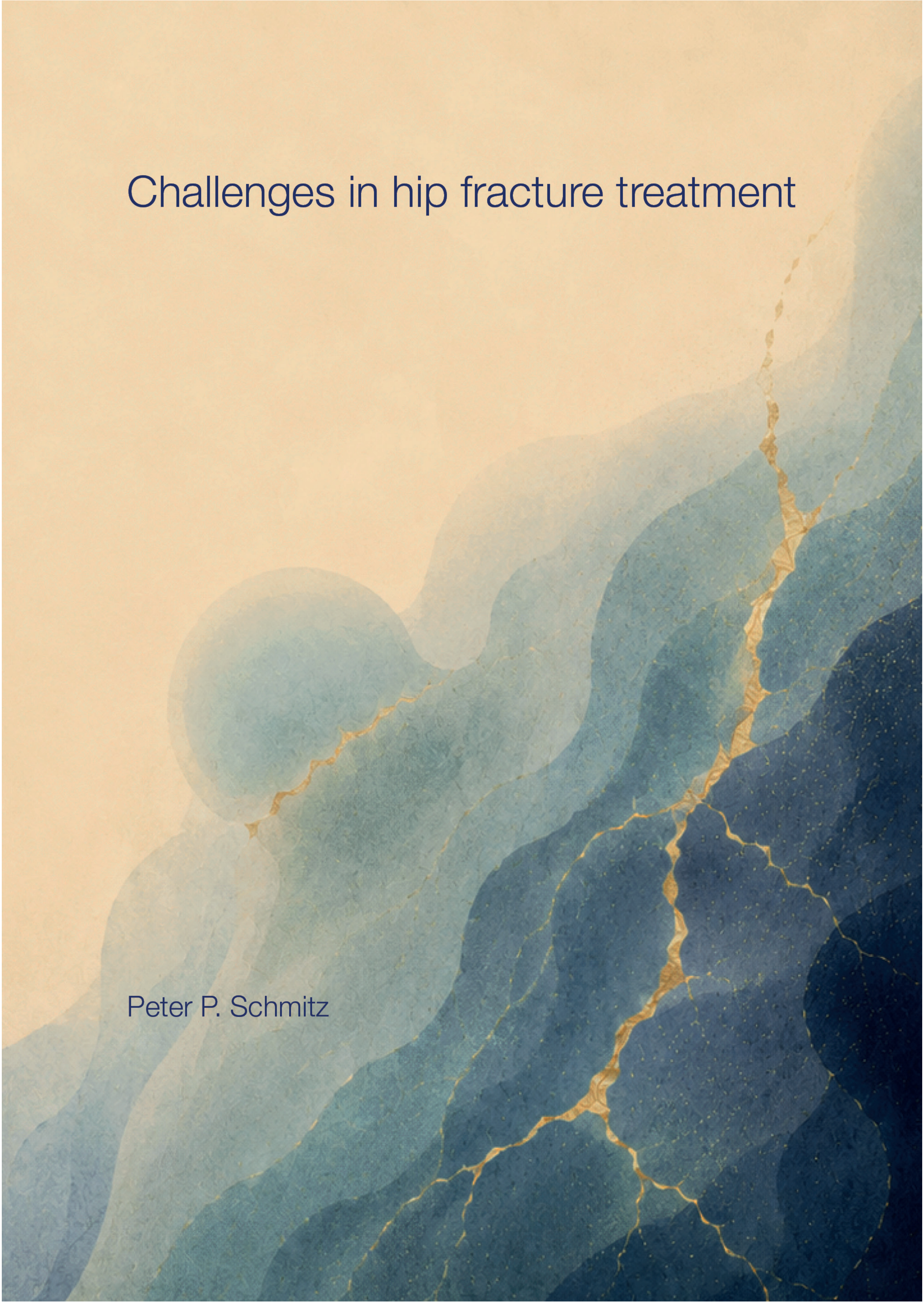
Challenges in hip fracture treatment



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Challenges in hip fracture treatment

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CHAPTER 1

General Introduction and Thesis Outline

Hip fractures

Globally, approximately 14 million people experience a hip fracture each year. Between 1990 and 2019, the incidence nearly doubled (1), and with the continued growth of the aging population, it is projected to double again by 2050. In the Netherlands the incidence of hip fractures is even expected to rise with a 4-fold increase (2). Hip fractures are associated with high mortality rates, which can become as high as 55% within 6 months after the injury in institutionalized frail patients. Furthermore, health-related quality of life, both on physical and psychosocial dimensions, is strongly affected in patients suffering from a fracture of the hip (3, 4). As such, this rising elderly population with concomitant hip fractures is a major public health concern.

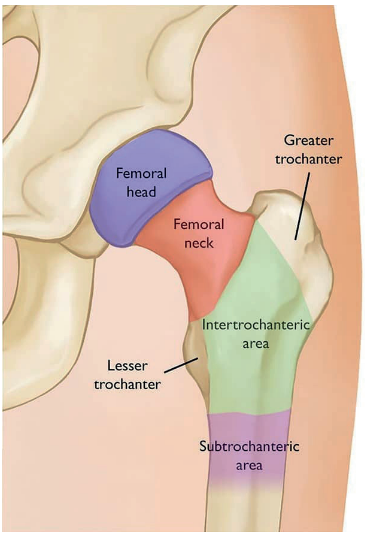

Figure 1 | Anatomy of the proximal femur.

The so called 'hip fracture' is defined as a fracture of the proximal femur. Hip fractures can be classified according to the involved anatomic region divided into femoral neck fractures and trochanteric fractures. It is important to differentiate between these two regions since treatment of fractures differ based on their anatomic characteristics. As shown in **Figure 1**, the femoral neck links the femoral head to the trochanteric region, which comprises the lesser and greater trochanter. Several tendons insert on the trochanteric region which can lead to dislocation of bony fragments in case of fracture in this area whereas no tendons insert on or originate from the femoral neck or head. The femoral head and neck in adulthood are mainly vascularized by retrograde blood supply from the medial femoral circumflex artery originating from the deep femoral artery. Dislocation of a fracture of the femoral neck can cause damage to the blood supply of the femoral head and lead to avascular necrosis of the femoral head possibly leading to revision surgery. The trochanteric region receives its primary blood supply from branches of the lateral circumflex femoral artery; therefore, avascular necrosis is generally not a concern in this type of fracture.

Treatment

In general, trochanteric fractures are treated with internal fixation and seldomly (hemi) arthroplasty is performed. Surgical treatment options for femoral neck fractures are less uniform and consist of internal fixation, hemiarthroplasty or total hip arthroplasty.

Despite the high incidence of these hip fractures and the associated health related and economic burden, there is limited consensus about the best treatment of different types of hip fractures. This lack of consensus is particularly related to the subcategory of femoral neck fractures where, despite extensive research, several controversies concerning the optimal treatment persist.

The optimal treatment of hip fractures is based on specific patient factors such as age and comorbidity. In general, young patients may benefit from internal fixation in an attempt to preserve the native hip joint whereas older patients and patients suffering from comorbidities are mainly treated with arthroplasty since the chance of failure of internal fixation is high (5). Still, the optimal treatment remains unclear in several of these patient subgroups. Despite extensive research into the best choice of arthroplasty in the treatment of femoral neck fractures, an important controversy in femoral neck fracture management concerns treatment with either total hip arthroplasty or hemiarthroplasty. Furthermore, the most appropriate treatment for patients between 60 and 70 years remains controversial since preservation of the normal hip joint is often aimed for whereas failure rates of internal fixation are high and a subsequent total hip arthroplasty is at higher risk of complications if performed as a salvage procedure after fixation failure. Another controversy concerns frail elderly patients with limited life expectancy suffering from a hip fracture. Discussion about the best treatment with either operative or non-operative management is ongoing since evidence is limited.

Review of dominant controversies in hip fracture surgery

A narrative review was performed to discuss aforementioned controversies in the surgical treatment of hip fractures and in particular for femoral neck fractures. We reviewed the literature for the best available evidence on each controversy and establish whether trends in daily practice were evidence-based, using data from national registries around the world. It was beyond the scope of the study to provide a true review and meta-analysis following PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines (6). Instead, a narrative form of the current knowledge is presented.

For this review 3 dominant controversies in the surgical management of femoral neck fractures were selected:

I. Total hip arthroplasty versus hemiarthroplasty
II. Hip arthroplasty versus internal fixation
III. Operative versus non-operative treatment

For each controversy a literature search was performed using PubMed from inception through July 2020 for available systematic reviews, (randomized controlled) trials and registry studies. In particular consensus from available reviews and meta-analyses following PRISMA guidelines (6) were used to discuss and summarize the best level of evidence regarding each controversy. References from reviews and meta-analysis were analyzed for missed (randomized controlled) trials and registry studies which were subsequently incorporated separately.

Besides a narrative review on the best available evidence on each controversy, an attempt was made to obtain data on annual trends in the management of femoral neck fractures from the public domain available data of several national registries (Sweden, Norway, The Netherlands, Australia & New Zealand) (7-10). For each controversy available national annual trends in clinical practice variation in the management of femoral neck fractures were elucidated. Subsequently, recommendations on each controversy obtained from the available literature were balanced against data on clinical practice from available national registers.

I. Total hip arthroplasty versus hemiarthroplasty

An important controversy in femoral neck fracture management concerns treatment with either total hip arthroplasty or hemiarthroplasty (**Figure 2**). There has been extensive research performed to determine the best choice of arthroplasty in the treatment of femoral neck fractures. Two systematic reviews regarding patients with a fracture of the femoral neck treated with either total hip arthroplasty or hemiarthroplasty identified 13 RCTs enrolling 1364 patients (11) and 7 RCTs combined with 8 retrospective cohort studies enrolling 1890 patients (12), respectively. Both reviews conclude with a lower reoperation rate and a higher Harris Hip Score after total hip arthroplasty, whereas an overall higher risk of dislocation after total hip arthroplasty is also reported (11, 12). Furthermore, a separate randomized controlled trial showed no difference in hip function and health-related quality of life nor in reoperations and complications in octogenarians and nonagenarians (13). Two recent registry studies focusing on treatment with hemiarthroplasty or total hip arthroplasty reveal contradictory results on secondary procedures. Moerman et al. (2018) found a higher and Hansson et al. (2017) a lower risk of secondary procedures after total hip arthroplasty (14, 15).

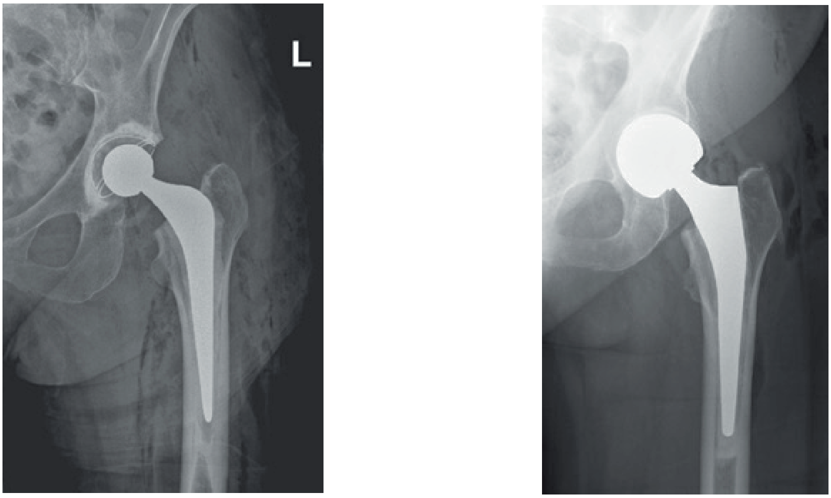

Figure 2 | Radiograph of a total hip arthroplasty with the use both a femoral and an acetabular component (left) and a hemiarthroplasty with only a femoral component (right).

From these reviews and recent studies, one may conclude that total hip arthroplasty and hemiarthroplasty are both viable surgical treatment options for elderly patients with a femoral neck fracture. Clearly, the available literature falls short in discriminating between age-groups, which is also important in weighing the balance between total or hemi arthroplasty. This dilemma of weighing the balance has been further elucidated by another recent landmark study by Bhandari et al. where 1495 randomized patients with a mean age of 79 years old failed to reveal clinically important advantages of total hip arthroplasty versus hemiarthroplasty (16). Still, this study used a relatively short follow-up of 2 years and one may argue whether the conversion rate of hemiarthroplasty towards total hip arthroplasty may increase with longer follow-up. This assumption is, however, not supported by other studies with longer follow-up of hemiarthroplasty (17, 18). In summary, recent literature indicates that the benefits of total hip arthroplasty over hemiarthroplasty for the surgical treatment of femoral neck fractures should not be overestimated and may in the best case probably be reserved for relatively young patients with an age below 70 years old.

Data on annual trends from the public domain of the national registries of Sweden, Norway, the Netherlands, Australia and New Zealand were available to elucidate on this controversy (**Figure 3**) (7, 8, 10, 19). Overall, data reveal that between 10 and 35 percent of femoral neck fractures are treated with a total hip arthroplasty. Within this range there appears to be an increasing trend in the use of total hip arthroplasty versus hemiarthroplasty from 2010 on for most countries (Sweden, Norway, Australia and New Zealand) whereas for The Netherlands a slight decline appears to be present (**Figure 3**). Moreover, this data reveals wide differences in the use of total hip arthroplasty versus hemiarthroplasty between countries since the part of patients treated with total hip arthroplasty varies from a third in Sweden, a fourth in the Netherlands and a fifth in Norway (**Figure 3**). The observed increasing trend in the use of total hip arthroplasty does not correspond with the available evidence in the literature where clear superiority of total hip arthroplasty is not supported. It will be interesting to follow these trends after the appearance of the recent landmark study (16). Obviously, no firm conclusions can be drawn from registry data but it seems safe to conclude that national trends in choosing total or hemiarthroplasty for treatment of femoral neck fractures do not correspond with the available evidence in the literature.
The observed increase in use of total hip arthroplasty suggests that many factors may play a role in surgical decision making. Balancing the extensive research performed regarding this controversy against data from national registries reveals a discrepancy between evidence in the literature and daily practice in several countries.

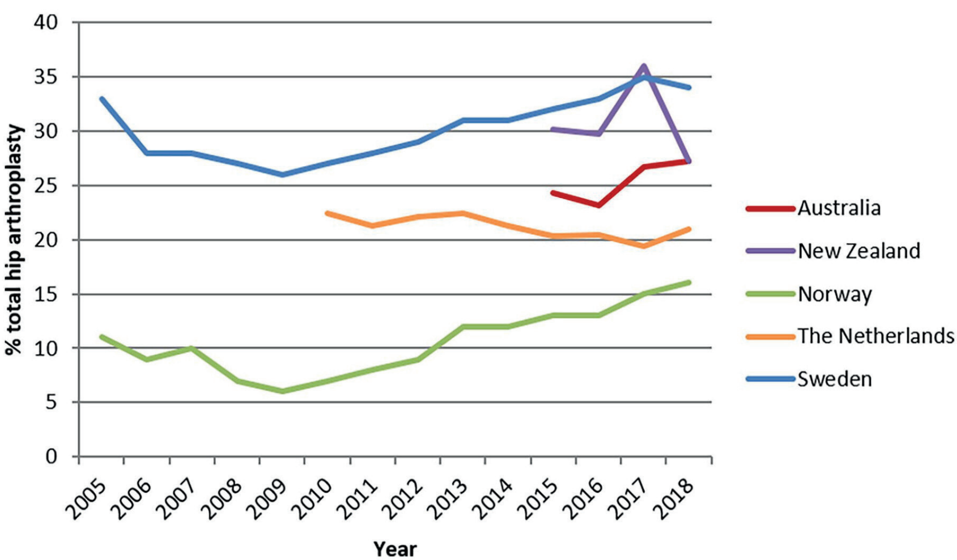

Figure 3 | Rates of total hip arthroplasty as percentage of all arthroplasties (total hip arthroplasty plus hemiarthroplasty) as treatment for femoral neck fractures. Rates were retrieved from data in national registries available on the public domain.

II. Hip arthroplasty versus internal fixation

The type of surgical treatment of femoral neck fractures is widely analyzed. However, the choice of treatment with either (hemi)arthroplasty or internal fixation remains an important controversy in literature (**Figure 4**). Systematic reviews involving internal fixation versus (hemi)arthroplasty, concerning 14 RCTs (20) and 2 RCTs combined with 1 observational study (21), respectively, show better results after both types of arthroplasty in terms of secondary interventions, complications and function (20, 21). These conclusions have also been confirmed by other well-performed randomized controlled trials (22-25) which were not incorporated in the systematic reviews above. These perceived benefits of arthroplasty have to be balanced against the main benefit of internal fixation, preservation of the native hip joint. As such, the patients age appears to play an important role in weighing the respective potential benefits of an arthroplasty versus internal fixation. The literature appears to be conclusive for patients over 70 years of age; this group of patients can best be treated with an (hemi)arthroplasty (22-25). Obviously, the potential benefits of preservation of the native hip joint only apply to younger patients and as such internal fixation is preferred over arthroplasty in younger patients less than 60 years old (26).

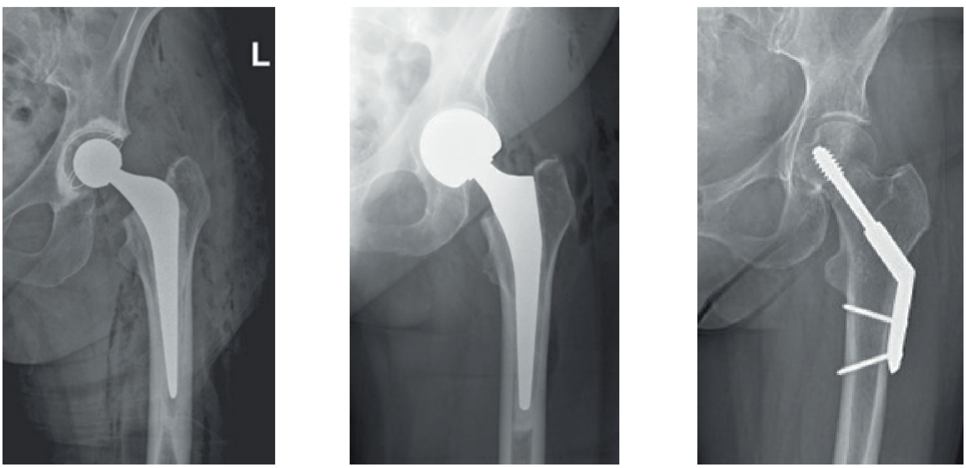

Figure 4 | Radiograph of a total hip arthroplasty (left), a hemiarthroplasty (middle) and an internal fixation by means of a dynamic hip screw (right).

Thus, in particular treatment of femoral neck fractures in the age group of 60-70 years is still the most controversial (26) and unfortunately, literature on this group is scarce. A study involving patients between 55 and 70 years, using data from the Norwegian Hip Fracture Register, showed a reoperation rate of 27 percent in patients treated with internal fixation compared to 2.8 percent and 3.8 percent after total hip arthroplasty and hemiarthroplasty, respectively. In addition, patient-reported outcome measures showed better results after arthroplasty (5). From these high failure rates and inferior patient satisfaction after internal fixation one may support arthroplasty in this relatively young age group. Nevertheless, proponents of internal fixation could argue that in case of failure of internal fixation of femoral neck fractures a total hip arthroplasty can still be used as a salvage procedure. However, this option is not without a counter side. An important aspect of good clinical practice is not to "burn any bridges" with any treatment and it is well recognized that total hip arthroplasty as a salvage procedure after a failed osteosynthesis has higher rates of revision and complications compared to total hip arthroplasty in femoral neck fractures as an index procedure (27-29).

Clearly, there is a lack of high-quality evidence for the best treatment for femoral neck fractures in particular in the age group of 60-70 years. The limited results available in literature raise the question whether this group of patients does indeed benefit from preservation of the hip joint or whether this theoretical advantage is generally overestimated. This group of patients should be counseled about the relatively high risk of failure of internal fixation and the potentially higher risk of complications after total hip arthroplasty as a salvage procedure, but must also understand that hip replacement is not a panacea. Shared decision making should be encouraged between clinician and patient with appropriate documentation of the risks and benefits discussed of each option. Well performed future studies in this population may provide more evidence to support decision making in this difficult group of patients.

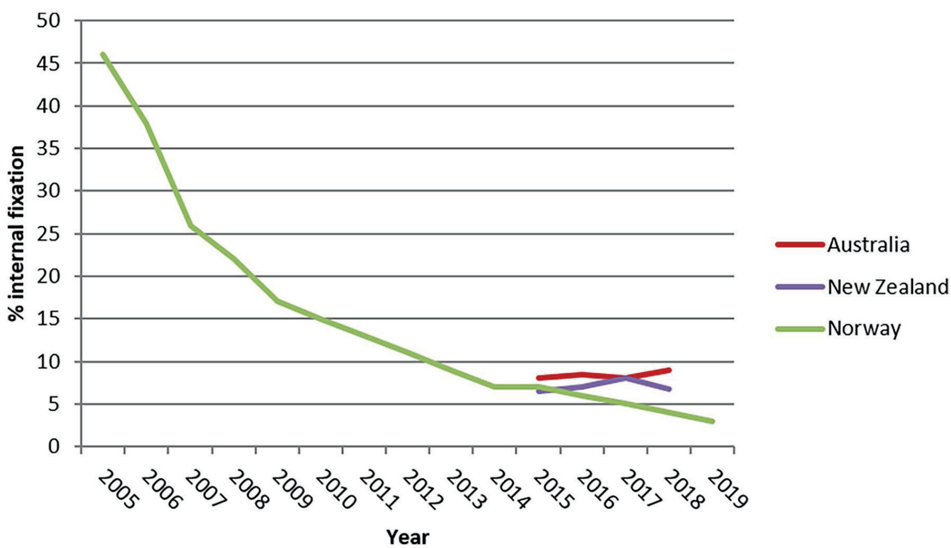

Figure 5 | Rates of internal fixation as percentage of all types of treatment (internal fixation plus hemi(arthroplasty)) as retrieved from data in national registries available on the public domain.

Data on annual trends from the public domain of national registries were searched resulting in only limited data from Norway, Australia and New Zealand to elucidate on treatment of femoral neck fractures with either (hemi)arthroplasty or internal fixation (7, 8). Registry data from the Netherlands and Sweden were not available since these registries report no data concerning internal fixation (9, 10). However, in the Netherlands The Dutch Hip Fracture Audit (30) started in 2016 to collect data for internal fixation in hip fractures. Unfortunately, no valid information could be obtained from this starting registry since available data proved incomplete from a recent start-up and biased from concomitant inclusion of trochanteric fractures. Specifically, data from Norway reported on comprehensive changes in the use of internal fixation versus (hemi)arthroplasty (**Figure 5**). In 2005 in Norway almost half of femoral neck fractures were treated with internal fixation whereas, following a rapid decline, only 3 percent of femoral neck fractures were treated with internal fixation in 2019. The rising use of (hemi)arthroplasty in this registry data is in accordance with the favorable results of arthroplasty compared to internal fixation. However, this data does not solve the controversy in the age group of 60-70 years since it concerns patients of all ages. In contrast to data regarding both types of arthroplasty, data with regard to internal fixation versus arthroplasty is poorly represented in national registers. Further data is needed to solve the controversy in patients between 60 and 70 years old.

III. Operative versus non-operative treatment

Aims of treatment in the frail elderly population with a femoral neck fracture should focus on pain relief and early mobilization. The postoperative overall 1-year mortality rate in these hip fracture patients is as high as 27% (31) and in specific groups, such as those patients with end-stage dementia, mortality may be as high as 55% within 6 months (32). Nevertheless, operative treatment is still performed in nearly all patients with a femoral neck fracture since non-operative treatment has the reputation to result in persistent pain, major patient discomfort, high risk of pneumonia and early death (33, 34). However, there is a lack of well performed studies to support these assumptions, particularly around patient discomfort and for a small group of very fragile patients mortality risk is very high irrespective operative treatment or not (33, 34).

Only 1 single systematic review involving operative and non-operative treatment of hip fractures is available (33). This review found only 7 non-randomized studies and concludes with increased 1-year mortality rates after non-operative treatment. None of these studies however reported on patients' participation in the treatment choice, pain, subsequent quality of life or perceived patient discomfort. Randomized controlled trials are not available since randomization between operative and non-operative treatment would not be feasible in this group of patients. As such, in the available studies non-operative treatment resulted in a significantly increased mortality rate, however prolonging life may not be in a patients' best interest or choice in the very frail and elderly. Recently, a 2-arm non-randomized multicenter prospective cohort study was performed comparing the outcome of 84 operative treated hip fractures versus non-operative treatment of 88 hip fractures in the frail institutionalized patients who either are malnutritioned, have mobility issues or severe comorbidities (American Society of Anesthesiologists (ASA) class 4 or 5) (35). To the best of our knowledge this is the first study where the option of non-operative treatment is actively offered to a selective group of frail patients. Besides mortality rates, pain, and perceived patient comfort are also important outcome parameters. Quality of dying is also assessed using a validated outcome score (36). This FRAIL-HIP study reported that treatment satisfaction was high in both groups. Adverse events were less frequent in the non-operative group and 30-day mortality rate was higher after non-operative (83%) compared to operative management (25%). Quality of dying, reported by proxies and caregivers, was good in 51% of patients. This study possibly suggests the time has come to explore non-operative care for hip fractures as a viable treatment option in a selective group of frail patients with limited life expectancy, for whom comfort and pain are more relevant than survival. Such an approach can only succeed in tight collaboration with ortho-geriatric palliative trauma care. So far, data from the national registries are not available regarding this controversy.

In conclusion, this introduction reveals that important controversies in the management of femoral neck fractures persist. Irrespective of conclusive consensus in literature, data from trends in clinical practice from national registries suggest that clinical evidence is not adequately integrated in daily practice. Implementation of evidence based daily practice proves to be complex. Several factors, such as personal or national preferences and non-medical incentives, do play a role besides available high-quality evidence. We feel that studies where clinical evidence is balanced against daily practice such as in this narrative review are important to monitor to which extend evidence-based practice is incorporated in clinical practice and to which extend differences between countries exist. Exploring treatment trends in national registries balanced against the best available evidence stimulates discussion whether differences are justified or not. This will lead to improvement of implementation and will reduce inconsistencies in clinical practice.

Thesis outline

The discussed controversies form important challenges in hip fracture treatment. This thesis will elaborate on these three important controversies and specific aims are outlined to provide further insight into these controversies.

Part 1: Total hip arthroplasty or hemiarthroplasty

Elderly patients suffering from a hip fracture are mostly treated with hemiarthroplasty. In case of a hemiarthroplasty only a femoral component is placed and the native acetabulum is left alone, whereas in a total hip arthroplasty the acetabulum is replaced as well. The clear advantage of the hemiarthroplasty is less surgical exposure for the patient and lower costs. However, the femoral component will then articulate directly with the native acetabular cartilage and with time this may lead to secondary cartilage damage and subsequent reoperation to place an acetabular component after all. As such, patient (biological) age is an important factor to select the adequate treatment choice between hemiarthroplasty and total hip arthroplasty. For example, placement of hemiarthroplasty in relatively young and high demanding patients will lead to failure of this hemiarthroplasty and the need for conversion to total hip arthroplasty after all.

Besides patients age, several other factors, are important and may influence the choice between treatment with hemiarthroplasty or total hip arthroplasty. For example, to which extend the converted hemiarthroplasty may give an equal end result for the patient as a total hip arthroplasty to begin with plays an important role in the choice of index treatment. Literature is scarce concerning information on converted hemiarthroplasty. In **Chapter 2**, we provide a systematic review and meta-analysis to the outcome of conversion of hemiarthroplasty to total hip arthroplasty. Furthermore, it should be evaluated to which extend the need for conversion of a hemiarthroplasty is a clinically significant problem after all. In other words, how frequently/often does conversion from hemiarthroplasty to total hip arthroplasty actually occur? In **Chapter 3**, we assess the conversion rate of hemiarthroplasty to total hip arthroplasty in patients under 75 years of age. Finally, postoperative care of fragile femoral neck fracture patients may be improved by a decrease in hospital follow-up. To date, postoperative follow-up visits with radiographs at the outpatient department are standard of care in many countries from an assumption that in this way possible complications can be detected. For many of these fragile patients and their caregivers such a hospital visit could be a significant burden and it is unclear whether this postoperative follow-up is clinically relevant. Therefore, in **Chapter 4**, we evaluate the (un)necessity of regular postoperative follow-up of hemiarthroplasty for femoral neck fractures.

Part 2: Hip arthroplasty or internal fixation

The clinical decision to treat a hip fracture with a hip arthroplasty or with internal fixation is often difficult and mainly applies to the patient group around retirement age. Several factors play a role in this clinical dilemma, such as the age of the patient, comorbidities, failure rates of internal fixation and eventual revision risk of hip arthroplasty. For example, failure of internal fixation will lead to the need for subsequent salvage total hip arthroplasty after all. From this need for second surgery the outcome of this salvage total hip arthroplasty may have inferior outcome than a (acute) total hip arthroplasty to begin with. In weighing the balance between arthroplasty or internal fixation as first treatment of choice for a hip fracture better understanding is necessary about the outcome of salvage total hip arthroplasty after failed internal fixation. To evaluate complications and survival of total hip arthroplasty after failed primary osteosynthesis compared to acute total hip arthroplasty for femoral neck fractures we present a multicenter study in **Chapter 5**. In **Chapter 6**, we assess the revision risk of salvage versus acute total hip arthroplasty following femoral neck fractures with the use of data from a national joint registry.

Furthermore, there is an established high risk of early implant failure after internal fixation and this risk varies between different types of implants. Innovative internal fixation implants can only be durable with equal or improved risks of failure compared to available implants. As such, innovative implants should be monitored carefully on the risk of failure of internal fixation before widespread use is recommended. In **Chapter 7**, we evaluate the results of the newly introduced TFNA and compared failure rates with Gamma Nail for trochanteric fractures.

Part 3: Operative versus non-operative treatment

Hip fractures in frail elderly patients concern a life-threatening condition. Surgical treatment is still the mainstay of care even in these frail elderly since surgery of hip fractures will extend life and improve mobility. However, non-operative management may be considered in a subgroup of frail elderly hip fracture patients since life expectancy could be limited (3). Surgical intervention for a hip fracture may not always be optimal for every patient, especially among a subgroup of frail elderly individuals where non-operative management may better align with patient preferences. To date there is a lack of information on the course of non-operative management in a carefully selected group of very frail patients for this purpose. Information on patient comfort and the life expectancy with tailored non-operative management is important to provide further insight into non-operative management of frail hip fracture patients. Therefore, in **Chapter 8**, we evaluate mortality rates in non-operative management of hip fractures.

A general discussion is presented in **Chapter 9** and followed by a summary of this thesis in **Chapter 10** and **Chapter 11**.

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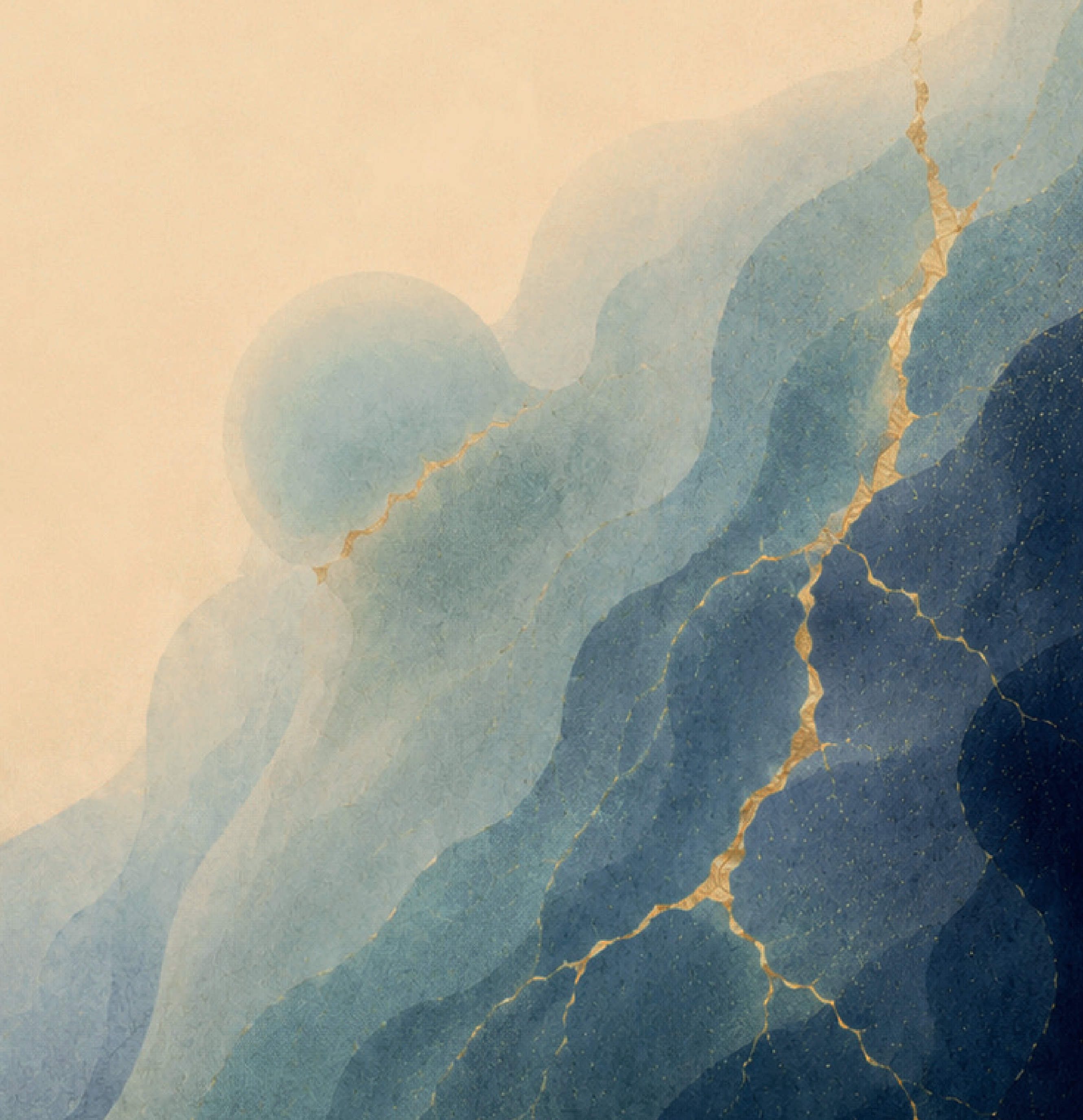
Part 1:
Total hip arthroplasty versus hemiarthroplasty



CHAPTER 2

The outcomes of conversion of hemiarthroplasty to total hip arthroplasty, a systematic review and meta-analysis

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Abstract

Introduction

Acetabular erosion is an important complication in hemiarthroplasty and may lead to total hip arthroplasty as a conversion. The results of total hip arthroplasty as a conversion remain unclear. We performed a systematic review and meta-analysis to compare the outcome of total hip arthroplasty as a conversion with primary total hip arthroplasty.

Methods

PRISMA guidelines were used and Pubmed, Embase and the Cochrane libraries were searched. Both, studies comparing the outcome of total hip arthroplasty as a conversion with the outcome of primary total hip arthroplasty and the outcome of cohort studies limited to total hip arthroplasty as a conversion, were included. Risk of bias was assessed using the Methodological Index for Non Randomized Studies checklist. Meta-analysis was performed concerning pooled annual revision, dislocation and infection rates.

Results

A total of 27 studies were available for analysis; four comparative studies and 23 cohort studies. Comparative studies were defined as high quality and cohort studies as medium quality. Analysis revealed a significantly higher overall revision risk (Hazard Ratio 1.72, 95% confidence interval 1.39 to 2.14) after total hip arthroplasty as a conversion compared to primary total hip arthroplasty. The annual revision rate of total hip arthroplasty as a conversion was 1.63% (95% confidence interval 1.14 to 2.33) in the comparative studies and 1.40% (95% confidence interval 1.17 to 1.66) in the cohort studies. A pooled infection rate of 4.34% (95% confidence interval 2.66 to 7.01) and dislocation rate of 4.79% (95% confidence interval 3.02 to 7.53), was found.

Conclusions

Literature concerning the results of total hip arthroplasty as a conversion is limited. The risk of revision after conversion of hemiarthroplasty is higher compared to primary total hip arthroplasty.

Introduction

Femoral neck fractures are operatively treated with either internal fixation (IF) or a form of arthroplasty. Treatment with IF is preferred over arthroplasty in younger patients (less than 60–70 years old) (1) whereas patients above 60–70 years old are primarily treated with either hemiarthroplasty (HA) or total hip arthroplasty (THA). The optimum choice of the type of arthroplasty is important given the large number of performed (hemi)arthroplasties following femoral neck fractures. For example, in the U.S. more than 100.000 patients are treated with any type of arthroplasty following femoral neck fractures each year (2). Despite extensive high quality research concerning the optimum choice of treatment of femoral neck fractures with either HA or THA, no superiority of treatment is found in literature (3). Both HA and THA can be a definitive treatment in patients suffering from a femoral neck fracture. However, complications can occur and mostly concern dislocation, periprosthetic fractures, infection and implant loosening (3, 4). In addition, acetabular erosion is an important complication in HA (4) and may lead to THA as a conversion of hemiarthroplasty (CTHA).

The results of CTHA are important since even minor differences may have significant impact in this large population. Information concerning CTHA may influence the choice of index treatment with either HA or THA since we do not want to "burn any bridges" for a potential THA in case a HA needs conversion. Though, the results of CTHA are scarce since mostly small studies are performed without the use of a comparison group. The aim of this study was to review literature on the outcome of a CTHA versus primary THA.

Materials and methods

Protocol and registration

This systematic review was prospectively registered with PROSPERO with registration number CRD42020206277 in September 2020. The review was performed with the use of the PRISMA (Preferred Reporting Items for Systematic reviews and MetaAnalyses) guidelines (5).

Eligibility criteria

The search strategy was primarily focused on studies concerning the outcome of CTHA compared to the outcome of THA as an index treatment for femoral neck fractures. Additionally, cohort studies limited to the outcome of CTHA without a comparison to THA with at least 10 patients were included. Non-English articles were translated.

Information sources

A comprehensive literature search was performed in PubMed (Medline), Embase and Cochrane Central Register of Controlled Trials in April 2022. The search strategy was developed after consultation with a medical library strategist (**Supplementary Data A**).

Study selection

Two independent authors (PS and MS) performed the study selection. After duplicate studies were removed, the titles and abstracts of the remaining studies were screened using Rayyan (6). For studies passing this stage, the full-text articles were evaluated. Reasons for exclusion are shown in **Figure 1**. At each stage, disagreements were discussed with a third reviewer (JvS).

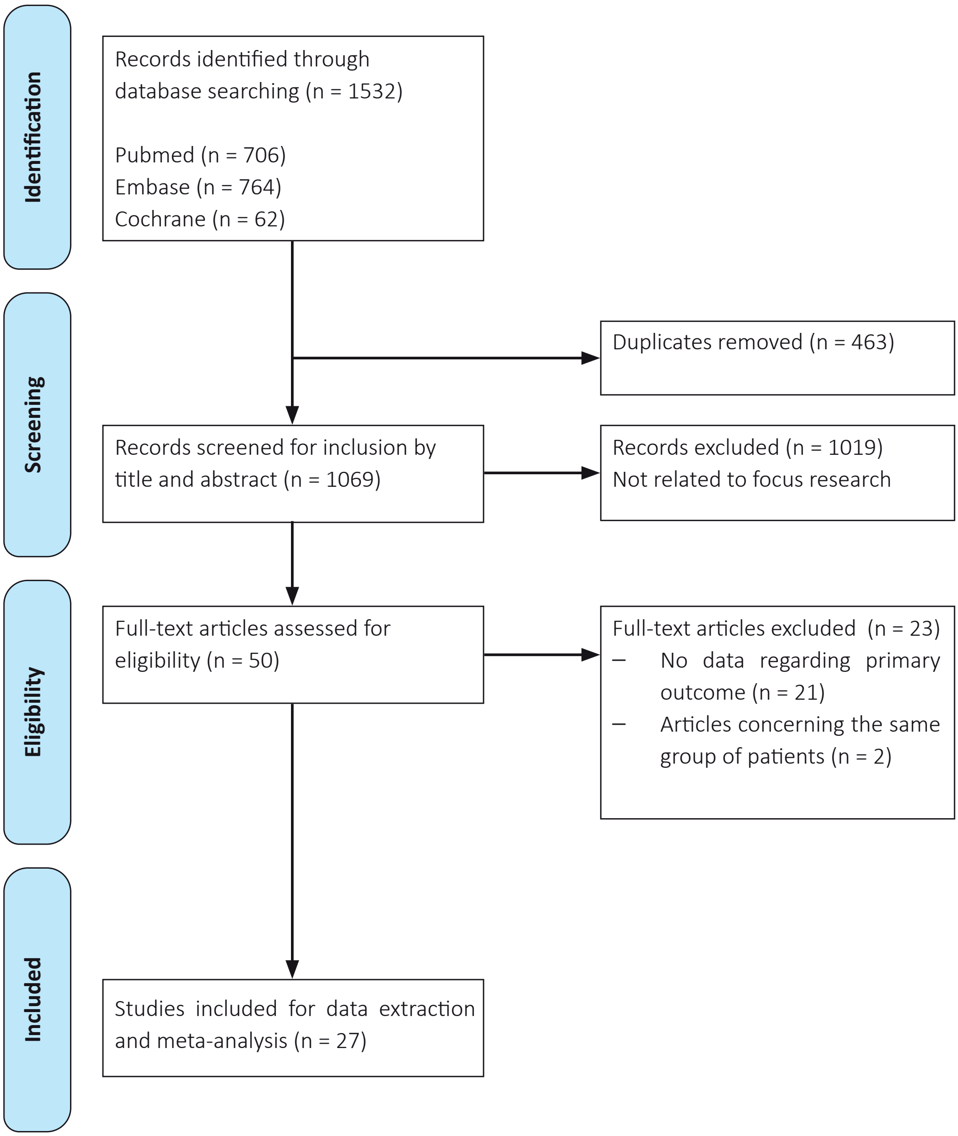

Figure 1 | PRISMA flowchart showing identification, screening and inclusion of studies for review.

Data extraction

Extracted data included patient characteristics, follow-up, time interval between hemiarthroplasty and conversion, reason for conversion, implants used for conversion, revised components, fixation technique (cemented/uncemented), surgical approach, hip function after conversion, complication rate of conversion and revision rate of conversion.

Methodological quality

Risk of bias of the included studies was assessed using the Methodological Index for Non Randomized Studies (MINORS) checklist (7). Studies were scored on the 8 items for non-comparative and 12 items for comparative studies with zero, one or two points indicating "not reported", "reported but incomplete" and "reported and complete", respectively. In total, using this method a maximum score of 16 can be assigned for non-comparative studies, in which 1–6 was defined as low quality, 7–11 as medium quality and 12–16 as high quality. Comparative studies can be assigned with a maximum score of 24, in which 1–8 was defined as low quality, 9–16 as medium quality and 17–24 as high quality (7).

Meta-analyses

Pooled Hazard Ratios (HR) and 95% confidence intervals (CI) were derived by calculation of the log HR with accompanying standard errors (SE). In case HRs and confidence intervals were not reported, incidence density rates were calculated as annual revision rates (ARR) for CTHA and THA groups separately, and HRs were estimated using incidence rate ratios (IRR) according to Bender et al. (8). Log HRs were pooled using the random effect model with inverse variance weighting. Pooled HRs with 95% CI were obtained by back-transforming the log HR. To assess the effect of large sample size and imbalance of follow-up on the pooled estimate, sensitivity analyses were performed by exclusion of one register study and one study with imbalanced follow-up, respectively. Significance was assessed using the confidence interval at 95% level. Pooled ARRs, and dislocation and infection rates were calculated separately for the cohort studies by pooling log transformed estimates and the use of random effect model with inverse variance weighting. Heterogeneity between studies was assessed by the I^2 and χ^2 statistics. Heterogeneity was considered low in case I^2 was 25%, moderate when 50%, and high when 75% (9). R version 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria) with Meta Package (version 4.15-1) was used to perform the meta-analysis.

Ethics, funding and potential conflict of interest

Ethical approval was not applicable. No funding was obtained and the authors have no conflicts of interest to declare. Data will be made available on request.

Results

Search results

The search strategy is presented in **Figure 1**, which resulted in 27 studies reflecting the results of CTHA. The electronic database search resulted in 1532 records (PubMed: 706, Embase: 764 and Cochrane: 62). After a screening of titles and abstracts was performed, 50 articles were considered potentially eligible, out of which 6 comparative studies and 21 cohort studies matched the eligibility criteria (10-36). Four of the comparative studies could be pooled for the comparative analysis since these studies reported on CTHA versus THA (19, 21, 24, 31) whereas the remaining two comparative studies used revision of THA as a comparison group (18, 30). The groups with CTHA from these two studies were included as a cohort study. One study was excluded due to double publication of the results (37). However, relevant data of the study population which was not published in the included studies, was used for analysis. All 27 studies were used for pooled analysis of overall revision and complication risks concerning CTHA.

Methodological quality

The results of the quality assessment showed that the comparative studies were defined as high quality with a MINORS score of 17 (14–19) out of 24 whereas the cohort studies appeared to be of medium quality with a MINORS score of 10 (7–12) out of 16 (**Supplementary Data B**).

Study characteristics comparative studies; CTHA versus primary THA

As mentioned before, four studies compared CTHA with a primary THA; one large registry study and three retrospective studies (19, 21, 24, 31). Figved et al. performed a register study from Norway and included 595 patients treated with a CTHA and 74,865 patients with a primary THA (19). Sarpong et al. retrospectively matched a group of 60 patients with a CTHA to 65 patients with a femoral neck fracture treated with a primary THA for mean age, gender body mass index and American Society Anesthesiologists score (31). Hernandez et al. matched 389 patients treated with CTHA with 778 patients undergoing primary THA for osteoarthritis on age, sex and year of surgery (21). Llinas et al. performed a retrospective comparative study of 99 CTHA and 825 primary THA for osteoarthritis (24). These four comparative studies together included 1143 patients treated with a CTHA and 76,533 patients with a primary THA with a mean follow-up ranging from 2.8 to 9.3 years. The average age of these patients was 63 to 78 years and gender distribution varied between 65% and 81% women, as presented in **Table 1**. Indication for primary HA was reported in two of these studies (655 patients); 100% of the HAs were placed in patients suffering from a femoral neck fracture (19, 31). Reason for CTHA was mentioned in two studies (449 patients); 261/449 (58%) CTHA were performed for acetabular erosion, 9/449 (2%) for dislocation, 147/449 (33%) for femoral loosening, 19/449 (4%) for periprosthetic fractures and 13/449 (3%) for other reasons (21, 31). A mean time of 7.4 years from initial HA to CTHA was found, although this was only reported by Sarpong et al. (31). Type of fixation was presented by three studies (754 patients); 506/754 (67%) HA were converted with the use of cement, 60/754 (8%) were uncemented and 188/754 (25%) hybrid conversions were performed (19, 21, 24). All studies (1143 patients) reported on component revision in which 835/1143 (73%) femoral stem revisions were performed. Type of implanted acetabular and femoral components and surgical approach were widely variable.

Study characteristics cohort studies

The 23 included cohort studies consisted of a total of 2311 patients treated with CTHA with a mean follow-up ranging from 2.7 to 8 years. The average age of these patients was 59 to 86 years and gender distribution varied between 35% and 88% women, as presented in **Table 1**. Indication for primary HA was reported in only 12 studies (1669 patients); 1608/1669 (96%) HA were placed in patients suffering from femoral neck fractures and 61/1669 (4%) for other reasons, mainly for osteonecrosis of the femoral head and in few cases for tumor or septic arthritis (10-12, 14, 15, 17, 28, 30, 33-36). Reason for CTHA was mentioned in 20 studies (2186 patients) (11-18, 20, 23, 25-30, 32, 33, 35, 36). Out of these 2186 CTHA, 749 (34%) were performed for acetabular erosion, 208 (9%) for dislocation, 754 (35%) for femoral loosening, 206 (9%) for periprosthetic fractures and in 279 (13%) for other reasons. Mean time from initial HA to CTHA was 3.2 to 14.9 years (reported by 14 studies) (10, 12-15, 22, 23, 25, 28-30, 32-34). Type of fixation was presented by 15 studies (814 patients) of which 472 (58%) HA were converted with the use of cement, 284 (35%) were uncemented and 58 (7%) were hybrid conversions (11-15, 20, 22, 23, 26-28, 32-35). 13 studies (701 patients) reported on component revision in which 538 (77%) femoral stem revisions were performed (12, 14, 15, 17, 18, 22, 23, 26, 28-30, 32, 33). Again, type of implanted acetabular and femoral components and surgical approach were widely variable.

Outcome measures comparative studies

Meta-analysis of comparative studies concerning CTHA versus primary THA revealed a significantly higher overall revision risk (HR 1.72, 95% CI 1.39 to 2.14) after CTHA (**Figure 2**) (19, 21, 24, 31). Hernandez et al. presented results for two periods separately (1985–1999 and 2000–2014), so HRs of both periods were included in this analysis (21). A pooled annual revision rate of 1.63% (95% CI 1.14 to 2.33) in patients treated with CTHA was found in these four studies (**Figure 3**). Only Sarpong et al. reported on postoperative infection and dislocation rates and found an infection rate of 0.6% and a dislocation rate of 2.4% in the group with CTHA whereas no infection or dislocation occurred in the group with primary THA (31).

Outcome measures cohort studies

Meta-analysis of all cohort studies revealed a pooled annual revision rate of 1.40% (95% CI 1.17 to 1.66) in patients treated with CTHA (**Figure 3**). The pooled infection rate was 4.34% (95% CI 2.66 to 7.01). The pooled dislocation rate was 4.79% (95% CI 3.02 to 7.53) as shown in **Table 2**.

Table 1 | Baseline characteristics of included studies.

Author	Year	Study type	Number of CTHA	Number of primary THA	Follow-up months (range)	Mean age years (range)	Women %	Indication For CTHA	Mean time to CTHA years (range)
Comparative studies									
Figved (19)	2007	Register	595	74865	61	78 (61-98)	81	-	-
Hernandez (a) (21)	2019	Retrospective	389	778	111,6 (0,1-341)	72 (+-12 SD)	72	241 AE, 4 D, 120 FL, 12 O, 12 PF	-
Llinas (24)	1991	Retrospective	99	825	89 (1-240)	63	67	-	-
Sarpong (31)	2019	Retrospective	60	65	34	74 (31-94)	65	20 AE, 5 D, 27 FL, 1 O, 7 PF	89 (1-300)
Cohort studies									
Amstutz (10)	1979	Retrospective	41		36.5	62.7 (18-80)	83	-	66 (10-264)
Bayam (11)	2019	Retrospective	42		75.7 (25-171)	70 (51-80)	88	26 AE, 10 FL, 5 O, 1 PF	-
Bhosale (12)	2012	Retrospective	89		96 (60-156)	68 (57-91)	61	31 AE, D 6, 36 FL, 10 O, 6 PF	58 (1-144)
Bilgen (13)	2000	Retrospective	15		32	59	87	15 AE	88 (10-144)
Carulli (14)	2016	Retrospective	31		46	75	58	31 D	38 (24-72)
Chalmers (15)	2017	Retrospective	16		36 (24-60)	75 (57-93)	75	9 AE, 7 D	72 (2-360)
Cossey (16)	2002	Retrospective	46		-	76	72	22 AE, 22 FL, 2 O	-
Diwanji (17)	2008	Retrospective	25		86 (36-192)	59 (25-82)	52	21 AE, 4 PF	-
Fichman (18)	2015	Retrospective	46		47 (6-149)	68 (23-95)	70	25 AE, 7 D, 13 FL, 1 O	-

Table 1 continued

Author	Year	Study type	Number of CTHA	Number of primary THA	Follow-up months (range)	Mean age years (range)	Women %	Indication For CTHA	Mean time to CTHA years (range)
Hammad (20)	2006	Retrospective	47		44 (24-84)	64 (54-83)	68	18 AE, 8 D, 11 FL, 6 O, 4 PF	-
Hoskins (36)	2021	Register	985		66 (0-216)	78 (36-99)	72	486 FL, 168 PF, 108 D, 223 O	-
Huang (22)	2019	Retrospective	47		74 (60-94)	86 (83-89)	68	-	68 (36-85)
Kaku (23)	2017	Retrospective	61		62 (12-224)	68 (47-86)	72	55 AE, 2 D, 4 O	179 (12-324)
Morsi (25)	2016	Retrospective	217		74 (48-156)	59 (54-79)	53	155 AE, 9 D, 38 FL, 8 O, 7 PF	84 (4-132)
Mounsey (26)	2015	Retrospective	28		70 (25-124)	80 (35-93)	86	16 AE, 8 D, 2 O, 2 PF	-
Nabil (27)	2015	Prospective	42		36	59 (46-69)	48	42 AE	-
Pankaj (28)	2008	Prospective	44		77 (24-108)	62 (42-75)	68	14 AE, 3 D, 15 FL, 10 O, 2 PF	84 (14-144)
Park (29)	2018	Retrospective	48		74 (24-138)	69 (28-80)	54	31 AE, 4 D, 13 FL	80 (60-144)
Sah (30)	2018	Retrospective	89		60 (12-144)	64 (30-91)	58	52 AE, 3 D, 34 FL	134 (12-420)
Sharkey (32)	1998	Retrospective	45		35 (24-79)	65 (32-85)	76	45 AE	44 (5-132)
Sierra (33)	2002	Prospective	132		85 (61-184)	73 (SD 10)	82	100 AE, 22 FL, 8 O, 2 PF	59 (SD 73)
Suominen (34)	1989	Retrospective	37		50 (SD 38)	69 (SD 10)	76	-	87 (SD 68)
Taheriazam (35)	2017	Prospective	138		42 (36-60)	64 (25-87)	35	72 AE, 12 D, 54 FL	-

AE: acetabular erosion, (c)THA: (converted) total hip arthroplasty, D: dislocation, FL: femoral loosening, O: other, PF: periprosthetic fracture

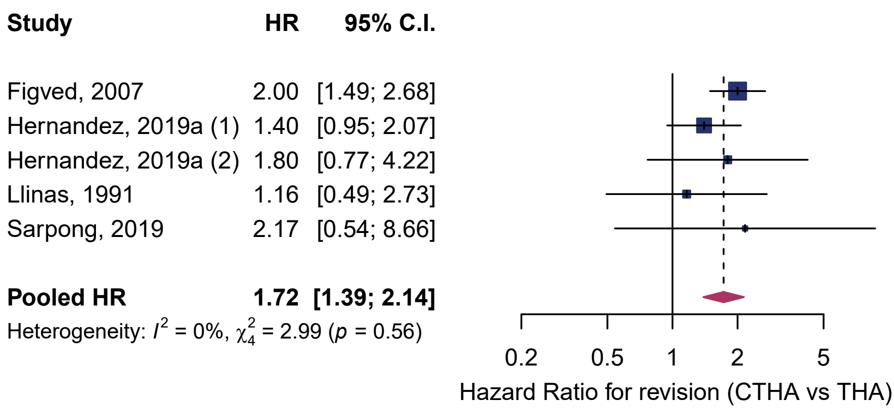

Figure 2 | Meta-analysis of overall revision risk of conversion THA (CTHA) versus primary THA.

Hernandez et al. presented results for two periods separately (1985-1999 and 2000-2014). HRs of both periods were included in this analysis. Hernandez et al. (1) Cohort operated between 1985-1999, Hernandez et al. (2) Cohort operated between 2000-2014
(c)THA: (converted) total hip arthroplasty, HR: Hazard Ratio, CI: confidence interval

Table 2 | Annual revision rates (ARR), infection rates and dislocation rates of comparative and cohort studies.

		CTHA				THA		
	Number of studies	N	Events	Outcome, % (95% CI)*	I2	Events	Outcome, % (95% CI)*	I2
Comparative								
Pooled ARR [19, 21, 24, 31]^	4	754	67	1.63 (1.14; 2.33)	70%	75755	0.95 (0.92; 0.98)	72%
Pooled infection rate [31]	1	60	1	0.59 (0.08; 4.05)	NA	0	0	NA
Pooled dislocation rate [31]	1	60	4	2.35 (0.67; 1.31)	NA	0	0	NA
CTHA Cohort								
Pooled ARR [10-15, 17, 18, 20, 22, 23, 25-30, 32-36]#	22	2265	154	1.40 (1.17; 1.66)	4%	-	-	-
Pooled infection rate [10-18, 20, 22, 23, 25-30, 32-36]	23	2311	68	4.34 (2.66; 7.01)	71%	-	-	-
Pooled dislocation rate [10-18, 20, 22, 23, 25-30, 32-36]	23	2311	96	4.79 (3.02; 7.53)	74%	-	-	-

*Outcomes are pooled based on random effect model with inverse variance weighting.
^ The ARR of Hernandez et al, was analysed with data from Hernandez (b)[37], a study with the same study population as Hernandez (a)[21].
#The ARR couldn't be analysed if no follow-up data were available[16].
ARR: Annual Revision Rate (revisions per 100 person years), (c)THA: (converted) total hip arthroplasty, CI: confidence interval, I2: Heterogeneity between studies.

Study	ARR (%)	95% C.I.
Comparative		
Figved,2007	1.82	[1.40; 2.36]
Hernandez,2019b	1.41	[1.07; 1.85]
Llinas,1991	0.82	[0.37; 1.81]
Sarpong,2019	3.53	[1.59; 7.63]
Pooled ARR	***1.63***	***[1.14; 2.33]***
Heterogeneity: I^2 = 64%, χ^2_3 = 8.29 (p = 0.04)		
Cohort		
Amstutz,1979	2.41	[0.78; 7.19]
Bayam,2019	1.51	[0.57; 3.95]
Bhosale,2012	0.56	[0.21; 1.49]
Bilgen,2000	0.00	[0.08; 16.72]
Carulli,2016	0.00	[0.03; 6.31]
Chalmers,2017	0.00	[0.06; 14.32]
Diwanji,2008	0.56	[0.08; 3.85]
Fichman,2015	2.78	[1.16; 6.49]
Hammad,2006	0.58	[0.08; 4.00]
Hoskins, 2021	1.41	[1.13; 1.76]
Huang,2019	0.00	[0.01; 2.69]
Kaku,2017	0.63	[0.16; 2.50]
Morsi,2016	1.12	[0.68; 1.85]
Mounsey,2015	2.45	[0.92; 6.34]
Nabil,2015	0.00	[0.02; 5.97]
Pankaj,2008	0.35	[0.05; 2.47]
Park,2018	0.34	[0.05; 2.36]
Sah,2018	2.02	[1.06; 3.84]
Sharkey,1998	1.52	[0.38; 5.89]
Sierra,2002	1.82	[1.13; 2.91]
Suominen,1989	1.30	[0.32; 5.04]
Taheriazam,2017	1.45	[0.69; 3.01]
Pooled ARR	***1.40***	***[1.17; 1.66]***
Heterogeneity: I^2 = 4%, χ^2_{21} = 21.84 (p = 0.41)		
Pooled ARR	***1.46***	***[1.24; 1.72]***
Heterogeneity: I^2 = 21%, χ^2_{25} = 31.51 (p = 0.17)		
Test for subgroup differences: p = 0.45		

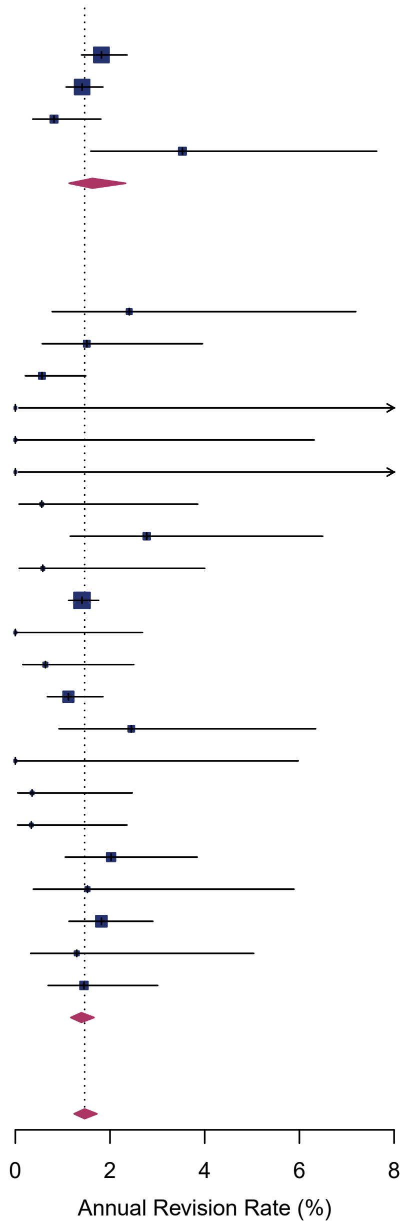

Figure 3 | Annual revision rate (ARR) of converted total hip arthroplasties (CTHA) of all studies.

(c)THA: (converted) total hip arthroplasty, CI: confidence interval
The ARR of Hernandez et al, was analysed with data from Hernandez (b)(37), a study with the same study population as Hernandez (a)(21).

Discussion

We performed a systematic review and meta-analysis of 27 studies to explore the results of conversion of hemiarthroplasty to total hip arthroplasty; four comparative studies concerning CTHA versus primary THA and 23 cohort studies concerning only CTHA were included. The primary finding of this study was a significantly higher overall revision risk (HR 1.72, 95% CI 1.39 to 2.14) after CTHA compared to primary THA. Furthermore, pooled analysis of the comparative and the cohort studies revealed an annual revision rate of 1.63% (95% CI 1.14 to 2.33) and 1.40% (95% CI 1.17 to 1.66) in patients treated with CTHA, respectively. The cohort studies showed a pooled infection and dislocation rate of 4.34% (95% CI 2.66 to 7.01) and 4.79% (95% CI 3.02 to 7.53), respectively. One of four comparative studies reported on complication risk and found an infection rate of 0.6% and a dislocation rate of 2.4% in the group with CTHA whereas no infection or dislocation occurred in the group with primary THA. The best treatment of displaced femoral neck fractures remains a controversial topic. No consensus is established whether to treat such fractures with HA or THA. Over the past decade, an increasing trend has been observed in the use of THA versus HA. However, this increasing trend does not correspond to the results of a recent high impact randomized controlled trial in which no difference was found in the incidence of secondary procedures between patients treated with HA or THA (3). Advocates of HA mention the association of THA with a higher risk of dislocation (3). Concurrently, concerns are raised regarding acetabular cartilage wear in HA caused by articulation with a metal head leading to CTHA. Results concerning CTHA can play an important role in this ongoing debate concerning treatment with HA or THA since small differences can influence the initial treatment of femoral neck fractures. Despite an extensive use of HA worldwide as a treatment for femoral neck fractures, less is known about the results of CTHA. This study revealed a significantly higher overall revision risk (HR 1.72, 95% CI 1.39 to 2.14) after CTHA versus primary THA. It is important to mention that only one of these four comparative studies included primary THA for femoral neck fractures whereas the other three studies included primary THA for osteoarthritis. One could argue that this has potentially influenced the results since primary THA for femoral neck fractures show a higher risk of revision in comparison to total hip arthroplasties for osteoarthritis (38). Nevertheless, a relatively high annual revision rate of 1.46% (95% confidence interval (CI) 1.24 to 1.72) in patients treated with CTHA found in a pooled analysis of all studies support the finding from the comparative studies. Though, the clinical dilemma regarding the best index treatment of femoral neck fractures is ongoing since literature shows a relatively low conversion risk of HA (39, 40). Furthermore, HA remains a viable option in the elderly patient as it is associated with less complex surgery with a shorter operation time (39). The initial choice of index treatment for femoral neck fractures with either HA or THA could potentially be influenced by the results of the current study since treatment with HA seems to affect the good results of THA in case HA needs conversion. This may help in weighing the balance in clinical decision making concerning the best index treatment in patients suffering from femoral neck fractures. A limitation of this review is the inclusion of mostly retrospective cohort studies. The quality of these studies was not errorless as reflected by the medium MINORS scores for cohort studies. Critical information concerning the index operation such as grade of osteoarthritis and type of fixation was not reported in the majority of the included studies. The presence of acetabular osteoarthritis at the time of index operation is important since these patients should rather be treated with total hip arthroplasty. Type of fixation is important since in older patients the use of uncemented stems show higher rates of revision in comparison to cemented stems (41). Despite that, the comparative studies appeared to be of high quality. Another limitation is the small number of patients included by the majority of studies since only five studies included over 100 patients (19, 21, 25, 33, 36). Furthermore, heterogeneity in duration of follow-up was encountered in the included studies ranging from 32 to 111 months. Therefore, sensitivity analysis was performed concerning heterogeneity in follow-up in the comparative studies and no relevant different results were found. Finally, this systematic review and meta-analysis included several studies published over 10 years ago. Since literature is scarce concerning CTHA, we think these studies are still valuable to this systematic review and meta-analysis.

Conclusions

In conclusion, this systematic review found that literature concerning the results of conversion of hemiarthroplasty is limited. A higher risk of revision after conversion of hemiarthroplasty compared to primary total hip arthroplasty was found. These results should be considered in the decision making process regarding the index treatment of femoral neck fractures with either hemiarthroplasty or total hip arthroplasty.

Author contributions

Conceptualization: Schmitz and Somford; Methodology: Schmitz and Somford; Formal analysis: Sierevelt; Writing: Schmitz; revision of writing and supervision: Van Susante and Somford.

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Supplementary Information

Supplementary data A | Search History.

Pubmed

Search	Query
#1	"Hemiarthroplasty"[Mesh] OR Hemiarthroplast*[tiab] OR Hemi-Arthroplast*[tiab]
#2	(Hip[tw] OR THA[tiab]) AND (Conversion*[tiab] OR revision*[tiab] OR failed*[tiab])
#3	#1 AND #2

Embase

No.	Query
#1	hip hemiarthroplasty/ OR Hemiarthroplast*.ti,ab,kw. OR Hemi-Arthroplast*.ti,ab,kw.
#2	((Hip.mp. OR replacement arthroplasty/ OR THA.ti,ab,kw.) AND (conversion* OR revision* OR failed*).ti,ab,kw.)
#3	#1 AND #2

Cochrane

ID	Search
#1	[mh "Hemiarthroplasty"] OR Hemiarthroplast*:ti,ab,kw OR Hemi-Arthroplast*:ti,ab,kw
#2	(([mh "Arthroplasty, Replacement, Hip"] OR hip:ti,ab,kw OR THA:ti,ab,kw) AND (revision* OR failed* OR Conversion*):ti,ab,kw)
#3	#1 AND #2

Supplementary data B | Quality assessment of the included studies using MINORS.

Author	A	B	C	D	E	F	G	H	I	J	K	L	Total
Comparative studies													
Figved	1	2	1	2	2	2	2	0	1	2	1	2	18
Hernandez	2	2	1	2	2	2	0	0	2	2	2	2	19
Llinas	1	2	0	2	0	2	1	0	2	2	0	2	14
Sarpong	2	2	0	2	2	2	2	0	1	2	2	2	19
Cohort studies													
Amstutz	1	2	2	1	0	2	2	0					10
Bayam	1	2	0	2	0	2	2	0					9
Bhosale	2	2	2	2	0	2	2	0					12
Bilgen	1	1	2	2	0	2	0	0					8
Carulli	1	2	1	2	0	2	2	0					10
Chalmers	2	2	1	2	0	2	2	1					12
Cossey	1	2	0	2	0	0	2	0					7
Diwanji	2	1	0	2	1	2	2	0					10
Fichman	2	2	1	2	0	2	2	0					11
Hammad	1	2	0	2	0	2	2	0					9
Hoskins	2	1	1	2	0	2	2	0					10
Huang	1	2	2	2	2	2	1	0					12
Kaku	1	2	0	2	0	2	2	0					9
Morsi	1	2	0	2	0	2	2	0					9
Mounsey	1	2	2	2	0	2	1	0					10
Nabil	2	2	2	2	0	2	2	0					12
Pankaj	2	2	2	2	0	2	1	0					11
Park	2	2	0	2	0	2	2	0					10
Sah	2	2	0	2	0	2	1	0					9
Sharkey	1	2	0	2	2	2	1	0					10
Sierra	1	2	2	2	0	2	1	0					10
Suominen	1	2	1	2	0	2	1	0					9
Taheriazam	1	2	2	2	0	2	1	0					10

The items are scored 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate). The global ideal score being 16 for non-comparative studies and 24 for comparative studies.

A. A clearly stated aim: the question addressed should be precise and relevant in the light of available literature.
B. Inclusion of consecutive patients: all patients potentially fit for inclusion (satisfying the criteria for inclusion) have been included in the study during the study period (no exclusion or details about the reasons for exclusion).

C. Prospective collection of data: data were collected according to a protocol established before the beginning of the study.
D. Endpoints appropriate to the aim of the study: unambiguous explanation of the criteria used to evaluate the main outcome which should be in accordance with the question addressed by the study. Also, the endpoints should be assessed on an intention-to-treat basis.
E. Unbiased assessment of the study endpoint: blind evaluation of objective endpoints and double-blind evaluation of subjective endpoints. Otherwise the reasons for not blinding should be stated.
F. Follow-up period appropriate to the aim of the study: the follow-up should be sufficiently long to allow the assessment of the main endpoint and possible adverse events.
G. Loss to follow up less than 5%: all patients should be included in the follow up. Otherwise, the proportion lost to follow up should not exceed the proportion experiencing the major endpoint.
H. Prospective calculation of the study size: information of the size of detectable difference of interest with a calculation of 95% confidence interval, according to the expected incidence of the outcome event, and information about the level for statistical significance and estimates of power when comparing the outcomes.

Additional criteria in the case of comparative study
I. An adequate control group: having a gold standard diagnostic test or therapeutic intervention recognized as the optimal intervention according to the available published data.
J. Contemporary groups: control and studied group should be managed during the same time period (no historical comparison).
K. Baseline equivalence of groups: the groups should be similar regarding the criteria other than the studied endpoints. Absence of confounding factors that could bias the interpretation of the results.
L. Adequate statistical analyses: whether the statistics were in accordance with the type of study with calculation of confidence intervals or relative risk.

CHAPTER 3

Low conversion rates toward total hip arthroplasty after hemiarthroplasty in patients under 75 years of age

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Abstract

Introduction

An intracapsular fracture of the femoral neck is frequent in the elderly. Patients can be treated with either total hip arthroplasty or hemiarthroplasty. There is a continuous discussion about the treatment in elderly patients who are still healthy, active and mentally untroubled. A potential consequence of hemiarthroplasty, especially in the relatively young elderly, could be conversion to total hip arthroplasty. The conversion rate must be acceptable, and clinical outcome must be sufficient to justify the treatment with hemiarthroplasty in this group of patients. This study evaluates the conversion rate of hemiarthroplasty to total hip arthroplasty and clinical outcome in patients under 75 years of age.

Methods

This study identified 248 patients, younger than 75 years at time of operation, with a fracture of the femoral neck treated with hemiarthroplasty. Patient-reported outcome measurements (VAS pain during rest and activity and WOMAC) were assessed by telephone interviews. Furthermore, radiographic evaluation for the presence of acetabular wear was performed.

Results

At a follow-up of 5.1 (0.9–9.6) years, the conversion rate was 7.3%. Mean VAS pain in rest was 0.89 (0–10), the mean VAS pain during activity was 2.2 (0–10), and the WOMAC showed a mean of 16.51 (0–64). At time of follow-up, 38.7% of patients had died. Radiographic evaluation of the unrevised group showed in one patient signs of acetabulum wear.

Conclusions

Hemiarthroplasty in the relatively young elderly after a fracture of the femoral neck demonstrates an acceptable conversion rate. Furthermore, unrevised patients show low complaints of pain. To prevent one conversion to total hip arthroplasty, 13.7 patients should be treated with total hip arthroplasty that will not undergo a conversion at a later stage. Therefore, hemiarthroplasty remains a viable treatment of femoral neck fractures in relatively young patients. There seems to be no space for standardized decision making concerning the choice of treatment. An individual approach is required.

Introduction

An intracapsular fracture of the femoral neck frequently occurs in the elderly. A fracture of the femoral neck can be treated with internal fixation, hemiarthroplasty or total hip prosthesis. The type of treatment depends on different factors such as, but not limited to, the patient's age, the level of cognitive function, the degree of fracture displacement, the degree of physical fitness and the functional state of the patients. All treatments have certain advantages and disadvantages, and therefore, all target groups require a specific treatment (1-6). Internal fixation is used in young healthy patients with a fracture that is not displaced (3). Total hip arthroplasty is often used in patients with a fracture of the femoral neck in combination with osteoarthritis or rheumatoid arthritis (3). Finally, hemiarthroplasty is commonly used in fragile elderly with low functional demands, who do not suffer from rheumatoid arthritis or osteoarthritis of the hip (3, 7). Advantages of hemiarthroplasty compared to total hip replacement are decreases in surgery complexity, blood loss, operation time and chance of dislocation (2, 4, 6, 8-10). Protrusion of the femoral prosthesis into the acetabulum over time is a potential disadvantage of hemiarthroplasty (2, 4-6, 8, 11-13). Pressure and movement of the head of the prosthesis into the acetabulum can cause damage of the cartilage of the acetabulum. This acetabular wear can cause complaints of pain. A potential consequence of hemiarthroplasty is therefore the need for a conversion to total hip arthroplasty over time. Only a few articles investigated the results of hemiarthroplasty in patients younger than 75 years (1, 8, 13, 14). These studies show variable conversion rates. Of course, the conversion rate must be acceptable to justify the treatment of hemiarthroplasty in this group of patients. In this paper, we evaluate the conversion rate after hemiarthroplasty when placed in relatively young patients (75 years) over time. Furthermore, patient-reported outcome measurements (PROM's) are evaluated.

Methods

For this retrospective cohort study, we identified all patients younger than 75 years, treated in our institution, between June 2008 and December 2017 with monopolar hemiarthroplasty of the hip, due to a displaced intracapsular fracture of the femoral neck. Patients were treated with cemented hemiarthroplasty through a posterolateral approach. As a start, we screened the medical files of all patients. We searched for patient characteristics, presence of revision and reason for revision. We calculated the conversion rate as the percentage of revised patients of the total number of patients. Patients with a fracture caused by an oncological origin were excluded. Approval from the local ethics committee was obtained (2018-1175).

PROM's

Patients who were still alive and unrevised were contacted by phone and were asked to complete questionnaires. These consisted of a visual analogue scale (VAS) for pain in rest and during activity (15, 16) and the validated Dutch version of the Western Ontario McMaster

Universities osteoarthritis index (WOMAC) (17, 18). Patients were asked whether a revision of their hemiarthroplasty in another hospital had taken place and about their current living situation as well. Questionnaires by regular mail were sent to patients who were not able to answer telephone interviews. Patients with severe mental disorders were thought not to be eligible for telephone interviews because of the chance of unreliable results.

Radiographic evaluation

The most recent pelvic radiographic images available were used to evaluate the presence of acetabular wear. The radiographic follow-up was the time from operation to the date of the most recent image. There was no standardized follow-up sequence of this type of surgery. According to Baker et al., the images were scored as: normal, no erosion (grade 0), no bone erosion (grade 1), acetabular bone erosion and early migration (grade 2) and protrusion acetabuli (grade 3). Pre-operative images were scored as well.

Statistical analysis

The statistical analysis was performed with SPPS 24.0 (SPSS Inc. Chicago, IL). The variables were examined for normal distribution by means of the Shapiro–Wilk test. Statistical significance is set at $p<0.05$. The analysis took paired data into account.

Results

We identified 248 patients with a fracture of the femoral neck younger than 75 years, treated with hemiarthroplasty. At the time of operation, the mean age of the patients (23.8% men) was 70.5 (54.3–74.9) years. After a mean follow-up of 5.1 years (range 0.9–9.6), 18 of 248 (7.3%) patients were converted to a total hip arthroplasty after a mean of 1.6 (0–6.5) years. Among the revised patients, one patient was deceased. At the time of follow-up, 96 of 248 (38.7%) patients had died. Among those patients, the cumulative incidence of death was 47.9% at 1 year, 56.3% at 2 years, 68.8% at 3 years and 86.5% at 5 years. After 81 months, 100% of these 96 patients were deceased. Furthermore, 28 patients were not eligible for telephone interviews due to severe mental disorders and two patients were not approached due to severe physical disorders (**Figure 1**). This has resulted in a group of 105 patients who were contacted by phone. As shown in **Figure 1**, a total of 81 patients responded (response rate 77%). No additional responses came after sending questionnaires by regular mail. At the time of follow-up, an independent living situation was reported in 85% of the patients, a home for elderly in 10% and a nursing home in 5%.

PROM's

The mean VAS pain in rest and during activity was 0.89 (range 0–10, SD = 2.1) and 2.2 (range 0–10, SD = 2.8), respectively. The WOMAC showed a mean of 16.51 (range 0–64, SD =15.62) (**Table 1**). The radiographic evaluation according to Baker et al. after a mean follow-up of 1.5 years (range 0–10) showed in 78 patients a score of 0, in 1 patient a score of 1 and no patients scored 2 or 3. The patient with a score of 1 scored a 0 on the preoperative X-ray.

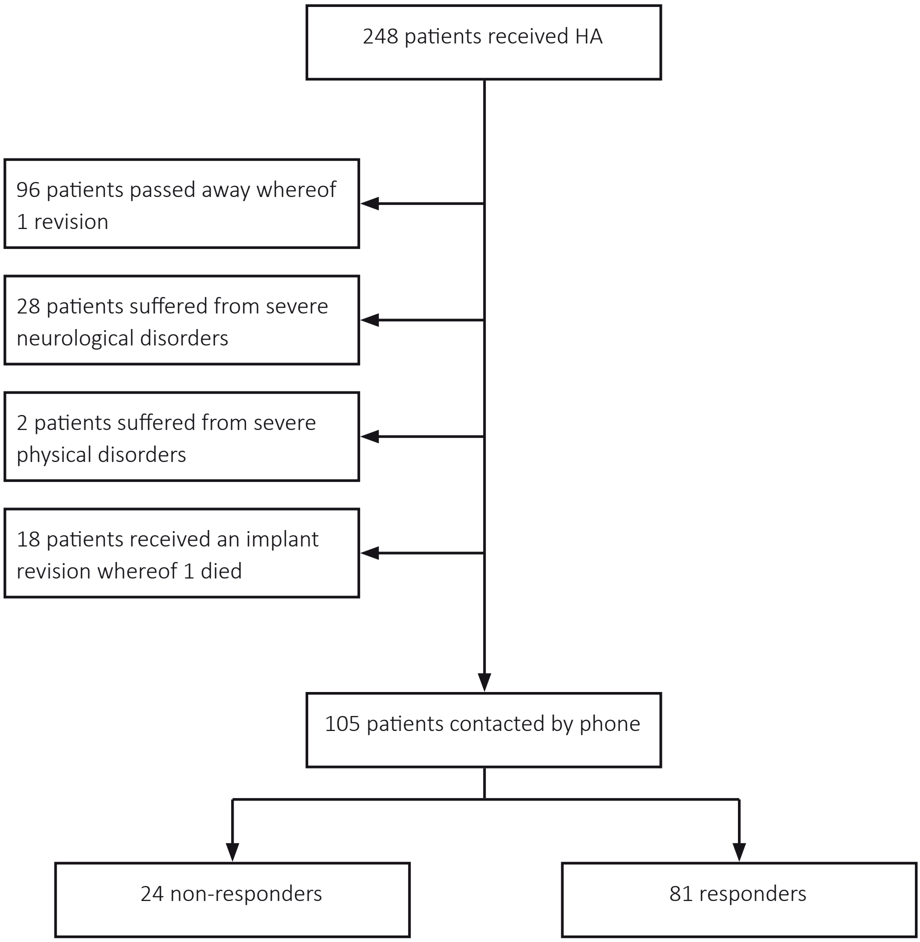

Figure 1 | Flowchart inclusion.

Table 1 | Clinical outcome scores.

	Follow-up mean (st. deviation)
VAS pain rest	0.89 (2.1)
VAS pain activity	2.2 (2.8)
WOMAC pain	2.17 (3.5)
WOMAC stiffness	0.91 (1.8)
WOMAC functioning	13.42 (12.1)
WOMAC total	16.51 (15.6)

Table 2 | Revision.

	Revision (% of total amount of revisons)
Acetabulum wear	5/248 (2.0%)
Pain without abnormalities x-ray	9/248 (3.6%)
Dislocation	3/248 (1.2%)
Deep infection	1/248 (0.4%)
Superficial infection	0/248 (0%)
Periprosthetic fracture	0/248 (0%)
Total	18/248 (7.3%)

Conversion

In total, 18 of the 248 patients (7.3%) were converted to total hip arthroplasty, of which one patient was deceased at time of follow-up. Among those patients, four conversions to total hip arthroplasty had taken place in another hospital. With this conversion rate, the number needed to treat is 13.7. Reason for conversion was in 14 (5.6%) patients suspected wear of the acetabulum and pain (Table 2). When scoring the last X-rays before conversion according to Baker et al., in only five (2.0%) patients acetabular wear was found: a score of 1 in three patients and a score of 2 in two patients. Thus, in nine (3.6%) patients the implant was revised due to complaints of pain without any abnormality seen on the X-rays. Besides, two patients were converted because of a dislocation and one patient was revised due to a deep infection.

Complications

The overall complication rate was 13/248 (5.2%): 6 dislocations, 5 deep infections, 1 superficial infection and 1 periprosthetic fracture. Among the unrevised, in four patients a deep infection had occurred, in one patient a superficial infection, in three patients a dislocation and one patient had suffered from a periprosthetic fracture.

Discussion

Conversion rate

In this cohort study concerning hemiarthroplasty after femoral neck fractures in relatively young patients (75 years), we found a conversion rate of 7.3% after a mean follow-up of 5.1 years. Reason for revision was in three patients a dislocation and in one patient an infection. After correction for infection and dislocation, reason for conversion was in 5.6% suspected wear of the acetabulum. Correction is justified, since dislocations are more common in total hip arthroplasty compared to hemiarthroplasty (2, 4, 5, 10, 19). There is no consensus on the best treatment in patients with femoral neck fractures younger than 75 years and research is scarce (4, 19). In comparison with the few published reports, our conversion rate of 7.3% is relatively low. Murena et al. described 137 patients with hemiarthroplasty under the age of 70 with a mean follow-up of 20 years (8). At follow-up, the conversion rate was 12/37 (32%) which was only measured in living patients. Van den Bekerom et al. followed 302 patients until conversion or death (13). The conversion rate was 38% in patients younger than 75 years compared to 6% in patients older than 75 years. The study did not mention the total amount of patients younger than 75 years of age. The higher revision rates of Murena and Van den Bekerom can be explained by the long follow-up and the low survival rates. Kannan et al. studied arthroplasty in femoral neck fractures in national registries of Sweden, Australia and Italy (1). Conversion rates, in the group of patients under 75 years of age, were 8.1%, 17.4% and 8.1% with a mean follow-up of 5, 7 and 9 years, respectively. Furthermore, Grosso et al. described a study with 686 patients after hemiarthroplasty with a mean follow-up of 1.9 years (14). The conversion rate in patients younger than 75 years old was 5.3% compared to 1.4% in the older cohort. A conversion rate of 7.3% shows a high number needed to treat. Hence, 13.7 patients should be treated to prevent one conversion to total hip arthroplasty. Furthermore, the unrevised patients show a mean VAS pain in rest of 0.87 (0–10) and a mean VAS pain during activity of 2.14 (0–10). The acceptable conversion rate of this study together with low scores of pain demonstrates that hemiarthroplasty remains a viable treatment option in the young elderly with femoral neck fractures.

Acetabular erosion

A major disadvantage of hemiarthroplasty in young patients in particular is wear of the acetabulum (2, 4-6, 8, 11-13). In this study, in only 5/18 revised hips X-ray showed signs of acetabular wear (in three patients Baker 1 and two patients Baker 2). Furthermore, nine patients were converted due to suspected wear of the acetabulum without any abnormality seen on the X-rays. These results suggest that the correlation between clinical and radiographic signs of acetabular wear seems to be low.

3

Periprosthetic fracture

In this study, only one of the 248 patients (0.4%) suffered from a periprosthetic fracture. In a Dutch register study, Moerman et al. described a periprosthetic fracture in 52/183 (28%) of uncemented hemiarthroplasties compared to 5/243 (2%) of cemented hemiarthroplasties (20). Grosso et al. found a significantly lower rate of periprosthetic fractures in the cemented implant group (0.4 vs 3.5%, p value 0.02) as well (14). Since all patients in our study are treated with a cemented fixation of the hemiarthroplasty, the low amount of periprosthetic fractures is therefore probably explained.

Limitations

There are a number of limitations to our study and still important lessons can be learnt. First, this study has a retrospective aspect and no standardized follow-up sequence is used. Next, the choice of treatment at the time of injury could be influenced by the characteristics and comorbidities of the patients. Despite this, we probably studied a healthy group of patients, since 61.3% of patients are still alive and 85% of patients still live independently. Furthermore, the radiographic follow-up is relatively short. However, apparently the patients did not visit our department with complaints of their hip anymore. Another limitation of this study is the response rate of 77% since there is a possibility that the non-responded patients show better results of the PROM's. Nevertheless, there is no reason for this motivation because only three non-responders showed signs of acetabular wear (Baker 0: 24 patients, Baker 1: 2 patients, Baker 2: 1 patient).

Conclusion

This study provides important lessons that can be used in the process of decision making between total hip arthroplasty and hemiarthroplasty in relatively young elderly with femoral neck fractures. The conversion rate of 7.3% found in this study is acceptable, and the unrevised patients show low complaints of pain. Therefore, it is concluded that hemiarthroplasty remains a viable treatment of femoral neck fractures in relatively young patients. There seems to be no space for standardized decision making concerning the choice of treatment. Hence, an individual approach is needed.

Compliance with ethical standards

Conflict of interest

All authors declare that they have no conflict of interest.

Ethical statement

The procedures followed were in accordance with the ethical standards of the institutional and/or research committee and with the 1964 Helsinki Declaration and its later amendments.

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CHAPTER 4

The (un)necessity of regular postoperative follow-up of hemiarthroplasty for femoral neck fractures

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Injury, 2021

Abstract

Introduction

Postoperative follow-up after hemiarthroplasty is part of routine based practice. However, these visits appear to be a significant burden since it concerns a frail population. The aim of this study was to confirm the current common practice regarding postoperative visits of patients treated with hemiarthroplasty and to evaluate the complication detection rate at these visits.

Methods

A national short survey was conducted among orthopedic surgeons working in 26 large Dutch teaching hospitals to test the hypothesis that postoperative follow-up is indeed common practice. Furthermore, a retrospective patient review was performed in all hemiarthroplasties implanted between January 2014 and December 2019.

Results

The response of the national survey was complete and showed that postoperative follow-up in patients treated with hemiarthroplasty is part of standard care according to 89% of respondents. A total of 1055 hips (1026 patients) were implanted with hemiarthroplasty during the studied period. Implantrelated complications were identified in 68 hemiarthroplasties, with 31 of these hips going on to reoperation. Only 2 of these complications were picked up at standard planned follow-up leading to a complication detection rate of 0.3%. In contrast, complication detection rates of 47% and 16% were found at unplanned visits at the Emergency Department and the outpatient department, respectively.

Conclusions

Postoperative follow-up in patients treated with hemiarthroplasty is still the standard of care. However, this study revealed that the majority of implant-related complications are detected at unplanned visits and almost no at standard follow-up visits. Postoperative follow-up of patients treated with hemiarthroplasty could be abandoned in this frail population.

Introduction

Annually, 1 to 2 million of patients are suffering from hip fractures worldwide and the incidence is predicted to rise to 4.5 million in 2050 (1, 2). An intracapsular femoral neck fracture is one of the most common types of hip fracture and in older adults this type is commonly treated with hemiarthroplasty. Complications after hemiarthroplasty occur in up to 16.3% of patients (3) of which the most common are dislocation, infection and periprosthetic fracture (4). To monitor the development of complications following hemiarthroplasty, these patients are usually planned to visit the outpatient department postoperatively. In the absence of specific evidence-based guidelines these postoperative follow-up visits are part of commonly accepted routine practice based on local postoperative care protocols and orthopedic surgeons' experiences. One could argue that postoperative follow-up visits in patients treated with hemiarthroplasty are not useful because there is only a small chance that these acute complications are detected during such visits. In addition, these postoperative visits appear to be a significant burden to the usually frail patients as well as to their caregivers (5). Due to the high incidence of patients treated with hemiarthroplasty, these postoperative visits are a high burden to the outpatient department as well. Because of the aforementioned reasons, the usefulness of postoperative visits in patients treated with hemiarthroplasty is questionable. The issue regarding usefulness of postoperative visits has also been questioned in other surgical procedures. For example postoperative follow-up visits of patients with a trochanteric fracture treated with an intramedullary nail did not lead to treatment changes (6, 7). Besides that, the usefulness of routine follow-up of patients treated with total hip arthroplasty has also extensively been debated and is still questionable (8). In a recent study regarding routine visits in patients treated with total hip arthroplasty, only 2.5% of complications necessitating revision surgery were picked up during these routine visits while self-referral of patients to the orthopedic department appeared to be the most important route of referral (9). Due to the ongoing debate regarding the usefulness of routine postoperative visits in total hip arthroplasty, one could argue that the usefulness of postoperative visits in patients treated with hemiarthroplasty is even more questionable since it concerns a frail population. However, evidence regarding the usefulness of postoperative follow-up in these patients is lacking. The aim of this study was to explore the current common practice regarding postoperative visits of patients treated with hemiarthroplasty and to evaluate the detection rate of implant-related complications identified during these planned postoperative visits.

Methods

In this study we conducted a short survey and a retrospective patient chart review. The study was approved by the Local Research Ethics Committee (2020-1672).

National short survey

A national short survey was conducted to explore the current common practice regarding postoperative visits of patients treated with hemiarthroplasty. The survey was sent by email to 26 orthopedic surgeons affiliated to all 26 large non-academic teaching hospitals, united in the Organization for Topclinical Hospitals (STZ) in the Netherlands. The two survey-items used categorical responses and were developed for this study to collect information about the frequency and timing of postoperative follow-up visits.

Retrospective patient review

The electronic patient charts of all patients who received a cemented hemiarthroplasty (Original M.E. Muller Straight Stem, Unipolar, Zimmer, Winterthur, Switzerland) following a femoral neck fracture between January 2014 and December 2019 were screened. Patients with a history of a previous operation of the ipsilateral hip and patients with a fracture caused by metastatic disease were excluded. From each eligible patient characteristics regarding age, gender, American Society of Anesthesiologists (ASA) score and cognitive status were collected. Cognitive status was judged by a geriatrician within three months postoperatively and categorized as undisturbed, mild cognitive impairment or severe cognitive impairment (dementia).

All postoperative visits were categorized by one of four types of consultation: standard planned outpatient visit, unplanned outpatient visit, unplanned visit at the Emergency Department (ED) or inpatient visit. The latter was defined as a 'visit' during the initial admission in hospital after treatment with hemiarthroplasty. In accordance with our hospital's current postoperative care protocol only one postoperative visit at the outpatient department was planned for all patients treated with hemiarthroplasty. All medical notes reported during these different types of postoperative visits as well those noted during the patients' admission in hospital were reviewed for information about the three most common implantrelated complications. The latter were categorized as infection, dislocation and periprosthetic fracture.

Statistical analysis

The orthopedic surgeons' responses to the survey questions were expressed in frequencies and as a percentage of the total number of responses. Patient characteristics were presented descriptively in terms of medians (range) and frequencies (percentage of total). The number and type of complications identified per type of consultation were also expressed in frequencies (percentage of total). The complication detection rate per type of consultation, defined as the chance of detecting any of the reviewed complications during a single visit to either the outpatient department (planned or unplanned) or the ED, was calculated by dividing the number of complications detected during these different types of consultation by the total number of follow-up visits of this type of consultation and multiplied by 100. All data were summarized using descriptive statistics (performed in SPSS Statistics for Windows, Version 22.0; IBM Corp, Armonk, NY).

Results

National short survey

All 26 orthopedic surgeons who were approached for participation in the survey completed both questions. The responses of this survey are presented in **Table 1**. The majority of respondents (89%) reported that postoperative follow-up in patients treated with hemiarthroplasty is part of standard care. The respondents further indicated that according to local protocols, patients were invited for a first postoperative follow-up at the outpatient departments after an average of 6 weeks.

Table 1 | Response frequencies regarding the survey questions.

Survey item	Response frequencies (%) 26 = 100%
Frequency of postoperative planned follow-up?	
No visits	3 (11%)
1 visit	13 (50%)
2 visits	9 (35%)
3 or more visits	1 (4%)
Mean (range) timing of postoperative planned follow-up?	
No visits	N/A
First visit (weeks)	6 (2-12)
Second visit (weeks)	30 (6-52)
Third or more visits (weeks)	12 (12-12)

Retrospective patient review

A total of 1055 hemiarthroplasty surgeries were carried out in 1026 patients. Characteristics of all hemiarthroplasty cases are shown in **Table 2**. For 710 (67%) of the total amount of hemiarthroplasty cases a first post-operative follow-up visit was actually planned. So, in 33% of patients the current hospital's protocol was not followed. In this group of hemiarthroplasty cases that did not receive an invitation for a follow-up, 68% were suffering from dementia or mild cognitive impairment. The first planned follow-up was visited in 602/710 (85%) of the hemiarthroplasty cases. Subsequently, 56/602 (9%) and 22/56 (39%) were planned for a second visit and three or more visits, respectively. From the charts of 67 (6%) hemiarthroplasty cases a total of 68 implant-related complications were identified. These were 35 cases of single or recurrent dislocations, 26 infections and 7 periprosthetic fractures. These complications led to 31 reoperations, consisting of 20 infections, 9 dislocations and 2 periprosthetic fractures, which took place at a median of 17 (range 5-1310) days after the initial surgery. The characteristics of the 68 hemiarthroplasty cases resulting in a complication are also shown in **Table 2**. Three percent (n = 2) of all identified complications were diagnosed during a planned follow-up visit at the outpatient department, 13% (n = 9) during unplanned visits to the outpatient department, and 57% (n = 39) during a visit to the ED. Furthermore 27% (n = 18) of all identified complications were diagnosed while the patient was still admitted in hospital. The complication detection rate for planned outpatient visits was 0.3% compared to complication detection rates of 47% for unplanned visits at the ED and 16% for unplanned visits to the outpatient department, as shown in **Table 3**. The number of complications identified per type of consultation are presented in **Figure 1**.

Table 2 | Patient characteristics based on all hemiarthroplasty surgery cases.

Characteristic	Total N=1055* (%)	Cases with complications N=68 (%)
Follow-up interval in months, median (range)	23 (0-78)	22 (0-76)
Gender, female (%)	719 (68.2%)	45 (66.2%)
Age, median (range)	83 (53-100)	83.5 (55-99)
ASA- 1	21 (2.0%)	2 (2.9%)
ASA- 2	319 (30.2%)	17 (25.0%)
ASA- 3	569 (53.9%)	41 (60.3%)
ASA- 4	146 (13.9%)	8 (11.8%)
Cognitive status		
Undisturbed	596 (56.5%)	33 (48.5%)
Mild cognitive impairment	193 (18.3%)	11 (16.2%)
Severe cognitive impairment (dementia)	266 (25.2%)	24 (35.3%)
Length of stay in days, median (range)	8 (1-52)	8 (2-48)

HA, hemiarthroplasty; ASA, American Society of Anesthesiologists score
Values are frequencies (%) unless stated otherwise.
**Of the 1026 patients, 29 received two arthroplasties (left and right hip), resulting in a total of 1055 arthroplasty cases. The values of all characteristics are based on this total number of cases.*

Table 3 | *Frequency (%) of complications identified and complication detection rate (defined as the chance of detecting any of the reviewed complications during a single visit) per type of consultation.*

Type of consultation	Frequency (%) of complications	Total number of follow-up visits	Complication detection rate (%)	Type of complication
Planned outpatient	2 (2.9%)	602	2/602 (0.3%)	1 infection, 1 dislocation
Unplanned outpatient	9 (13.2%)	58	9/58 (16%)	7 infections, 1 dislocation, 1 periprosthetic fracture
ED	39 (57.4%)	83	39/83 (47%)	10 infections, 25 dislocations, 4 periprosthetic fractures
Inpatient	18 (26.5%)	-	-	

ED, Emergency department

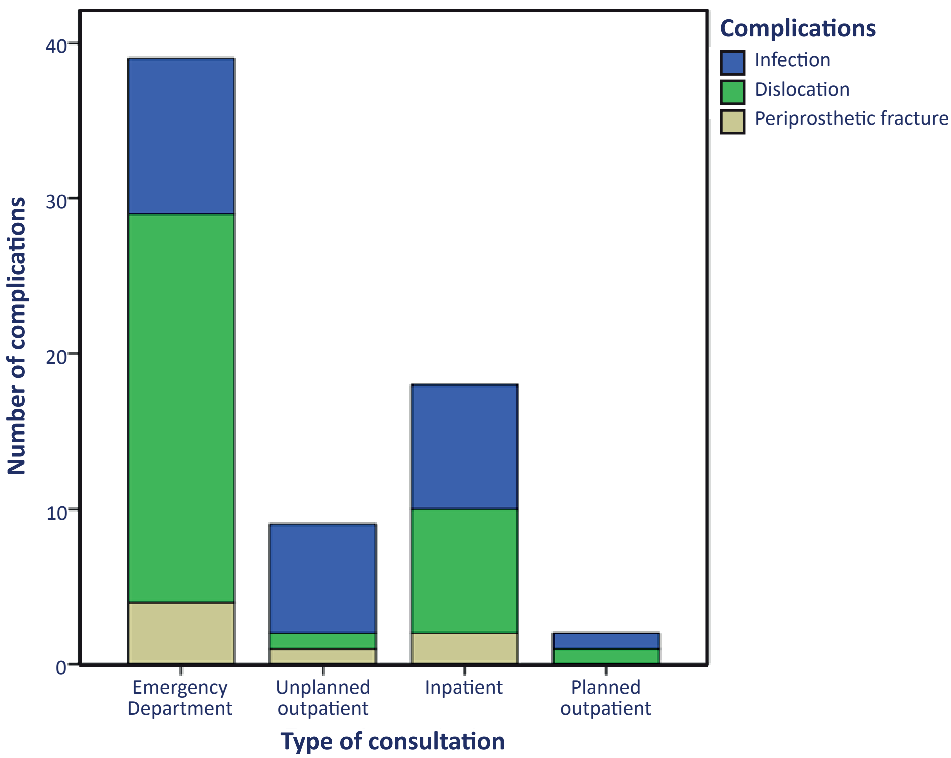

Figure 1 | Number of complications identified per type of consultation.

Discussion

The results of this study have confirmed that postoperative follow-up of patients treated with hemiarthroplasty after a femoral neck fracture is indeed standard of protocolized care in the vast majority of hospitals. Despite the fact that our local hospital's care protocol prescribes to plan a follow-up visit 10 weeks postoperatively, for only 67% of hemiarthroplasty cases this follow-up visit was actually planned. Sixty-eight percent of patients who were not planned for postoperative follow-up suffered from cognitive impairments. Besides that, during only 0.3% of postoperative planned visits an implant-related complication was detected whereas complication detection rates of 47% and 16% were found for unplanned visits at the ED and for unplanned visits at the outpatient department, respectively. The necessity of routine postoperative follow-up has been studied in other surgical procedures previously. For example, conducting routine follow-up has been shown to be unnecessary in patients treated with internal fixation after trochanteric fractures (6, 7). In case of hemiarthroplasties, one could argue that postoperative follow-up after hemiarthroplasty is even less relevant since important potential technical complications of internal fixation such as cut-out, implant migration and poor fracture healing do not occur after hemiarthroplasty. Secondly, routine follow-up after primary total hip arthroplasty is also still extensively debated (8-10). The reason for routine follow-up in patients treated with total hip arthroplasty is to detect asymptomatic patients who might benefit from early revision to prevent failure due to polyethylene wear or osteolysis (8, 9). However, these complications are hardly ever detected during routine visits (9). In fact, the most common route of referral among patients with revised total hip arthroplasties is by self-referral (9). The current study found that most complications following hemiarthroplasty were diagnosed during unplanned visits as well. Remarkably, although no literature is available regarding the usefulness of postoperative follow-up in the frail group of patients treated with hemiarthroplasty, postoperative follow-up is still widely performed according to the national survey presented in this study. Next to this a retrospective study found a similar (8%) complication rate as the current study in patients treated with hemiarthroplasty in the absence of postoperative follow-up (11). Apparently, the complications appear independently of the use of routine in-person follow-up. Patients treated with hemiarthroplasty appeared to be fragile, since 33% were not able to visit the outpatient department and 68% of these patients suffered from cognitive impairment which underlines the need to critically assess the usefulness of postoperative follow-up. Visitation of the outpatient department is a high burden to these frail older patients and their relatives. Postoperative follow-up of patients treated with hemiarthroplasty seems to be an unnecessary burden to patients since almost no treatment changes are performed during these visits. This study is not without limitations. Firstly, the results may be influenced by patients who may have been presented to other hospitals. Secondly, the selection of Dutch hospitals that participated in the national survey may have introduced selection bias, although these hospitals are united in the Organization for Topclinical Hospitals (STZ) which represents most large non-academic hospitals in the Netherlands. The strength of study is the large group of patients treated with hemiarthroplasty after a femoral neck fracture. Furthermore, to the best of our knowledge this is the first study regarding the necessity of postoperative follow-up in patients treated with hemiarthroplasty. The complication detection rate of 0.3% of planned visits found in this study emphasizes the need to consider alternative follow-up methods for patients treated with hemiarthroplasty after femoral neck fractures. For example, research has shown that patients treated with total hip arthroplasty are satisfied with web-based follow-up (12). However, the frail population of patients treated with hemiarthroplasty may struggle with such a digital alternative. The results of the current study have prompted a care protocol modifcation in our institution whereby postoperative follow-up will now be conducted by phone. Future prospective research is warranted to determine the effect of the introduction of this new follow-up method on patients' and their relatives' satisfaction.

In conclusion, postoperative follow-up of hemiarthroplasty is still the standard of care according to a short national survey despite of a low detection rate of implant-related complications. Postoperative follow-up of patients treated with hemiarthroplasty could be abandoned and alternative follow-up methods need to be studied to improve postoperative care of this frail population.

Declaration of Competing interest

This form concerning conflict of interest is written by the corresponding author, on behalf of all authors. The authors have nothing to declare which will be disclosed in the following:

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Part 2:
Hip arthroplasty versus internal fixation

CHAPTER 5

Complications and survival of conversion to total hip arthroplasty after failed primary osteosynthesis compared to primary total hip arthroplasty in femoral neck fractures

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Injury, 2022

Abstract

Introduction

Surgical treatment options for patients with an intracapsular fracture of the femoral neck (FFN) are primary osteosynthesis as a femoral head-spearing technique or primary (hemi) arthroplasty. The most common complications after primary osteosynthesis, such as avascular necrosis (AVN) or non-union, can result in conversion to Total Hip Arthroplasty (cTHA). Data concerning complications and survival rates of cTHA in comparison to primary Total Hip Arthroplasty (pTHA) after FFN are limited due to the absence of well-designed studies.

Methods

A multicentre retrospective cohort study was conducted in three Dutch hospitals comparing the rate of postoperative dislocations, periprosthetic fractures, prosthetic joint infections, blood loss during surgery (>1000 mL), postoperative cardiac- and pulmonary complications after pTHA and cTHA in the first year after surgery. As a secondary outcome implant survival of pTHA and cTHA in terms of revision rates was evaluated.

Results

In total 548 patients were included (pTHA n = 264 and cTHA n = 284) with a mean follow-up of 5 years (±3.5 SD). No significant differences were found in postoperative complications rates. The revision rate in the pTHA group was 7.2% in comparison to 7.7% in the cTHA group ($p = 0.81$). No difference in the short-term implant survival was found between both groups ($p = 0.81$).

Conclusions

This study showed no significant differences in terms of postoperative complication rates in the first year after pTHA and cTHA in patients with FFN. Also, no significant difference in short-term implant survival of primary and conversion total hip arthroplasty was found.

Introduction

Fractures of the femoral neck (FFN) are a major public health concern that frequently requires surgical intervention in order to stabilize the fracture (1-5). Primary Total Hip Arthroplasty (pTHA) is recommended in vital elderly (i.e. >70 years) suffering from a dislocated FFN combined with a pre-existent osteoarthritis (OA) of the hip joint (3, 6). In contrast, relatively younger patients (i.e. <70 years), especially those with a nondisplaced FFN without signs of pre-existent OA, are treated with primary osteosynthesis. For example, fractures in this group of patients can be treated with a Dynamic Hip Screw (DHS) or multiple (cannulated) screw (MCS) fixation (**Figure 1**) (5, 7). Failure of these types of internal fixation is not uncommon and hence revision surgery is needed more frequently after this type of treatment compared to after primary arthroplasty (8). Failure of primary osteosynthesis is mainly caused by avascular necrosis (AVN), non-union, mal-union, infection and development of posttraumatic OA, resulting in pain or functional disabilities (1, 4, 5, 9-13). Fixation of a FFN with a DHS or MCS fails in 5.3% and 13% of the cases, respectively (7). Failure of primary osteosynthesis occurs frequently in the first year, mostly due to AVN, non-union or pain (1, 5, 14). For instance, AVN is present in 6-32% of the nondisplaced FFNs and non-union in 6.4-39% (1, 15, 16). The reported average time of these complications occurring after fracture and fixation failure is between 5 to 32 months (14). Failure of primary osteosynthesis is mostly treated with removal of internal fixation and conversion to Total Hip Arthroplasty (cTHA) (**Figure 1**) (5, 8, 9, 11). cTHA is performed in approximately 3-11% of patients (1, 2, 9-11). Previous studies have shown that cTHA after failed fixation can result in (early) complications such as dislocation, periprosthetic fractures, increased blood loss during surgery, superficial and deep infections and mortality (5, 9, 11, 14, 17, 18). Functional outcomes after (cemented) cTHA, e.g. in terms of pain, mobility and social dependency, showed less favourable results in comparison to the functional outcomes after pTHA (5). However, well-powered and well-designed studies comparing the complications and survival rates after pTHA and cTHA after FFN are scarce (14). The aim of this study is to evaluate differences in clinically relevant complication rates and short-term survival rates between pTHA and cTHA after FFN. These results may help clinicians to determine which type of THA is more or less prone to complications and inform clinicians in deciding which course of action to take after FFN.

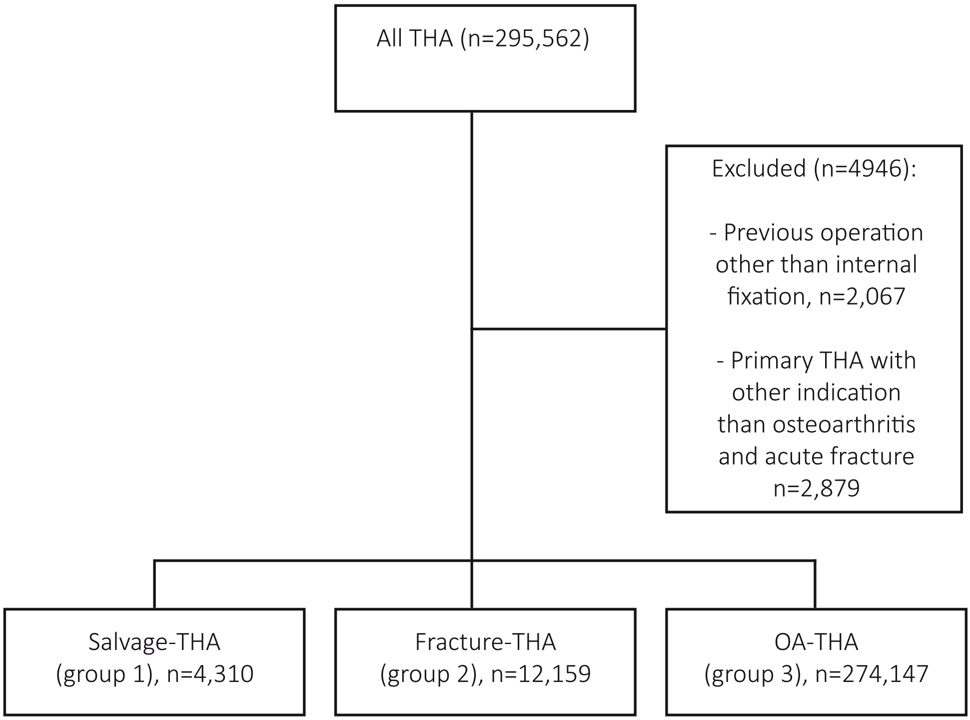

Figure 1 | Treatment options of fractures of the femoral neck. Abbreviations: cTHA, conversion to Total Hip Arthroplasty; DHS, Dynamic Hip Screw; FFN, Fracture of the Fermoral Neck; MCS, Multiple Cannulated Screws; OA, Osteoarthritis; pTHA, primary Total Hip Arthroplasty.

Methods

Design and participant eligibility criteria

A multicentre retrospective cohort study was conducted using data from patients from three large hospitals united in the Organisation for Topclinical Hospitals (STZ) in the Netherlands. Patients ≥18 years were eligible for inclusion if they had a FFN treated with either pTHA or cTHA after failed primary osteosynthesis with DHS, DHS with anti-rotation screw (ARS) or MCS between January 2006 and February 2020. Patients with polytrauma (≥2 distracting fractures), pathological fracture, metastatic disease or a contralateral hip fracture were excluded. This study was approved by the regional medical research ethics committee (study number 2020- 6321) which granted a waiver of approval.

Outcomes

The main study outcomes were postoperative complication rates in the first year after THA expressed in frequencies of major complications; dislocations, periprosthetic fractures, prosthetic joint infections (PJI), blood loss during surgery, cardiac related complications (i.e.

myocardial infarction and cardiac failure), pulmonary related complications (i.e. pulmonary embolism and pulmonary infection) and mortality. Secondary analysis included the short-term survival of pTHA and cTHA implants, expressed as a revision rate of the total hip arthroplasty. Also the short-term survival of cemented and uncemented THA was analysed.

Data collection

The following patient characteristics were collected: gender, age at THA procedure, American Society of Anaesthesiologists (ASA) classification, Body Mass Index (BMI), smoking, status of osteoporosis, length of stay (LOS) in hospital, time to failure of primary osteosynthesis, cause of failure primary osteosynthesis, approach of THA, type of implant (cemented/uncemented), one-stage versus two-stage arthroplasty in case of cTHA and use of Dual-Mobility cup (DM cup).

Sample size calculation

Based on an expected higher frequency of complications in the pTHA group compared to the cTHA group (difference ≥ 5%), a minimum of 208 participants were required for each group.

Data analysis

The number of complications per group (pTHA versus cTHA) were summarized descriptively using frequencies (percentages of total). Continuous data were first tested for normality using the Shapiro-Wilk test. The Chi-square test was used to analyse the differences in frequencies between the two groups. Effect sizes were expressed using odds-ratios (95% confidence interval). The Cox regression analysis was used and corrected for death and loss of follow up to analyse the implant survival. Level of significance was set at 5%. All analyses were performed in SPSS (SPSS, version 22.2; IBM Corp, Armonk, NY).

Results

In total 548 patients were included in this study. Their mean follow-up time was 5 years (SD ± 3.5, range 14.4) with a minimum of one year and a maximum total follow-up time of 12 years. Patient characteristics and THA specific details in each group are presented in **Table 1**. In brief, the majority of participants were female, had a ASA level II and had a posterolateral surgical approach. The mean BMI and frequencies of osteoporosis, diabetes mellitus and smoking status were comparable across the two groups. Age and length of stay differed significantly ($p = 0.001$) between the two groups. Type of primary osteosynthesis and causes of failure of the osteosynthesis in the cTHA group are listed in **Table 2**. The most frequent causes of failure were AVN, posttraumatic osteoarthritis and non-union. A break-out of the primary osteosynthesis, defined as femoral head screw penetration through the femoral head, occurred in 32 patients (11%). Mean time to failure of the osteosynthesis was 1.8 year (SD ± 2.6). Twenty-eight percent of the patients received their cTHA during a two-stage surgical procedure. Reasons for a two-stage procedure were posttraumatic OA in 36.8% (n = 29), AVN in 23.8% (n = 19), non-union in 12.5% (n = 10), malunion in 12.5% (n = 10), infection in 8.8% (n = 7) or pain and refracture in 6.3% (n = 5).

Table 1 | Patient characteristics per group.

Patient characteristic	pTHA (n = 264)	cTHA (n = 284)
Gender, female	176 (66.7)	184 (64.8)
Age, years, mean (SD)	66,5 (8.2)*	64,0 (9.5)*
BMI, kg/m2, mean (SD)	25.8 (13.9)	25.3 (9.6)
ASA classification		
ASA I	50 (18.9)	52 (18.3)
ASA II	136 (51.5)	175 (61.6)
ASA III	48 (18.2)	48 (16.9)
ASA IV	3 (1.1)	6 (2.1)
Smoking, yes	63 (23.9)	67 (23.6)
Osteoporosis, yes	51 (19.3)	60 (21.1)
Diabetes Mellitus, yes	22 (8.3)	19 (6.7)
LOS, mean (SD)	5.2 (3.8)*	4.2 (2.9)*
THA specific details		
Surgical approach of THA		
Posterolateral	251 (95.1)	263 (92.6)
Direct anterior	11 (4.2)	19 (6.7)
Direct superior	2 (0.8)	1 (0.4)
Straight lateral	0 (0)	1 (0.4)
Type of THA		
Cemented	120 (45.5)	81 (28.5)
Uncemented	127 (48.1)	183 (64.4)
Hybrid	6 (2.3)	10 (3.5)
Reversed-Hybrid	11 (4.2)	10 (3.5)
DM-cup	56 (21.2)	36 (12.7)

Note: all data are frequencies, n (% of total group), unless stated otherwise.
Abbreviations: ASA, American Society of Anaesthesiologists classification; BMI, Body Mass Index; cTHA, conversion to Total Hip Arthroplasty; DM-cup, Dual Mobility cup; LOS, length of stay; pTHA, primary Total Hip Arthroplasty; SD, standard deviation; THA, total hip arthroplasty.
* significant difference in age (t = 3.3, df = 546, p = 0.001, mean difference 2.5, 95%-CI of the difference 1.03 – 4.05) and length of stay (t = 3.5, df = 546, p = 0.001, mean difference 1.0, 95%-CI of the difference 0.44- 1.58) between the groups.

Table 2 | Type of primary osteosynthesis after fracture of the femoral neck and causes of failure in the patients that received cTHA.

Type of primary osteosynthesis	**cTHA (n = 284)**
DHS	43 (15.1)
DHS + ARS	114 (40.1)
MCS	127 (44.7)
Cause of failure primary osteosynthesis	
Avascular necrosis	100 (35.2)
Non-union	54 (19.0)
Mal-union	33 (11.6)
Infection	7 (2.5)
Pain	6 (2.1)
Posttraumatic osteoarthritis	72 (25.4)
Refracture	8 (2.8)
Malposition of osteosynthesis	2 (0.7)
Not reported / unknown	2 (0.7)

Note: all data are frequencies, n (% of total group).
Abbreviations: cTHA, conversion to Total Hip Arthroplasty; DHS, Dynamic Hip Screw; DHS + ARS, Dynamic Hip Screw with Antirotation Screw; MCS, Multiple cannulated screws.

Postoperative complications

Complications occurring in the first year after pTHA or cTHA are presented in **Table 3**. In total, 44 (16.7%) patients developed one or more of these major complications after pTHA compared to 49 (17.3%) patients after cTHA ($p = 0.86$; OR 1.04, 95% CI 0.67-1.63). Overall, the most frequently reported complications were dislocation, periprosthetic fracture and blood loss (≥1000 mL). Most periprosthetic fractures occurred during surgery or were caused by a femoral crack or after a new trauma. In the cTHA group the frequency of PJI was 11. Of these, 8 occurred after a one-stage procedure and 3 after a two-stage procedure. In total, 48 patients died in the first years during follow-up due to reasons unrelated to surgery; 21 in the pTHA group (mean 4.1 (SD ± 3.3) years) and 27 in the cTHA group (mean of 5.3 (SD ± 3.7) years).

Table 3 | Group frequencies, odds-ratios and the between-group p-values of complications reported in the first year after total hip arthroplasty.

Complication	pTHA (n = 264)	cTHA (n = 284)	OR (95% CI)	p-value
Dislocation	19 (7.2)	13 (4.6)	0.62 (0.30-1.28)	0.19
Patients with unipolar cup	16 (6.1)	12 (4.2)	0.61 (0.28-1.32)	0.21
Patients with DM cup	3 (0.05)	1 (0.03)	0.51 (0.05-5.05)	0.55
Periprosthetic fracture	7 (2.7)	14 (4.9)	1.90 (0.76-4.80)	0.17
PJI	4 (1.5)	11 (3.9)	2.63 (0.83-8.36)	0.09
Blood loss (≥1000mL)	10 (3.8)	15 (5.3)	1.60 (0.70-3.63)	0.26
Cardiac related complications	7 (2.7)	3 (1.1)	0.39 (0.10-1.53)	0.16
Pulmonary related complications	6 (2.3)	3 (1.1)	0.46 (0.11-1.86)	0.26

Note: all data are frequencies, n (% of total group).
Abbreviations: cTHA, conversion to Total Hip Arthroplasty; CI, confidence interval; DM cup, Dual-Mobility cup; OR, odds ratio; PJI. Prosthetic Joint Infection; pTHA, primary Total Hip Arthroplasty.

Survival of pTHA and cTHA implants

In total 41 patients underwent revision of THA. Revision rate in the pTHA group was 7.2%, compared to 7.7% in the cTHA group (p = 0.81; OR 1.08, 95% CI 0.57-2.05). Reason for revision was dislocation in 36.6% (pTHA n = 7; cTHA n = 8), periprosthetic fracture in 22.0% (pTHA n = 3; cTHA n = 6), infection in 19.4% (pTHA n = 4; cTHA n = 4), and other (aseptic loosening n = 2 in both groups, metal-on-metal implants pTHA n = 1; cTHA n = 2, cup insert luxation pTHA n = 1, cup-wear pTHA n = 1). Survival analysis (see **Figure 2**) showed no significant influence of time on implant survival in both groups (regression coefficient -0.77 (p = 0.81, hazard ratio 0.93, 95% CI 0.50-1.71)). A sub-analysis of the survival of the cemented stems (cemented and hybrid THA) and uncemented stems (uncemented and reversed hybrid THA) showed no significant differences in FFN patients (regression coefficient -0.24 (p = 0.53, hazard ratio 0.80, 95% CI 0.40-1.61), see **Figure 3**. The pTHA group showed a regression coefficient of -0.53 (p = 0.32, hazard ratio 0.59, 95% CI 0.21-1.68) and the cTHA group showed a regression coefficient of 0.10 (p = 0.84, hazard ratio 1.10, 95% CI 0.43-2.84).

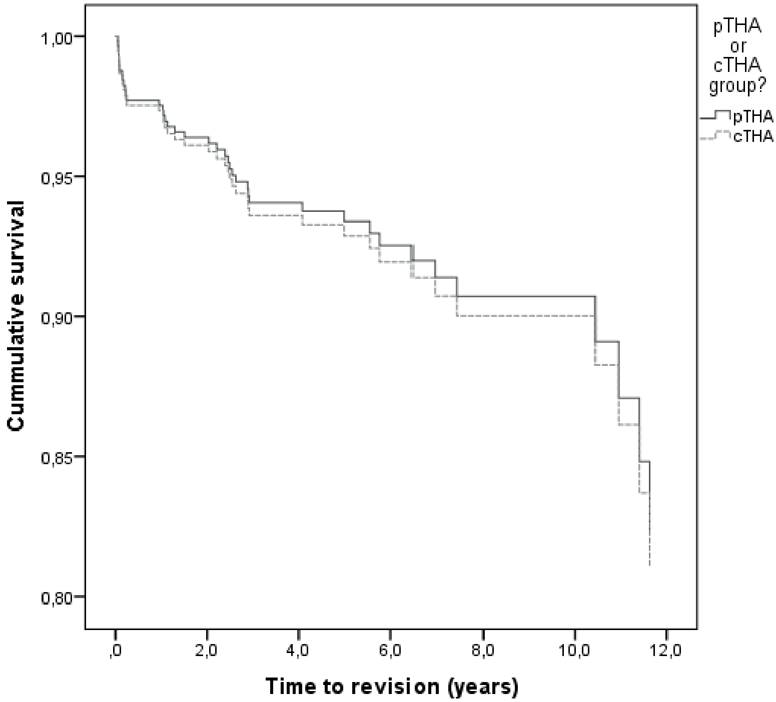

Figure 2 | Survival analysis of pTHA versus cTHA.

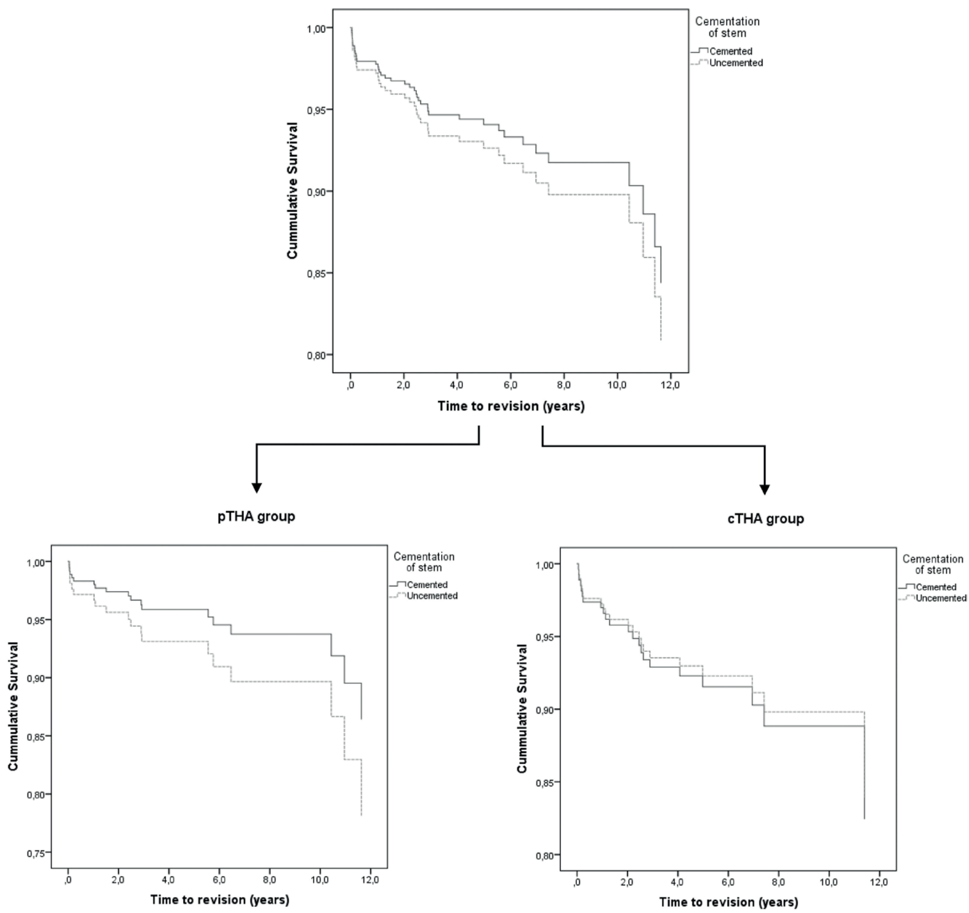

Figure 3 | Survival analysis of cemented and uncemented stem.

Discussion

The results of this retrospective multicentre cohort study in patients after FFN showed no differences in complication rates in the first year after pTHA or cTHA. Similarly, short-term revision rates of the implant in pTHA and cTHA patients were comparable. Based on clinical experiences as well as previous findings reported in the literature, we hypothesized a higher percentage of postoperative complications after cTHA compared to pTHA after FFN (5, 18, 19). For example, a previous study using 107 matched pairs of patients reported a higher percentage of dislocations in the first year after cTHA compared to pTHA (5). In contrast, in our study we found no significant differences in the rates of dislocations between both groups using a sample more than twice as large (n = 548). This may be explained by the fact that studies with smaller sample sizes are more likely to report larger differences between groups than large trials. The patients in our study had more comorbidities (ASA III or IV) in comparison to McKinley et al., of which 91% of the patients were classified as

ASA I. More comorbidities are associated with an increased patients' risk of revision due to complications such dislocation (20). Nevertheless, 75.4% of our study population had an ASA-classification of I/II, which is not a risk factor for revision and thus may explain our outcomes as well (20). Furthermore, we found no significant differences in the frequency of PJIs between the two groups. Although this result is in line with outcomes of several other studies (11, 21), a systematic review and meta-analysis found an increased risk of PJIs after cTHA (14). Regarding the latter it is of note that the rate of PJIs in the cTHA group in our study was more than twice the rate of PJIs in the pTHA group (3.9% versus 1.5%, respectively). Also, the incidence of PJIs in our cTHA group was higher than the incidences of between 0.2% and 2.2% reported in primary elective THA (13, 22). Whilst our study was underpowered to show significant between-group differences in the rates of PJIs only, this increased PJI outcome is still clinically relevant. A potential reason for a higher incidence in PJIs in the cTHA group could be explained by the prolonged surgery time in case of one-stage procedures (13). Also, low-grade infections of the primary osteosynthesis may have predisposed patients to the development of AVN, delayed union or non-union (13, 23). Especially for the cTHA patients who underwent one-stage cTHA, which represents 72,3% of the PJI cases found in the cTHA-group. These infections might not be recognised before conversion to THA due to an inadequate preoperative work up (e.g. laboratory blood samples, aspiration of joint fluid and intra-operative tissue cultures) (23). Future research investigating the influence of surgery time and type of surgical procedure on the development of PJI after pTHA and cTHA using larger samples are warranted to confirm these assumptions. Finally, in our sample 2.7% and 4.9% of patients in the pTHA and cTHA groups, respectively, suffered from periprosthetic fractures. These percentages are higher than those reported in the literature, with an incidence of up to 1% (24). These differences could be explained by the fact that the patients from our sample had in 24.6% an ASA III/IV classification and were frequently (19 - 21%) codiagnosed with a joint or bone disease such as osteoporosis (20). Also, the majority (67.8%) of our cTHA patients were treated with an uncemented femoral stem THA (uncemented THA or reversed hybrid). Despite the fact that the current study found no significant differences in revision rates between cemented and uncemented stems in the full sample, there was a trend visible of earlier revisions in uncemented THA after FFN. The same trends were seen in the pTHA and cTHA groups. This is in line with the results of previous research that has indeed shown that periprosthetic fractures, but also aseptic loosening and dislocation occur more frequently after uncemented THA (20, 25, 26). This increase in periprosthetic fractures will also lead in an increase of revision in uncemented THA after FFN (20, 26, 27). Therefore, these uncemented THA procedures are not recommended in THA after FFN. As a secondary outcome, this study showed no difference in implant survival between the pTHA and cTHA groups. This contrasts the results of a previous study in which the overall survivorship was significantly better after pTHA at five and ten years (5). The difference in these results should be interpreted in light of the differences in sample size (214 versus 548 patients) and sample population (i.e. age and comorbidities) between the studies. In addition to these differences, the study by McKinley et al. also analysed the survival of cemented hip prosthesis implanted in the period around 1998 which were revised mainly due to loosening of the implant at five and ten years. Improvements in implant design, medical education, surgical techniques, cement quality and infection prevention have arguably contributed to improved implant survival since then (24). In addition, it is unclear if McKinley et al. corrected for death or loss of follow up in their survival analysis, which may have biased their results. It would be worthwhile to collect and analyse the ten-year data of our sample in the near future in order to compare our results to other studies evaluating ten-year data. A major strength of this study is that, to our knowledge, this is the largest retrospective multicentre study to date comparing the frequencies of complications and survival rates of patients who received either pTHA or cTHA after FFN. Although both groups were largely comparable in terms of baseline patient characteristics, selection bias cannot be ruled out. The main limitation of this study is its retrospective design. As such, the results should be interpreted with caution due to confounding factors. The significant differences in age between both groups were small (2.5 years) which is not surprising, given that in The Netherlands it is common for younger patients with FFN to be treated with primary osteosynthesis and older patients with pTHA. We believe that this small difference in age between the groups had no clinical relevant influence on the participants' baseline comorbidities and their complications after THA. Previous literature confirmed the effect of age on comorbidities expressed in ASA, but using a between age class differences of a minimum of 10 years and thus our age difference seems to be too small (28). Furthermore, different orthopaedic surgeons from three participating hospitals used different types of THA (e.g. cemented, uncemented, DM cup) and operation techniques (e.g. posterolateral, direct anterior), all associated with their own specific advantages and risks (18, 20). Future well-powered (prospective) studies are therefore needed to evaluate the effect of different approaches and types of implants on complication rates in cTHA and pTHA after FFN. Also, knowledge regarding the long-term survival of THA implants after FFN is scarce, and our results showed no insight in the long term survival. A comparison of our results with those of (inter)national registry studies could be worthwhile in evaluating implant survival in the longer (≥ 10 years) term. Taken together, the results of this study may have several implications. The knowledge gained during this study about the differences and similarities in short-term survival rates and complication rates between pTHA and cTHA, might be helpful for clinicians to properly educate patients after FFN about the prognosis and risk of complications of THA after FFN. Interestingly, these results are in contrast with the current literature.

Conclusion

This study showed no significant difference in the rates of major complications after pTHA versus cTHA in the first year postoperatively in patients with FFN. Also there was no difference in the short term implant survival between patients with cTHA and pTHA. Further research is recommended to evaluate long term survival and determinants influencing THA outcome after FFN.

Declaration of Competing Interest

None.

Acknowledgments

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CHAPTER 6

Revision risk of salvage compared with acute total hip arthroplasty following femoral neck fracture: an analysis from the Dutch Arthroplasty Register

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Acta Orthopaedica, 2023

Abstract

Introduction

There is no consensus on the treatment of patients with femoral neck fractures between internal fixation (IF) or directly treated with a total hip arthroplasty (fracture-THA) in particular for the age group 60–70 years. Failure of IF is not uncommon, resulting in salvage total hip arthroplasty (salvage-THA). The aim of our study was to compare revision rates of salvage-THA with fracture-THA and osteoarthritis (OA)-THA.

Methods

Revision rates and reasons for revision were compared. Data collected in the Dutch Arthroplasty Register (LROI) between 2007 and 2018 was used. The study included 4,310 salvage-THAs, 12,159 fracture-THAs, and 274,147 OA-THAs. We performed Kaplan– Meier survival analyses and Cox regression to evaluate THA survival.

Results

No statistically significant difference in revision rates between salvage-THAs and fracture-THAs was found (HR 1.0, 95% CI 0.7–1.3) whereas the revision rate was higher compared with OA-THAs (HR 1.3, CI 1.0–1.5). The 5-year revision rate was 5.0% (CI 4.4–5.8) in salvage-THAs, 4.5% (CI 4.1–5.0) in fracture-THAs, and 3.1% (CI 3.0–3.2) in OA-THAs. A higher revision rate for infection was found in salvage-THAs in comparison with fracture-THAs (HR 1.6, CI 1.0–2.3).

Conclusions

We found no difference in revision rates for salvage-THAs compared with fracture-THAs. The risk of revision for infection was higher for salvage-THA.

Introduction

In general, elderly patients with a displaced femoral neck fracture are treated with (hemi) arthroplasty, whereas internal fixation of the fracture is mainly reserved for non-elderly patients in an attempt to preserve the hip joint. However, there is a lack of consensus in the literature concerning the best treatment in the age group 60–70 years (1). Failure of internal fixation is not uncommon, even in the non-elderly (10–59%) (1-5). Consequently, THA is still required after these failures, but now as a salvage procedure (salvage-THA). Internal fixation may negatively influence the outcome of these salvage-THAs, for example by higher complication rates such as infection (6). However, literature is inconclusive regarding the results of salvage-THA. A systematic review found a statistically significant higher risk of complications after salvage-THA compared with fracture-THA (7). A retrospective study reported on the survival of a salvage-THA in comparison with a fracture-THA and found a higher risk of revision after salvage-THA (8). On the other hand, a study from the Swedish Hip Arthroplasty Register found a similar revision rate for both groups (9). If there is a higher risk of revision of salvage-THA in comparison with fracture-THA, it needs to be weighed against any benefits of preserving the hip joint by internal fixation of the fracture. Consequently, this information can be used in shared decision-making to choose between fracture-THA or internal fixation. A study based on national registers offers possibilities other than single or multicenter studies to monitor revision rates in salvage-THA versus fracture-THA. The aim of our study was to determine the revision rates of salvage-THAs after failed internal fixation in comparison with fracture-THAs and OA-THAs. Furthermore, we compared the 3 most common reasons for revision in these groups.

Patients and methods

The LROI is a nationwide population-based register, covering all hospitals in the Netherlands, collecting data on arthroplasties. The database has a completeness of 98% for primary THA, 88% for hip revision arthroplasty to 2018 (10), and 98% for both primary and revision THA from 2018 (11). In 2007, the LROI started to collect data prospectively on patient, procedure, and prosthesis characteristics. Earlier ipsilateral hip interventions such as internal fixation, arthroscopy, arthrodesis, osteotomy, and Girdlestone resection were registered as well. In mid-2013, body mass index, smoking behavior, and Charnley score were added to the database (10). We included all registered patients who were treated with THA in the Netherlands between January 2007 and December 2018. Patients with any previous operation on the affected hip other than internal fixation of a femoral neck fracture were excluded. Based on indication and the history of the affected hip, 3 groups were distinguished: (1) THA as a salvage procedure for a failed previous internal fixation (salvage-THA), (2) THA as a direct treatment for a femoral neck fracture (fracture-THA), and (3) THA for primary osteoarthritis (OA-THA). Revision arthroplasty was defined as any change, addition, or removal of at least 1 component of the prosthesis (10). In the LROI more than 1 cause of revision could be registered. Therefore, a hierarchical order of reasons for revision was used, i.e., infection, aseptic loosening, periprosthetic fracture, dislocation, and other (12). The study is reported according to the STROBE guidelines (13).

Statistics

Kaplan–Meier survival analyses were performed to evaluate revision rates of the implants in all 3 groups. Results of Kaplan–Meier analyses (KM) were reported with 95% confidence intervals (CI). The median follow-up time and interquartile range (IQR) was calculated using the reversed Kaplan–Meier method (14). The proportional hazard (PH) assumption was assessed through visual assessment of KM curves, log(−log) plots and testing of scaled Schoenfeld residuals. As the PH assumption was violated, we used weighted Cox regression as described in detail by Dunkler (2018) and Schemper (2009) (15, 16) to compare revision rates in the 3 groups adjusted for age, sex, American Society of Anesthesiologists (ASA) score, approach (anterior, direct lateral, posterolateral, other), type of fixation (cemented, uncemented, hybrid), and implanted femoral head size. As missing values in potential confounders ranged between 0.2% and 6.6% and were assumed to be missing completely at random, listwise deletion (i.e., complete case analysis) was preferred to multiple imputation as biases and loss of power are both likely to be inconsequential (17). Statistical analyses were performed using R (version 4.1.2, R Foundation for Statistical Computing, Vienna, Austria) with package “coxphw” (version 4.0.2; Dunkler 2018).

Ethics, funding, data sharing, and disclosures

Ethical approval was not applicable. Within the LROI data the personal identity number is encrypted; as such, all data received by the researchers were completely anonymous. Data is available from the LROI but restrictions apply to the availability of this data, which was used under license for the current study. No funding was obtained, and the authors have no conflicts of interest to declare. Completed disclosure forms for this article following the ICMJE template are available on the article page, doi: 10.2340/17453674.2023.17743.

Results

Between January 2007 and December 2018, 4,310 salvage-THAs (4,174 patients), 12,159 fracture-THAs (11,750 patients), and 274,147 OA-THAs (273,692 patients) were registered (**Figure 1**). Mean age at time of primary operation was 67.7 (standard deviation [SD] 12.3) years, 70.2 (SD 9.4) years, and 69.7 (SD 9.5) years in these 3 groups, respectively. Median time of follow-up (IQR) was 4.8 (2.3–7.8) years for all patients, and 4.0 (1.9–6.4) years after salvage-THA, 3.5 (1.5–6.2) years after fracture-THA, and 4.9 (2.3–7.9) years after OA-THA. Patient and implant characteristics are listed in **Table 1**.

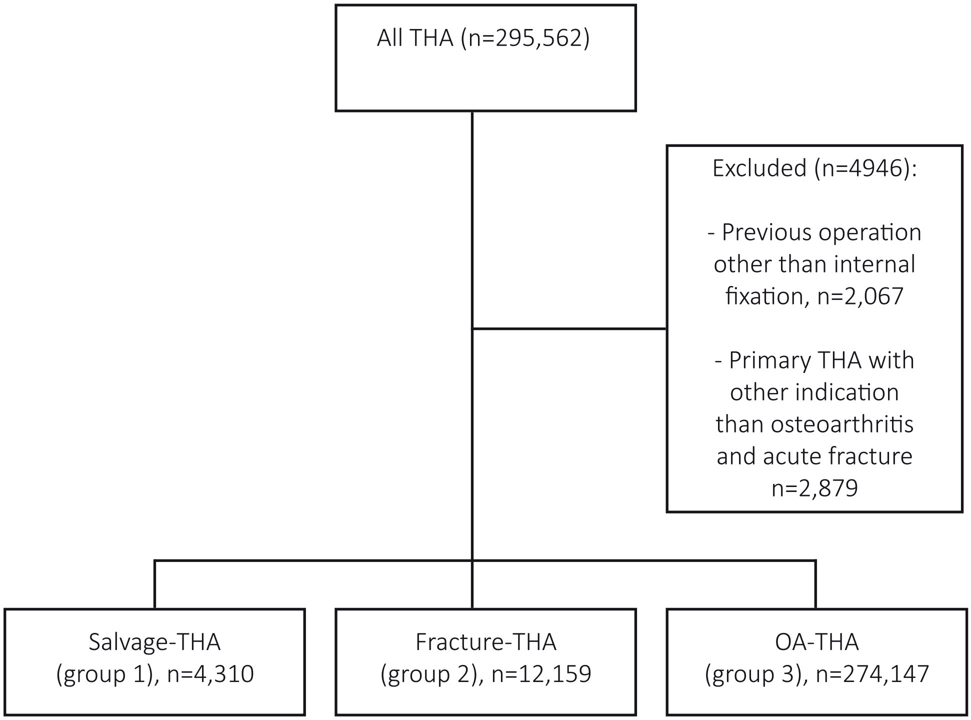

Figure 1 | Flowchart patient selection.

Revision rates

The 5-year revision rates of the salvage-THAs were 5.0% (CI 4.4–5.8) and 6.8% (CI 5.7–8.2) after 10 years. The revision rates of the fracture-THAs were 4.5% (CI 4.1–5.0) at 5-year follow-up and 5.8% (CI 5.2–6.5) after 10 years. The OA-THAs showed a revision rate of 3.1% (CI 3.0–3.2) after 5-year follow-up and 4.7% (CI 4.6–4.8) after 10 years (**Figure 2**). After adjustment for potential confounders, no statistical difference in revision rates between salvage-THAs and fracture-THAs was found (HR 1.0, CI 0.7–1.3). Both salvage-THAs and fracture-THAs showed a higher revision rate than OA-THAs (HR 1.3, CI 1.0–1.5 and HR 1.3, CI 1.1–1.7, respectively). Unadjusted hazard ratios (CI) for revision among the 3 groups are presented in **Table 2**.

Table 1 | Patient and implant characteristics (January 2007 to December 2018). Values are count (%) unless otherwise specified.

	Group 1 – Salvage-THA N=4,310	Group 2 – Fracture-THA N=12,159	Group 3 – OA-THA N=274,147
Age, mean (SD)	67.7 (12.3)	70.2 (9.4)	69.8 (9.6)
Missing	0 (0.0)	0 (0.0)	0 (0.0)
Sex			
Male	1,617 (38)	3,782 (31)	90,824 (33)
Female	2,691 (62)	8,356 (69)	182,882 (67)
Missing	2 (0.0)	21 (0.2)	441 (0.2)
ASA			
1	717 (17)	1,767 (15)	56,085 (21)
2	2,479 (57)	6,787 (56)	17,1135 (62)
3-4	1,071 (25)	3,196 (26)	39,669 (14)
Missing	43 (1.0)	409 (3.4)	7,258 (2.6)
Charnley [a, b]			
A	1,678 (39)	2,916 (24)	65,399 (24)
B1	149 (3.5)	387 (3.2)	47,146 (17)
B2	143 (3.3)	451 (3.7)	34,763 (13)
C	63 (1.5)	158 (1.3)	3,857 (1.4)
Missing	2,277 (53)	8,247 (68)	122,982 (45)
BMI a, mean (SD)	25.58 (4.30)	25.02 (4.30)	27.48 (4.53)
Missing	1422 (33)	4436 (36)	113467 (41)
Smoking [a]			
Yes	555 (13)	1,156 (9.5)	16,000 (5.8)
No	2,246 (52)	6,638 (55)	138,275 (50)
Missing	1,509 (35)	4,365 (36)	119,872 (44)
Approach			
Anterior	247 (5.7)	1,253 (10)	48,077 (17)
Anterolateral	253 (5.9)	937 (7.7)	17,840 (6.5)
Straight lateral	892 (21)	2,553 (21)	46,357 (17)
Posterolateral	2,899 (67)	7,258 (60)	158,287 (58)
Other	12 (0.3)	46 (0.4)	1,364 (0.5)
Missing	7 (0.2)	112 (0.9)	2,222 (0.8)
Fixation			
Cemented	1,626 (38)	4,280 (35)	72,441 (26)
Uncemented	1,951 (45)	6,277 (52)	176,180 (64)
Hybrid	703 (16)	1,426 (12)	23,297 (8.5)
Missing	30 (0.7)	176 (1.4)	2,229 (0.8)
Femoral head size, mm			
>38	40 (0.9)	592 (4.9)	3,674 (1.3)
36	632 (4.7)	2,283 (19)	51,284 (19)
32	1,953 (45)	4,946 (41)	133,025 (48)
22–28	1,401 (32)	3,539 (29)	70,811 (26)
Missing	284 (6.6)	799 (6.6)	15,353 (5.6)

a BMI, smoking behavior and Charnley score were registered since mid-2013. b Charnley score is a 4-item clinical classification system; A: one joint affected; B1: both joints affected; B2: contralateral joint with a prosthesis; C: several joints affected or a chronic disease that affects quality of life.

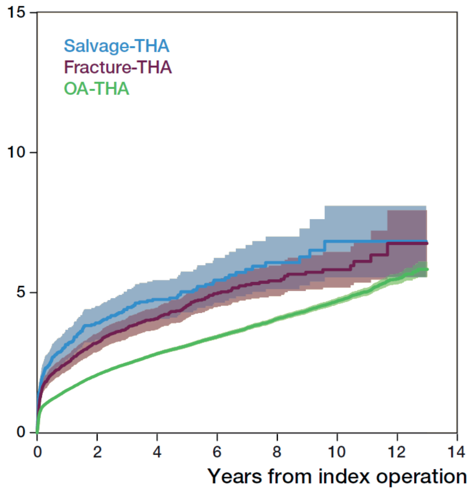

Figure 2 | Crude analysis of Kaplan-Meier curves for revision with 95% confidence intervals in the three groups.

Table 2 | Unadjusted Hazard ratios (95% CI) for revision and reason for revision among the 3 groups (before weighted Cox regression).

	Salvage-THA versus fracture-THA	**Salvage-THA versus OA-THA**	**Fracture-THA versus OA-THA**
Total revision	1.17 (0.94-1.45)	1.44 (1.22-1.69)	1.23 (1.05-1.44)
Infection	1.90 (1.31-2.79)	2.13 (1.59-2.86)	1.12 (0.87-1.44)
Aseptic loosening	1.06 (0.62-1.80)	1.12 (0.78-1.60)	1.06 (0.70-1.59)
Dislocation	0.78 (0.54-1.15)	1.55 (1.15-2.10)	1.98 (1.53-2.56)

Reason for revision

The 3 most common reasons for revision were infection, dislocation, and aseptic loosening. Infection was the reason for revision in salvage-THAs, in the fracture-THAs, and in OA-THAs in 1.2%, 0.6%, and 0.6%, dislocation in 1.2%, 1.4%, and 0.7%, and aseptic loosening in 1.0%, 1.0%, and 0.8%, respectively (**Figure 3** and **Table 3**). After adjustment for potential confounders, a higher revision rate for infection was found in salvage-THAs than in fracture-THAs (HR 1.6, CI 1.0–2.3) and OA-THAs (HR 1.6, CI 1.2–2.2). The revision rate for dislocation was not different in salvage-THAs compared with fracture-THAs (HR 0.7, CI 0.4–1.1), whereas a higher revision rate for dislocation was found in both salvage-THAs (HR 1.5, CI 1.1–2.0) and fracture-THAs (HR 2.1, CI 1.5–3.0) than in OA-THAs. No differences were found in revision rates for aseptic loosening in salvage-THAs compared with fracture-THAs (HR 0.6, CI 0.3–1.3) and OA-THAs (HR 0.8, CI 0.5–2.1).

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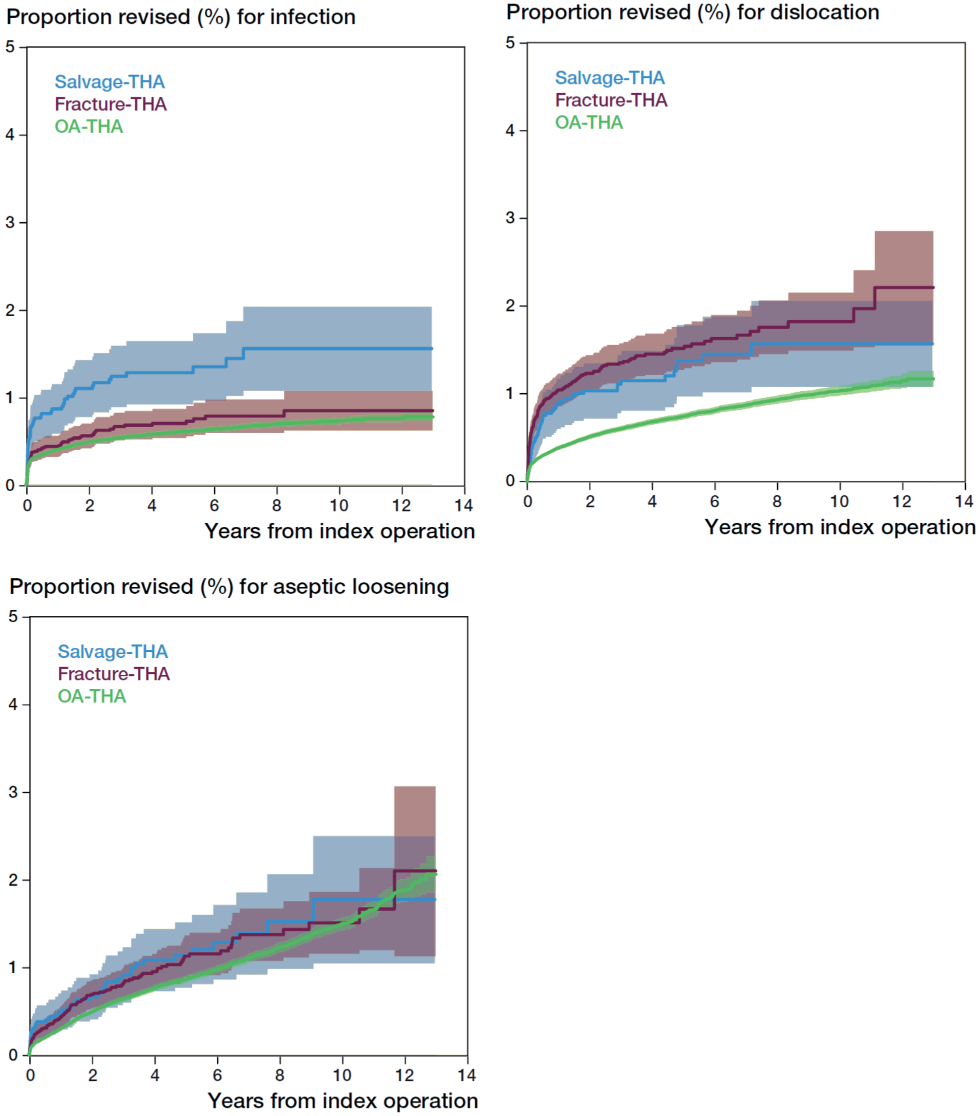

Figure 3 | Crude analysis of Kaplan-Meier curves for reason of revision with 95% confidence intervals in the three groups (infection, dislocation, and aseptic loosening).

Table 3 | Reason for revision. Values are count (%).

	Salvage-THA n = 4,310	Fracture-THA n = 12,159	OA-THA n = 274,147
Infection	52 (1.2)	76 (0.6)	1,584 (0.6)
Aseptic loosening	43 (1.0)	108 (1.0)	2,403 (0.8)
Periprosthetic fracture	17 (0.4)	67 (0.6)	826 (0.3)
Dislocation	50 (1.2)	165 (1.4)	1,958 (0.7)
Other	31 (0.7)	52 (0.4)	1518 (0.6)

Discussion

This study found no certain difference in revision rate in salvage-THAs in comparison with fracture-THAs. The 5-year revision rate was 5.0% in salvage-THAs and 4.5% in fracture-THAs. Both groups had higher revision rates than OA-THAs. Notably, a higher revision rate for infection was found in salvage-THAs than in fracture-THAs. Only a few studies report implant survival of salvage-THA in comparison with fracture-THA, and their results are inconclusive. Our findings are in accordance with a study from the Swedish Hip Arthroplasty Register where a subgroup analysis on the revision rate of salvage-THA and fracture-THA found a similar revision rate for these groups (9). On the other hand, a retrospective cohort study comparing a group of 107 salvage-THAs with an age- and sex-matched group of 107 fracture-THAs found a significantly higher revision rate in the salvage-THA after 1, 5, and 10 years of follow-up (8). The authors found complications in 36% of salvage-THAs and 13% complications after fracture-THAs. Functional outcome was significantly worse in the salvage-THA group. Furthermore, a systematic review consisting of 11 studies found a significantly higher risk of complications after salvage-THA in comparison with fracture-THA (7). Lastly, a small study report found better hip function after fracture-THA compared with salvage-THA (18). Several studies reported on the results of salvage-THA without the use of a direct comparison with fracture-THA. A large Norwegian register study found a higher revision rate in both salvage-THA and fracture-THA compared with OA-THA (19). Salvage-THA had a higher revision rate due to dislocation and periprosthetic fracture. The revision rate for infection was similar after salvage-THA and OA-THA. Prosthetic joint infection (PJI) was identified as the dominant reason for revision in the salvage-THA group in our study. A higher risk of PJI in THA after hardware removal has also been recognized in a retrospective case-series (6). A higher risk of infection-related revision after salvage-THA (7%) in comparison with fracture-THA (2%) was also found by McKinley et al. (8). It is well established that the risk for infection is increased by reoperations (20, 21). The latter probably explained the higher risk of infection-related revision after salvage-THA encountered in our study. A higher risk of PJI after earlier internal fixation is important, as it may affect the clinical outcome of a THA (22). As such, the doubled infection rate after a salvage-THA versus fracture-THAs (1.2% versus 0.6%), which was encountered in our registry-based study, is relevant. The knowledge that internal fixation may negatively influence the outcome of a potential future THA, as well as the finding of a similar total revision rate after both fracture-THA and salvage-THA, is important for clinical decision-making in treatment of femoral neck fracture. These findings are particularly relevant to the group aged 60–70 years, where no optimum treatment yet has been established (1, 2).

Limations and strengths

A strength of this registry study is the high number of fracture-related THAs in comparison with the available literature. Some potential limitations must be discussed. First, the data on salvage-THAs is not detailed in terms of fracture type. Predominantly, a femoral neck fracture will have been the indication for a total hip arthroplasty, but inclusion of some trochanteric fractures cannot be ruled out. Second, information on BMI, smoking, and Charnley classification has only been registered in the LROI since 2013, preventing us from modelling these covariates in the period 2007 to 2013. However, a sensitivity analysis performed using complete data registered between 2014 and 2019 showed our results to be robust. Third, a Cox regression model was performed, adjusted for available covariates. Despite adjustment for covariates, confounding bias could play a role because differences in unmeasured covariates may still exist. Fourth, underestimation of septic loosening is a known problem as registration of infection is often not sufficient (23).

Conclusions

We found no difference in revision rates for salvage-THAs that are different from those in fracture-THAs. The risk of revision for infection was higher for salvage-THAs.

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CHAPTER 7

Increased failure rates after the introduction of the TFNA proximal femoral nail for trochanteric fractures: implant related or learning curve effect?

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Abstract

Introduction

Trochanteric fractures are often treated using intramedullary fixation. In our institution, the TFN-Advanced Proximal Femoral Nailing System (TFNA) was introduced as replacement for the Gamma Trochanteric Nail (GTN3) for the treatment of these fractures as a result of a hospital-driven change of trauma implant supplier. We compared trochanteric fracture fixation failure rate between these 2 intramedullary nails.

Methods

All trochanteric fractures treated surgically from 2011 to 2019 were retrospectively reviewed for fixation failure. From 2016 only the TFNA was used. Fixation failure was defined as implant cut-out, implant breakage, non-union, malpositioning of the screw/blade requiring reoperation, new fracture around the nail, or miscellaneous. Propensity score matching was used to balance distribution of covariates and to compare failure rates between TFNA and GTN3 groups. Learning curve analyses were performed.

Results

After exclusion, 797 GTN3s (779 patients) and 542 (536 patients) TFNAs were available for analysis. A higher risk of fixation failure was found in the TFNA group (14%) compared with the GTN3 group (7.0%) (hazard ratio [HR] 2.0, 95% confidence interval [CI] 1.2–3.5). This was mainly attributed to a higher risk of cut-out (HR 2.2; CI 0.9– 5.7), malpositioning (HR 4.7; CI 0.7–34), and new fracture around the nail (HR 4.0; CI 1.0–16). Learning curve analyses indicated no clear learning curve effect.

Conclusions

Failure of fixation increased after a switch from the GTN3 to the TFNA proximal femoral nail for the treatment of trochanteric fractures. Cut-out and malpositioning of the calcar screw or blade appeared to be the most dominant failure mechanisms. Modifications in implant design may have played a role in this increased risk of failure of fixation. In our institution a new implant device was introduced without solid clinical evidence behind it. This study may help to underline the need for medical doctors with a critical and scientific background to be involved in implant choices.

Introduction

Trochanteric fractures are mostly treated with intramedullary fixation. Failures of fixation are not uncommon (4–7%) and lead to reoperation in most cases (1). The third generation of the Gamma Trochanteric Nail (GTN3; Stryker, Mahwah, NJ, USA) is a widely used implant with established reliability and safety as documented in several clinical studies (2, 3). In 2015, the TFN-Advanced Proximal Femoral Nailing System (TFNA) was introduced to the global market, claiming to potentially decrease fixation failure rates through a number of implant changes. From 2016 the TFNA (DePuy Synthes, West Chester, PA, USA) was used in our institution as replacement for the GTN3 (Stryker) for the treatment of trochanteric fractures. This switch in implant found its origin in a hospital-driven change of trauma implant supplier. We now compare trochanteric fracture fixation failure rates between the 2 intramedullary nails, Gamma Trochanteric Nail (GTN3) and the TFN-Advanced Proximal Femoral Nailing System (TFNA) and evaluate the responsible underlying mechanisms of failure. Since the TFNA was introduced as a new device we also assessed a potential learning curve effect.

Patients and methods

Electronic files of all patients treated with an intramedullary nail following a trochanteric fracture between June 2011 and July 2019 were screened. Patients suffering from pathological fractures were excluded. The TFNA was introduced to treat trochanteric fractures in our institution in 2016 whereas the GTN3 had been used since 2004. No GTN3-nail option was available after the introduction of the TFNA in 2016. Patient characteristics regarding age, sex, BMI, smoking status, and ASA score were collected. Length of stay and operation time were noted. Furthermore, type of fracture was defined according to the AO fracture classification system (4). As implant positioning may influence chances of failure of fixation (5), the tip–apex distance (TAD) (6) was assessed on intraoperative anterior–posterior and axial fluoroscopy as proxy measure for implant positioning.

Outcomes

This study assesses radiographic failure of fixation. 6 categories of failure were established and each case was allocated to 1 of the following: 1) implant cut-out, 2) implant breakage, 3) non-union, 4) malpositioning of the screw/blade in the femoral head, 5) new fracture around the nail, and 6) miscellaneous. An implant cut-out was defined as clear migration of hardware in the femoral head and implant breakage as a discontinuity in the device. Non-union was defined as radiographic absence of bone bridging at the fracture site for which reoperation had occurred to remove the distal locking screw. Malpositioning of the screw/blade in the femoral head was defined as an inadequate position requiring early re-intervention according to established consensus from the weekly trauma meeting. A new fracture around the nail was defined as the occurrence of a fracture related to a new fall. Lastly, a small remaining heterogeneous group of failures from collapse of the femoral head, either post-traumatic or from avascular necrosis, was classified as miscellaneous.

Implants and surgery

The TFNA and GTN3 are roughly similar implants (**Figure 1**) and are both available in long and short nails. The standard nail has a diameter of 11 mm for both implants and a length of 200 mm in the TFNA versus 180 mm in the GTN3. Both implants have the option for a femoral neck angle of 125 or 130 degrees. For both implants a calcar screw can be used, whereas for the TFNA this screw could now be replaced by a helical blade, which was 1 of the main modifications in implant design (**Figure 1**). This helical blade was designed to compress bone during insertion to enhance implant anchorage and to reduce the risk of cut-out (7). A blade was used within the TFNA in all patients above 70 years old. For both types of implants we used a similar operative technique. Patients were operated on in a supine position with the use of a traction table and fluoroscopy for closed reduction. All patients received preoperative cefazolin 2,000 mg and nadroparin 2850 IE anti-Xa till 5 weeks postoperatively. Postoperatively, patients were encouraged to fully weight-bear. With an incidence of around 150 trochanteric fractures per year in our institution all surgeries were performed by or under direct supervision of a certified (orthopedic) trauma surgeon.

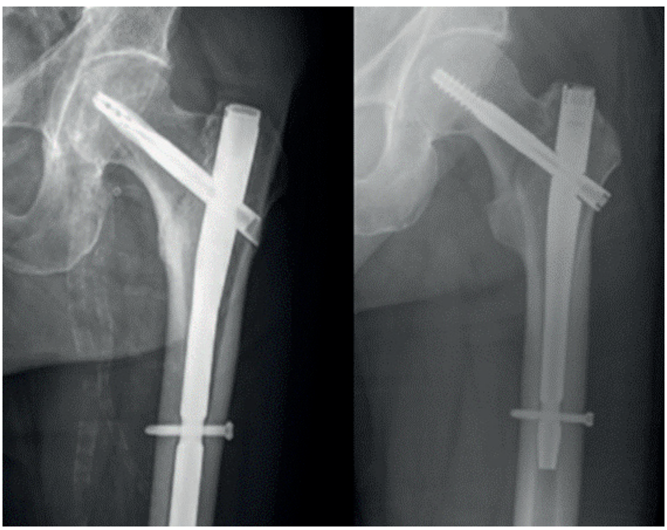

Figure 1 | A TFN-Advanced Proximal Femoral Nail (TFNA; left) and a third-generation Gamma Trochanteric Nail (GTN3; right). Note the TFNA's implant modifications: the use of a blade instead of a screw, oblique cut on lateral end of the blade, different bowing, smaller proximal diameter, and different design of the proximal hole.

Statistics

As a crude analysis, Kaplan–Meier analysis was performed to determine the failure of fixation rates, stratified for implant type (GTN3 or TFNA). Multiple imputation by chained equations was used to account for missing data. We generated 30 imputed datasets, as current guidance recommends that 1 imputation should be performed per percent of incomplete observations (8). ASA score, BMI, smoking status, and nail size had 2.6%, 5.8%, 30%, and 0.3% missing values, respectively (**Table 1**). To adjust for potential confounding baseline characteristics, we matched patients based on their propensity scores. The propensity score was defined as the probability of being treated with either TFNA or GTN3 dependent on a case's recorded baseline characteristics. Propensity scores were estimated for each imputed dataset, using a logistic regression model with the group (TFNA or GTN3) as the dependent variable in relation to the following baseline characteristics: age, sex, ASA score, BMI, smoking, fracture type, and length of nail (short or long). The selection of which variables to include in our analyses in order to minimize bias was done using directed acyclic graphs based on the approaches described by Shrier and Pearl (9, 10). A 1:1 nearest-neighbor matching algorithm was applied without replacement to match cases on their corresponding propensity scores within a caliper of 0.2 standard deviations of the logit of the propensity score (11). The balance between the 2 groups after matching was checked graphically and descriptively. A standardized difference of less than 10% indicates an appropriate balance (11). Mean standardized mean differences (SMD) with their range across the 30 multiple imputed datasets are presented in **Figure 2** and **Table 2** (see **Supplementary data**). On each of the 30 imputed and propensity score-matched datasets, we used Cox regression to analyze the effect of intramedullary nail on failure of fixation (12). The resulting hazard ratios (HRs) and absolute risk differences were pooled using Rubin's rule. Absolute risk differences were estimated at 3 years' follow-up. 95% confidence intervals (CI) were calculated for the HRs and absolute risk differences. As the TFNA was newly introduced in our institution, we used the exponential weighted moving average (EWMA) method to assess a potential learning curve. EWMA is a well-known statistical process monitoring tool because of its exceptional pace in catching infrequent variations in the process parameters, and is commonly used to monitor hospital data (13). By the choice of weighting factor, λ, the EWMA procedure can be made sensitive to either detect a small change or a trend in the process. We used a λ of 0.005 to discern a trend in the observed outcomes (14). We performed a learning curve analysis on overall fixation failures, operation (OR) time, cut-out, and malpositioning. Besides overall fixation failures, OR time was chosen because a relatively prolonged operation time is anticipated on the introduction of a new implant. Both cut-out and malpositioning were chosen from the subcategories for a learning curve analysis as for these 2 in particular a potential learning curve effect can be anticipated. In addition, we performed sensitivity analyses excluding the first 50, 150, and 250 TFNA cases to assess the influence of a potential learning curve on the results. Statistical analyses were performed using R 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria) using packages "mice," "cobalt," "MatchIt," and "riskRegression."

Table 1 | Patient characteristics and missing data among the TFNA and GTN3 groups from the unadjusted cohort.

Characteristic	TFNA (n=542)	TFNA Missing, n (%)	GTN3 (n=797)	GTN3 Missing, n (%)
Mean age, yrs (SD)	78.8 (13.5)	0 (0.0)	79.9 (11.8)	0 (0.0)
Gender, female, n (%)	378 (70)	0 (0.0)	589 (74)	0 (0.0)
ASA score, n (%)		0 (0.0)		35 (4.4)
1	32 (5.9)	N/A	35 (4.4)	N/A
2	134 (25)	N/A	315 (40)	N/A
3	276 (51)	N/A	362 (45)	N/A
4	90 (17)	N/A	37 (4.6)	N/A
5	10 (1.8)	N/A	13 (1.6)	N/A
Mean BMI, (SD)	24.1 (4.4)	21 (4)	24.0 (4.2)	56 (7)
Smoking status, yes, n (%)	90 (17)	0 (0.0)	112 (14)	398 (50)
Fracture type, n (%)		0 (0.0)		0 (0.0)
A1	206 (38)	N/A	290 (36)	N/A
A2	234 (43)	N/A	326 (41)	N/A
A3	80 (15)	N/A	131 (16)	N/A
Subtrochanteric	22 (4.1)	N/A	50 (6.3)	N/A
Screw/blade, n (%)		0 (0.0)		0 (0.0)
Screw	142 (26)		797 (100)	
Blade	400 (74)		N/A	
Size, n (%)		0 (0.0)		4 (0.5)
Short	419 (77)	N/A	620 (78)	N/A
Long	123 (23)	N/A	173 (22)	N/A
Mean TAD (SD)	19.8 (6.8)	28 (5.2)	17.6 (6.1)	41 (5.1)
Length of stay, days (SD)	8.8 (6.1)	0 (0.0)	9.6 (7.1)	0 (0.0)
Operation time, minutes (SD)	45.1 (21.7)	0 (0.0)	43.8 (23.4)	0 (0.0)

GTN3, Third generation of the Gamma Trochanteric Nail; N/A, not applicable; TAD, tip-apex-distance TFNA, TFN-Advanced Proximal Femoral Nailing System.

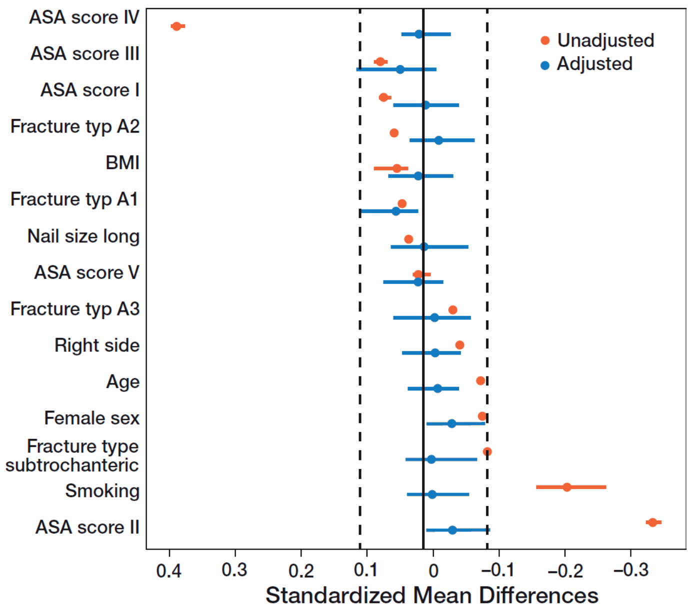

Figure 2 | Love plot showing mean standardized mean differences (between TFNA and GTN3) with their range across the 30 multiple imputed datasets before (unadjusted) and after propensity-score matching (adjusted).

Ethics, data sharing, funding, and potential conflicts of interest

Ethical approval for the study was granted by the Institutional Review Board (decision 2020-1596). The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. No funding was obtained and the authors have no conflicts of interest to declare.

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Results

1,377 intramedullary nails were implanted in 1,353 consecutive patients. In 562 (556 patients) trochanteric fractures a TFNA was placed, and 815 (797 patients) trochanteric fractures were treated with a GTN3. After exclusion of 20 patients in the TFNA group and 18 patients in the GTN3 group due to a pathologic fracture, 542 (536 patients) TFNAs and 797 (779 patients) GTN3s were included in this study. Fixation failure rates for both groups are presented in **Figure 3**.

TFNA vs. GTN3 after propensity-score matching

The Cox regression analysis revealed a failure of fixation of 14% in the TFNA group versus 7.0% in the GTN3 group, resulting in a hazard ratio (HR) of 2.0. The absolute risk difference of fixation failure in the TFNA group was 6.8% higher at 3 years’ follow-up compared with the GTN3 group (**Table 3**).

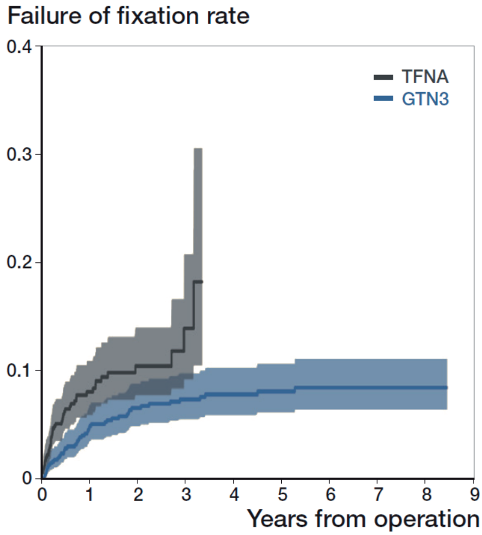

Figure 3 | Cumulative incidence with 95% CI of failure of fixation for TFNA and GTN3. P-value = 0.002 (log-rank test). For TFNA and GTN3 abbreviations, see Table 1.

The failures in the TFNA group versus the GTN3 group for each subgroup were: cut-out in 4.8% and 2.2%, implant breakage in 0.6% and 0.6%, non-union in 1.6% and 1.7%, malpositioning in 1.5% and 0.3%, new fracture around the nail in 5.2% and 1.4%, and miscellaneous in 1.2% and 1.0% (**Table 3**).

Table 3 | Hazard ratios and estimated absolute risk differences at 3 years in each group.

	HR (95%CI)	TFNA (%)	GTN3 (%)	Risk difference (% (95%CI))
Overall failure	2.0 (1.2 – 3.5)	14	7.0	6.8 (1.7 – 12)
Cut-out	2.2 (0.9 – 5.7)	4.8	2.2	2.6 (0.1 – 5.2)
Implant breakage	1.1 (0.1 – 9.0)	0.6	0.6	0.0 (-1.2 – 1.2)
Non-union	0.9 (0.3 – 3.3)	1.6	1.7	-0.2 (-2.4 – 2.1)
Malpositioning	4.7 (0.7 – 34)	1.5	0.3	1.2 (0.0 – 2.5)
Fracture around nail	4.0 (1.0 – 16)	5.2	1.4	3.9 (-0.8 – 8.5)
Miscellaneous	1.2 (0.2 – 8.2)	1.2	1.0	0.1 (-1.9 – 2.2)

GTN3, Third generation of the Gamma Trochanteric Nail; TFNA, TFN-Advanced Proximal Femoral Nailing System.

Learning curve

The TFNA EWMA plots revealed fluctuating curves around the mean without a clear decreasing trend in time for all 4 outcomes, indicative of the absence of a clear learning curve effect in the TFNA group (**Figure 4**). A separate sensitivity analysis excluding the first 50, 150, and 250 TFNA cases showed our results for fixation failure of the TFNA versus the GTN3 to be robust (**Table 4**, see **Supplementary data**).

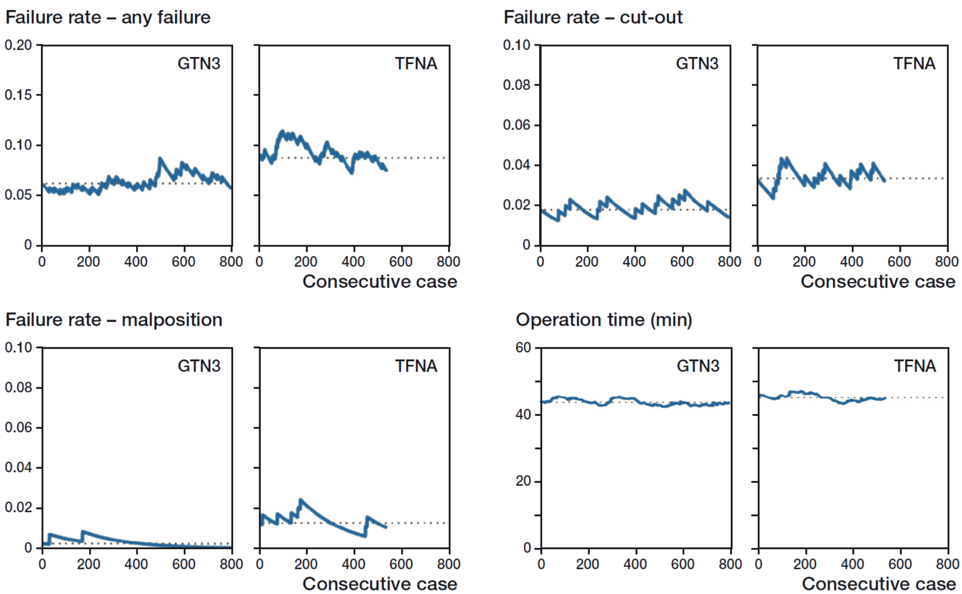

Figure 4 | Exponentially weighted moving average (EWMA) plots for overall failures, implant cut-out, malpositioning, and operation time for both TFNA and GTN3. Dotted lines illustrate the mean failure rates during the study period. For TFNA and GTN3 abbreviations, see **Table 1**.

Discussion

This study revealed an increased risk of fixation failure in the TFNA group. We found a hazard ratio (HR) of 2.0 (CI 1.2– 3.5) for fixation failure in the TFNA group compared with the GTN3 group. Cut-out and malpositioning appeared to be the most commonly encountered failure mechanisms. Learning curve analyses revealed that the potential influence of a learning curve could only have been minimal. The TFNA was introduced to the global market with a number of innovative implant modifications to improve clinical performance. To date, literature regarding the TFNA is limited to a few small case series reporting fixation failure rates of 2–7% (15-18). Amongst these case series, 2 recent studies also reported concerns about mechanically failed TFNA implants (17, 18). The higher risk of fixation failure in the TFNA group we found was mainly attributed to a higher risk of cut-out, malpositioning, and new fracture around the nail. In particular, the failure mechanisms cut-out and malpositioning may have been influenced by surgical technique. As learning curve analyses revealed no clear learning effect the encountered increase in fixation failures appears to be at least partly implant related. Several different features were introduced at a time within the TFNA such as a different anatomical fit, a smaller proximal diameter (LATERAL RELIEF CUT design), an oblique cut on the lateral end of the blade/screw, and a different design of the proximal hole (BUMP CUT design) (7). Lastly, the blade has been introduced to replace the calcar screw. Biomechanical studies presented in the manufacturer's value analysis brief reported a significantly higher resistance to cut-out of the TFNA helical blade compared with the TFNA screw (7, 19). 2 clinical studies using the TFNA reported on higher rates of implant cut-out with the use of a helical blade compared with lag-screw fixation in the treatment of trochanteric fractures with intramedullary devices (20, 21). These reports are in line with our study where 4.8% fixation failure was encountered in the TFNA group from implant cut-out versus 2.2% in the GTN3 group (Table 3). Of note is that a blade was used in 74% of our cases in the TFNA group because an age cut-off above 70 years old was used for the blade. As such, one may argue whether this concept of a blade versus a screw is indeed an improvement. In fact, the blade is hammered into the femoral head and so fracture distraction is introduced whereas compression is commonly accepted to increase chances of fracture healing. Furthermore, the oblique cut on the lateral end of the blade/screw was introduced to reduce lateral protrusion on the soft tissues (7). One could argue that the higher risk of malpositioning encountered in the TFNA group may partly have been the consequence of this innovation as the blade/screw can now only be inserted in the femoral head with steps of 360 degrees of rotation to align the lateral cortex while before more subtle 90-degree steps of insertion were an option. Our study has limitations. Due to the retrospective design, confounding is likely to be present. In an attempt to minimize this potential confounding, we performed propensity-score matching of patients on important confounding factors. Despite matching of patients on a subset of baseline characteristics, differences in unmeasured covariates probably still exist. For example, both an inter- and intra-surgeon difference concerning indication for reoperation cannot be ignored.

This potential bias appears to be limited, as indication for reoperation was established by consensus between all orthopedic/ trauma surgeons in weekly trauma meetings throughout the entire study period, thus avoiding single-surgeon decisions. Nevertheless, a randomized controlled trial is the ideal tool to control for bias. Furthermore, relatively small absolute differences are found in fixation failure rates between groups, and one may argue whether these differences are clinically relevant. Nonetheless, modifications in implant designs are aimed to improve clinical results and as such a decrease in clinical outcome, irrespective of a small margin, does not match with true gain in sustainability. Lastly, we did not correct for correlated bilateral cases in the analysis, while the methods of our statistical analysis do assume independent observations. However, previous studies showed bilateral surgeries do not introduce dependency problems in register studies (22, 23). From the limited data available in the literature on TFNA together with the encountered relatively high risk of fixation failure in this study there is reason to raise questions concerning the clinical benefit of the modifications applied to this device. In general, there is a tendency to overestimate the benefit of a newly introduced device (24). Newly introduced implants are often embraced by professionals after strong marketing without solid evidence (25). This rapid uptake of newly introduced implants into the market is, however, not without risks, in particular patients' health-related risks. For this reason, a structured introduction and regulated clinical monitoring of implant innovations has repeatedly been recommended (25). Such regulation and monitoring may also apply to trauma devices for internal fixation. In hindsight, we regret that also in our institution a new implant device was introduced without solid clinical evidence behind it. An institution-driven larger change of (trauma) implant supplier was the driving force behind this. This study may help to underline the need for medical doctors with a critical and scientific background to be at least involved in implant choices. In conclusion, this study revealed an increased risk of fixation failure in the TFNA proximal femoral nail in comparison with the Gamma nail (GTN3) for the treatment of trochanteric fractures. Cut-out and malpositioning were the most commonly encountered failure mechanisms. Modifications in implant design may have played a role in this increased risk of failure of fixation, because no clear learning curve effect was found.

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Supplementary data

Table 2 | Balance across multiple imputations before and after propensity score matching.

	Balance across imputations before PSM			Balance across imputations after PSM		
Characteristic	**TFNA**	**GTN3**	**Mean SMD (range)**	**TFNA**	**GTN3**	**Mean SMD (range)**
Mean age, yrs (SD)	78.8 (13.5)	79.9 (11.8)	-0.09 (-0.09 to-0.09)	79.0 (12.7)	79.2 (12.7)	-0.02 (-0.06 to 0.02)
Female, %	70	74	-0.09 (-0.09 to-0.09)	71	72	-0.04 (-0.10 to-0.01)
ASA score, %						
1	5.9	4.5	0.06 (0.05 to 0.07)	5.6	5.8	-0.003 (-0.06 to 0.05)
2	25	41	-0.36 (-0.37 to-0.35)	28	30	-0.04 (-0.10 to-0.01)
3	51	45	0.068 (0.06 to 0.08)	56	54	0.04 (-0.02 to 0.10)
4	17	4.6	0.39 (0.37 to 0.40)	8.0	7.8	0.01 (-0.04 to 0.03)
5	1.8	1.6	0.01 (-0.01 to 0.02)	2.1	2.0	0.010 (-0.03 to 0.06)
Mean BMI, (SD)	24.1 (4.4)	24.0 (4.2)	0.04 (0.02 to 0.08)	24.1 (4.4)	24.1 (4.3)	0.01 (-0.05 to 0.05)
Smoking status, yes, %	17	26	-0.23 (-0.29 to-0.18)	18	18	-0.01 (-0.07 to 0.03)
Fracture type, n (%)						
A1	38	36	0.03 (0.03 to 0.03)	40	38	0.04 (-0.01 to 0.01)
A2	43	41	0.05 (0.05 to 0.05)	40	41	-0.02 (-0.08 to 0.02)
A3	15	16	-0.05 (-0.05 to-0.05)	15	16	-0.02 (-0.07 to 0.05)
Subtrochanteric	4.1	6	-0.10 (-0.10 to-0.10)	4.6	4.7	-0.01 (-0.08 to 0.03)
Size, %						
Short	77	78	0.023 (0.02 to 0.02)	78	78	-0.001 (-0.07 to 0.05)
Long	23	22		22	22	

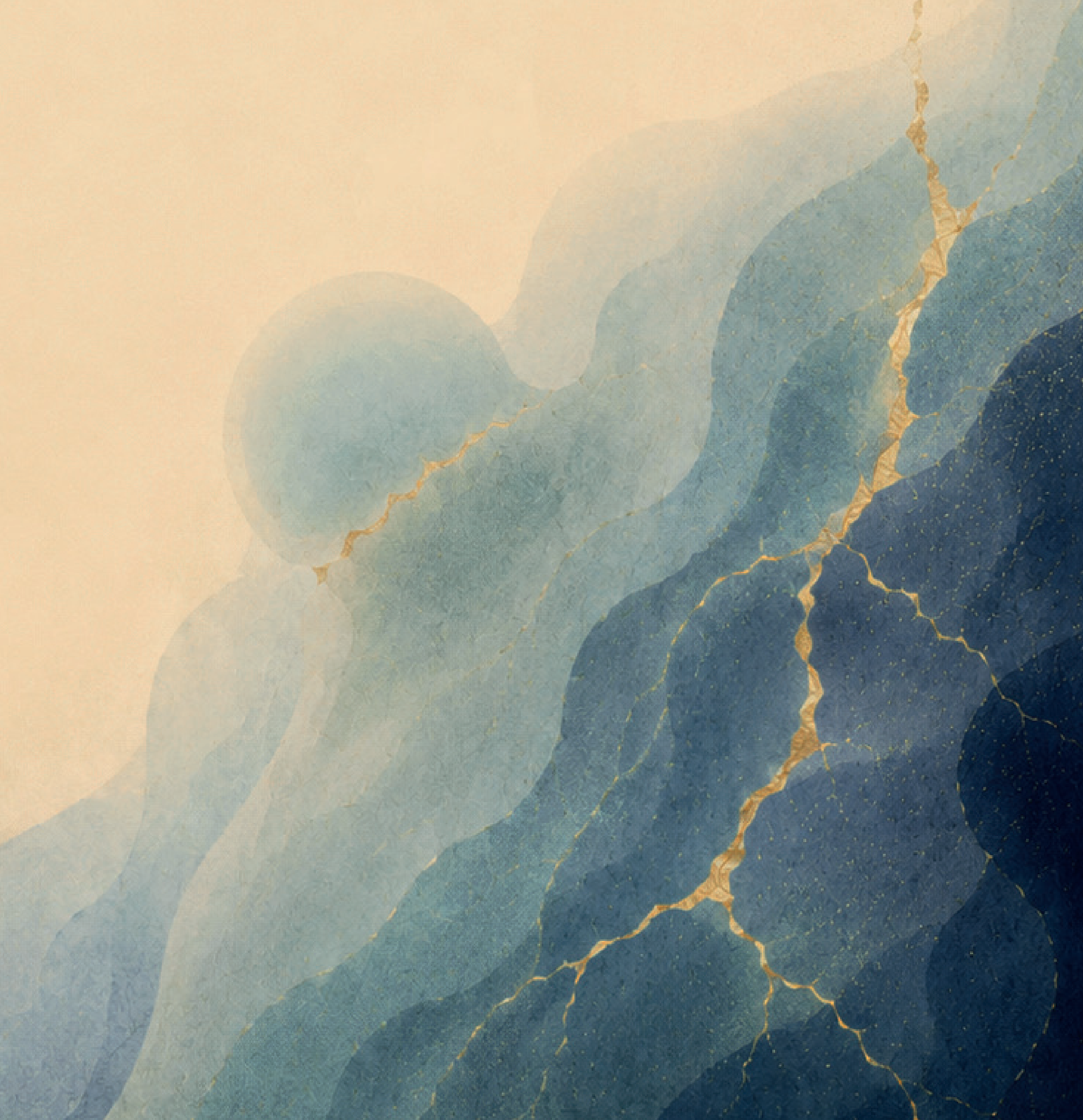
Balance between groups is presented as mean standardized mean differences (SMD) with the corresponding minimum and maximum standardized mean differences across the 30 multiple imputed datasets. Patient characteristics are presented as pooled mean (SD) for continuous variables or as pooled percentages for binary or categorical variables across multiple imputations. For TFNA and GTN3 abbreviations, see Table 1.

Table 4 | Hazard ratios of fixation failure of the TFNA with scenario's excluding different numbers of TFNA cases to elucidate a potential learning curve effect.

Scenario	HR (95%CI)
All cases	2.0 (1.2 – 3.3)
First 50 TFNA cases excluded	2.1 (1.1 – 3.7)
First 150 TFNA cases excluded	1.6 (0.8 – 3.0)
First 250 TFNA cases excluded	2.4 (1.0 – 5.9)

TFNA, TFN-Advanced Proximal Femoral Nailing System.

Part 3:
Operative versus non-operative treatment



CHAPTER 8

Nonoperative management of hip fractures in very frail elderly patients may lead to a predictable short survival as part of advance care planning

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Acta Orthopaedica, 2021

Abstract

Introduction

Surgical treatment is still the mainstay of care even in very frail elderly hip fracture patients. However, one may argue whether surgery is in the best interest of all patients. We elucidated mortality rates of nonoperative management (NOM) of a hip fracture after shared decision-making in a cohort of very frail elderly patients.

Methods

Orthogeriatric patients (age > 70 years) admitted with a hip fracture between 2011 and 2019 were included. In the presence of fragility features the motivation for surgery or NOM was supported by advance care planning (ACP) and shared decision-making through geriatric assessment. Mortality rates after NOM were assessed and also presented for the remaining surgical group for reference.

Results

In 1,279 out of 3,467 patients, geriatric assessment was indicated and subsequently 1,188 (93%) had surgery vrsus 91 (7%) NOM. The motivation for NOM was based on patient and family preferences in only 20% of patients, medical grounds in 54%, and a combination of both in 26%. The 30-day and 1-year mortality in the frail NOM group was 87% and 99% respectively, whereas this was 7% and 28% in the surgery group. No statistical comparison between groups was performed due to profound bias by indication.

Conclusions

This study provides further insight into the predictable and high short-term mortality after NOM in carefully selected very frail elderly hip fracture patients. This information may help to consider NOM as an alternative treatment option to surgery when no significant gain from surgery is anticipated.

Introduction

The incidence of hip fractures in frail patients is rising due to an increase in life expectancy and cumulative comorbidities (1-3). In particular, frail elderly patients experience a substantial decrease in quality of life and mobility in the 12 months after hip fracture surgery (4). Deliberations whether to operate or not in these frail elderly patients are common in daily practice (5-7). Surgery is still the mainstay of treatment because it results in a better mobility and survival (8, 9) and nonoperative management (NOM) is often characterized by problematic after-treatment with substantial patient discomfort. One may argue, however, whether surgery is in the best interest of all patients. It may be that the time has come to re-evaluate to what extent frail patients should always be treated surgically. Frailty is negatively associated with quality of life after a hip fracture and may require tailored treatment, especially in patients with a short life expectancy and anticipated postoperative functional decline (10, 11). A hip fracture is a life-threatening condition in these frail patients and as such may be considered an opportunity to discuss end-of-life care, personal goals, and the preference for surgery or NOM with their potential pros and cons (5) This concept is also known as "advance care planning" (ACP) (12, 13). The literature on life expectancy after nonoperative management (NOM) is limited. For example, 30-day and 1-year mortality rates after NOM ranging from 5–65% and 30–95% have been reported (14). These wide ranges of early mortality rates reflect differences in patient characteristics and fracture types between studies and extrapolation of information from these studies towards shared decision-making in clinical practice is difficult. There is increasing awareness that operative treatment of a hip fracture may not always be the best option in all patients and that in a subgroup of frail elderly patients NOM should be considered and may also be patients' preference. For this purpose it is important to obtain valid information on what can be expected in terms of survival after NOM in a well-selected subgroup of very frail patients. In this way informed consent and shared decision-making on treatment options for fragility hip fractures can be improved. We elucidated mortality rates in a consecutive group of 91 out of 1,279 patients with a fragility hip fracture treated with NOM after ACP and shared decision-making. Survival for the remaining surgically treated patients is also presented for reference.

Patients and methods

Study population

We performed a retrospective study to elucidate the course of mortality after NOM of a hip fracture. All consecutive hip fracture patients aged 70 years and older treated on the orthogeriatric ward were included between January 2011 and June 2019. Indication for admittance to the orthogeriatric ward was set by the orthogeriatric team after a comprehensive geriatric assessment on the somatic, psychiatric, functional, or social domain in order to identify fragility features. Patients with 1 or more fragility features were admitted to the orthogeriatric ward, whereas relatively vital and mostly younger patients were admitted to the surgical ward. The latter group of patients was not part of this study (**Figure 1**). Exclusion criteria were pathological hip fractures and periprosthetic hip fractures due to their impact on mortality. The decision for surgery or NOM was made as a shared decision-making consultation with the patient and relatives. ACP was applied by mutually exploring treatment preferences, mobility, quality of life, goals in life, and survival in a comprehensive geriatric assessment (6). Surgery consisted of either hemiarthroplasty or internal fixation. The NOM approach focused on optimal comfort for the patient and mainly consisted of treatment of symptoms, in particular pain with analgesics. Patients returned to their homes or residential care facilities if feasible or were discharged to a nursing home with hospice care facilities.

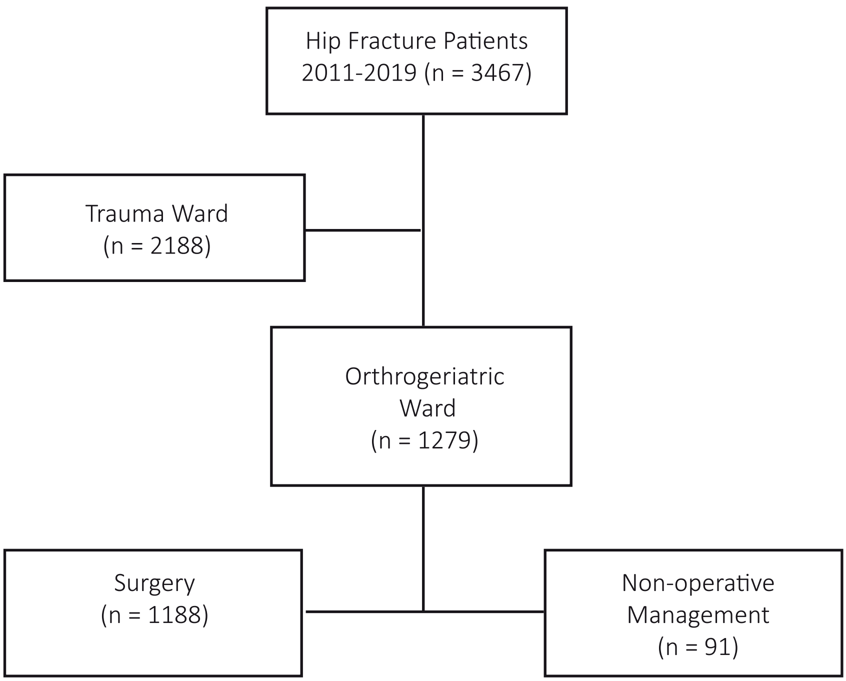

Figure 1 | Flowchart of patient selection.

Study variables

The following parameters were retrospectively collected from the patient records: age, sex, Charlson Comorbidity Index (CCI), mobility, living situation, cognitive status (dementia), type of fracture, and type of surgery. Reports from the shared-decision consultation resulting in a choice for NOM were reviewed. The reason for NOM was scored independently by 2 authors (HW and DT) as (1) based on patient and family preferences, (2) obvious medical grounds with unacceptable high perioperative risk, or (3) a combination of both. In the case of disagreement consensus was subsequently achieved by discussion between both authors. If applicable, date of death was obtained from the medical records or from the

Dutch Personal Records Database, which contains personal data of people who live in the Netherlands. Subsequently 30-day mortality and 1-year mortality rates were determined.

Statistics

From a profound bias by indication together with a relatively small group on NOM no statistical analysis on differences between groups was performed.

Ethics, funding, and potential conflicts of interest

Ethical approval for the study was granted by the Institutional Review Board (decision 2016-938). No funding was obtained and the authors have no conflicts of interest to declare.

Results

Baseline characteristics

Between 2011 and 2019, 3,467 hip fracture patients were admitted to our hospital of which 1,279 frail elderly hip fracture patients (37%) were admitted to the orthogeriatric ward (**Table 1**). From this study group 1,188 patients received surgical treatment whereas for 91 NOM was chosen. As such NOM was offered to 7.1% (91/1,279) of patients admitted to the orthogeriatric ward and to 2.6% (91/3,467) of all patients (**Figure 1**). As anticipated, the 1,188 patients in the surgery group were younger than the 91 patients in the NOM group—84 (SD 6.7) years versus 87 (SD 6.3) years, respectively. Pre-fracture mobility was better in patients who were operated on compared with those who were not, reflected by 45% of surgery patients being able to walk independently compared with 12% of patients in the NOM group. Further, dementia and living situation were different in the 2 groups, which is probably a reflection of the confounding bias by indication (15).

Motivation for nonoperative management

In 18 of 91 patients the decision for NOM was clearly based on patient and family preference whereas medical grounds were not evident. In 49 patients NOM was almost completely dictated on medical grounds (comorbidity and high perioperative risk) and in 24 patients this was a combination of both.

Mortality rates after nonoperative management and surgery

The 30-day and 1-year mortality rates in the frail NOM group were 87% and 99%, respectively (**Figure 2**). Of the 91 patients in the NOM group only 21 survived after 2 weeks, 12 were alive after 30 days, and only 3 after 3 months. Mean survival was 0.7 months in the nonoperatively managed patients. The 30-day and 1-year mortality rates in the surgery group were 7% and 28%, respectively (**Figure 2**). Mean survival was 36 months in the surgically managed patients.

Table 1 | Patients' characteristics at baseline.

Population variable	Surgery n=1188	Non-operative n=91	p-value
Age in years (SD)	84 (6.7)	87 (6.3)	<0.001
Sex (female)	877 (74%)	59 (65%)	0.06
Type of hip fracture			0.18
Femoral neck	639 (54%)	53 (58%)	
Trochanteric	444 (37%)	35 (39%)	
Other	105 (9%)	3 (3%)	
Charlson Comorbidity Index			0.06
<3	877 (74%)	59 (65%)	
≥3	311 (26%)	32 (35%)	
Living situation			<0.001
Independent	725 (61%)	26 (29%)	
Sheltered Care	149 (13%)	19 (21%)	
Nursing home	200 (17%)	46 (50%)	
Missing	114 (9%)		
Dementia	317 (27%)	48 (53%)	<0.001
Mobility			<0.001
Without assistance	511 (43%)	9 (10%)	
Cane/walker	614 (52%)	53 (58%)	
Wheelchair/bedridden	24 (2%)	13 (14%)	
Missing	39 (3%)	16 (18%)	

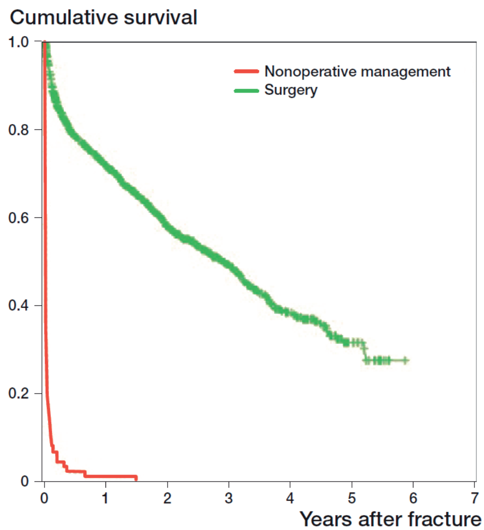

Figure 2 | Kaplan-Meier survival analysis after nonoperative management (91 patients) and surgery (1,188 patients).

Discussion

This study was primarily conducted to provide more insight into the course of NOM in a selected group of very frail elderly hip fracture patients in whom ACP with patients and relatives had resulted in a shared decision not to operate to prolong life. The 30-day and 1-year mortality rates in this group were 87% and 99%, respectively. In contrast the reference 30-day and 1-year mortality rates in the surgery group were 7% and 28%, respectively. The choice for NOM was at least partly based on patient or family preference in almost half of these patients (46%), whereas the other half was treated nonoperatively mainly based on medical grounds (54%). We found a very high 30-day mortality of 87% in nonoperatively managed hip fracture patients. These findings differ from other previously published studies with a 30-day mortality ranging from 5% to 65% (14, 16). A recent review has already pointed out that these large differences in mortality rates are most probably caused by differences in patient characteristics such as pre-fracture mobility, prevalence of dementia, and living situation (14). The clinical dilemma whether to decide for NOM and subsequent palliative care mainly applies to very frail elderly hip fracture patients. As such, it should be noted that the nonoperatively managed patients in our study were typically identified on the basis of their frailty with a low functional pre-fracture mobility who have not much to gain from surgery. In contrast, patients from available studies so far were less frail and had a better pre-fracture mobility, resulting in a treatment focus on active mobilization to regain function and prolong life (14). For example, Berry et al. (2018) found a lower mortality rate of 54% at 6 months in a retrospective cohort study of 468 nonoperatively treated nursing home patients with advanced dementia and a hip fracture and Hossain et al. (2009) reported a mortality rate of 19% at 1 month in a retrospective cohort study of 21 nonoperatively treated patients (9, 17). Again, we feel this can be explained by a different inclusion of patients for NOM. For example, Berry et al. also included patients with pelvic fractures and palliative care was initiated in only 34% of the patients, whereas in our study this accounted for all patients (9). In turn, Hossain et al. seemed to have used a different selection of patients as well, as a substantial number of non-displaced and impacted femoral neck fractures were included in which case NOM is an established approach to achieve healing of the fracture (17). Again, this is an important confounder because nonoperative fracture treatment in non-displaced femoral neck fractures is entirely different from the palliative care approach in our study. The choice of NOM in very frail elderly patients with a hip fracture is delicate and ethical, cultural, and legal issues apply, which can be different for countries. We believe that there is an increasing awareness that, in spite of the fact that—in general—surgery increases survival and the chances of regaining mobility, not all patients prefer surgical treatment. Instead, we should aim to improve recognition of this small group of very frail patients who have not much to gain from surgery and often do not wish to prolong life. This phenomenon is also well illustrated by a recent article of the Dutch association for medical doctors in which half of the nursing home patients indicated a preference for NOM above surgery should they be admitted to hospital with a hip fracture, irrespective of possible shorter survival (18). A retrospective evaluation of the reason for NOM in our study confirmed that patient preference is an important reason for NOM in almost half of the patients. A thorough decision-making process is essential to recognize this specific group of very frail elderly patients in which NOM of a hip fracture may be considered. Frail elderly patients require ACP where multiple comorbidities, short life expectancy, anticipated postoperative functional decline, and low quality of life are discussed, together with patient preference personal goals and end-of-life wishes (10, 11). In this ACP the frail patients, their relatives, and healthcare professionals participate and decide together on NOM or surgery. The concept of patient-centered tailored treatment, ACP, was first conceptualized in the United States (12) with the purpose to receive medical care consistent with one's preferences (5, 7, 13). ACP is increasingly integrated in daily care for frail elderly patients with a hip fracture in European countries, although there is still room for improvement (19). This study has its limitations. The most important limitation is the recognized “confounding bias by indication” because the decision for NOM is typically made in a subgroup of frail patients with more comorbidities, higher age, lesser mobility, and dementia. In spite of the fact that these confounders can be corrected for in statistical models, we feel that this would oversimplify the problem and that profound bias would remain. One may argue whether this confounding is truly relevant with regards to the interpretation of the results. We decided to simply present the survival curves for NOM and surgery as reference, because it is beyond the scope of this study to compare mortality rates in NOM and operative treatment of hip fractures in elderly patients. Moreover, this study aimed to gain insight into the course of NOM with palliative care so that this option can be incorporated in balanced (shared) decision-making. Perhaps more importantly, from the mortality observed in the NOM group it appears that a rapid decline can be expected. Second, the inclusion of patients was limited to those patients admitted to the orthogeriatric ward, also indicating selection bias. However, these frail elderly patients in particular, selected by a comprehensive geriatric assessment, reflect the population of concern in the clinical dilemma of NOM of hip fractures. We feel that this clear selection bias may also reflect the high 30-day and 1-year mortality rates encountered in this study as compared with the available literature. Besides limitations, important strengths also apply. In this study a rather homogeneous group of 91 very frail hip fracture patients were treated nonoperatively. This provided important information on the course of treatment and mortality, which is lacking in the available literature with a smaller number of patients and more importantly inhomogeneous fragility features (8). This information is important as it can be applied directly towards the clinical setting where we encounter the dilemma of whether surgery is indeed in the best interests of and in accordance with the preference of a patient with a fragility hip fracture. In conclusion, this study revealed a predictable short survival after NOM of hip fractures in a group of very frail elderly patients where prolonged survival was not considered to be the primary goal of treatment. These results may reassure clinicians, patients, and their relatives that NOM can be regarded as a relevant treatment option with a predictable outcome in very frail hip fracture patients. In the case of limited life expectancy, information regarding nonoperative supportive management and well-managed pain in a palliative setting might help patients and their families to come to a wellfounded decision in line with their wishes, goals, and end-of-life expectations. Therefore, in our opinion, NOM should gain more attention and ACP should be part of standardized preoperative hip fracture care in the frailest patients.

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CHAPTER 9

General Discussion

The incidence of femoral neck fractures is high and extensive research is performed worldwide. Nevertheless, several controversies in hip fracture treatment persist:

I. Total hip arthroplasty versus hemiarthroplasty
II. Hip arthroplasty versus internal fixation
III. Operative versus non-operative treatment

The optimal treatment for the individual hip fracture patient remains a subject of ongoing debate which depends on a complex interplay of patient and fracture characteristics. So far literature has focused on large patient cohorts, however it seems that detailed evaluation of subgroups of patients is needed to make the best choice of treatment in the individual patient since each case varies significantly in terms of these characteristics. This thesis explored several aspects of three recognized controversies to help clarify the best treatment for the individual patient.

Part 1: Total hip arthroplasty versus hemiarthroplasty

The controversy concerning the most appropriate treatment for femoral neck fractures with either total hip arthroplasty (THA) or hemiarthroplasty is still ongoing. Despite extensive research, including numerous randomized controlled trials and systematic reviews with large number of patients, no consensus has been reached (1). The choice between these two types of arthroplasty largely depends on the patient's characteristics. Hemiarthroplasty is commonly used for frail elderly patients with low functional demands, as these individuals benefit from shorter operation times and a lower risk of dislocation of hemiarthroplasty versus THA (2, 3). However, in more active patients with a significant life expectancy wear of the acetabular cartilage may eventually lead to the need to convert hemiarthroplasty to total hip arthroplasty.

Since no consensus exists concerning the best treatment with either total hip arthroplasty or hemiarthroplasty, the potential need for and outcomes of potential future interventions becomes more relevant when making the initial treatment choice. For example, to which extend a hemiarthroplasty can still be converted towards a total hip arthroplasty without affecting the eventual outcome of the latter is an important factor. As such, **Chapter 2** studied the outcome of conversion of hemiarthroplasty to total hip arthroplasty. A systematic review and meta-analysis of 27 studies, including 4 comparative studies and 23 cohort studies, found that the revision risk of a THA after conversion of a hemiarthroplasty was higher than that of primary THA after a neck fracture (Hazard Ratio (HR) 1.7, 95% confidence interval (CI) 1.4-2.1). The annual revision rate after conversion of hemiarthroplasty to THA was 1.63% (95%CI 1.1-2.3) in comparative studies and 1.40% (95%CI 1.2-1.7) in cohort studies. An infection rate of 4.34% (95%CI 2.7-7.0) and a dislocation rate of 4.79% (95%CI 3.0-7.5) were found. This study shows that conversion of hemiarthroplasty to total hip arthroplasty influences the results of the latter. This is important information in weighing the balance in clinical decision making concerning the best index treatment in patients suffering from femoral neck fractures.

As mentioned earlier, hemiarthroplasty is predominantly used for elderly patients since there is a potential need for conversion towards THA in younger patients. However, only a few studies have reported on its use in younger patients and thus limited data are available on the clinical relevance of this issue. **Chapter 3** presents a retrospective cohort study of 248 patients younger than 75 years old treated with hemiarthroplasty for a femoral neck fracture. The conversion rate to total hip arthroplasty and the subsequent patient-reported outcome measurements (PROMS) were evaluated. The conversion rate was found to be 7.3% after a mean follow-up of 5.1 years. In 77% of these revisions, acetabular wear was identified as the reason for conversion. Unrevised hemiarthroplasties reported low pain scores. This study may suggest that the indication for hemiarthroplasty may be expanded towards younger patients in selected cases, especially to those with serious comorbidities and expected low-demand mobilization since a limited conversion rate was encountered in a cohort of patients with an age below 75.

Furthermore, a protocolized postoperative follow-up of hip fractures, especially in case of frail elderly individuals, could be a significant burden for these patients and their relatives. This follow-up is common daily practice and patients are typically scheduled for outpatient follow-up visits to monitor for complications. To date, it remains unclear whether these visits are effective in detecting complications following hemiarthroplasty. **Chapter 4** describes a retrospective study and a national survey to evaluate the use of routine follow-up and the complication detection rate at postoperative visits of patients treated with hemiarthroplasty. The survey showed that postoperative follow-up is indeed the standard of care after hemiarthroplasty in most hospitals. The complication detection rate during planned visits at the outpatient department appeared to be 0.3%. The vast majority of complications was detected, besides these protocolized visits, through a visit at the emergency unit. One could argue that alternative follow-up protocols are needed since routinely planned visits do not detect complications after hemiarthroplasty while these visits are a high burden for patients and health care professionals. Alternative follow-up methods should be focused on persisting pain and restoration of function, and could be detected by phone consultations or visits by general practitioners or physiotherapists. This discussion on the utility of routine follow-up also extends to other hip fracture treatments. For instance, follow-up after internal fixation of trochanteric fractures has been shown to be unnecessary and the need for routine follow-up after THA is also debated (4-6).

Part 2: Hip arthroplasty versus internal fixation

Another important controversy in hip fracture management concerns the best treatment for femoral neck fractures with either arthroplasty or internal fixation. Literature suggests that (hemi)arthroplasty is generally the best option for patients over 70 years of age, while internal fixation is favored for those under 60, as it preserves the native hip joint (7-10). Therefore, treatment of femoral neck fractures in the 60- to 70-year age group is still most controversial (11). However, detailed information regarding patient characteristics, implant type and the results of future interventions are needed to make the best choice of treatment in this controversial group. Although literature describes studies performed with groups of patients with a wide variety of characteristics and fracture patterns, literature still lacks information concerning these specific characteristics. For example, the risk of future reinterventions and their outcome need to be part of the shared decision-making process concerning the index-treatment, especially in this relatively young age group. Therefore, it is important to know whether the choice of treatment with internal fixation affects the results of an eventual future total hip arthroplasty since failure of internal fixation is common and is often treated with total hip arthroplasty as a salvage procedure. Both **Chapters 5** and **6** address the revision risk of salvage total hip arthroplasty (salvage-THA) in comparison to total hip arthroplasty as a primary treatment of a femoral neck fracture (fracture-THA). **Chapter 5** presented a multicenter retrospective cohort study in which complications and implant survival were studied in 284 salvage-THAs and 264 fracture-THAs. After a mean follow-up of 5 years no statistical significant differences were found between salvage-THA and fracture-THA in terms of complications and survival. In a subsequent register-based study, **Chapter 6** further investigated the revision risk of salvage-THA with the use of the Dutch Arthroplasty Register (LROI). This study included 4,310 salvage-THAs and 12,159 fracture-THAs. The data of total hip arthroplasties placed for osteoarthritis (274,147 hips) were used as a third reference group. We found no significant difference in revision rates between salvage-THAs and fracture-THAs. The 5-year revision rate was 5.0% (95%CI 4.4-5.8) in salvage-THAs and 4.5% (95%CI 4.1-5.0) in fracture THAs. However, both groups had higher revision rates compared to THAs performed for osteoarthritis. Prosthetic joint infection (PJI) was identified as the dominant reason for revision in the salvage-THA group which aligns with existing literature (12). Thus, while revision rates for salvage- and fracture-THA are similar, internal fixation may negatively influence THA outcomes due to the higher infection risk associated with salvage procedures. This information is valuable for shared decision-making, especially in patients aged 60–70 years who may require salvage THA. These patients should be informed about the high chance of reoperation up to 27% leading to salvage total hip arthroplasty (13). On the other hand, patients in this age group without an early revision after internal fixation, benefit from their native hip joint since a good result of internal fixation will extend the time to total hip arthroplasty or even prevent them from this.

The implant choice of internal fixation also plays a critical role. The failure risk after internal fixation of hip fractures in general is high and this risk widely varies between implants. In particular innovative devices, of course claiming better outcomes, have to be monitored critically on complication and failure rates and compared to available gold standard internal fixation devices. In **Chapter 7,** we retrospectively compared 797 hip fractures treated with the use of the third generation of the Gamma Trochanteric Nail (GTN3) and 542 hip fractures treated with the newly introduced TFN-Advanced Proximal Femoral Nailing System (TFNA). After propensity score matching, a higher risk of fixation failure was found in the TFNA group (14%) compared with the GTN3 group (7.0%) (HR 2.0, 95%CI 1.2–3.5). This was mainly attributed to a higher risk of cut-out (HR 2.2; 95%CI 0.9–5.7), malpositioning (HR 4.7; 95%CI 0.7–34), and new fractures around the nail (HR 4.0; 95%CI 1.0–16). The TFNA was introduced to the global market with a number of innovative implant modifications to potentially improve clinical performance. However, despite the wide use of the TFNA, literature concerning this implant is limited to a few small case series (14-17). The manufacturer's value analysis letter only reports some biomechanical studies with small series. From the limited data available in the literature on TFNA, together with the encountered relatively high risk of fixation failure in this study, there is reason to raise questions concerning the clinical benefit of the modifications applied to this device. One modification of this device is the use of a helical blade instead of a screw. In contrast to the earlier device with a screw, this helical blade is hammered into the femoral neck and head by which means the blade forces itself a way through the bone in a rotating spin. This way of blade introduction generates fracture distraction whereas a screw would commonly apply compression on the fracture which is commonly accepted to increases chances of fracture healing. While the manufacturer's value analysis letter reported a significantly higher resistance to cut-out of the TFNA helical blade compared with the TFNA screw (18, 19), two clinical studies show higher rates of cut-out with the use of a TFNA helical blade (20, 21). So, in particular the use of the helical blade could have caused the higher failure risk in patients treated with the TFNA found in our study and should be the focus of a critical analysis.

In general, there is a tendency to overestimate the benefit of a newly introduced device. Newly introduced implants are often embraced by professionals after strong marketing without solid evidence. This rapid uptake of newly introduced implants into the market is, however, not without risks, in particular patients' health-related risks. For this reason, a structured introduction and regulated clinical monitoring of implant innovations is recommended (22). The performance of orthopaedic arthroplasties is strictly monitored by the Orthopaedic Data Evaluation Panel (ODEP) (23). Such regulation and monitoring may also be extended to trauma devices for internal fixation, in order to prevent the use of implants lacking robust evidence regarding their reliability and safety.

In conclusion, these studies elucidated on the risk of complications and re-operations in subgroups of patients with a hip fracture in the age group of 60-70 years old and contributed to gain better insight into the risk of future interventions and their outcomes. The best treatment of a femoral neck fracture in the age group of 60-70 years old, with either internal fixation or arthroplasty, still depends on a complex interplay of characteristics of the patient, fracture and implant. The risk of complications and re-operations widely differ between patients with different characteristics and fracture patterns. The results from the presented studies in this thesis contribute to a more tailored decision making and consent to make the best choice of treatment in the individual patient.

Part 3: Operative versus non-operative treatment

The debate about whether frail elderly patients with limited life expectancy should receive operative or non-operative management (NOM) is ongoing due to limited evidence, cultural differences between countries and ethical dilemmas. Surgical treatment remains the standard of care, even for very frail patients, and has a proven prolonged life expectancy for the patient. However, it can be argued that surgery may not always be in the best interest of all patients, and in some cases non-operative management may be preferred. Although several studies have highlighted the increased early mortality rates associated with non-operative treatment, the focus for frail patients may need to shift towards optimal pain relief and patient comfort rather than prolonging life. The increasing interdisciplinary collaboration in ortho-geriatric trauma care can improve the delivery of patient-centered care and offer shared decision making when possible and could consider non-operative palliative care for the most fragile patients.

For this purpose, it is important to obtain valid information on what can be expected in terms of survival after non-operative management in a well-selected subgroup of very frail patients. **Chapter 8** presents a study on mortality rates in a cohort of 91 frail hip fracture patients with a mean age of 87 years who were treated with non-operative management after advanced care planning and shared decision-making. Survival of surgically treated patients in the same age group was presented for reference. Motivation for non-operative management was based on patients and family preference in only 20% of patients, in 54% motivation was based on medical grounds and in 26% a combination of both. In this cohort, the 30-day and 1-year mortality rates were 87% and 99%, respectively. In contrast, surgically treated patients within the same age group had 30-day and 1-year mortality rates of 7% and 28%, respectively. Due to confounding by indication no direct comparison between these two groups can be made since the decision for NOM is typically made in a subgroup of frail patients with more comorbidities, higher age, lesser mobility, and dementia. The choice of non-operative management in very frail elderly patients with a hip fracture is delicate and ethical, cultural and legal issues apply, which may vary across countries. We believe that there is an increasing awareness that, in spite of the fact that in general surgery increases survival and the chances of regaining mobility, not all patients prefer surgical treatment. Instead, we should aim to improve recognition of this small group of very frail patients who have not much to gain from surgery and often do not wish to prolong life. A thorough decision-making process is essential to recognize this specific group of very frail elderly patients in which non-operative management of a hip fracture may be considered. Frail elderly patients require advanced care planning where multiple comorbidities, short life expectancy, anticipated postoperative functional decline, and low quality of life are discussed, together with patient preferences and end-of-life wishes (24, 25). In this advanced care planning the frail patients, their relatives, and healthcare professionals participate and decide together on non-operative management or surgery. This study revealed a predictable short survival after non-operative management of hip fractures in a group of very frail elderly patients where prolonged survival was not considered to be the primary goal of treatment. These results may reassure clinicians, patients, and their relatives that non-operative management can be regarded as a relevant treatment option with a predictable outcome in very frail hip fracture patients. In the case of limited life expectancy, information regarding nonoperative supportive management and well-managed pain in a palliative setting might help patients and their families to come to a well-founded decision in line with their wishes, goals, and end-of-life expectations. Therefore, in our opinion, non-operative management should gain more attention and advanced care planning should be part of standardized preoperative hip fracture care in the frailest patients.

Conclusion

The rising elderly population with concomitant hip fractures is a major public health concern. This population is a high burden to the healthcare system since it concerns high numbers of patients with dependency of both in and out of hospital care. Hip fractures often result in long hospital stays, high risk of complications, and the need for extensive rehabilitation which further strain healthcare resources. The socio-economic impact extends beyond direct medical costs, as many patients require long-term support from caregivers and social services. Given the projected increase in the aging population worldwide, developing effective, personalized treatment strategies is essential to improve outcomes and maintain viability within healthcare systems.

In conclusion, this thesis provided further insight into the controversies in hip fracture treatment. Each study focused on one of these controversies elucidating on the importance of specific patient and implant characteristics. The studies in this thesis led to several conclusions:

1. Conversion of hemiarthroplasty to total hip arthroplasty affects the outcome of the latter.
2. From the observed low need for conversion towards an acetabular component, hemiarthroplasty could be a viable treatment option in well selected patients with an age below 75.
3. Regular postoperative follow-up in patients treated with hemiarthroplasty is not useful in detection of complications and should be abandoned as the standard of care.
4. Internal fixation may negatively influence the outcomes of subsequent salvage total hip arthroplasty due to the higher infection risk as compared to a direct THP after fracture.
5. TFN-Advanced Proximal Femoral Nailing System (TFNA) has a higher risk of fixation failure compared to the Gamma Trochanteric Nail (GTN3) in trochanteric fractures.
6. Non-operative management should be part of shared decision making in the very frail elderly hip fracture patient.

Future Perspectives

The findings of this thesis highlight that treatment decisions of fractures of the proximal femur should be based on a detailed understanding of individual patient profiles, fracture types and implant options. Chronological age is often the predominant factor influencing clinical decision-making due to its easy accessibility. However, it does not capture the full complexity of a patient's physiological condition. In clinical practice, considerable variation exists among patients of the same age in terms of general health, functional status and mobility. Chronological and biological age can differ significantly. In my opinion the choice of treatment with either, internal fixation, total hip arthroplasty, hemiarthroplasty or non-operative management should primarily be influenced by the biological age of the patient as the most important patient characteristic. Therefore, research should focus on improved quantification of biological age in the future. Still, patients biological age remains complex and hard to express in exact numbers. However, comorbidity, life expectancy, mobility, cardiopulmonary condition and ASA-classification (American Society of Anesthesiologists), are more objective reflections of biological age and should be used in future research as surrogate measures to differentiate between treatment strategies.

Development of a hip fracture prediction tool regarding the outcome of both internal fixation and arthroplasty in terms of risk of complication and/or re-operation based on specific patient characteristics and fracture patterns would be ideal to eventually be able to predict the best treatment in the individual patient and make a tailored decision. Well defined and well registered data is essential to develop a tool like this. National registries could contribute, as they concern large groups of patients. However most registries currently do not cover all treatment options in hip fracture management. Besides that, only a small part of relevant data is collected in registries to limit burden of administration. A potential solution could involve combining data from multiple registries. After completion of this tool, the prediction model could continuously be update with new data to gradually obtain an increasingly improving prediction of a tailored treatment for the individual patient. This prediction tool could also help us in the decision-making process between operative and non-operative management of hip fractures in very frail elderly patients. In this thesis we described a predictable and high short-term mortality after non-operative management with a 30-day mortality of 87%. Still, selecting patients for non-operative management by this decision-making process remains difficult in the individual patient since evidence focusses on groups of patients. The influence of comorbidity, mobility, level of care dependency and cognitive state on the results of both operative and non-operative management in very frail elderly hip fracture patients is still unclear. Future research should focus on these aspects and should feed this prediction tool to create more clear expectations after both treatment options.

Hip fracture patients represent a large and growing population worldwide. Although the differences in treatment outcomes are often modest, even small improvements can have a significant impact on this extensive group. Therefore, it is essential that evidence-based treatments are applied consistently, and that clinical guidelines are harmonized across countries. For instance, the literature clearly demonstrates superior outcomes for cemented hemiarthroplasty compared to uncemented hemiarthroplasty, primarily due to the higher incidence of periprosthetic fractures associated with the latter (26, 27). Nevertheless, current registry data indicate that uncemented hemiarthroplasty continues to be used in up to 20% of cases in several Western countries (28). This continued use may be influenced by other factors, such as operative efficiency, given the shorter procedure time associated with uncemented implants. However, in light of the robust evidence in favor of cemented hemiarthroplasty, the use of uncemented hemiarthroplasty should, in my opinion, be abandoned from hip fracture care.

The optimal treatment strategy for femoral neck fractures in patients aged 60–70 remains a topic of debate. In individuals with a higher biological age, internal fixation is associated with a considerable risk of failure. Conversely, more active patients with better bone quality face a lower risk of failure and may benefit from preservation of the native hip joint. When internal fixation fails, salvage total hip arthroplasty is often required, which entails additional surgery and prolongs the recovery period. Recognizing the high failure rate associated with internal fixation may prompt a shift toward more frequent use of arthroplasty in this age group. In my view, careful patient selection is crucial when choosing between total hip arthroplasty and internal fixation for individuals aged 60–70 years. As previously discussed, a reliable prediction tool could play a key role in optimizing treatment decisions in this cohort.

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CHAPTER 10

Summary
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Hip fractures are among the most serious injuries affecting the elderly, associated with significant morbidity, mortality, and socio-economic burden. Globally, the incidence of hip fractures continues to rise due to ageing populations, with projections suggesting a doubling by 2050. Despite substantial advances in orthopedic surgery, the optimal management of femoral neck fractures remains controversial. This thesis addresses three critical dilemmas in hip fracture treatment:

I. Total hip arthroplasty versus hemiarthroplasty
II. Hip arthroplasty versus internal fixation
III. Operative versus non-operative treatment

Part 1: Total hip arthroplasty versus hemiarthroplasty

The first part of this thesis explored the long-standing debate between total hip arthroplasty (THA) and hemiarthroplasty in treating displaced femoral neck fractures. While hemiarthroplasty is often favored for frail, low-demand elderly patients due to its shorter operative time and lower risk of dislocation, THA may offer better long-term functional outcomes in healthier, more active individuals.

Acetabular erosion is an important complication in hemiarthroplasty and may lead to THA as a conversion. The results of THA as a conversion remain unclear. In **Chapter 2**, we performed a systematic review and meta-analysis to compare the outcome of THA as a conversion with primary THA. Both, comparative and cohort studies were included. A total of 27 studies were available for analysis; four comparative studies and 23 cohort studies. Analysis revealed a significantly higher overall revision risk (Hazard Ratio (HR) 1.7, 95% confidence interval (CI) 1.4-2.1) after THA as a conversion intervention compared to primary THA. The annual revision rate of THA as a conversion was 1.63% (95%CI 1.1-2.3) in the comparative studies and 1.40% (95%CI 1.2-1.7) in the cohort studies. A pooled infection rate of 4.34% (95%CI 2.7-7.0) and dislocation rate of 4.79% (95%CI 3.0-7.5), was found.

A potential consequence of hemiarthroplasty could be conversion to THA due to acetabular erosion, especially in the relatively young elderly. The conversion rate must be acceptable, and clinical outcome must be comparable to total hip arthroplasty to justify the treatment with hemiarthroplasty in this group of patients. In **Chapter 3**, we evaluated the conversion rate of hemiarthroplasty to THA and the clinical outcome in patients under 75 years of age. This study included 248 patients, younger than 75 years at time of operation, with a fracture of the femoral neck treated with hemiarthroplasty. At a follow-up of 5.1 years, the conversion rate was 7.3%. Mean VAS pain in rest was 0.89 (range 0–10) and the mean VAS pain during activity was 2.2 (range 0–10). At time of follow-up, 38.7% of patients had died. Radiographic evaluation of the unrevised group showed in one patient signs of acetabular wear. This study demonstrates an acceptable conversion rate after hemiarthroplasty in the relatively young elderly after a fracture of the femoral neck. Furthermore, unrevised patients show low pain scores. To prevent one conversion to THA, 13.7 patients should be treated with THA that will not undergo a conversion at a later stage. Therefore, hemiarthroplasty remains a viable treatment of femoral neck fractures in relatively young patients. There seems to be no space for standardized decision making concerning the choice of treatment. Therefore, an individual approach is required.

Postoperative follow-up after hemiarthroplasty is part of routine-based practice. However, these visits appear to be a significant burden since it concerns a frail population. In **Chapter 4**, we performed a national survey among orthopedic surgeons working in 26 large Dutch teaching hospitals to test the hypothesis that postoperative follow-up is indeed common practice. Furthermore, a retrospective patient review was performed in 1055 hemiarthroplasties (1026 patients). The response of the national survey was complete and showed that postoperative follow-up in patients treated with hemiarthroplasty is part of standard care according to 89% of respondents. From the study cohort 602 cases visited the outpatient department. Implant-related complications were reported in 68 hemiarthroplasties, with 31 of these hips undergoing reoperation. Only 2 of these complications were picked up at standard planned follow-up leading to a complication detection rate of 0.3%. In contrast, complication detection rates of 47% and 16% were found at unplanned visits at the Emergency Department and the outpatient department, respectively. This study demonstrates that postoperative follow-up in patients treated with hemiarthroplasty is still the standard of care. However, most implant-related complications are identified during unplanned visits, with very few detected at routine follow-up appointments. Therefore, postoperative follow-up of patients treated with hemiarthroplasty could be abandoned in this frail population.

Part 2: Hip arthroplasty versus internal fixation

The second part of the thesis addresses the ongoing debate in hip fracture management around the optimal treatment for femoral neck fractures with arthroplasty or internal fixation. Research indicates that (hemi)arthroplasty is typically the preferred choice for patients over 70, while internal fixation is usually recommended for those under 60, as it maintains the natural hip joint. However, the best approach for individuals in the 60- to 70-year age range remains a point of discussion.

The most common complications after internal fixation, such as avascular necrosis (AVN) or nonunion, can result in total hip arthroplasty as a salvage procedure (salvage-THA). Data concerning the results of salvage-THA after failed internal fixation is limited. **Chapters 5** and **6** both report on the results of salvage-THA in comparison to primary total hip arthroplasty placed in femoral neck fracture (fracture-THA) patients. In Chapter 5, a multicenter retrospective cohort study was conducted in three Dutch hospitals comparing the complication rate and revision rate after 284 salvage-THAs and 264 fracture-THAs in patients suffering from a femoral neck fracture with a mean follow-up of 5 years. No statistically significant differences were found in postoperative complications rates. The revision rate in the fracture-THA group was 7.2% in comparison to 7.7% in the salvage-THA group ($p = 0.81$). This study showed no statistically significant differences in terms of revision or complication rates after salvage-THA or fracture-THA patients. In **Chapter 6**, a registry study was performed with the use of Dutch Arthroplasty Register (LROI). Again, salvage-THA was compared with fracture-THA. In this study, a third group with THA placed for osteoarthritis was used as a reference. The study included 4,310 salvage-THAs, 12,159 fracture-THAs and 274,147 THAs placed for osteoarthritis. No statistically significant difference in revision rates between salvage-THA and fracture-THA was found (HR 1.0, 95%CI 0.7–1.3) whereas the revision rate was higher compared with THAs placed for osteoarthritis (HR 1.3, 95%CI 1.0–1.5). The 5-year revision rate was 5.0% (95%CI 4.4–5.8) in salvage-THAs, 4.5% (95%CI 4.1–5.0) in fracture-THAs, and 3.1% (95%CI 3.0–3.2) in THAs after osteoarthritis. However, a higher revision rate for infection was found in salvage-THA in comparison with fracture-THAs (HR 1.6, 95%CI 1.0–2.3).

The choice of implant for internal fixation is also crucial. The risk of failure following internal fixation of hip fractures is generally high, and this risk can vary depending on the type of implant used. In **Chapter 7**, a study was conducted to compare the TFN-Advanced Proximal Femoral Nailing System (TFNA) and the Gamma Trochanteric Nail (GTN3) for the treatment of trochanteric fractures. The fixation failure rates were compared between these 2 intramedullary nails. The study analyzed 797 GTN3s (779 patients) and 542 (536 patients) TFNAs. A higher risk of fixation failure was found in the TFNA group (14%) compared with the GTN3 group (7.0%) (HR 2.0, 95%CI 1.2–3.5). This was mainly attributed to a higher risk of cut-out (HR 2.2; 95%CI 0.9–5.7), malpositioning (HR 4.7; 95%CI 0.7–34), and new fracture around the nail (HR 4.0; 95%CI 1.0–16). Learning curve analyses indicated no clear learning curve effect. In conclusion, failure of fixation increased after a switch from the GTN3 to the TFNA proximal femoral nail for the treatment of trochanteric fractures. Cut-out and malpositioning of the calcar screw or blade appeared to be the most dominant failure mechanisms. Modifications in implant design may have played a role in this increased risk of failure of fixation.

Part 3: Operative versus non-operative treatment

The final part of this thesis examined the role of non-operative management (NOM) in extremely frail elderly patients. In selected cases, surgery may not improve survival or quality of life whereas non-operative management with palliative care could be a relevant treatment option.

Surgical treatment is still the mainstay of care, even in very frail elderly hip fracture patients. However, one may argue whether surgery is in the best interest of all patients. **Chapter 8**, elucidated on mortality rates of non-operative management (NOM) of a hip fracture after shared decision-making in a cohort of very frail elderly patients. Mortality rates after NOM were assessed and also presented for the remaining surgical group for reference. In the presence of fragility features the motivation for surgery or NOM was supported by advance care planning (ACP) and shared decision-making through geriatric consultation. In 1279 geriatric assessment was indicated and subsequently 1188 (93%) had surgery versus 91 (7%) NOM. The motivation for NOM was based on patient and family preferences in only 20% of patients, medical grounds in 54%, and a combination of both in 26%. The 30-day and 1-year mortality in the frail NOM group was 87% and 99% respectively, whereas this was 7% and 28% in the surgery group. This study provides further insight into the predictable and high short-term mortality after NOM in carefully selected very frail elderly hip fracture patients.

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Summary
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Heupfracturen behoren tot de ernstigste letsels bij ouderen, met aanzienlijke morbiditeit, mortaliteit en een grote sociaaleconomische last. Wereldwijd blijft de incidentie van heupfracturen stijgen door de vergrijzing van de bevolking en naar verwachting zal dit aantal tegen 2050 ongeveer verdubbeld zijn. Ondanks aanzienlijke vooruitgang in de orthopedische chirurgie blijft de optimale behandeling van collumfracturen controversieel. Dit proefschrift behandelt drie kritieke vraagstukken in de behandeling van heupfracturen:

I. Totale heupprothese versus kophalsprothese
II. Heupprothese versus interne fixatie
III. Operatieve versus niet-operatieve behandeling

Deel 1: Totale heupprothese versus kophalsprothese

Het eerste deel van dit proefschrift behandelt de voortdurende discussie over de beste behandeling van collumfracturen met een totale heupprothese (THP) of een kophalsprothese. Een kophalsprothese wordt vaak geplaatst bij kwetsbare, oudere patiënten vanwege de kortere operatietijd en het lagere luxatierisico, terwijl THP's mogelijk betere functionele resultaten bieden bij gezondere, actievere individuen.

Acetabulaire slijtage is een belangrijke complicatie bij een kophalsprothese en kan leiden tot een conversie naar een THP. De resultaten van geconverteerde THP's zijn echter nog onduidelijk. In **Hoofdstuk 2**, hebben we een systematische review en meta-analyse uitgevoerd om de resultaten van een geconverteerde THP te vergelijken met een primaire THP. Zowel vergelijkende studies als cohort studies werden meegenomen. In totaal waren 27 studies beschikbaar voor analyse; vier vergelijkende studies en 23 cohortstudies. De analyse toonde een significant hoger revisierisico (Hazard Ratio (HR) 1.7, 95% betrouwbaarheidsinterval (BI) 1.4-2.1) na een geconverteerde THP in vergelijking met een primaire THP. Het jaarlijkse revisierisico van de geconverteerde THP's was 1,63% (95%BI 1,1-2,3) in de vergelijkende studies en 1,40% (95%BI 1,2-1,7) in de cohortstudies. Een pooled infectierisico van 4,34% (95%BI 2,7-7,0) en een luxatierisico van 4,79% (95%BI 3,0-7,5) werd gevonden.

Een mogelijke consequentie van een kophalsprothese zou, vooral bij de relatief jonge ouderen, een conversie naar een THP kunnen zijn vanwege acetabulaire slijtage. Het conversierisico moet aantoonbaar lager zijn dan alternatieve behandelingen en de klinische uitkomsten op het gebied van functie en pijnvermindering moeten beter zijn om een kophalsprothese in deze patiëntengroep te rechtvaardigen. In **Hoofdstuk 3**, evalueerden we het conversierisico van een kophalsprothese naar een THP alsmede de klinische uitkomst, bij patiënten onder de 75 jaar. In deze studie werden 248 patiënten geïncludeerd die op het moment van het plaatsen van een kophalsprothese jonger waren dan 75 jaar. Na een follow-up van 5,1 jaar was het conversierisico 7,3%. De gemiddelde VAS-pijn in rust was 0,89 (range 0-10) en de gemiddelde VAS-pijn tijdens activiteit was 2,2 (range 0-10). Bij de follow-up was 38,7% van de patiënten overleden. Radiografisch onderzoek van de niet-gereviseerde groep toonde bij één patiënt tekenen van slijtage van het acetabulum.

Deze studie toont een acceptabel conversierisico na kophalsprothese bij de relatief jonge ouderen na een fractuur van het collum. Bovendien vertonen niet-gereviseerde patiënten weinig pijnklachten. Om één conversie naar een THP te voorkomen, zouden 13,7 patiënten behandeld moeten worden met een THP die later geen conversie zullen ondergaan. Daarom blijft een kophalsprothese een geschikte behandeling van collumfracturen bij relatief jonge patiënten. Er lijkt geen ruimte te zijn voor gestandaardiseerde besluitvorming met betrekking tot de keuze van de behandeling. Een individuele benadering is vereist.

Postoperatieve follow-up na een kophalsprothese maakt deel uit van de standaardzorg. Deze bezoeken blijken echter een aanzienlijke belasting te vormen voor deze kwetsbare populatie. In **Hoofdstuk 4** voerden we een nationale enquête uit onder orthopedisch chirurgen die werkzaam zijn in 26 grote Nederlandse ziekenhuizen om de hypothese te testen dat postoperatieve follow-up inderdaad de gangbare praktijk is. Bovendien werd een retrospectief patiëntonderzoek uitgevoerd bij 1055 kophalsprotheses (1026 patiënten). De reactie op de nationale enquête was volledig en toonde aan dat postoperatieve follow-up bij patiënten die behandeld werden met een kophalsprothese volgens 89% van de respondenten onderdeel was van de standaardzorg. Na 602 van de kophalsprotheses werd de polikliniek bezocht. Implantaat gerelateerde complicaties werden gerapporteerd in 68 kophalsprotheses, waarvan er 31 opnieuw werden geopereerd. Slechts 2 van deze complicaties werden opgemerkt bij standaard geplande follow-up afspraken, wat leidde tot een detectiegraad van complicaties van 0,3%. Daarentegen werd een complicatie-detectiegraad van 47% en 16% gevonden bij ongeplande bezoeken op de spoedeisende hulp en de polikliniek, respectievelijk. Deze studie toont aan dat postoperatieve follow-up bij patiënten die behandeld werden met een kophalsprothese nog steeds de standaardzorg is. De meerderheid van de implantaat gerelateerde complicaties werd echter gedetecteerd tijdens ongeplande bezoeken en bijna niet bij standaard follow-up bezoeken. Om deze reden zou postoperatieve follow-up bij patiënten behandeld met een kophalsprothese in deze kwetsbare populatie kunnen worden afgeschaft.

Deel 2: Heupprothese versus interne fixatie

Het tweede deel van dit proefschrift behandelt de voortdurende discussie over de optimale behandeling van collumfracturen met ofwel een heupprothese ofwel een osteosynthese. Onderzoek toont aan dat een heupprothese meestal de voorkeur heeft in patiënten boven de 70 jaar, terwijl een osteosynthese meestal wordt aanbevolen voor patiënten onder de 60 jaar, vanwege het intact laten van het natuurlijke heupgewricht. De beste aanpak voor individuen in de leeftijdsgroep van 60- tot 70 jaar blijft echter punt van discussie.

De meest voorkomende complicaties na osteosynthese, zoals avasculaire necrose (AVN) of non-union, kunnen resulteren in een THP als een revisie-operatie. Gegevens over de resultaten van deze THP's geplaatst na een mislukte osteosynthese zijn beperkt. **Hoofdstukken 5** en **6** rapporteren beide over de resultaten van deze THP's geplaatst na falen van een osteosynthese in vergelijking met primaire THP's bij patiënten met een collumfractuur. In **Hoofdstuk 5** werd een multicenter retrospectieve cohortstudie uitgevoerd in drie Nederlandse ziekenhuizen, waarbij het complicatie- en revisierisico werd vergeleken bij 284 THP's na gefaalde osteosynthese en 264 primair geplaatste THP's bij patiënten met een collumfractuur, met een gemiddelde follow-up van 5 jaar. Er werden geen statistisch significante verschillen gevonden in postoperatieve complicatierisico's. Het revisierisico in de groep primaire THP's was 7,2% in vergelijking met 7,7% in de groep THP's geplaatst als revisie (p = 0,81). Deze studie toonde geen statistisch significante verschillen in revisie- of complicatiepercentages na een THP als revisie na gefaalde osteosynthese ten opzichte van primaire THP's bij patiënten met een collumfractuur. In **Hoofdstuk 6** werd een registerstudie uitgevoerd met behulp van de Landelijke Registratie Orthopedische Interventies (LROI). Opnieuw werden THP's na gefaalde osteosynthese vergeleken met primaire THP's na een collumfractuur. In deze studie werd een derde groep met THP's voor artrose als referentie gebruikt. De studie bevatte 4.310 THP's na gefaalde osteosynthese, 12.159 primaire THP's na fractuur en 274.147 THP's voor artrose. Er werd geen statistisch significant verschil in revisierisico's tussen THP's na gefaalde osteosynthese en primaire THP's gevonden (HR 1,0, 95%BI 0,7–1,3), terwijl het revisierisico hoger was vergeleken met THP's voor artrose (HR 1,3, 95%BI 1,0–1,5). De revisiekans na 5 jaar was 5,0% (95%BI 4,4–5,8) bij THP's na gefaalde osteosynthese, 4,5% (95%BI 4,1–5,0) bij primaire THP's na fractuur en 3,1% (95%BI 3,0–3,2) bij THP's na artrose. Er werd echter een hoger revisierisico door infectie gevonden bij THP's na osteosynthese in vergelijking met primaire THP's na een fractuur (HR 1,6, 95%BI 1,0–2,3).

De keuze voor het type implantaat als osteosynthese is ook van cruciaal belang. Het risico op falen van de osteosynthese van heupfracturen is over het algemeen hoog en dit risico kan variëren afhankelijk van het type implantaat dat wordt gebruikt. In **Hoofdstuk 7** werd een studie uitgevoerd om het TFN-Advanced Proximal Femoral Nailing System te vergelijken met de Gamma Trochanteric Nail (GTN3) voor de behandeling van pertrochantere fracturen. De kans op falen van de osteosyntese werd vergeleken tussen deze 2 intramedullaire implantaten. De studie analyseerde 797 GTN3's (779 patiënten) en 542 TFNA's (536 patiënten). Een hoger risico op falen van de osteosynthese werd gevonden in de TFNA-groep (14%) in vergelijking met de GTN3-groep (7,0%) (HR 2,0; 95%BI 1,2–3,5). Dit werd voornamelijk toegeschreven aan een hoger risico op uitbreken (HR 2,2; 95%BI 0,9–5,7), malpositie (HR 4,7; 95%BI 0,7–34) en een nieuwe breuk rond de pen (HR 4,0; 95%BI 1,0–16). Leercurve-analyse gaf geen duidelijk leercurve-effect aan. Concluderend verhoogde het risico op falen van de osteosynthese na een overstap van de GTN3 naar de TFNA voor de behandeling van pertrochantere fracturen. Uitbreken en malpositie van de schroef of blade bleken de meest dominante faalmechanismen te zijn. Wijzigingen in het ontwerp van het implantaat kunnen een rol hebben gespeeld in dit verhoogde risico op fixatiefalen.

Deel 3: Operatieve versus niet-operatieve behandeling

Het laatste deel van dit proefschrift onderzoekt de rol van een niet-operatieve behandeling bij extreem kwetsbare oudere patiënten. In geselecteerde gevallen kan een operatie de overleving of kwaliteit van leven niet verbeteren, terwijl een niet-operatieve behandeling met palliatieve zorg een goede behandelingsoptie kan zijn.

Operatieve behandeling is momenteel nog steeds de standaardbehandeling, zelfs bij zeer kwetsbare oudere patiënten met een heupfractuur. Er kan echter worden betwijfeld of een operatie wel in het beste belang is van alle patiënten. **Hoofdstuk 8** beschrijft de mortaliteitscijfers bij een niet-operatieve behandeling van een heupfractuur na gezamenlijke besluitvorming in een cohort van zeer kwetsbare oudere patiënten. De mortaliteitscijfers na een niet-operatieve behandeling werden geëvalueerd en uitgezet tegen een operatieve groep ter referentie. Bij kwetsbare oudere patiënten werd het besluit voor operatieve of niet-operatieve behandeling gevormd met behulp van advance care planning (ACP) en een geriatrische beoordeling. Bij 1279 patiënten was een geriatrische beoordeling geïndiceerd en vervolgens ondergingen 1188 patiënten (93%) een operatieve versus 91 patiënten (7%) een niet-operatieve behandeling. De motivatie voor een niet-operatieve behandeling was gebaseerd op de voorkeuren van patiënt en familie in 20%, op medische gronden in 54%, en een combinatie van beide in 26%. De mortaliteit na 30 dagen en 1 jaar in de kwetsbare niet-operatieve groep was respectievelijk 87% en 99%, terwijl dit 7% en 28% was in de operatieve groep. Deze studie biedt inzicht in de voorspelbare en hoge mortaliteit op korte termijn na niet-operatieve behandeling bij zorgvuldig geselecteerde zeer kwetsbare oudere patiënten met een heupfractuur.

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Research data management

Ethics and privacy

This thesis is based on the results of research involving human participants, conducted in accordance with relevant national and international legislation, regulations, guidelines, codes of conduct, and Radboudumc policy. The studies did not fall within the remit of the Medical Research Involving Human Subjects Act (WMO) and were conducted in accordance with the Declaration of Helsinki.

This thesis utilizes data from electronic patient records at Rijnstate Hospital in Arnhem and from the Dutch Arthroplasty Register (LROI). The Scientific Advisory Board and the board of the LROI approved the study in chapter 6. The institutional ethical review board at Rijnstate Arnhem approved the use of medical records for the other studies presented in this thesis.

To ensure patient privacy, all data were pseudonymized, and personal information was removed. Participants' privacy was protected through the use of encrypted and unique individual subject codes that corresponded with codes on patient and physician files.

Data collection and storage

The data acquired during this PhD were securely stored in digital format. Data from chapters 3, 5, and 7 were stored in the Electronic Data Capture Data Manager from Research Manager. Data from chapters 1, 2, 4, and 8 were stored on the local server of Rijnstate Hospital's orthopedic department (on G:\ drive). The dataset from chapter 6 was available from the LROI; however, restrictions apply to the availability of this dataset, which was used under license for the study.

Subject data obtained from the electronic patient file systems of Rijnstate were entered into SPSS (SPSS Inc., Chicago, Illinois, USA) datasets. SPSS was used to perform the statistical analyses in chapters 3, 4, 5, and 8. In chapters 2, 6, and 7, statistical analyses were performed using R (R Foundation for Statistical Computing, Vienna, Austria).

Availability of data

The data concerning this thesis will be archived for 15 years after the termination of the corresponding study (i.e., publication of the analysis that used the data). Access to the database is restricted to the project members working at Rijnstate Hospital. The datasets generated and analyzed can be obtained by contacting the corresponding authors. The LROI data underlying chapter 6 is findable and accessible through the LROI. This LROI dataset is archived in the secure environment of the LROI server for at least 15 years.

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Radboud Graduate School Portfolio

Graduate School: Orthopedics
PhD period: 01/01/2020 – 25/09/2026
PhD Supervisor(s): Prof. dr. B.W. Schreurs
PhD Co-supervisor(s): Dr. J.L.C. van Susante, Dr. G.J. Hannink, Dr. M.P. Somford

Training activities

Courses

ATLS Provider (2021)
CASH 1 (2021)
PACONU (2021)
AO Basic Principles of Fracture Management (2022)
Cursus heupprothesiologie (2022)
Cursus knieprothesiologie (2023)
Basiscursus arthroscopie knie (2024)
Basiscursus arthroscopie schouder (2024)
Stralingshygiëne voor medisch specialisten en AIOS (2024)
Radboudumc – Introduction day (2024)
Radboudumc – Introduction for PhD candidates (2024)
Scientific Integrity Course (2024)
Dissectiecursus onderste extremiteit (2024)
AO Advanced Principles of Fracture Management (2025)

Seminars

Seminars and lectures (Rijnstate, Sint Maartenskliniek, Radboudumc, approx. 100) (2025)

Conferences

European Hip Society, The Hague, The Netherlands (2018) – poster presentation
Werkgroep Hand en Pols, Nederlandse Orthopedische Vereniging (2019) – oral presentation
European Hip Society, Lille, France (2021) – 2 oral presentations
World Arthroplasty Congress, online (2021) – 2 oral presentations
Jaarcongres Nederlandse Orthopedische Vereniging, online (2021) – oral presentation

Teaching activities

Supervision of internships / other

Supervision of master medical student (2021)
Supervision of a graduated doctor (2025)

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About the Author

Peter Paul Schmitz werd geboren op 14 oktober 1992 in Nijmegen, waar hij samen met zijn ouders en broer Rob opgroeide. In 2011 behaalde hij zijn gymnasium-diploma aan het Canisius College in Nijmegen. In deze periode besteedde hij graag tijd aan sport, met name hockey.

In datzelfde jaar startte hij de opleiding Geneeskunde aan de Radboud Universiteit in Nijmegen. Hij wijdde het laatste jaar van zijn studie aan de orthopedie, te beginnen met een wetenschappelijke stage onder begeleiding van dr. Van Susante en dr. Van Loon. In 2018 studeerde hij af en begon hij zijn loopbaan als basisarts orthopedie in het Elkerliek Ziekenhuis in Helmond. In 2019 startte hij in een vergelijkbare functie in het Rijnstate Ziekenhuis in Arnhem en werd hij toegelaten tot de opleiding Orthopedie. In 2021 begon hij de vooropleiding Heelkunde in het Rijnstate Ziekenhuis. Vanaf juli 2022 vervolgde hij zijn opleiding orthopedie in de Sint Maartenskliniek in Nijmegen, het Radboudumc in Nijmegen en het Rijnstate Ziekenhuis. Tijdens zijn opleiding zette hij ook zijn wetenschappelijke carrière voort onder begeleiding van dr. Van Susante, dr. Somford, dr. Hannink en prof. dr. Schreurs. Dit proefschrift is hiervan het resultaat. Dit jaar rondt Peter zijn opleiding tot orthopedisch chirurg af.

Momenteel woont Peter in Lent samen met zijn vriendin Kim Ligtenbarg en hun zoon Teun.

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Een promotietraject naast je opleiding, betekent werk verrichten in vrije tijd. Die vrije tijd is mede mogelijk gemaakt door mijn vrienden en familie. Zij hebben mij de tijd geboden en hebben ervoor gezorgd dat ik in de resterende vrije tijd, de ontspanning had om mezelf op te laden om dit proefschrift te voltooien. Ik wil dan ook naast mijn promotor, copromotoren en andere collega's, zeker mijn familie en vrienden in dit dankwoord benoemen.

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Gerjon Hannink, ook onze eerste ontmoeting weet ik me nog als de dag van gisteren te herinneren. Voor mij was snel duidelijk dat ik nog erg veel te leren had in de wetenschap. Jouw kennis heeft mij erg veel gebracht. Ik mocht altijd, op een laagdrempelige manier, gebruik maken van jouw expertise. De samenwerking, onder het genot van een kopje koffie, heb ik als zeer prettig ervaren.

Dan wil ik uiteraard mijn promotor **Professor Wim Schreurs** hartelijk danken voor de begeleiding. Je nuchterheid, positieve blik en kritische feedback hebben enorm geholpen. Je persoonlijke en toegankelijke benadering heb ik altijd erg gewaardeerd.

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De **orthopedisch chirurgen** van het **Elkerliek Ziekenhuis** te Helmond, wil ik eveneens bedanken. Mijn eerste baan en dus de introductie in de orthopedie heb ik onder jullie vleugels mogen doormaken. Het was een prettige omgeving waarin mijn enthousiasme voor de orthopedie nog meer is aangewakkerd.

Chirurgen van het **Rijnstate**, vanaf het begin van mijn vooropleiding, voelde ik me meteen serieus genomen. Op vakinhoudelijk gebied heb ik door jullie enorme stappen kunnen zetten. Hard werken in een prettige sfeer heeft ervoor gezorgd dat ik in 1,5 jaar enorm veel geleerd heb. Bedankt daarvoor.

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Arthur, **Freek**, **Jaap**, **Joris**, **Mathijs** en **Thijs**, oftewel de '**GF**', sinds onze ontmoeting op onze middelbare school, het Canisius College in Nijmegen, zijn we goede vrienden. Wij hebben een ontelbare hoeveelheid verhalen gemaakt. Tijdens onze studententijd is een groot deel uitgevlogen over Nederland en heeft iedereen zijn eigen pad bewandeld. **Jaap** bleef ik als huisgenoot veel zien, maar ook de rest is hierna weer meer naar elkaar toegetrokken. Prachtig dat een aantal zijn weg terug naar Nijmegen gevonden heeft. Het is bijzonder dat het voor onze vriendschap niet uit lijkt te maken hoelang we elkaar niet zien. Er zijn dan weinig woorden nodig om het snel vertrouwd te laten voelen.

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