet, USA) and Optimys (Mathys, Switzerland) were the most frequently used short stems. The 10-year overall revision rates (4.8%, 95% confidence interval [CI] 3.7–6.3 vs. 4.5%, CI 4.4–4.6) and femoral stem revision rates (3.0%, CI 2.2–4.2 vs. 2.3%, CI 2.2–2.4) were comparable for short-stem and standard-stem THAs. Fitmore and Optimys showed short-term revision rates similar to those of standard-stem THAs, while other short stems had higher 10-year overall (6.3%, CI 4.7–8.5) and femoral stem (4.5%, CI 3.1–6.3) revision rates. Short-stem THAs showed no statistically significant difference in overall revision risk (HR 1.4, CI 0.9–2.1). However, there was a statistically significant higher risk for femoral stem revision (HR 1.5, CI 1.0–2.4) compared to standard-stem THAs, adjusted for age, sex, ASA score, diagnosis, and surgical approach. No clinically relevant differences were found between short-stem and standard-stem THA patients in PROM scores.

In **Chapter 3**, primary uncemented short-stem THAs registered in the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the LROI were compared in terms of patient, procedure and prosthesis characteristics. Furthermore, we compared incidence and overall revision rates. We included primary THAs with uncemented short stems registered between 2009 and 2021 in the AOANJRR (n = 9,328) and LROI (n = 3,352). Kaplan-Meier survival analyses and multivariable Cox regression analyses with data from 2009 to 2021 and 2015 to 2021 were performed with overall revision as endpoint. In Australia, the proportion of male patients, patients with ASA III–IV scores, BMI $\geq$ 30 kg/m^2, and femoral heads of 36 mm were higher than in the Netherlands. Optimys was the only short stem widely used in both countries. In 2021, the annual incidence of short-stem THAs was 377 per 10,000 THAs in Australia and 389 per 10,000 THAs in the Netherlands. Short-stem THAs in Australia and the Netherlands showed no statistically significant difference in 10-year revision rates (3.4%, CI 2.9–4.0 vs. 4.8%, CI 3.7–6.3). The risk for revision was higher for short-stem THAs performed in the Netherlands (HR 1.8, CI 1.1–2.8) using data from 2009 to 2021, adjusted for sex, age, and diagnosis. However, the risk for revision was not statistically significantly different with data from 2015 to 2021 (HR 0.8, CI 0.5–1.3) and when adjusted (HR 0.9, CI 0.5–1.7) for more potential confounders (i.e., sex, age, diagnosis, BMI, ASA score, and surgical approach).

Chapter 4 focused on the stems used in the first stem revision of primary uncemented short-stem and standard-stem THAs. We used combined data from the AOANJRR, LROI, and Swedish Arthroplasty Register (SAR). Moreover, overall revision and re-revision rates of uncemented short-stem and standard-stem THAs were presented. We included primary uncemented short-stem THAs (n = 15,771) registered between 2007 and 2022, and a propensity score-matched cohort with the 3 most commonly used uncemented standard-stem THAs (n = 31,542) in each registry. The cohorts were matched 1:2 on sex, age, year of procedure, diagnosis, bearing material, and surgical approach. Overall revision and re-revision rates were calculated using Kaplan-Meier survival analyses. The type of stem used during the first stem revision was classified as standard (< 160 mm) or long (≥ 160 mm). Both the 12-year overall revision rates (4.7%, CI 4.0–5.5 vs. 5.1%, CI 4.5–5.7) and 5-year overall re-revision rates (20.9%, CI 16.8–25.8 vs. 20.4%, CI 17.3–23.9) were comparable between primary short-stem and standard-stem THAs. In first-time stem revisions of short-stem THAs, a standard stem was used more often (58%) than in revisions of standard-stem THAs (46%; p = 0.01).

Part 2: Enrichment & linking with other (non-)arthroplasty registries

In **Chapter 5**, the incidence of reported PJIs in THAs and TKAs in the LROI was validated, using data from PREZIES. Primary THAs and TKAs from the LROI were matched with those performed in consenting hospitals (52% of all Dutch hospitals) from PREZIES between 2012 and 2018. Matching was based on date of birth, date of surgery, sex, hospital, and type of procedure (THA n = 91,208; TKA n = 80,304). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for PJIs registered in the LROI, using PREZIES as a reference. Patient status was assessed for non-captured PJIs in the LROI to determine the proportion of PJIs that were rightly not reported. The incidence of PJIs in THAs was 1.2% in PREZIES and 0.5% in the LROI. For TKAs, this was 0.7% and 0.4%, respectively. In THAs, PJIs in the LROI had a sensitivity of 0.32 (CI 0.29–0.35), specificity of 1.00 (CI 1.00–1.00), PPV of 0.74 (CI 0.70–0.78), and NPV of 0.99 (CI 0.99–0.99). In TKAs, the sensitivity, specificity, PPV, and NPV were 0.38 (CI 0.34–0.42), 1.00 (CI 1.00–1.00), 0.65 (CI 0.59–0.70), and 1.00 (CI 1.00–1.00), respectively. Most THA (87%) and TKA (89%) patients with non-captured PJIs were alive without revision 1 year after primary THA or TKA.

Chapter 6 described the microorganisms that cause early PJIs in primary THAs and TKAs in the Netherlands, using the combined dataset from the LROI and PREZIES. Additionally, mortality and re-revision rates after PJI were examined. Furthermore, the most common microorganisms causing PJIs were categorized based on patient and implant survival. We included all PREZIES-confirmed PJIs (n = 1,648)

from the combined dataset. In this combined dataset, primary THAs and TKAs registered between 2012 and 2018 in the LROI and PREZIES were case-level matched. Kaplan-Meier survival analyses were performed to determine mortality and PJI re-revision rates following PJI revision. The most prevalent microorganism in both THAs and TKAs was *Staphylococcus aureus* (THA 34%; TKA 39%). This was followed by coagulase-negative *staphylococci* (THA 20%; TKA 19%), with *Staphylococcus epidermidis* (THA 12%; TKA 11%) being the most common subtype. Next, *Enterococcus* species (THA 8.6%; TKA 5.9%) were the most commonly reported. The 5-year mortality rate was 15% (CI 13–18) for THA patients and 18% (CI 14–21) for TKA patients. The 5-year PJI re-revision rate was 28% (CI 24–34) for THAs and 30% (CI 24–38) for TKAs. In deceased THA patients with a PJI, *Enterococcus* species (14%) were more often registered than *S. epidermidis* (8.5%).

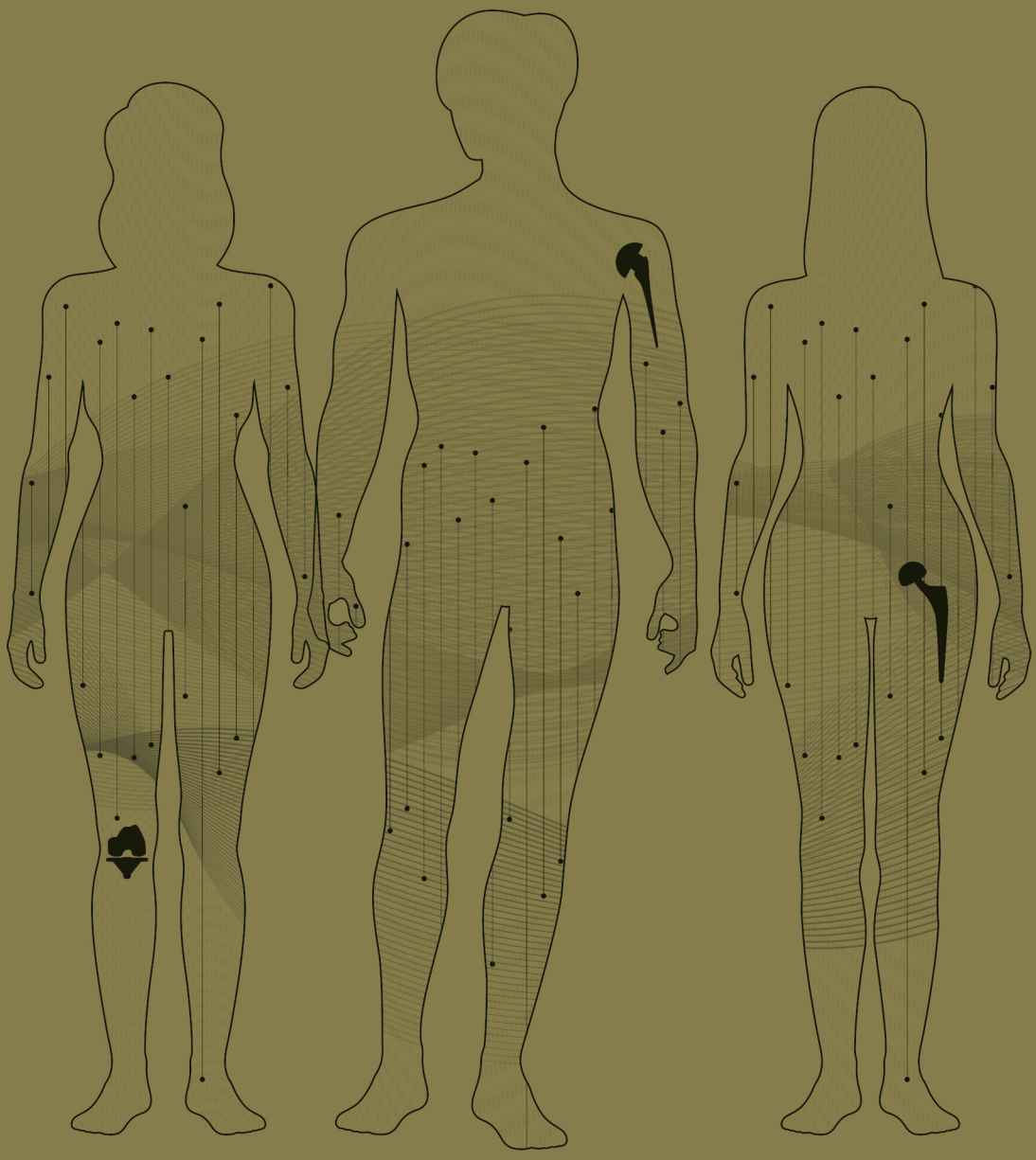
In **Chapter 7**, we used LROI data to evaluate the long-term survival and complications of cemented short Exeter (Stryker, UK) stems in primary THAs performed at the Radboudumc. We included primary THAs with a cemented short Exeter stem (≤ 125 mm) performed between 1993 and 2021 from the hospital's electronic patient records (n = 394). LROI data were used to complete and cross-check the data. Kaplan-Meier survival analyses were performed to determine survival rates with stem revision for any indication, septic loosening, femoral component fracture and aseptic loosening as endpoints. Femoral component fractures were described in detail. The 20-year stem survival rates were 85.4% (CI 73.9–92.0) for revision for any indication, 96.2% (CI 90.5–98.5) for revision for septic loosening and 92.7% (CI 78.5–97.6) for revision for femoral component fracture. No stems were revised for aseptic loosening. The most common reason for stem revision was infection (7 out of 21 cases). Femoral component fracture occurred in 4 THAs (1.0%) at 6.6, 11.6, 16.5, and 18.2 years of follow-up, respectively. Of these, 3 were transverse fractures at the level of the lesser trochanter and 1 was a fracture at the neck of the component.

Part 3: Prevalence & patterns

In **Chapter 8**, estimates were made of the number of people living in the Netherlands with at least one hip, knee, or shoulder arthroplasty. We included the first hip (n = 416,333), knee (n = 314,569), or shoulder (n = 23,751) arthroplasty for each patient aged ≥ 40 years between 2007 and 2022 (hip and knee) or 2014 and 2022 (shoulder) from the LROI. Data on the size of the Dutch population were obtained from Statistics Netherlands. Annual incidences and deaths since 2010 (hip and knee) and since 2015 (shoulder) were observed from the LROI. Annual incidences and deaths before those years were estimated using Poisson regression analyses and parametric survival models based on a Gompertz distribution. In 2022, 791,000 (CI 787,000–

794,000) people in the Netherlands were living with at least one joint arthroplasty. This represents 8.4% (CI 8.4–8.5) of the Dutch population aged ≥ 40 years. For hip, knee, and shoulder arthroplasties, these were 436,000 (CI 433,000–438,000), 383,000 (CI 380,000–386,000), and 34,000 (CI 33,000–36,000) people, respectively. This corresponds to 4.7% (CI 4.6–4.7), 4.1% (CI 4.1–4.1), and 0.4% (CI 0.3–0.4) of the Dutch population, respectively.

Chapter 9 presented the recovery trajectories after total shoulder arthroplasty (TSA) based on the Oxford Shoulder Score. We also examined potential risk factors associated with these recovery trajectories. We included primary anatomical and reversed TSAs (ATSAs and RTSAs) for osteoarthritis, cuff arthropathy, or cuff rupture registered between 2016 and 2022 in the LROI (n = 3,358). These included cases had Oxford Shoulder Scores available at least at 2 out of 3 time-points (i.e., preoperative, 3-month, and/or 12-month postoperative). Latent class growth modeling was used to identify recovery patterns. We used multinomial logistic regression analyses to investigate associations between potential risk factors and class membership. We identified 3 recovery patterns: 'Fast responders' (59%), 'Steady responders' (27%), and 'Poor responders' (14%). Factors associated with 'Steady responders' vs. 'Fast responders' were female sex (OR 2.0, CI 1.5–2.7), ASA III–IV vs. I (OR 1.9, CI 1.2–3.1), Walch classification A1 vs. B2 (OR 1.6, CI 1.1–2.5), and most vs. medium socioeconomic deprivation (OR 1.4, CI 1.1–1.9). Factors associated with 'Poor responders' vs. 'Fast responders' were ASA II vs. I (OR 2.0, CI 1.1–3.6), ASA III–IV vs. I (OR 3.0, CI 1.6–5.5), Walch classification A1 vs. B2 (OR 2.1, CI 1.3–3.3), previous shoulder surgeries (OR 1.8, CI 1.3–2.4), most vs. medium socioeconomic deprivation (OR 1.5, CI 1.2–2.0), RTSA for osteoarthritis vs. ATSA for osteoarthritis (OR 1.8, CI 1.2–2.7), and RTSA for cuff arthropathy or rupture vs. ATSA for osteoarthritis (OR 2.3, CI 1.5–3.4).



12

Nederlandse samenvatting

Het doel van dit proefschrift was om verschillende aspecten van registerstudies voor orthopedische implantaten te bekijken. Hiervoor is gebruik gemaakt van heup-, knie- en schoudergegevens uit de Landelijke Registratie Orthopedische Interventies (LROI). Gegevens uit nationale registers voor orthopedische implantaten kunnen helpen bij onderzoek dat gericht is op het verbeteren van de zorg en resultaten voor orthopedische patiënten. Dit proefschrift is onderverdeeld in 3 delen.

In *Deel 1* zijn gegevens van meerdere nationale registers gecombineerd en vergeleken om de uitkomsten van totale heupprothesen (THP's) met een ongecementeerde korte steel te bestuderen. Dit is een type heupprothese dat relatief weinig wordt gebruikt. THP's met een korte steel zijn ontworpen om het proximale femorale bot (i.e. de bovenkant van het bovenbeenbot) te sparen. Dit kan vooral waardevol zijn als een revisieoperatie (i.e. het vervangen van één of meerdere componenten van de prothese) bij jongere patiënten nodig is. Deze botbesparende eigenschappen moeten nog bevestigd worden. Deze eigenschap wordt echter irrelevant als THP's met een korte steel tot hogere revisiepercentages leiden dan THP's met een standaard steel.

In *Deel 2* zijn LROI-gegevens gekoppeld aan gegevens van het register van PREventie van ZIEkenhuisinfecties door Surveillance (PREZIES). In het landelijke register van PREZIES worden infecties in Nederlandse ziekenhuizen vastgelegd. De koppeling is gedaan om het aantal geregistreerde peri-prothetische infecties na het plaatsen van THP's en totale knieprothesen (TKP's) in de LROI te bestuderen. Een peri-prothetische infectie is een infectie die ontstaat rondom een geplaatste gewrichtsprothese, zoals een THP of TKP. Peri-prothetische infecties worden niet altijd goed in nationale registers voor orthopedische implantaten geregistreerd. We hebben gekeken hoe compleet deze infecties in de LROI zijn vastgelegd. Door de koppeling van LROI- en PREZIES-gegevens konden we ook bekijken welke bacteriën deze peri-prothetische infecties in Nederland veroorzaken. Daarnaast werden LROI-gegevens gebruikt om gegevens van het Radboud universitair medisch centrum (Radboudumc) aan te vullen en te controleren.

In *Deel 3* zijn studies uitgevoerd om trends, patronen en associaties te onderzoeken. Zo hebben wij registerdata gebruikt om het aantal mensen met een gewrichtsprothese in Nederland te schatten. Dit geeft inzicht in het aantal individuen dat risico loopt op complicaties na een gewrichtsprothese, wat mogelijk kan leiden tot een nieuwe operatie. Daarnaast hebben wij registerdata gebruikt om herstelpatronen van patiëntgerapporteerde uitkomsten na een totale schouderprothese en hun mogelijke risicofactoren te identificeren. Dit kan helpen bij de klinische besluitvorming.

Deel 1: Samenwerking en vergelijking tussen nationale registers voor orthopedische implantaten

Hoofdstuk 2 geeft een overzicht van de ongecementeerde korte heupstelen die in Nederland zijn gebruikt. Ook bevat dit hoofdstuk een vergelijking van THP's met een ongecementeerde korte steel en een ongecementeerde standaard steel. Patiënt-, procedure- en prothesekenmerken, maar ook de totale revisiepercentages en steelrevisiepercentages zijn vergeleken. Daarnaast hebben we gekeken naar de door de patiënt gerapporteerde kwaliteit van leven, pijn en fysiek functioneren van patiënten met een korte of standaard heupsteel. We includeerden primaire THP's met ongecementeerde korte (n = 3.352) en standaard (n = 228.917) stelen die in de LROI geregistreerd waren tussen 2009 en 2021. De revisiepercentages en het risico op revisie werden berekend, waarbij er gecorrigeerd werd voor verschillende factoren. Patiënten met een korte heupsteel waren jonger, hadden betere gezondheidsscores en hadden vaker een normaal gewicht vergeleken met patiënten met een standaard heupsteel. Ook ondergingen zij vaker de operatie in privéklinieken en werden zij vaker geopereerd via de voorste benadering. De meest gebruikte korte stelen waren de Fitmore (Zimmer Biomet, VS) en de Optimys (Mathys, Zwitserland) steel. De 10-jaars totale revisiepercentages (4,8%, 95%-betrouwbaarheidsinterval [BI] 3,7–6,3 vs. 4,5%, BI 4,4–4,6) en steelrevisiepercentages (3,0%, BI 2,2–4,2 vs. 2,3%, BI 2,2–2,4) waren niet statistisch significant verschillend tussen THP's met een korte steel en met een standaard steel. Fitmore en Optimys hadden op korte termijn vergelijkbare revisiepercentages als die van standaard stelen. Andere korte stelen hadden hogere 10-jaars totale revisiepercentages (6,3%, BI 4,7–8,5) en steelrevisiepercentages (4,5%, BI 3,1–6,3). THP's met een korte steel hadden geen statistisch significant verschillend risico op totale revisie (HR 1,4, BI 0,9–2,1) vergeleken met THP's met een standaard steel. Het risico op steelrevisie (HR 1,5, BI 1,0–2,4) was echter hoger voor THP's met een korte steel. Bij het berekenen van deze risico's werd er gecorrigeerd voor leeftijd, geslacht, gezondheidsscore, diagnose en chirurgische benadering. Er waren geen verschillen in de door de patiënt gerapporteerde kwaliteit van leven, pijn en fysiek functioneren tussen beide stelen.

In **Hoofdstuk 3** hebben we gekeken naar primaire THP's met een ongecementeerde korte steel die zijn geplaatst in Australië en Nederland. We vergeleken de patiënt-, procedure- en prothesekenmerken en de totale revisiepercentages van de korte heupstelen in Australië en Nederland. Ook onderzochten we hoe vaak deze korte heupstelen werden geplaatst. We includeerden primaire THP's met ongecementeerde korte stelen, geregistreerd tussen 2009 en 2021 in het Australische register (n = 9.328) en in de LROI (n = 3.352). De revisiepercentages en het risico op revisie werden berekend, waarbij we gegevens uit 2009 tot 2021 en uit 2015 tot 2021

hebben gebruikt. In Australië waren er meer mannelijke patiënten geopereerd, en ook meer patiënten met slechtere gezondheidsscores, een hogere BMI (≥ 30 kg/m^2) en heupkoppen van 36 mm of groter dan in Nederland. Optimys was de enige korte heupsteel die in beide landen veel werd gebruikt. In 2021 werden in beide landen ongeveer relatief evenveel korte heupstelen geplaatst, namelijk 377 per 10.000 THP's in Australië en 389 per 10.000 THP's in Nederland. Het 10-jaars revisiepercentage van THP's met een korte steel was niet statistisch significant verschillend tussen Australië en Nederland (3,4%, BI 2,9-4,0 vs. 4,8%, BI 3,7-6,3). Het risico op revisie was hoger voor THP's met een korte steel in Nederland (HR 1,8, BI 1,1–2,8) op basis van gegevens uit 2009 tot 2021. Hierbij werd gecorrigeerd voor geslacht, leeftijd en diagnose. Het risico op revisie was echter vergelijkbaar met gegevens uit 2015 tot 2021 (HR 0,8, BI 0,5–1,3) en wanneer we corrigeerden voor meer factoren (HR 0,9, BI 0,5–1,7), zoals geslacht, leeftijd, diagnose, BMI, gezondheidsscore en chirurgische benadering.

Hoofdstuk 4 richt zich op de soorten stelen die werden gebruikt bij de eerste steelrevisie van primaire THP's met ongecementeerde korte en standaard stelen. Hiervoor hebben we gegevens gecombineerd uit Australië, Nederland en Zweden. Ook hebben we de eerste en tweede totale revisiepercentages (i.e. revisie en re-revisie) van THP's met ongecementeerde korte en standaard stelen onderzocht. We includeerden primaire THP's met ongecementeerde korte stelen (n = 15.771) en met de 3 meest geplaatste ongecementeerde standaard stelen (n = 31.542), die tussen 2007 en 2022 in Australië, Nederland of Zweden zijn geregistreerd. Voor elke THP met een korte steel werd in ieder register twee vergelijkbare procedures gezocht met een standaard steel, waarbij werd gelet op een vergelijkbaar geslacht, leeftijd, operatiejaar, diagnose, articulatie en chirurgische benadering. De soorten stelen die werden gebruikt bij de eerste steelrevisie werden verdeeld in 2 groepen: een standaard steel (korter dan 160 mm) of een langere steel (160 mm of langer). Zowel de 12-jaars revisiepercentages (4,7%, BI 4,0–5,5 vs. 5,1%, BI 4,5–5,7) als de 5-jaars re-revisiepercentages (20,9%, BI 16,8–25,8 vs. 20,4%, BI 17,3–23,9) waren vergelijkbaar voor primaire THP's met korte en standaard stelen. Bij de eerste steelrevisie van een korte steel werd vaker gekozen voor een standaard steel (58%) dan bij de eerste steelrevisie van een standaard steel (46%; p = 0,01).

Deel 2: Verrijking & koppeling met andere (niet-)orthopedische dataregisters

In **Hoofdstuk 5** is het aantal peri-prothetische infecties na primaire THP's en TKP's, geregistreerd tussen 2012 en 2018 in de LROI, gecontroleerd met behulp van gegevens van PREZIES. Gegevens van THP's en TKP's uit de LROI werden gekoppeld aan de PREZIES-gegevens van THP's en TKP's die waren uitgevoerd in ziekenhuizen

(52% van alle Nederlandse ziekenhuizen) die toestemming gaven voor deelname aan deze studie. De gegevens werden gekoppeld op basis van geboortedatum, operatiedatum, geslacht, ziekenhuis en type procedure (THP n = 91.208; TKP n = 80.304). We hebben berekend hoe goed peri-prothetische infecties in de LROI zijn geregistreerd vergeleken met de peri-prothetische infecties die aan PREZIES zijn gemeld. Hiervoor hebben we naar 4 aspecten gekeken: sensitiviteit (i.e. aandeel terecht geregistreerde infecties in de LROI van alle infecties in PREZIES), specificiteit (i.e. aandeel terecht geregistreerde niet-infecties in de LROI van alle niet-infecties in PREZIES), positieve voorspellende waarde (PVV; i.e. aandeel terecht geregistreerde infecties in de LROI van alle infecties in de LROI) en negatieve voorspellende waarde (NVV; i.e. aandeel terecht geregistreerde niet-infecties in de LROI van alle niet-infecties in de LROI). Daarnaast hebben we de patiënten met een gemiste peri-prothetische infectie in de LROI bestudeerd om te bepalen of deze terecht niet waren geregistreerd. Het percentage peri-prothetische infecties na THP's was 1,2% in PREZIES en 0,5% in de LROI. Voor TKP's was dit respectievelijk 0,7% en 0,4%. Bij THP's hadden peri-prothetische infecties in de LROI een sensitiviteit van 0,32 (BI 0,29-0,35), specificiteit van 1,00 (BI 1,00-1,00), PVV van 0,74 (BI 0,70-0,78) en NVV van 0,99 (BI 0,99-0,99). Voor TKP's waren de sensitiviteit, specificiteit, PVV en NVV respectievelijk 0,38 (BI 0,34-0,42), 1,00 (BI 1,00-1,00), 0,65 (BI 0,59-0,70) en 1,00 (BI 1,00-1,00). De meeste THP- (87%) en TKP-patiënten (89%) met niet-geregistreerde peri-prothetische infecties waren 1 jaar na de primaire THP of TKP in leven zonder revisie. Mogelijk zijn deze patiënten behandeld met een heroperatie zonder dat (een deel van) de prothese is vervangen of alleen met antibiotica, waardoor zij niet in de LROI zijn geregistreerd.

Hoofdstuk 6 beschrijft welke bacteriën peri-prothetische infecties veroorzaken bij primaire THP's en TKP's in Nederland. Dit werd onderzocht met behulp van de gekoppelde LROI- en PREZIES-gegevens. Daarnaast hebben we de mortaliteits- en re-revisiepercentages na peri-prothetische infecties onderzocht. Ook werden de meest voorkomende bacteriën gecategoriseerd op basis van patiënt- en implantaat-overleving. Alle peri-prothetische infecties volgens PREZIES (n = 1.648) uit de gecombineerde dataset werden geïncludeerd. In deze dataset werden primaire THP's en TKP's, geregistreerd tussen 2012 en 2018 in de LROI, gekoppeld aan PREZIES-gegevens. De meest voorkomende bacterie bij zowel THP's als TKP's was *Staphylococcus aureus* (THP 34%; TKP 39%). Ook coagulase-negatieve *stafylokokken* (THP 20%; TKP 19%) werden vaak gerapporteerd, waarvan *Staphylococcus epidermidis* (THP 12%; TKP 11%) de meest voorkomende subsoort was. Daarna werden *Enterococcus*-soorten (THP 8,6%; TKP 5,9%) het meest gerapporteerd. Het 5-jaars mortaliteitspercentage was 15% (BI 13–18) voor THP-patiënten en 18% (BI 14–21) voor TKP-patiënten. Het 5-jaars re-revisiepercentage vanwege een peri-prothetische

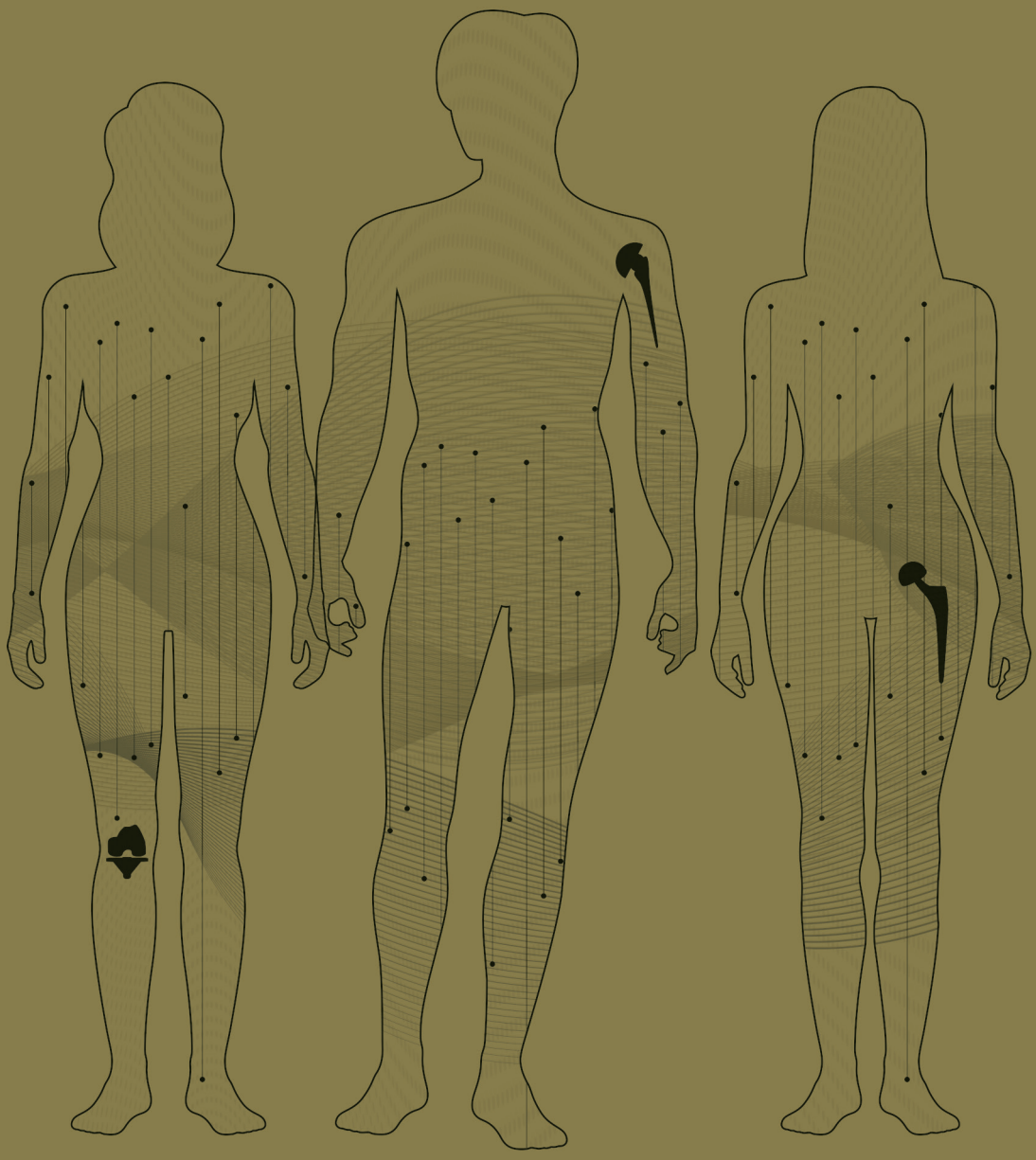
infectie was 28% (BI 24–34) voor THP's en 30% (BI 24–38) voor TKP's. Bij overleden THP-patiënten met een peri-prothetische infectie werden *Enterococcus*-soorten (14%) vaker geregistreerd dan *Staphylococcus epidermidis* (8,5%).

In **Hoofdstuk 7** is gekeken naar de implantaatoverleving en complicaties van een bepaald type heupsteel, de gecementeerde korte Exeter steel (Stryker, VK), die bij primaire THP's zijn geplaatst in het Radboudumc. We includeerden alle primaire THP's met deze gecementeerde korte Exeter steel (125 mm of korter), geplaatst tussen 1993 en 2021, uit de elektronische patiëntendossiers van het ziekenhuis (n = 394). LROI-gegevens werden gebruikt om de ziekenhuisgegevens aan te vullen en te controleren. De overlevingspercentages van de steel werden berekend, waarbij gekeken werd naar 4 verschillende redenen voor de steelrevisie: elke indicatie, septische (i.e. infectie) loslating, steelbreuk en aseptische (i.e. niet-infectie) loslating. De 20-jaars overlevingspercentages voor de steel waren 85,4% (BI 73,9–92,0) voor revisie om welke reden dan ook, 96,2% (BI 90,5–98,5) voor revisie vanwege septische loslating en 92,7% (BI 78,5–97,6) voor revisie vanwege steelbreuk. Er werden geen stelen vervangen vanwege aseptische loslating. De meest voorkomende reden voor steelrevisie was infectie (7 van de 21 steelrevisies). Een steelbreuk van de prothese deed zich voor bij 4 THP's (1,0%) na respectievelijk 6,6, 11,6, 16,5 en 18,2 jaar. Van deze steelbreuken waren er 3 door het gedeelte van de steel dat zich in het bovenbeenbot bevindt, en 1 was een breuk ter hoogte van de hals van de steel, net onder het heupkopje.

Deel 3: Prevalentie & patronen

In **Hoofdstuk 8** zijn schattingen gemaakt van het aantal Nederlanders dat met ten minste één heup-, knie- of schouderprothese leeft. We includeerden de eerste heup- (n = 416.333), knie- (n = 314.569) of schouderprothese (n = 23.751) van iedere patiënt van 40 jaar of ouder tussen 2007 en 2022 (heup en knie) of tussen 2014 en 2022 (schouder) uit de LROI. Gegevens over de grootte van de Nederlandse bevolking werden verkregen van het Centraal Bureau voor de Statistiek (CBS). De gegevens over het aantal prothese-ingrepen en sterfgevallen per jaar sinds 2010 (heup en knie) en sinds 2015 (schouder) kwamen uit de LROI. Het aantal prothese-ingrepen en sterfgevallen in de jaren daarvoor tot 1990 werd geschat met behulp van statistische modellen. In 2022 hadden 791.000 (BI 787.000–794.000) Nederlanders ten minste één gewrichtsprothese. Dit betekent dat 8,4% (BI 8,4–8,5) van de Nederlandse bevolking van 40 jaar of ouder minstens één gewrichtsprothese had. Er waren respectievelijk 436.000 (BI 433.000–438.000), 383.000 (BI 380.000–386.000) en 34.000 (BI 33.000–36.000) Nederlanders met ten minste één heup-, knie- of schouderprothese in 2022. Dit komt overeen met respectievelijk 4,7% (BI 4,6–4,7), 4,1% (BI 4,1–4,1) en 0,4% (BI 0,3–0,4) van de Nederlandse bevolking van 40 jaar of ouder.

Hoofdstuk 9 gaat over de hersteltrajecten na een totale schouderprothese (TSP) op basis van de door de patiënt gerapporteerde pijn en fysiek functioneren. Ook hebben we gekeken naar mogelijke risicofactoren die samenhangen met deze hersteltrajecten. We includeerden patiënten met primaire anatomische en reversed (i.e. omgekeerde) TSP's (ATSP's en RTSP's) vanwege artrose, cuff artropathie of onherstelbare cuff ruptuur, geregistreerd tussen 2016 en 2022 in de LROI (n = 3.358). Pijn en fysiek functioneren werd gemeten met de Oxford Shoulder Score. We gebruikten statistische modellen om herstelpatronen te identificeren en om de associaties tussen mogelijke risicofactoren en herstelpatronen te onderzoeken. We identificeerden 3 herstelpatronen: 'Snelle herstellers' (59%), 'Stabiele herstellers' (27%) en 'Slechte herstellers' (14%). Factoren die geassocieerd zijn met 'Stabiele herstellers' vs. 'Snelle herstellers' waren vrouwelijk geslacht (OR 2,0, BI 1,5–2,7), ASA score III–IV vs. I (OR 1,9, BI 1,2–3,1), Walch classificatie A1 vs. B2 (OR 1,6, BI 1,1–2,5), en hoogste vs. middelmatige sociaaleconomische deprivatie (OR 1,4, BI 1,1–1,9). Factoren die geassocieerd zijn met 'Slechte herstellers' vs. 'Snelle herstellers' waren ASA score II vs. I (OR 2,0, BI 1,1–3,6), ASA score III–IV vs. I (OR 3,0, BI 1,6–5,5), Walch classificatie A1 vs. B2 (OR 2,1, BI 1,3–3,3), eerdere schouderoperaties (OR 1,8, BI 1,3–2,4), hoogste vs. middelmatige sociaaleconomische deprivatie (OR 1,5, BI 1,2–2.0), RTSP voor artrose vs. ATSP voor artrose (OR 1,8, BI 1,2–2,7), en RTSP voor cuff artropathie of onherstelbare cuff ruptuur vs. ATSP voor artrose (OR 2,3, BI 1,5–3.4).



13

Appendices

List of publications
Research Data Management
Radboud Graduate School Portfolio
Dankwoord
Curriculum Vitae

List of publications

Rilby K, **van Veghel MHW**, Mohaddes M, van Steenbergen LN, Lewis PL, Kärrholm J, Schreurs BW, Hannink G. Do cumulative revision rate and first-time re-revision rate vary between short and standard femoral stem lengths? A multinational registry study. Clin Orthop Relat Res 2025;483(6):1010-9. https://doi.org/10.1097/CORR.0000000000003354.

Visser J, **van Veghel MHW**, van Steenbergen LN, Swierstra BA, Bloemheuvel EM, Schreurs BW. Constrained acetabular liners in total hip arthroplasty: analysis of 265 primary and revision cases from the Dutch Arthroplasty Register (2007-2022). Hip Int 2025;35(3):273-7. https://doi.org/10.1177/11207000251331147.

van Veghel MHW, van Steenbergen LN, Visser CPJ, Schreurs BW, Hannink G. Identifying recovery trajectories following primary total shoulder arthroplasty: a cohort study of 3,358 patients from the Dutch Arthroplasty Register. Acta Orthop 2025;96:226-34. https://doi.org/10.2340/17453674.2025.43085.

van Veghel MHW, van Steenbergen LN, Gademan MGJ, van den Hout WB, Schreurs BW, Hannink G. How many people in the Netherlands live with a hip, knee, or shoulder replacement? Prevalence estimates using data from the Dutch Arthroplasty Register (LROI) and Statistics Netherlands. Bone Jt Open 2025;6(1):74-81. https://doi.org/10.1302/2633-1462.61.BJO-2024-0162.R1.

van Veghel MHW, van Steenbergen LN, Wertheim HFL, van der Kooi TII, Schreurs BW, Hannink G. Early periprosthetic joint infections in total hip and knee arthroplasty: microorganisms, mortality, and implant survival using a combined dataset from the Dutch Arthroplasty Register and the Dutch National Nosocomial Surveillance Network. J Arthroplasty 2025;40(1):208-13. https://doi.org/10.1016/j.arth.2024.07.019.

Husken MFT, Magre J, Willemsen K, van Steenbergen LN, **van Veghel MHW**, Weinans H, Sakkers RJB, Bekkers JEJ, van der Wal BCH. Association of osteotomy, age, and component fixation with the outcomes of total hip arthroplasty in patients with hip dysplasia: a Dutch population-based registry study. Acta Orthop 2024; 95:545-52. https://doi.org/10.2340/17453674.2024.41383.

van Veghel MHW, Belt M, Spekenbrink-Spooren A, Kuijpers MFL, van der Kooi TII, Schreurs BW, Hannink G. Validation of the incidence of reported periprosthetic joint infections in total hip and knee arthroplasty in the Dutch Arthroplasty Register. J Arthroplasty 2024;39(4):1054-9. https://doi.org/10.1016/j.arth.2023.10.040.

van Veghel MHW, van der Koelen RE, Hannink G, Schreurs BW, Rijnen WHC. Survival of cemented short Exeter femoral components in primary total hip arthroplasty: an analysis of 394 femoral components in total hip arthroplasties undertaken between 1993 and 2021. Bone Joint J 2024;106-B(3 Supple A):137-42. https://doi.org/10.1302/0301-620X.106B3.BJJ-2023-0826.R2.

van Veghel MHW, Hannink G, Lewis PL, Holder C, van Steenbergen LN, Schreurs BW. Short-stem hip arthroplasty in Australia and the Netherlands: a comparison of 12,680 cases between the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the Dutch Arthroplasty Register (LROI). Acta Orthop 2023;94:453-9. https://doi.org/10.2340/17453674.2023.18491.

van Veghel MHW, Hannink G, van Oldenrijk J, van Steenbergen LN, Schreurs BW. A comparison of uncemented short versus standard stem length in total hip arthroplasty: results from the Dutch Arthroplasty Register. Acta Orthop 2023; 94:330-5. https://doi.org/10.2340/17453674.2023.13652.

Research Data Management

1. Ethics and privacy

Medical and ethical approval

This thesis is based on the results of existing data from the Dutch Arthroplasty Register (LROI), the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR), the Swedish Arthroplasty Register (SAR), the Dutch National Nosocomial Surveillance Network (PREZIES) and electronic patient files, which were conducted in accordance with relevant national and international legislation and regulations, guidelines, codes of conduct and Radboud university medical center (Radboudumc) policy.

The Scientific Advisory Board and the board of the LROI have given approval to conduct the studies in chapters 2 to 6, and chapters 8 and 9 (LROI dossier numbers: LROI2021-081, LROI2022-095, LROI2023-110, LROI2018-036, LROI2023-109, LROI2023-106, LROI2024-133). The AOANJRR has given approval to conduct the studies in chapters 3 and 4 (AOANJRR dossier numbers: AOAAHR-3579, AOAAHR-3758). The National Ethical Board of Sweden has given approval to conduct the study in chapter 4 (SAR dossier number: 2022-06130-02). PREZIES has given approval to conduct the studies in chapters 5 and 6 (PREZIES dossier number: 2019-136). The institutional ethical review committee CMO Radboudumc, Nijmegen, the Netherlands, has given approval to conduct the study in chapter 7 (CMO Radboudumc dossier number: 2022-15846). A statement that the study was not subject to the Dutch Medical Research Involving Human Subjects Act (WMO), was also obtained from the institutional ethical review committee CMO Radboudumc, Nijmegen, the Netherlands (2022-15846).

Privacy of participants

The privacy of the participants in the studies in chapters 2 to 4, and chapters 8 and 9 was warranted by the use of fully de-identified data, as the LROI, AOANJRR, and SAR data for these chapters were received completely de-identified. The privacy of the participants in the studies in chapters 5 and 6 was warranted by the use of pseudonymization, which was performed by a Trusted Third Party (ZorgTTP, Houten, the Netherlands). According to Dutch legislation, data collection from electronic patient files for the study in chapter 7 was performed by personnel with a treatment relationship with the patient or by the researcher upon consent by the institutional ethical review committee CMO Radboudumc, Nijmegen, the Netherlands. The privacy of the participants in this study was warranted by the use of pseudonymization. The pseudonymization key was stored on a secured network drive that was only accessible to members of the project who needed access to it

because of their role within the project. The pseudonymization key was stored separately from the research data.

Informed consent

Informed consent was automatically obtained from participants to use their data in the studies in chapters 2 to 6, and chapters 8 and 9, as the LROI, the AOANJRR, the SAR and PREZIES use the opt-out system to obtain consent from patients. For chapter 7, data were used that was previously collected in the context of healthcare. To ensure responsible reuse of healthcare data, specific informed consent procedures were followed that are aligned with applicable laws, regulations and the national Code of Conduct for Health Research. Consent was not obtained for sharing the data after research for all studies.

Funding

All studies in this thesis were funded by the LROI. The study in chapter 4 was also funded by the Gothenburg Medical Association and the Swedish State under the agreement between the Swedish government and the county councils, the ALF agreement (721791).

2. Data collection and storage

The datasets from chapters 2 to 6, and chapters 8 and 9 were available from the LROI, the AOANJRR, the SAR and/or PREZIES. However restrictions apply to the availability of these data, which were used under license for these studies. Data for chapter 7 were extracted from electronic health records (EPIC). Data from chapters 2 to 6, and chapters 8 and 9 were stored and analyzed in the Digital Research Environment (DRE Portal (mydre.org)). Data from chapter 7 were stored and analyzed on the department server and in Microsoft Excel, and were only accessible by project members working at the Radboudumc. These secure storage options safeguard the availability, integrity and confidentiality of the data.

3. Data sharing according to the FAIR principles

Data used within this thesis were collected and stored according to the Findable and Accessible principles. The studies in chapters 2 and 3, chapters 5 and 6, and chapters 8 and 9 are published open access. The LROI data underlying chapters 2 to 6, and chapters 8 and 9 are findable and accessible through the LROI. These LROI data, along with the complete R syntax, are archived in the secure environment of the LROI server for at least 15 years. The LROI data used in these chapters are available upon reasonable request, subject to approval by the LROI. The AOANJRR, SAR, and PREZIES data underlying chapters 3 and 4, and chapters 5 and 6 are findable and accessible through the AOANJRR, SAR, and PREZIES, respectively, and

are archived according to the applicable registry laws and regulations. The data used in these chapters are available upon reasonable request, subject to approval by the corresponding registry. The data underlying chapter 7 are archived in a Data Acquisition Collection in the Radboud Data Repository for at least 15 years (DOI: 10.34973/9dsg-2618). These data, along with the complete R syntax, are also archived on a secure network of the Orthopaedic Research Laboratory of the Radboudumc for at least 15 years.

Radboud Graduate School Portfolio of M.H.W. van Veghel

Department: **Orthopedics**
PhD period: **15/03/2022 – 15/09/2025**
PhD Supervisor(s): **Prof. dr. B.W. Schreurs**
PhD Co-supervisor(s): **Dr. G.J. Hannink, Dr. L.N. van Steenbergen**

Training activities	Hours
Courses	
- EBROK course (2022)	26
- A Crash Course in Causality: Inferring Causal Effects from Observational Data (2022)	18
- Survival Analysis in R for Public Health (2022)	8
- Projectmanagement voor Promovendi (2022)	45
- RIHS Introduction course for PhD candidates (2022)	15
- Writing Scientific Articles (2023)	96
- Analysing longitudinal and multilevel data using R (2023)	96
- Presentation Skills (2023)	42
- Academic English Conversation and Pronunciation (2023)	43
- Causal Diagrams: Draw Your Assumptions Before Your Conclusions (2023)	18
- Scientific Integrity (2023)	20
- Causal inference in observational research (2023)	84
- Junior Refereren Epidemiologie (2024)	42
- Art of Finishing Up (2024)	10
- Career development for PhD candidates & postdocs "The next step in my career" (2025)	24
Seminars	
- Research Integrity Round #15 (2023)	1.5
- Research Integrity Round #16 (2023)	1.5
Conferences	
- NOV Jaarcongres, Utrecht, the Netherlands (2022)	8
- ISAR11th Annual International Congress of Arthroplasty Registries, Dublin, Ireland (2022) (oral presentation)	28
- De Kracht van Kwaliteitsregistraties, Utrecht, the Netherlands (2022)	6
- PhD Retreat (2022)	8
- ISAR12th Annual International Congress of Arthroplasty Registries, Montreal, Canada (2023) (oral presentation)	32
- NOV Jaarcongres, Utrecht, the Netherlands (2023)	7
- 15th Congress of the European Hip Society, Bern, Switzerland (2023) (oral presentation)	26
- PhD Retreat (2023)	12
- WEON Annual Epidemiological Congress, Zeist, the Netherlands (2024) (oral presentation and poster presentation)	30
- ISAR13th Annual International Congress of Arthroplasty Registries, Hamburg, Germany (2024) (3x oral presentation)	48
- Combined 61st NOF and NOV Jaarcongres, Rotterdam, the Netherlands (2024) (oral presentation)	26
- PhD Retreat (2024) (poster presentation)	22

Other	
- PREZIES Deelnemersdag: Ziekenhuisinfecties in Beeld door PREZIES, Bilthoven, the Netherlands (2023) (oral presentation)	12
- LROI Symposium, Utrecht, the Netherlands (2024) (oral presentation)	13
Teaching activities	
Lecturing	
- BMW Bachelorcursus Q6 Beweging en Stroming: Werkgroep Belasting & Belastbaarheid 2022-2023 (2023)	4
- BMW Minor 05 Moving questions: Journal club 2023-2024 (2023)	6
- BMW Bachelorcursus Q6 Beweging en Stroming: Werkgroep Belasting & Belastbaarheid 2023-2024 (2023)	6
- BMW Minor 05 Moving questions: Journal club 2024-2025 (2024)	6
- BMW Bachelorcursus Q6 Beweging en Stroming: Werkgroep Belasting & Belastbaarheid 2024-2025 (2024)	4
Total	**894**

Dankwoord

Graag wil ik iedereen bedanken die een bijdrage heeft geleverd aan het tot stand komen van dit proefschrift. In het bijzonder wil ik de volgende personen bedanken:

Wim, Gerjon & Liza, hartelijk dank voor de fijne begeleiding de afgelopen jaren en het vertrouwen dat jullie in mij hadden. Jullie verschillende expertises, in combinatie met een relaxte houding, zorgden voor een prettige samenwerking. Ik kon met al mijn vragen altijd bij jullie terecht en jullie tijdige feedback hield het tempo er lekker in. Zonder jullie deskundigheid was dit proefschrift er niet geweest. Dankjewel!

Wim, jouw enthousiasme, humor, positiviteit en belangstelling zorgen ervoor dat je een fijne promotor bent, waardoor ik met veel plezier dit promotietraject heb gedaan. Ondanks jouw pensioen maakte je toch iedere week tijd voor een overleg.

Gerjon, oftewel Hannink, jouw kritische en scherpe blik waren erg waardevol tijdens het schrijven van dit proefschrift. Je maakte altijd tijd vrij om mee te kijken naar analyses of om een R-scriptje in elkaar te zetten. Daardoor heb ik veel van jou geleerd over statistiek en R.

Liza, jouw hulp vanuit de LROI was onmisbaar tijdens mijn promotietraject. Daarnaast was je er altijd voor in om even gezellig te kletsen. Heel fijn dat jij mijn presentaties op het laatste ISAR-congres wilde houden, hoewel samen Nieuw-Zeeland verkennen een mooie ervaring zou zijn geweest.

Leden van de manuscriptcommissie, prof. dr. R. van Crevel, prof. dr. D.L. Gerritsen en prof. dr. R.W. Poolman, hartelijk dank voor de beoordeling van mijn proefschrift.

Ook wil ik graag de LROI bedanken voor de kans die jullie mij hebben gegeven om dit promotietraject te doen. Mijn carrière is bij jullie gestart als Junior Onderzoeker, waar mijn enthousiasme voor registerdata is begonnen. Toen Geke vroeg of ik interesse had in een promotietraject in het Radboudumc met LROI-data, was ik vrijwel meteen enthousiast. De tripjes naar het ISAR-congres waren altijd gezellig, of het nu in de Temple bar in Dublin was, in het zonnetje in Canada of in een rooftopbar in Hamburg. Dankjulliewel!

Jakob, Peter, Carl, Karin, Maziar, Johan, Maartje, Anneke, Martijn, Tjallie, Heiman, Remy, Wim, Maaike, Wilbert & Cornelis, dank voor jullie waardevolle input in de verschillende studies van dit proefschrift. Zonder jullie statistische, epidemiologische, orthopedische of vakinhoudelijke kennis zouden sommige studies niet succesvol zijn afgerond.

Collega's van het ORL, bedankt voor de fijne tijd op de afdeling. De barbecues, uitjes, borrels en etentjes waren altijd gezellig, evenals al die keren thee halen met Miriam, Erin, Dineke, Famke & Verena. Hoogtepunten van mijn tijd bij het ORL waren toch wel het weekendje zeilen met Corine, Thomas, Erim, Jasper & Jurre en de (afterparty van de) PhD Retreat in Den Bosch. Miriam & Erin, al die jaren naast elkaar en tegenover elkaar gezeten. Heel erg bedankt dat jullie mijn paranimfen willen zijn!

Fleur, Sanne, Scarlett & Mabel, ik kijk met veel plezier terug op alle gezellige etentjes en borrels tijdens onze studies en daarna. Dat er nog veel van dit soort momenten mogen volgen!

De kliek, de wekelijkse 'koffie'avondjes op woensdag en borrels in het weekend waren een aangename afleiding tijdens mijn promotietraject. Ik hoop dat we dit nog lang blijven doen.

Beste Cock, Berdi & Sander, bedankt dat ik al geruime tijd onderdeel van jullie gezin mag zijn.

Lieve Thijn & Mariska, dank voor de oprechte interesse die jullie in mijn studies hebben getoond. Benjamin & Jonah boffen maar met zulke ouders.

Lieve Bertus & Josette, dank voor de onvoorwaardelijke steun en kansen die jullie mij altijd geven. Jullie hebben mij gestimuleerd het beste uit mijzelf te halen.

Lieve Maarten en Nolan, Maarten, bedankt dat jij er al 13 jaar altijd voor mij bent. Ik bewonder jouw relativeringsvermogen en optimistische kijk op het leven. Op naar nog heel veel jaren samen! Nolan, wat ben ik blij dat jij er bent!

Curriculum Vitae

Mirthe van Veghel was born on November 29, 1995, in Uden, the Netherlands. She graduated from VWO (Atheneum) at the Udens College in 2014. She started the Bachelor Nutrition & Dietetics at the HAN University of Applied Science. After completing her Bachelor's, she continued with the Pre-Master and Master Health Sciences at the VU Amsterdam. During her Master's, she did a research internship at the Amsterdam University Medical Center, location Academic Medical Center, where she evaluated vitamin B1, B6, B12 and folic acid status, and risk factors of vitamin disruptions in intestinal failure patients on home parenteral nutrition. In 2021, she obtained her Master's degree in Health Sciences. Following this, she started as a Junior Researcher at the Landelijke Registratie Orthopedische Interventies (LROI). In March 2022, she became a PhD Candidate at the Orthopaedic Research Laboratory at the Radboud university medical center in Nijmegen, which was funded by the LROI. Her PhD focused on exploring various aspects of population-based registry studies using hip, knee, and shoulder data from the LROI.

LROI
Radboudumc university medical center
IN DEI NOMINE FELICITER
Radboud University