Revision Total Knee Arthroplasty

Optimizing the Journey

Paul van Rensch

Colofon

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Optimizing the Journey

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Optimizing the Journey

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- Voor Saar en de jongens -

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Chapter 1

General introduction and thesis outline

Revision total knee arthroplasty (rTKA), arthrodesis of the knee, or even above-the-knee amputation can be the end of a (usually long) medical journey. For an individual patient, this journey typically starts with the first symptoms of knee osteoarthritis (OA), often decades before a total knee arthroplasty is performed. OA is one of the chronic diseases that can have a major influence on quality of life. To give some more insight into OA's burden in general, the figures on OA and arthroplasty from the Netherlands are used as an example.

THE NETHERLANDS HAD 17.59 MILLION INHABITANTS IN 2021.
AROUND 9% OF THESE PEOPLE ARE SUFFERING FROM OA.
THE ANNUAL PREVALENCE OF OA OF THE KNEE IS 54.4 PER 1000
IN WOMEN AND 32.5 PER 1000 IN MEN.

GENERAL PRACTITIONERS DIAGNOSED AROUND 43,100 PEOPLE WITH KNEE OA
IN 2021, 62% OF WHOM WERE FEMALE.

https://www.volksgezondheidenzorg.info [1]

The Dutch national registry of orthopedic interventions (LROI) reported that 30,747 people received a primary knee arthroplasty (total or partial) in 2019 (more recent numbers are available, but not representable due to the COVID pandemic). The same register shows that the 10-year survival of average knee replacement has gone up to around 95% with endpoint revision for any reason. This successful treatment is considered highly cost effective.

The total medical costs of OA in general in the Netherlands, were 1.3 billion euro in 2015, 0.4 billion (31%) is related to knee OA. These costs of 1.3 billion equaled 1.6% of the overall healthcare costs at that time. Because OA concerns morbidity rather than mortality, its impact is often underestimated. During the recent COVID-19 pandemic, treatment for knee- and hip OA was considered as low priority care and most arthroplasty procedures were cancelled and postponed. Evaluation of patients waiting for knee- or hip arthroplasty during the pandemic has shown a considerable decrease in quality of life and work force participation for the society in 2020 and 2021 [2] Most likely, it has also resulted in reduced employability, as OA is one of the leading causes of sick leave in the Netherlands, with knee osteoarthritis accounting for an annual cost of approximately €26.9 million[3].
According to the Global Burden of Disease study of 2019, approximately 7% (more than 500 million people) of the global population suffers from osteoarthritis. The total number of affected people has increased with 48% between 1990 and 2019 [4]. When focusing on the Netherlands, based on data from Dutch general practices, there were approximately 1.59 million people with osteoarthritis (OA) in the Netherlands

in 2021 [1]. Of these patients, approximately 762,700 had OA of the knee, with an incidence of new knee OA cases of 5 per 1,000 per year [1].

From the onset of complaints, these patients are treated by the general practitioner with life style advice, medication, and physical therapy. At a certain point patients are referred to an orthopedic surgeon for counseling.

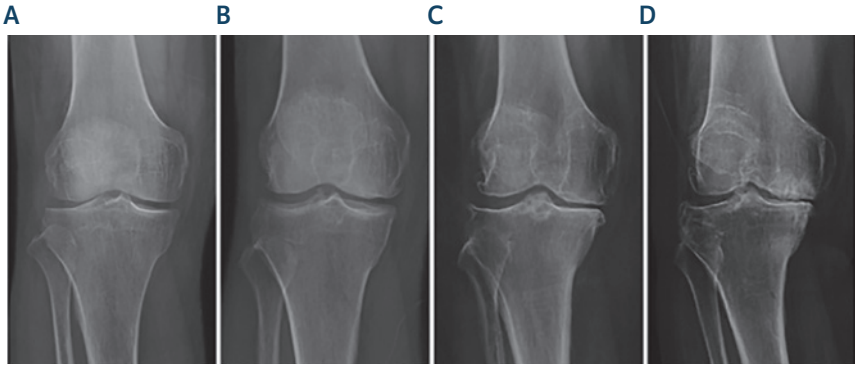


Figure 1. Kellgren and Lawrence classification for osteoarthritis [5].

Treatment options for OA of the knee in the orthopedic practice are either to continue conservative treatment or proceed to operative treatment, depending on personal presentation and situation. A major aspect in the decision making of the treatment plan is the degree of OA, which is classified according to Kellgren and Lawrence (KL) (Fig. 1) [5].

Conservative treatment

In mild to moderate OA, treatment usually starts non-operative with (a combination of) the following treatment options:

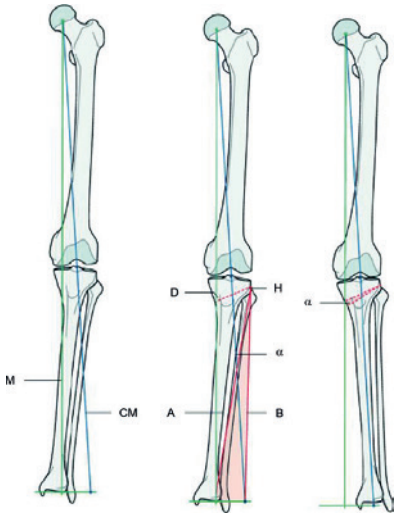
1) Lifestyle advice (weight reduction, exercise/mobility),
2) Pain medication (paracetamol and/or non-steroidal anti-inflammatory drugs (NSAIDs)),
3) Intra articular injections with corticosteroids or hyaluronic acid.

The form and/or combination of abovementioned options will differ for individual patients. Individual treatment plans are discussed with patients based on comorbidity, age, or other personal circumstances[6–8]. Shared decision making is an important part of these treatment plans in order to empower patients to take charge of their own treatment. If conservative treatment fails, surgical treatment can be considered.

Surgical treatment

Operative treatment can be roughly divided into joint preserving and joint replacing procedures. Joint preserving procedures historically consist of arthroscopy with debridement, and correction osteotomies around the knee. More recently, joint distraction was developed as a joint preserving technique.
In patients with axial deformities (varus/valgus), the biomechanical axis (Mikulicz line) passes either through the medial (varus) or the lateral (valgus) compartment of the knee joint. With progressing arthritis, this varus or valgus alignment worsens, resulting in increased loading of the affected compartment during weight bearing[9]. The aim of a correction osteotomy is to restore the native mechanical axis and thereby restore normal loading of the affected compartment of the knee (Fig. 2) [10]. In general, a varus leg alignment requires a valgus proximal tibia osteotomy or high tibial osteotomy (HTO). A valgus leg alignment usually requires a varus distal femur osteotomy. The reported success rates of HTO in postponing total knee arthroplasty (TKA) range from 51% to 95% at 10 years[11].

If a patient presents with end-stage OA and adequate conservative treatment has been given, joint replacing procedures (patellofemoral arthroplasty (PFA), unicompartmental knee arthroplasty (UKA) or total knee arthroplasty (TKA)) are indicated.



M = Mikulicz line
CM = Corrected Mechanical axis
D = Mediolateral diameter of the osteotomy
H = Hinge
A = Line connecting hinge and preoperative center of ankle joint
B = Line connecting hinge and postoperative center of ankle joint
α = Correction angle

Figure 2. Determining the correction angle in varus leg alignment[10].

Knee arthroplasty

Epidemiology

With the increasing number of people suffering from OA worldwide and the growing success rate of TKA, the number of knee arthroplasties has been steadily increasing[12]. The Dutch national orthopedic implant registry (LROI) has seen an increase in primary knee arthroplasties (PFA, UKA and TKA, Fig. 3 [13]) in the Netherlands from 20,610 in 2010 to 30,968 cases in 2019 [14].

Primary TKA

Arthroplasty of the knee is generally considered to be a very successful procedure for patients with end-stage OA of the knee. Studies have shown survival rates of primary TKA of over 95% at ten years [15–18]. However, patient satisfaction does not always seem to match with the survival of the implant. About 80%-85% of all patients report to be satisfied with the results of the surgery [12,19,20]. Failure to meet functional expectations and persisting pain are the most common reasons for dissatisfaction after surgery. In an attempt to increase survival and patient satisfaction, surgeons have looked at their surgical techniques and alignment strategies, and manufacturers have tried to improve the composition, function and fit of the prostheses.

A prerequisite for good survival of a TKA is proper fixation of the implant to the bone. This can be challenging when patients receives a TKA after a previous correction osteotomy for early osteoarthritis, for example. Both the distal femur and the

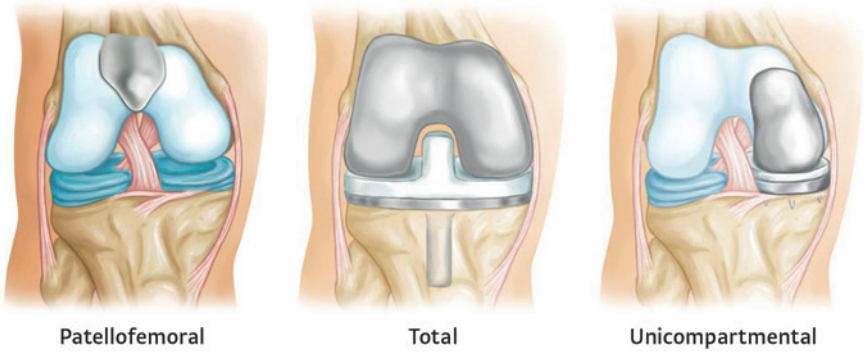


Figure 3. Three types of primary knee arthroplasty [13].

proximal tibia consist of three anatomical zones, the epiphysis, metaphysis and diaphysis. From revision TKA we know the importance of solid fixation in the different bony zones [21]. In primary TKA, solid metaphyseal fixation is also essential. Indications for primary TKA that have compromised metaphyseal bone stock are, among others, previous HTO or earlier sustained fractures of the knee joint. For these cases, a higher rate of aseptic loosening of the tibial plateau has been described[22–28]. We hypothesized that a possible explanation for higher revision rates in these groups with compromised metaphyseal bone is that the altered tibial bony architecture adversely affects fixation of the tibial plateau and keel in the metaphyseal bone. In rTKA cases, the role of tibial sleeves to improve metaphyseal fixation has been well described [29–32]. The use of sleeves in primary TKA has not previously been described in the literature and might be of use for proper metaphyseal fixation in patients with TKA after HTO or fractures and reduced metaphyseal bone.

Revision TKA

Although the survival of primary TKA has improved significantly we will see a raising question for revision knee arthroplasties (rTKA). Over the last decades, several trends are noticeable. The demands of elderly patients in everyday life increased, also older patients want to stay mobile and live independently. There is also an epidemic of obesity in middle- and high income countries [4,33]. Obesity leads to OA by means of increased mechanical loading and systemic effects of obesity-induced inflammation [34]. Therefore, obesity combined with the high success rate of TKA, results in TKA being more often performed at a relatively younger age. According to the Central Bureau of Statistics (CBS), mean life expectancy in the Netherlands has risen from 77.0 years to 82.8 in just over three decades [35]. This increase in life expectancy also

stimulates the demands of knee revisions. These trends together predict a continued increase in incidence of TKA in the coming years. And although techniques and prosthesis design are improving, the increasing incidence and prevalence of TKA will cause an increasing burden of rTKA procedures in the future. In the Netherlands, the number of revision procedures almost doubled in the period between 2010 and 2019 from 1,624 to 3,069 procedures annually [14].
Aside from the implications of rTKA for an individual patient (increased recovery time, higher complication rates, etc.), there is a large economic burden for rTKA as well. Okafor and colleagues showed that the costs for rTKA ranged from US$24,027 – US$38,109. This amount increased 2.5 times in case of a 2-stage revision for septic TKA (US$66,629 to US$81,938) [36].

The abovementioned developments stress the huge (personal and economic) implications of revision TKA[37–40]. Through the development of national registries, there has been a growing understanding of the survival of different (revision) TKA designs. These studies have provided a large amount of data on general patient groups. In the outpatient clinic, however, we are confronted with individual patients who often need a personalized approach, especially in (complex) rTKA cases. The options are discussed with the patient and, like with primary TKA, shared decision making is increasingly important. More insight in complications, functional outcome and patient satisfaction is needed to better inform our patients on the outcome that they can expect, as patient expectations are known to have a major impact on outcome and satisfaction[41]. Before 2000, the most common reason for failure of primary TKA was polyethylene wear. After technical improvements were made to the polyethylene insert, the main mode of failure of a TKA has shifted to aseptic loosening (usually late) and infection (usually early) [42]. Nowadays, the main reasons for rTKA are, in addition to aseptic loosening and infection, component malposition, knee instability, and severe stiffness [37,38,43,44]. Although these indications seems well defined, in the clinical practice an indication for revision surgery is commonly based on a combination of the abovementioned diagnoses. For instance, acute infections are easy to recognize, but the diagnosis of a low grade (more chronic) infection is less clear. Furthermore, knee instability can be caused by both implant malposition and trauma at or after primary TKA insertion (ligament ruptures or fractures). It is up to the surgeon to decide the main mode of failure and therefore the reason for revision. This means that comparing outcomes will always be biased by a subjective decision, which complicates comparison of studies dealing with revision knee arthroplasty.
Aseptic loosening is a term that is used for different modes of failure not involving (acute) infection. True aseptic loosening is seen in patients with a previously well fixed knee arthroplasty, which shows progressive loosening without obvious reasons at the implant bone interface or at the bone cement bone interface. This is usually a

late complication after TKA in an implant that often had been well functioning for several years. The etiology of this type of loosening is not well understood, although there are indications that repeating deep flexions (>120 degrees) of the knee after arthroplasty could increase the risk [45,46], as most TKA designs are designed with a maximum flexion of 120 degrees.
Early loosening, unfortunately also frequently referred to as aseptic loosening, is probably more caused by an initial fixation failure. Failure of fixation can develop because of surgical technique (poor cementing of the tibial stem/keel) or implant design (e.g. short tibial stems have higher rates of loosening).

Periprosthetic joint infection (PJI) is one of the most feared complications after knee arthroplasty. Over the years a lot of improvements have been made to infection prevention. Examples are laminar flow air systems in the operating room (OR), timely antibiotic prophylaxis, improved draping and antiseptics techniques, reduced surgical time and reducing OR traffic and door movements [47]. Despite these efforts, infections still account for a majority of revision cases. The incidence of PJI ranges in literature from 0.6% to 3%. In the US, PJI is reported to be the most common reason for revision (20.4% of all revisions after a primary TKA) [38]. By other authors, infection was found to attribute to up to 36.1% of revision cases [48]. A PJI can be divided in acute (<4 weeks), delayed (3-12 months), and late (>12-24 months) infection. Patients often present with redness, warmth and swelling of the knee, accompanied by fever and pain (Fig. 4).

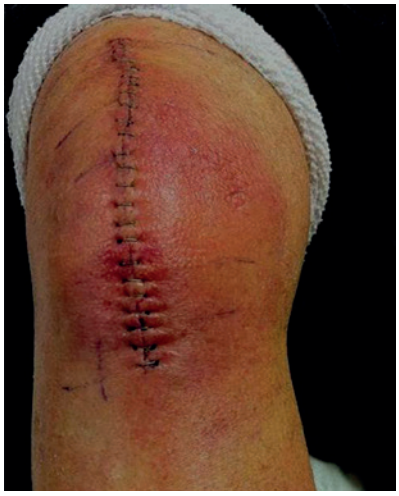


Figure 4. Swelling and redness on inspection with suspected acute periprosthetic TKA infection.

In acute infection, highly virulent bacteria are most frequently responsible and diagnosis is fairly straightforward when using the diagnostic criteria by the International Consensus Meeting on Musculoskeletal Infection[49]. In low grade (delayed) infection, tissue cultures are not always conclusive because of low virulent bacteria. In such cases, there is a risk of treating the infection like an aseptic loosening missing the infectious component causing the loosening, with persisting infection and multiple (increasingly difficult) surgeries as a result.
Malposition refers to suboptimal placement of components in knee arthroplasty, leading to complaints of pain, reduced functionality and possibly loosening. It stands to reason that a well-positioned implant will lead to better functional outcome and higher patient satisfaction. There is still discussion about what exactly is a well-positioned implant. Native coronal- and sagittal alignment differs from patient to patient. Therefore, some surgeons have proposed a more patient-specific approach to alignment. On the subject of rotation, there is more consensus. A femoral external rotation of 2^0 -5^0 is considered optimal for patellar tracking. With respect to tibial rotation, neutral to slight external rotation has been shown to have the best clinical results [50,51], although measuring correct tibial rotation has been shown to be unreliable [52]. Also, these rotation guidelines give an average recommendation that does not always account for the individual patient.
Instability can arise from implant failure (wear/breakage of polyethylene, loosening and osteolysis), ligamentous instability, or surgical error. Most commonly, instability arises from suboptimal balancing during implantation and midflexion instability is the most reported complaint. Midflexion instability results in dynamic functional difficulties, i.e. feeling of insecurity with flexion, difficulty in walking the stairs, recurrent swelling, and anterior knee pain [53]. Improving the understanding of gap balancing and improving surgical techniques might therefore be the key factor in improvement of patient outcome and reducing revision procedures.

Severe stiffness (arthrofibrosis) is defined as excessive scar tissue formation after TKA implantation (Fig. 5). It has a multifactorial etiology with risk factors both related to the patient as to the surgery (pre-, peri-, and postoperative) [54]. A predictive model for patients at risk, however, is lacking. Revision arthroplasty for severe stiffness has been studied by several authors [55–57]. It has been shown that patients who were revised for severely stiff TKA have the worst outcome at 2 years after rTKA with respect to range of motion (ROM), pain and satisfaction scores, and Knee Society Score (KSS) when compared to other indications [43]. Treatment options for severely stiff TKA consists of physiotherapy, manipulation under anesthesia, arthroscopic debridement or open debridement [54,58–62]. Revision arthroplasty is most commonly reserved for the correction of technical errors in the severely stiff TKA, such as malrotation, and instability [60,62,63].

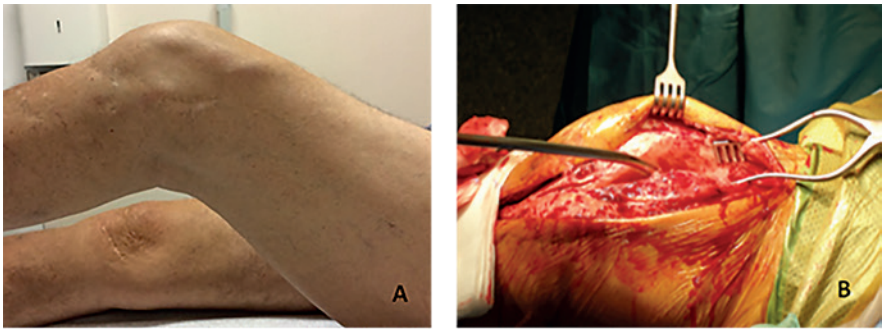


Figure 5. A. Impaired flexion after total knee arthroplasty. Patient showing maximal flexion. **B.** Peroperative view with the clamp pointing at extensive peripatellar fibrous tissue after TKA.

Centralization of care

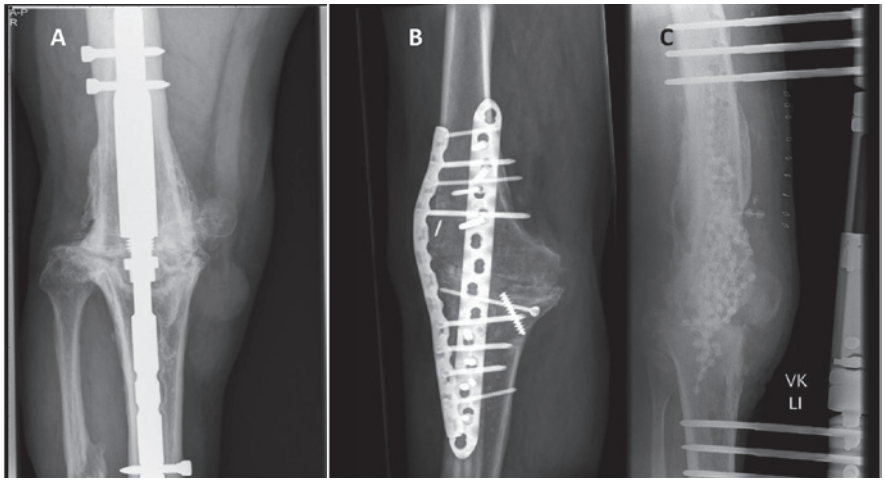
When looking at orthopedic surgery as a whole, a trend is seen towards super specialization and centralization, especially for technically demanding procedures. This is routine and generally accepted and advocated for orthopedic oncology, which requires a highly specialized multidisciplinary team for adequate treatment. In arthroplasty, ongoing centralization is already advocated for septic loosening [64]. If we consider all indications for revision, almost all of the 97 Dutch hospitals performing primary TKAs also perform rTKAs. Technical difficulty of a rTKA can range from a simple liner exchange to a full revision with managing of large bony defects. For the latter, specialized instrumentation and prostheses and extensive surgical experience are required. These procedures are associated with increased operation time and a complex aftercare treatment protocol [65].
For UKA, primary TKA and total hip arthroplasty (THA), better outcomes with increasing hospital volume have already been described [66–68]. On top of that, an increase of 90-day mortality rate (for THA) and higher re-revision rates (for TKA) in hospitals with fewer than 25 cases annually, have been shown [69,70]. The latter study, however, focused solely on aseptic rTKA and did not discriminate between different types of revision.

The most challenging rTKA cases are those where multiple previous procedures have been performed, resulting in large bone defects and poor surrounding soft tissue. This happens especially in cases with (difficult to treat) PJI. For these cases, a revision arthroplasty is sometimes not possible anymore and maintaining mobility and quality of life for a patient can require salvage options. These salvage options for rTKA are above-the-knee amputation and arthrodesis of the knee.

Arthrodesis of the knee

When a salvage procedure is warranted, above-the-knee amputation (AKA) is a viable option. However, many patients report a higher quality of life with an arthrodesis of the knee, compared to amputation [71,72]. Furthermore, an arthrodesis provides moderate recovery of mobility and significant pain reduction in patients with failed rTKA [73]. The outcome of an AKA, however, is greatly dependent on the ability to be fitted with a prosthesis, which provides more functionality compared to an arthrodesis. This needs to be addressed in the decision-making process.

Historically, arthrodesis of the knee has been performed mainly in cases of tuberculosis, advanced primary arthrosis and rheumatoid arthritis. Arthrodesis was usually performed using the Charnley clamps, with which solid fusion was reportedly achieved in 98.8 % of the cases. Because of poor stability and substantial increase in bone loss after removal of a rTKA, the solid fusion rate using de conventional clamp-technique by Charnley was markedly lower in comparison with primary arthrodesis using the same technique[74]. Therefore, other techniques have been explored and used. The most frequently documented fusion options are intramedullary nail fixation, plate fixation and external fixation Fig. 6) .



A. Intramedullary nail **B. Bilateral locking** **C. Monoplane**

Figure 6. Methods for arthrodesis of the knee.

Outline of the thesis

A painless and functional knee is the goal for every patient with OA of the knee, and for most patients, the journey that started with knee OA ends with a well-functioning TKA, or in some cases, a rTKA. However, some patients may require second revisions or sometimes even salvage procedures.To improve the results of rTKA and further surgeries, many factors need to be taken into account. One important aspect of improving outcome for patients is 'Getting it right the first time'. Therefore, improvement of the outcome for rTKA sometimes starts with (and often even before) the primary TKA.

A correction osteotomy is used in patients with progressing OA and aims to delay the need for TKA. There are concerns about fixation of the tibial plateau in TKA after an osteotomy. Therefore, in this thesis a possible option for improvement of tibial fixation in cases with impaired metaphyseal bone stock will be discussed in **Chapter 2**

Whereas a primary TKA for osteoarthritis can be seen as a standardized procedure, revision (and especially repeat revisions) TKA is much more heterogenic procedure. The consequence is that, in treating revision TKA patients, plans will be more complex and more individualized. As shared decision making is increasingly important, the relationship between indication for revision and longer term outcome after rTKA needs to be explored further to better inform patients in the outpatient clinic. In **Chapter 3** we will evaluate whether there is an association between reason for revision and clinical outcome at long term follow-up.

Severe stiffness following TKA is a complication that is difficult to manage. Revision arthroplasty for severely stiff TKA is mostly reserved for the correction of technical errors that are causing stiffness. In **Chapter 4** we describe a procedure with extensive tissue release in combination with revision to a hinged-type prosthesis to improve outcome in severely stiff TKA.

Overall, a rTKA can be a challenging operation and these procedures are not performed on a regular basis in all hospitals. In **Chapter 5**, we aim to determine if rTKA renders lower re-revision rates in high volume vs low volume hospitals. This will be studied for rTKA with different degrees of complexity.

Although primary TKA and rTKA are procedures with high satisfaction rates, a number of patients will be in need for more complex (and less favourable) salvage procedures, as a knee arthrodesis or amputation. In **Chapter 6**, a practical, and personalized algorithm for optimizing patient care following arthrodesis of the knee is presented.

Finally, this thesis ends with a General Discussion (**Chapter 7**) and summary in **Chapters 8 and 9,** including directions for future research and organization. As all chapters are based on published manuscripts and are intended to be read individually, some repetition or inconsistencies in terminology are inevitable.

Aim

The aim of this thesis is to explore the need for -and options in- a more personalized approach in the journey from knee OA to revision knee arthroplasty, while mainly focusing on the final surgical stages of this journey.

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Chapter 2

Tibial metaphyseal sleeves in primary total knee arthroplasty following high tibial osteotomy and tibial plateau fracture; preliminary mid-term survival and outcome

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C.J. van Loon

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Abstract

Background: Previous high tibial osteotomy (HTO), and tibial plateau fractures (TPF) may cause problems in subsequent total knee arthroplasty (TKA) due to altered metaphyseal bone structure. Higher rates of loosening of the tibial component have been described. In post-HTO and TPF cases, a more durable fixation could be achieved by tibial sleeves. This study investigates the preliminary short-to-midterm clinical and radiographic results in a cohort of these cases.
Methods: A cohort of 28 patients was selected, 11 following HTO, and 17 following TPF. Standard clinical and radiologic follow-up was performed at 6 weeks, and one and two years. Revision with removal of primary prosthesis for any reason was the primary outcome. Patient reported pre- and postoperative pain, satisfaction and general health scores were collected at one and two years. Postoperative radiographs were analyzed for radiolucent lines.
Results: There were no cases of aseptic loosening. Survival for all reasons was 96.4% (CI 77.2%–99.5%). One progressive radiolucent line was seen. Numerical rating scale (NRS) for pain with and without weightbearing at 2-year follow-up improved from 8 to 3 and from 5 to 2 points respectively. Overall general health scores improved with a median of 70 at 2 years, compared to 63 pre-operatively.
Conclusion: With no revision for aseptic loosening the use of tibial sleeves in primary TKA seems a safe and reliable method for fixation of the tibial component in metaphyseal bone with altered bone structure at short and mid-term follow-up.

Level of evidence: Level IV, cohort study

Introduction

Achieving stable fixation in the metaphyseal zone is usually not that difficult in primary total knee arthroplasty (TKA). Indications for primary TKA that may cause problems due to altered metaphyseal bone structure in the tibia are severe osteoporosis, (cystic) defects due to progressive osteoarthrosis (OA), previous high tibial osteotomy (HTO), and tibial plateau fractures (TPF). In patients receiving a TKA following fractures of the tibial plateau, a higher rate of (a)septic loosening of a standard tibial component has been described[1–3]. Bala et al described an increased revision rate with an odds ratio of 1.23, for all reasons for revision[1]. El-Galaly et al also found higher revision rates with a hazard ratio ranging from 1.5 to 2.4[2]. They noted increased septic loosening in early revision and increased aseptic loosening during mid-term follow-up. Also, for TKA following HTO, higher revision rates have been reported [4,5]. A recent meta-analysis by Chen et al confirmed this higher revision rate post HTO, with aseptic loosening as leading cause for revision[6]. A possible explanation for higher aseptic revision rates in these groups is that the altered tibial bone structure adversely affects fixation of the tibial plateau and keel in the metaphyseal bone.

The importance of zonal fixation has been demonstrated clearly in revision total knee arthroplasty (rTKA) [7]. The tibia and femur are divided in three zones: the epiphysial zone (zone 1), metaphyseal zone (zone 2), and diaphyseal zone (zone 3). For rTKA, stable fixation in at least two zones is advocated for better survival. In primary TKA, fixation in one zone is usually sufficient. In post-HTO and TPF cases, metaphyseal fixation is diminished while the epiphysial section and fixation is normal. In cases with altered tibial bone structure, this could be achieved by the use of tibial sleeves. For rTKA, excellent survivorship has been described while using sleeves[8–11]. In order to decrease the risk for revision, we started adding tibial sleeves to primary TKA in cases following HTO or TPF. The aim of the study was to investigate the preliminary short-to-midterm clinical and radiographic results of these cases.

Patients and Methods

Patients

Patient data and pre-operative x-ray were obtained from the hospital's electronic patient record (EPR) (Fig. 1). Patients were retrospectively included if they had received a tibial sleeve in combination with a primary TKA in the period between January 2011 and June 2018. A cohort of 28 patients was selected, 11 following HTO, and 17 following TPF. For each patient, data on surgical characteristics (date of operation, sleeve size) and patient characteristics (e.g., age at procedure, sex) were

collected. Patients were excluded if they received a tibial sleeve for an indication other than post HTO or TPF (Fig. 2). Standard clinical and radiologic follow-up was performed at 6 weeks, and one and two years. All patients were contacted and an outcome scores questionnaire was sent.

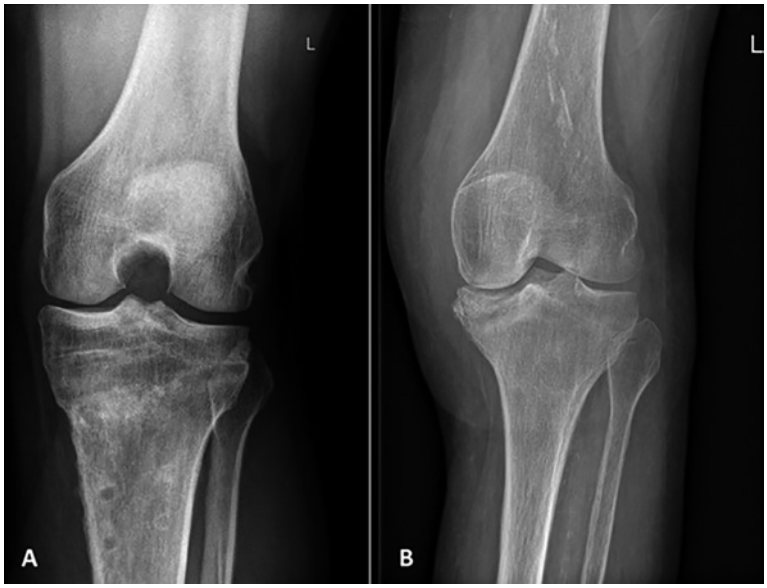

Figure 1. Pre-operative radiographs following HTO (A) and TPF (B) with signs of altered tibial bone structure.

Procedure

Each surgery was performed or supervised by one of two senior orthopedic surgeons. All patients were operated using a tourniquet. Two grams of Cefazolin were given pre-operatively. Tranexamic acid was given in two doses: one gram before start of the surgery and one gram during closure of the wound. The cemented Low Contact Stress (LCS) total knee arthroplasty system was used (Johnson & Johnson, New Jersey, USA). The sleeve used was a partially coated implant, oval-shaped for increased rotational stability and connected to the short tibial stem with a morse taper connection (Fig. 3). Standard operation procedures for a cemented primary TKA were followed, as previously described by Makaram et al[12]. For the tibia, a revision tray was used in combination with the tibial sleeve, aimed for 2 degrees of posterior slope. After the tibial cut, the trial sleeve was impacted. In each case, the smallest sleeve with a solid fixation was selected. Before final placement of the tibial component with sleeve,

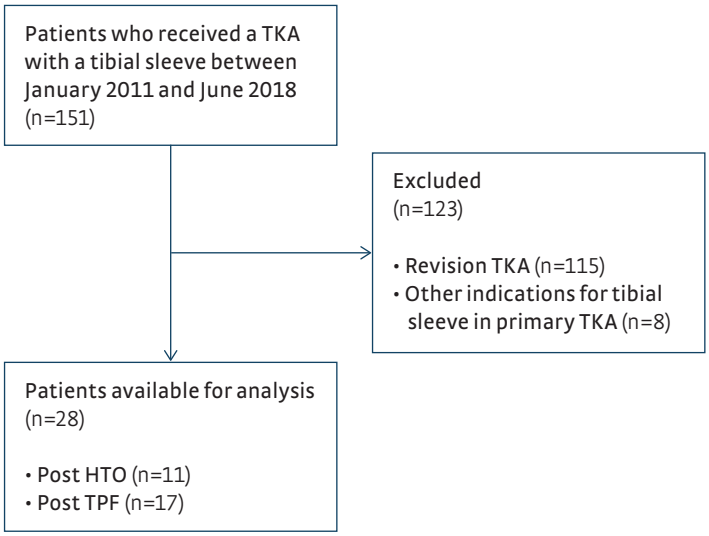

Figure 2. Patient selection.

cement fixation holes were drilled in the tibia. Cement was vacuum mixed and pressurized. During cementation, care was taken only to place cement below the base plate, not on the coated part of the sleeve. A patellar component was not routinely implanted.

Outcome

The primary outcome was a revision procedure with removal of primary prosthesis for any reason. Preoperative and postoperative (1 and 2 years) patient-reported pain, satisfaction and general health scores were collected when available. The outcome measurements that were collected in this database consisted of a 10-step numerical rating scale (NRS) score for pain (with and without weight bearing; 0 is no pain and 10 the worst pain imaginable), 10-step NRS scale for postoperative satisfaction (0 is very dissatisfied and 10 very satisfied), as well as a 100-mm visual analogue scales (VAS) for general health (0 is very unhealthy and 100 is very healthy), as scored by the patient. Complications were defined as any type of adverse events related to functioning of the implant, warranting significant additional (non)surgical treatment.

Postoperative radiographs were analyzed for radiolucent lines according to the Knee Society Scorings system[13] by one of the authors [PvR] (Fig 4).

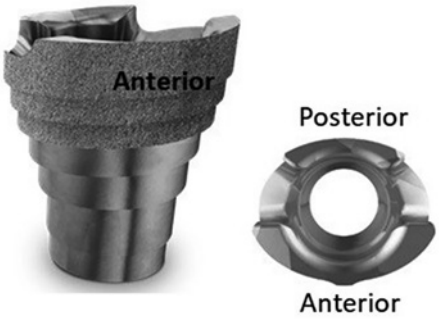

Figure 3. Partially (proximal) coated tibial sleeve with oval shape.

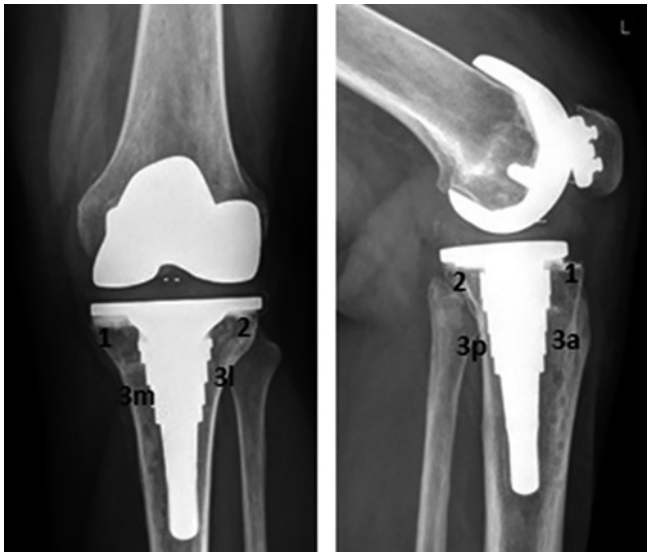

Figure 4. Standard AP and Lateral radiographs were used to evaluate for radiolucent lines. Zones for documentation are indicated.

Statistics

Survivorship was analyzed and presented graphically by using the Kaplan-Meier method. Outcomes and survivorship data were calculated by using time of the latest follow-up. Patients who died with the implant in situ and patients lost to follow-up were considered censored at the date of death and last follow-up, respectively.
Descriptive statistics [median (interquartile range)] were used to quantify clinical outcome. Statistical analysis was performed using STATA 13 (StataCorp, College Station, TX, USA). The level of statistical significance was set at $p < 0.05$.

Ethics, funding, and potential conflicts of interest

As the study was based on patient record data, without added procedures for the subjects, ethical approval was not required. Informed consent was obtained and logged in the EPR. This study received no funding.

Results

In the 28 patients that were evaluated, there were no bilateral cases. Median follow-up was 4 years (Range 1.5-9.5) (Table 1). When reviewing the patient records, it showed that standard follow-up was not performed for all patients. Most patients missed the 2 year follow-up appointment. For these patients, an appointment at the outpatient clinic was made for radiologic and clinical evaluation. All HTO cases were performed using the medial opening wedge osteotomy technique.

Table 1. Patient demographics.

Age (years) (median (range))	61 (45-81)
Gender (male: female)	10:18
Side (right: left)	13:15
Follow-up (years) (median (range))	3.1 (1.5-9.5)

The NRS for pain decreased after TKA placement. When comparing scores at ≥ 2 years with pre-operative, pain with and without weightbearing improved from 8 to 3 and from 5 to 2 points respectively. Overall, postoperatively, patients scored higher for general health compared to the preoperative situation: a median of 70 at ≥ 2 years, compared to 63 pre-operatively. (Table 2).

Table 2. Outcome scores, values are median (interquartile range).

Outcomes		Preop (N=14)	1 year (N=11)	≥ 2 years (N=16)
NRS	Pain wb*	8 (6-8)	2 (1-5)	3 (1-6)
	Pain nwb **	5 (2-6)	1 (1-5)	2 (0-5)
	Satisfaction	N/A ***	9 (7-10)	8 (6-10)
VAS	General health	63 (49–84)	75 (58-87)	70 (43-84)

* Weight bearing
** Non weight bearing
*** Not applicable

There were no cases of aseptic loosening. Survival for aseptic loosening at 9 years follow-up was 100% (CI 77.2% - 100%). Survival for all reasons for revision was 96.4% (CI 77.2% - 99.5%), with one two-stage revision for infection (Fig. 5). Survival analysis was cut-off with 10% of patients still in study, which was at 7.4 years of follow-up.

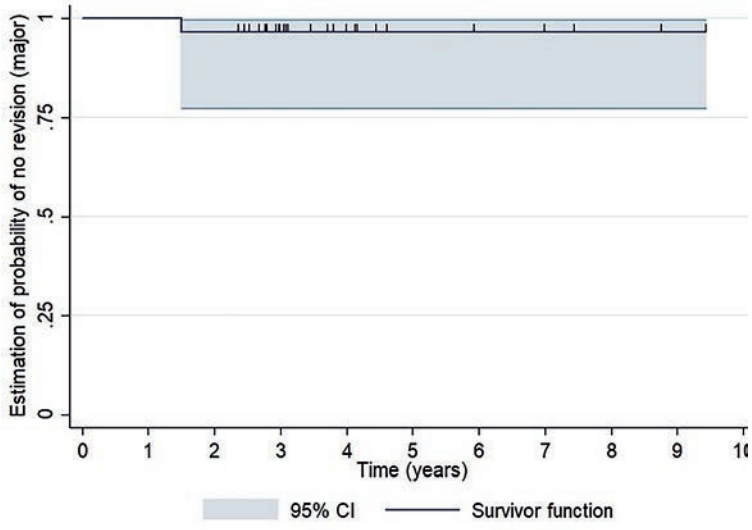

Figure 5. Kaplan-Meijer survival analysis; Major revision is classified as revision or explantation of at least one of the components.

In total, nine of the 28 patients, suffered one or more complications, ranging from persistent pain to implant revision (Table 3). Two of the patients developed arthrofibrosis, for which one patient asked a second opinion and treatment in a different hospital, the other patient was treated with manipulation under anesthesia (MUA) but encountered an infection, for which a 2-stage revision procedure was performed. Two patients complained of patellar pain, one of them was treated with placement of a patellar component.
Furthermore, one patient had a successful debridement and implant retention (DAIR) procedure because of a S. Aureus infection with retention of primary prosthesis. There was one case of mild medial instability, which was treated with a brace.
Two patients died during follow-up due to unrelated causes.

Table 3. Complications.

Complication	No cases	Treatment
Early infection	1	2x DAIR (3 and 4 weeks)
Late infection	1	2-stage revision (1.5 years)*
Arthrofibrosis	2	MUA in 1 patient (4 months) * treatment elsewhere for 1 patient
Patellar pain	2	Patellar component placement in 1 patient (3 years) no treatment in 1 patient
Medial instability	1	Brace

* same patient

Radiolucent lines

Radiolucent lines under the tibial tray were present in 10 of 28 patients, displaying radiolucent lines in one zone. In 9 cases, the lucent lines were at the component-cement interface, visible directly after implantation and it did not progress during follow-up. No lucent lines were observed at the bone-cement interface or at the bone-sleeve interface. There was one case of a new lucent line at 2 years follow-up below the lateral compartment of the tibial tray (zone 2) on the AP view. This patient, however, had a VAS satisfaction of 10 and a VAS pain of 0 with and without weight-bearing.

Of the 10 patients with lucent lines, there was one with a VAS pain of >5 at 2 years. This patient scored a VAS satisfaction of 0. Another patient had a VAS satisfaction of 6, but reported low VAS pain scores at 2 years (1 with weightbearing, 0 without weightbearing).

Discussion

The most important finding of this preliminary study was that, with no revision for aseptic loosening, the use of tibial sleeves in primary TKA seems a safe and reliable method for fixation of the tibial component in metaphyseal bone with altered bone structure. Radiolucent lines were a fairly common finding. However, in this series most lines were present directly postoperative. There was only one case of a progressive radiolucent line in an otherwise asymptomatic patient.
Patients reported lower pain scores and an increased feeling of general health. Also, postoperative satisfaction was high. There are not many publications that describe the outcome of TKA following previous surgery or fracture. Lim et al. showed that patients with prior surgery, such as a HTO and anterior cruciate ligament (ACL) reconstruction, had similar clinical and quality of life outcomes after TKA, compared to patients who haven't had previous surgery [14]. More recently, Wang et al showed good outcome and high patient satisfaction for patients receiving a TKA following fractures around the knee [15]. These results are consistent with the present findings.

Six of 28 patients had one or more complications. This is a relatively high number for primary TKA. It is, however, consistent with the findings of Putman et al, who noticed an increased incidence of complications in patients with TKA following previous surgery or trauma. Especially infection (4.5%), skin problems (8.3%), and stiffness (8.3%) were reported more frequently, compared to primary TKA patients without previous surgery or trauma [16].

Radiolucent lines in cemented TKA can be present early (immediate) or develop later. Wautier et al have recently described the development of radiolucent lines and how they should be interpreted[19]. Safe one, all radiolucent lines in this study were present directly after implantation at the cement-implant interface and are not indicative of loosening. Furthermore, these lines did not progress in two years of follow-up, indicating a fixation without signs of micromotion or instability. One radiolucent line was first visible at 2 years follow up, but again in the cement-implant interface. This can mean that the angle of the radiograph differed, or that there have been micromotions. No further evaluation has taken place in this patient, due to excellent reported clinical scores.

With regard to the extent of altered bone structure, a few connotations should be made. It could be argued that in HTO, a medial open wedge osteotomy (OW_HTO) will result in a more extensive area of altered bone structure, compared to a lateral closing wedge osteotomy (CW-HTO), because of the gap that has to be bridged. This has led to the decision of the authors to use a sleeve in TKA following HTO. In contrast

to the described increased revision rates for TKA following TPF, the literature is not conclusive on revision rates in TKA following HTO. There is some evidence pointing to a higher failure rate of TKA following CW-HTO. However, the current literature is inconclusive about the higher incidence of failure following OW- HTO.

Most authors analyzed the two techniques together. Of these, a few authors did not find an increased revision rate following HTO: El-Galaly et al did not observe an increased revision rate following HTO in the Danish population, except when posterior stabilized implants were used [17]. Also, Batailler et al did not see an increase in aseptic loosening of the tibial component when using uncemented TKA following HTO[18]. However, these studies were included in the most recent meta-analysis by Chen et al, and they did show an over-all significantly increased risk for rTKA after HTO, with aseptic loosening as most common reason for revision [6].

There are two studies that specify the difference between OW- and CW-HTO. Ehlinger et al and Robertsson et al showed higher rates of loosening in TKA after CW-HTO, compared to OW-HTO [20,21]. As Han et al described, these results are most probably due to more technical difficulties in TKA after closing wedge osteotomy, compared to open wedge HTO [22]. Interestingly, in the studies of Ehlinger and Robertsson, a higher incidence of stemmed implants were described (12.8% and 4% respectively) in TKA following HTO. El-Galaly et al reported the use of stems/cones/sleeves in up to 22% of cases following TPF, as opposed to 2% in primary osteoarthritis [2]. The use of stemmed implants was comparable between OW- and CW-HTO. These numbers indicate that surgeons in these studies had concerns with respect to tibial fixation in selected cases.

With respect to TKA following OW-HTO, when looking at the literature, routine use of a metaphyseal sleeve does not seem to be indicated. However, in selected cases added metaphyseal stability may be warranted. The use of a revision tray with a tibial sleeve is a more expensive implant and therefore it raises the question whether this can be considered as overtreatment. Taking the increased risk for revision into account, however, using a tibial sleeve following TPF or in selected cases following HTO may avoid a costly revision procedure. A tibial sleeve in primary TKA could also be considered in other cases with compromised tibial metaphyseal bone structure, such as severe osteoporosis, tunnel widening after ACL reconstruction, severe cysts in progressive OA, and like cases. Further research is needed to identify these specific cases, investigate the outcomes and to study cost effectiveness.

There are a few limitations to this study that need to be discussed. First, the sample size of this study is small, and there was no control group receiving standard tibial

trays without sleeves. We did not differentiate between Schatzker classification. It could be argued that the extent of compromised metaphyseal bone would be larger in Schatzker 4-6 fractures, compared to Schatzker 1 or 3 fractures. Due to the small sample size, this relation could not be analyzed in the present study. Further research will be needed to explore this.

Second, there were a lot of missing data in the outcome scores, partly because the hospital only started gathering outcome scores as part of standard care from 2016. All patients were contacted and sent an outcome scores questionnaire. Seven patients did not return the questionnaire, and several patients were unwilling to come to the hospital for follow-up because of COVID19. Statistical analysis was not performed for outcome scores, because of the small sample size and because only a few patients had data on all three follow-up moments.

Third, the time points for the last follow up were varying, due to the fact that standard protocol was not always followed. However, except for one septic revision at 1.5 years, all available patients were followed at least 2 years.

Fourth, it could be argued that bony ingrowth in the sleeve (and therefore implant stability) could be less with altered bone structure. However, a recent paper by Ihekweazu et al showed that sufficient fixation can be achieved with limited bony ingrowth (14.7% in tibial sleeves), which is comparable with bony ingrowth described for well-fixed acetabular components in total hip arthroplasty[23].

Conclusion

Preliminary results in terms of survival and outcome for the use of tibial sleeves in primary TKA following TPF and OW-HTO are satisfactory. Further research is needed to determine which patients profit from extra metaphyseal stabilization, and to analyze the long-term survival, outcome scores, and patient satisfaction in more detail.

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Chapter 3

Long Term Outcome following Revision Total Knee Arthroplasty is associated with indication for revision

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Abstract

Background: There is limited information about long-term clinical outcomes following revision total knee arthroplasty (TKA) in relation to the indication for revision. Previously, a clear relation between indication for revision and clinical outcome was shown after 2 years. Present study evaluated (1) whether the reported association at 2 year remains present at 7.5 years, and (2) how clinical outcome at 7.5 years developed compared to baseline and 2-year follow-up, and (3) whether patients had additional adverse events.
Methods: A cohort of 129 patients with a total system revision TKA was selected. Range of motion, Visual Analog Scale for pain and satisfaction, and clinical and functional Knee Society Score were obtained preoperatively, at 3 months, 1, 2, and 7.5 years. Reasons for revision were septic loosening, aseptic loosening, malposition, instability, and severe stiffness.
Results: Patients revised for severe stiffness had significantly worse outcomes. No difference was found between the other indications. The clinical outcome after revision TKA at 7.5 years remained stable for septic and aseptic loosening, malposition, and instability but deteriorated slightly for the severe stiffness group. Visual Analog Scale satisfaction remained constant for all indications. There were 11 additional complications between 2- and 7.5-year follow-up, 9 of which necessitated reoperation.
Conclusion: All indications except severe stiffness had a similar clinical outcome which was maintained up to 7.5-year follow-up. The severe stiffness group had worse outcomes and deteriorated slightly at longer follow-up. Outcome at 3 months seems predictive for long-term outcome. Additional complications did not differ significantly for the different reasons for revision.

Level of Evidence: Level III, prognostic study.

Introduction

With a growing demand for primary total knee arthroplasty (TKA), the number of rTKA surgeries is also continuing to rise [1–4]. The main reasons for revision of a total knee arthroplasty (TKA) are aseptic loosening, component malposition, knee instability, septic loosening, patellar instability and stiffness [1,2,5,6]. There have been numerous reports that show that rTKA in patients with unexplained pain renders inconsistent results [5,7–10]. Therefore, a detailed workup and clear diagnosis are advocated before revising a painful knee following TKA.
A number of authors report on the epidemiology and stress the huge (economic) implications of rTKA [1–4]. Despite a growing understanding of the survival of different (revision) TKA designs due to national registry studies, there remains a lack of knowledge regarding long term patient outcomes following rTKA surgery[11].
Previously, we reported on the clinical and functional outcome after rTKA at two years follow up, which showed that the reason for revision was associated with clinical and functional outcomes [6]. Satisfaction, pain reduction, and functional improvement were better and complication rates were lower after revision for aseptic loosening than for other causes of failure. For stiffness as reason for revision, pain, function, and satisfaction scores were the least favorable. Others have published similar results[12–16], however studies with longer follow-up are limited [11] and often have a mix of partial and total revisions and different types of implants [17], or do not differentiate between reasons for revision[18].

Therefore, we updated our previously published prospective cohort of patients receiving a fully revised TKA and evaluated 1) whether the previously reported association between reason for revision and clinical outcome at 2 years follow-up remains present at 7.5 years follow-up, 2) how clinical outcome after rTKA at 7.5 years developed compared to baseline and 2 years follow-up, and 3) whether patients suffered from additional adverse events between 2 and 7.5 years follow-up.

Patients and Methods

The original cohort consisted of 150 patients; 130 patients that were operated at our institution, and 20 patients that were operated at the University Hospital of Leuven, Belgium. In the present study, 129 patients that received a fully revised TKA using a single implant system at our institution (Table 1) were included. One patient of the original cohort was wrongly included because only the femoral component was revised and was therefore excluded in the present study (Fig. 1). The patients at the Leuven University hospital were not included in the current study.

Table 1. Baseline characteristics.

Variable	Value
Age at time of surgery (yrs) *	66 +/- 9.2
Sex (M:F) (number of patients)	42 : 87
Side (L:R) (number of patients)	48 : 81
Prosthesis (Genesis II® : Legion®)	57 : 72
Baseline values outcome parameters	
KSS clinical (points) *	48 +/- 18
KSS functional (points) *	39 +/- 23
VAS pain (points) *	63 +/- 20
ROM (degrees)*	95 +/- 23

* Values are mean +/- SD

Patients were included from June 2004 to June 2008. All patients were treated with either the Genesis II® or the Legion® revision system (Smith & Nephew, Inc, Memphis, TN, USA). Between June 2004 and August 2006, all patients were treated with the Genesis II® revision system. Thereafter, this system was replaced by the Legion® revision system. Both systems have similar femoral components, but the Legion® system allows the use of offset stems on the femoral and tibial sides. Patients receiving a partial revision, a hinged arthroplasty or revision of a hemiarthroplasty were not included. All revisions were performed by experienced, high volume orthopedic knee surgeons. Six tissue cultures were routinely taken during all procedures to rule out infection as main indication for revision.
The hospital investigational review board approved the study. The local Medical Ethical Review Board granted a waiver for this study (no. 2003/173).

Patients were allocated to one of five categories: septic loosening, aseptic loosening, component malposition, instability, and severe stiffness (Fig. 1). The mechanism of failure was based on preoperative evaluation and perioperative findings. If more than one reason for revision was identified, the main failure mechanism was chosen and used for further analysis (Table 2).

All patients were evaluated preoperatively, and postoperatively at 3 months, and 1, 2, 5 and 7.5 years. Questionnaires were completed by a physician or a nurse practitioner and the patient; a 100-mm Visual Analog Scale (VAS) for pain (0 = excellent) and patient satisfaction (100 = excellent) and the Knee Society Score (KSS) using the clinical and functional scores were included. In addition, Range of Motion (ROM), an item on the KSS clinical score, was analyzed separately.

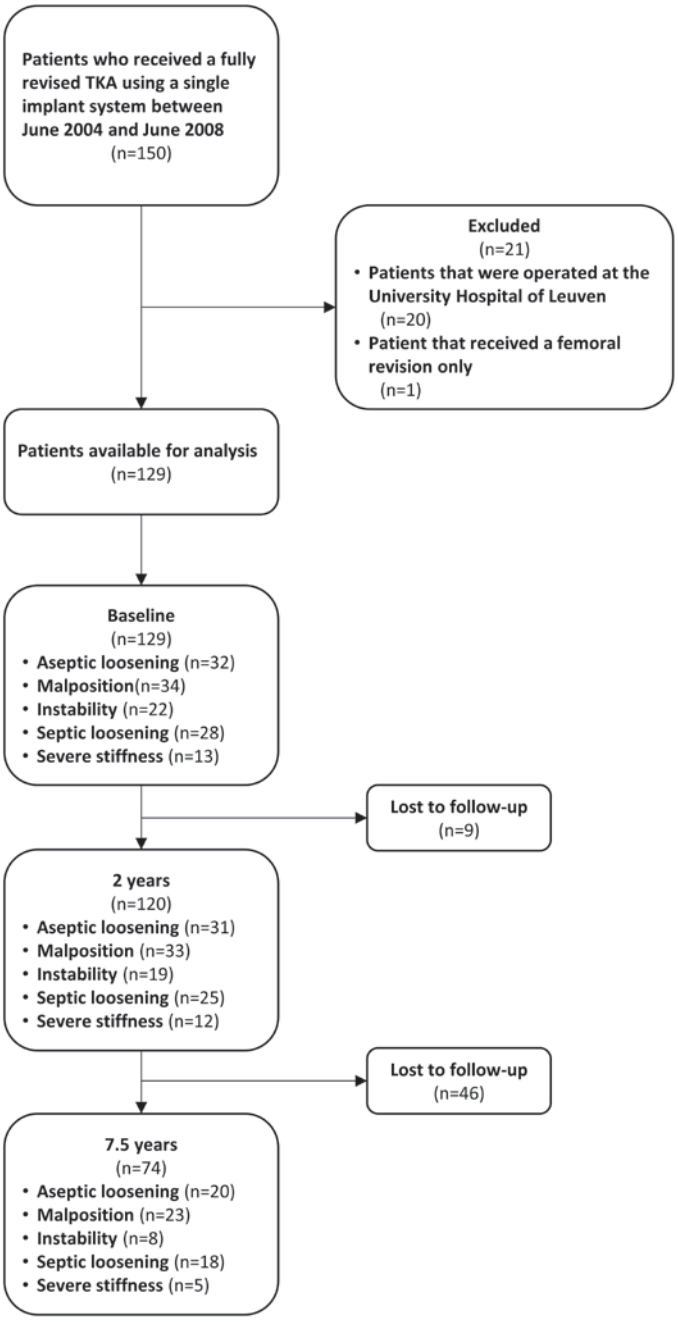

Figure 1. Flow chart.

Complications were defined as any adverse events related to the placement, or functioning of the revision implant. This also included events that did not require surgery, such as persisting pain and neurinoma.

Table 2. Definitions of Revision Reasons.

Reason for revision	Definition
Aseptic loosening	Loosening without signs of infection; polyethylene wear with emerging bone loss but no complete loosening also was included in this group.
Malposition	Presence of clear malposition or malrotation of one or both components, causing pain or patella maltracking.
Instability	A clinical diagnosis with pain and instability experienced by the patient caused by a collateral ligament laxity or PCL insufficiency without any sign of component malposition.
Septic loosening	All patients treated with a two-stage reimplantation based on clinical suspicion or proven infection; patients with negative culture samples remained in the septic loosening group because the two-stage treatment was similar to the proven infection cases.
Severe stiffness	A ROM $\leq 70^{\circ}$, (according to the International Consensus of the Definition and Classification of Fibrosis) [14], with or without pain; even if the stiffness was caused by a component malposition or other earlier defined main diagnosis, these patients were solely analyzed in this single group, with the exception of patients with stiffness caused by septic loosening. These patients remained in the septic loosening group.

PCL, posterior cruciate ligament; ROM, range of motion.

Statistical analysis

Descriptive statistics were used to summarize the data. Linear mixed models were used to study the relationship between reason for revision and repeated measurements of clinical and functional KSS scores, range of motion, VAS pain, and VAS satisfaction. Reason for revision and time of follow-up visit and the interaction between reason for revision and time of follow-up visit were used as fixed factors. Patient id was used as random factor. Pairwise comparisons were performed using Tukey's correction for multiple testing. Chi-square tests were used to compare the proportion of complications across the five revision categories.
Statistical analysis was performed using R version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria). The level of statistical significance was set at $p < 0.05$.

Results

At 7.5 years post rTKA, VAS pain, VAS satisfaction, KSS clinical and ROM were associated with reason for revision. Patients who were revised for severe stiffness scored significantly lower with respect to KSS clinical scores and ROM than patients with a revision for the other indications (Table 3-4). Furthermore, patients in the severe stiffness group showed significantly higher scores for VAS pain compared to septic loosening and a trend to higher VAS pain scores compared to revision for aseptic loosening (Table 3-4, fig 2a). VAS satisfaction was significantly higher for aseptic loosening compared to severe stiffness (Table 3-4, fig. 2b). KSS Functional scores did not differ significantly between reasons for revision.

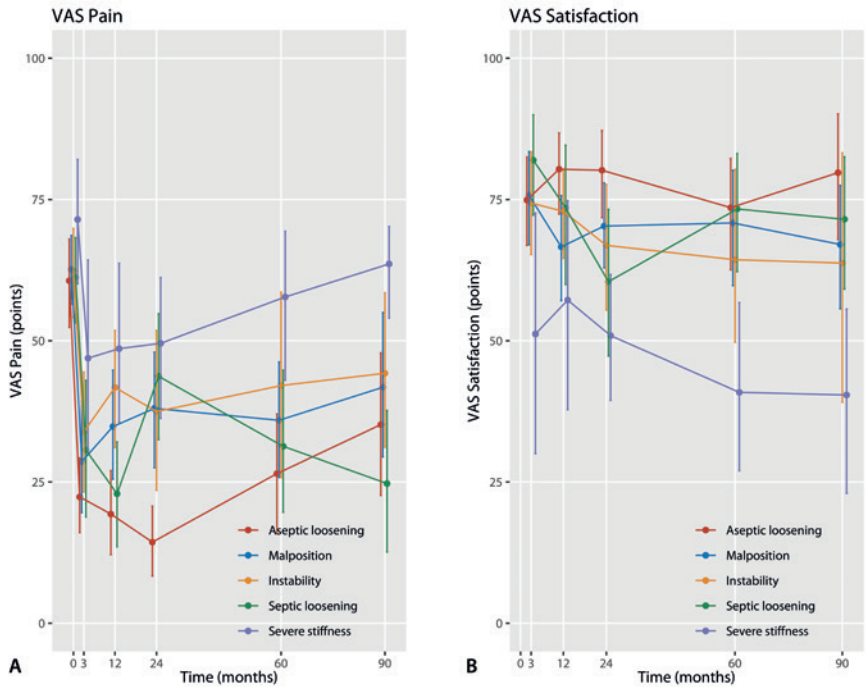

Figure 2. Development in time of (A) VAS Pain, and (B) VAS Satisfaction.

Table 3. Clinical outcome scores.

Value	Follow-up	Aseptic loosening	Malposition	Instability	Septic loosening	Severe stiffness
KSS clinical (points)	Pre-operative	52 ± 17 (n=32)	49 ± 16 (n=34)	50 ± 15 (n=22)	50 ± 20 (n=28)	30 ± 22 (n=13)
	2 years	87 ± 14 (n=30)	74 ± 23 (n=33)	77 ±18 (n=19)	74 ± 21 (n=24)	56 ± 17 (n=12)
	7.5 years	83 ± 15 (n=20)	82 ± 15 (n=22)	77 ± 13 (n=7)	77 ± 22 (n=14)	52 ± 29 (n=5)
KSS function (points)	Pre-operative	40 ± 21 (n=30)	47 ± 22 (n=34)	35 ± 22 (n=22)	29 ± 24 (n=27)	41 ± 24 (n=13)
	2 years	72 ± 22 (n=26)	61 ± 27 (n=31)	51 ± 21 (n=17)	61 ± 28 (n=22)	40 ± 42 (n=9)
	7.5 years	58 ± 30 (n=21)	64 ± 22 (n=23)	60 ± 27 (n=8)	64 ± 28 (n=18)	59 ± 7 (n=5)
ROM (°)	Pre-operative	107 ± 15 (n=30)	100 ± 16 (n=34)	101 ± 12 (n=22)	84 ± 24 (n=28)	58 ± 22 (n=12)
	2 years	112 ± 13 (n=31)	109 ± 15 (n=32)	117 ± 10 (n=19)	102 ± 16 (n=25)	83 ± 19 (n=12)
	7.5 years	118 ± 12 (n=20)	116 ± 12 (n=22)	113 ± 16 (n=7)	103 ± 22 (n=14)	62 ± 31 (n=5)
VAS Pain (points)	Pre-operative	61 ± 23 (n=29)	63 ± 28 (n=32)	62 ± 20 (n=22)	61 ± 20 (n=27)	71 ± 20 (n=13)
	2 years	14 ± 17 (n=28)	38 ± 29 (n=31)	37 ± 29 (n=17)	44 ± 30 (n=24)	50 ± 21 (n=11)
	7.5 years	35 ± 28 (n=20)	42 ± 31 (n=21)	44 ± 22 (n=8)	25 ± 29 (n=18)	64 ± 11 (n=5)
VAS satisfaction (points)	Pre-operative	-	-	-	-	-
	2 years	80 ± 21 (n=29)	70 ± 23 (n=30)	67 ± 24 (n=18)	60 ± 32 (n=24)	51 ± 20 (n=11)
	7.5 years	80 ± 27 (n=20)	67 ± 27 (n=21)	64 ± 34 (n=8)	72 ± 26 (n=18)	40 ± 22 (n=5)

Table 4. Differences in Outcome, Severe Stiffness Compared to Other Indications at 7.5 Years.

Reason for revision		KSS clinical	KSS functional	KSS ROM	VAS Pain	VAS Satisfaction
Severe stiffness vs	Aseptic loosening	-30.0 (-53.1 - -7.6) *p*= 0.003	-3.5 (-35.9 – 28.9) *p*=0.99	-53.1 (-74.4 - -31.9) *p*<0.0001	30.2 (-3.1 - 30.2) *p*=0.097	-41.1 (-73.9 - -8.2) *p*<0.0061
	Malposition	-30.1 (-52.7 - -7.5) *p*= 0.003	-12.0 (-44.1 – 20.1) *p*=0.84	-54.3 (-75.4 - -33.3) *p*<0.0001	24.0 (-9.2 – 57.1) *p*=0.28	-27.6 (-60.3 – 5.2) *p*=0.14
	Instability	-26.3 (-52.8 - -0.2) *p*= 0.05	-1.6 (-38.3 – 35.0) *p*=1.00	-53.1 (-75.7 - -26.9) *p*<0.0001	17.5 (-20.3 – 55.3) *p*=0.73	-26.5 (-63.7 – 10.6) *p*=0.29
	Septic loosening	-24.4 (-48.1 - -0.7) *p*= 0.04	-7.9 (-40.8 – 25.0) *p*=0.97	-41.6 (-63.7 - -19.5) *p*<0.0001	37.0 (3.2 – 70.7) *p*=0.024	-28.3 (-61.6 – 5.0) *p*=0.14

Values are mean effect size (95% CI)

Compared to the pre-operative scores, there was a statistically significant increase in the KSS clinical sub score for the aseptic loosening, malposition, instability and septic loosening groups at 7.5 years. The severe stiffness group did not show a significant increase in KSS clinical (Table 5, Fig. 3a). KSS functional sub score showed a significant increase at 7.5 years for malposition and septic loosening. KSS functional did not increase significantly in the aseptic loosening, instability, or severe stiffness groups (Table 5, Fig. 3b). VAS pain significantly decreased at 7.5 years for aseptic loosening, malposition, and septic loosening. No significant decrease was seen for severe stiffness, and instability, (Table 5, Fig. 2a).
Range of motion only significantly increased for the septic loosening, and malposition. (Table 5, Fig. 3c).

Table 5. Differences in Outcome, 7.5 Years Postoperative Compared to Baseline.

Reason for revision	KSS clinical	KSS functional	KSS ROM	VAS pain
Aseptic loosening	30.4 (17.5 - 43.3) $p<0.001$	15.6 (-1.0 - 32.2) $p=0.08$	8.1 (-2.6 – 18.8) $p= 0.26$	-27.8 (-46.2 - -9.5) $p=0.0003$
Malposition	33.9 (21.4 - 46.3) $p<0.0001$	18.1 (2.3 – 33.8) $p=0.01$	17.0 (6.9 – 27.1) $p<0.0001$	-22.3 (-39.9 - -4.6) $p=0.005$
Instability	28.7 (9.0 -48.3) $p= 0.0005$	19.4 (-5.3 – 44.0) $p=0.22$	13.4 (-3.1 - 29.8) $p= 0.19$	-16.6 (-43.1 – 9.9) $p=0.47$
Septic loosening	27.4 (12.7 - 42.1) $p< 0.0001$	32.2 (14.4 – 50.0) $p< 0.0001$	19.6 (7.3 – 31.8) $p=0.0001$	-35.4 (-54.5 - 16.2) $p<0.0001$
Severe stiffness	23.3 (-0.7 – 47.2) $p=0.06$	11.6 (-19.8 – 43.0) $p=0.90$	8.1 (-11.9 – 28.2) $p=0.85$	-8.2 (-41.9 – 25.6) $p=0.98$

Values are mean effect size (95% CI)

There were no clinically relevant nor statistically significant differences in any of the outcomes between 2 and 7.5 years for any reason for revision (Table 6).

Of the 55 patients that were lost to follow-up, 16 patients died during the follow-up period due to causes not related to the revision surgery. Of the other 39 patients that dropped out, patients mostly did not return for further evaluation due to an impaired health status or due to the travel distance to the clinic.

In total, 37 of the 129 (29%) patients suffered a complication, 20 of which required surgery (15%). (The re-revision rate was 8% (6 re-revisions). Complication rates for each indication were compared (Table 7). Of the 37 complications, 11 were seen between 2 and 7.5 years follow-up. There were two cases of instability, one of which was revised to a hinged implant. Two patients showed aseptic loosening of the tibial

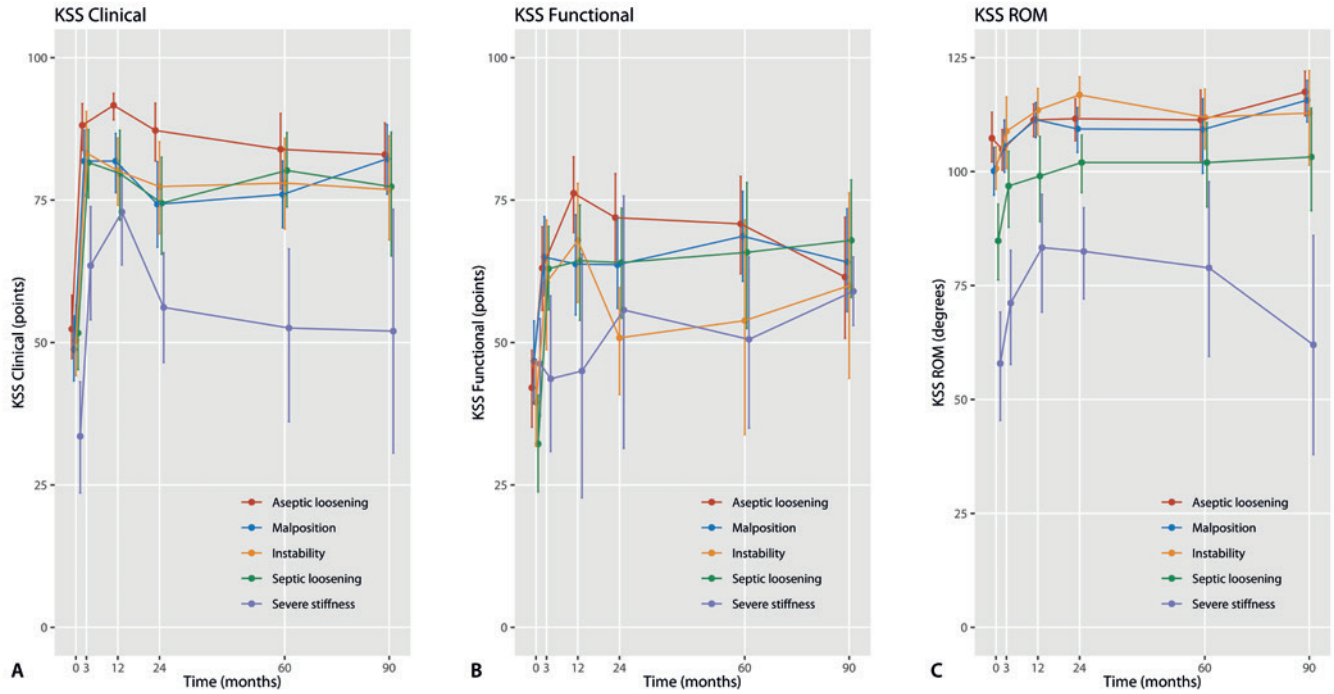

Figure 3. Development in time of (A) KSS Clinical, (B) KSS Functional, and (C) KSS ROM.

Table 6. Differences in Outcome, 7.5 Years Compared to 2 Years Postoperative.

Reason for revision	KSS clinical	KSS functional	KSS ROM	VAS pain	VAS satisfaction
Aseptic loosening	4.0 (-16.9 – 8.9) *p*=0.95	-15.9 (-33.1 – 1.3) *p*=0.09	4.4 (-6.2 – 15.1) *p*=0.84	17.6 (-1.0 – 36.1) *p*=0.08	0.6 (-15.9 – 17.1) *p*=1.0
Malposition	8.5 (-3.9 – 20.9) *p*=0.37	3.8 (- 12.3 – 19.9) *p*=0.98	7.4 (-2.9 – 17.6) *p*=0.31	2.2 (-15.7 – 20.1) *p*=0.99	-4.2 (-20.4 – 12.1) *p*=0.96
Instability	1.6 (-18.3 – 21.6) *p*=0.99	7.4 (-18.0 – 32.9) *p*=0.96	-2.9 (-19.6 – 13.8) *p*= 0.99	8.2 (-19.4 – 35.8) *p*=0.96	-1.0 (-25.7 – 23.7) *p*=1.0
Septic loosening	2.5 (-12.6 – 17.6) *p*=0.99	-1.6 (-20.2 – 17.0) *p*=0.99	5.9 (-7.6 – 17.3) *p*=0.87	-17.2 (-36.9 – 2.5) *p*=0.13	7.1 (-10.6 – 24.8) *p*=0.81
Severe stiffness	-3.2 (-27.2 – 20.7) *p*=0.99	10.1 (-23.6 – 43.7) *p*=0.96	-19.6 (-39.6 – 0.4) *p*=0.059	13.8 (-20.9 – 48.6) *p*=0.87	-11.2 (-42.8 – 20.4) *p*=0.87

Values are mean effect size (95% CI)

Table 7. Total Complications, Sorted by Indication for Revision

Complication	Aseptic loosening	Malposition	Instability	Septic loosening	Severe stiffness
Delayed wound healing	1	2	2	2	1
Infection					
DAIR	1				
Re-revision				1	
Arthrodesis				1	
Instability	1			1	
Insert change			2		
Revision to hinge	1				
Stiffness [a]			1	1	1
Aseptic loosening [b]				1	1
osteonecrosis patella	1				
Pain					
Stem Pain tibia		1[c]			
Anterior knee pain	1[d]	2	1[d]		
Lateral knee pain	1[e]				
Neurinoma				1	
Persisting pain e.c.i. [f]	1		2	3	
Periprosthetic fracture	1				
Knee luxation		1			
Total number of complications	**9**	**6**	**8**	**11**	**3**

a Requiring Movement Under Anesthesia (in 1 patient with arthroscopic release)
b Requiring total re-revision TKA
c Requiring revision of tibial component
d Requiring lateral facetectomy and/or lateral release
e Requiring iliotibial tract release
f e causa ignota, cause unknown

plateau, for which a total re-revision and tibial component re-revision were done. One patient had a recurrent infection, which was treated with a two-stage total rTKA. There was one knee dislocation, treated conservatively, one case of anterior knee pain, treated with resection of the lateral facet. One patient had osteonecrosis of the patella, for which the patellar component was removed. One periprosthetic fracture was seen, for which eventually a re-revision of the femoral component was

performed. One tibial component was revised due to stem pain and there was one case of arthrofibrosis, for which an arthroscopic release was done, with negative cultures. There was no significant difference in the complication rate between the various indications.

Discussion

This study shows that at 7.5 years follow up, outcome of rTKA remains associated with reason for revision with worst outcomes in the severe stiffness group. At 7.5 years follow-up the superior clinical outcome of the aseptic loosening group after 2 years follow-up regressed to the mean of the malposition, septic loosening, and instability groups. Although follow-up in current literature is shorter than in the present study, many have described this less favourable outcome in revision for severely stiff TKA [19–22]. A possible explanation for the lower KSS clinical scores is that this score, for a large part, depends on ROM (25%). Therefore, it is reasonable to conclude that patients following revision for severe stiffness have a limited ROM and experience more pain, yet are functionally comparable to patients that are revised for other reasons. Recently, better results were described with revision for severe stiffness using a hinged implant, compared to a condylar implant. Long term outcome of these revisions remain to be analysed [23,24].

No significant differences were seen for any indication when comparing the outcome at 2 and 7.5 years follow-up. There was a significant improvement compared to baseline, comparable to the improvement at 2 years post revision. Furthermore, van Kempen et al showed that the results at 3 months postoperative were indicative for the results at 2 years [6]. Although these results are not directly applicable to individual patients, they are useful in counselling patients' expectations in the outpatient clinic both pre- and postoperatively.
The results in this study are consistent with previous studies looking at outcome following rTKA [12–14,25] .

There are few authors that report on long term outcome in relation to indication for revision. The authors that did, showed results that are consistent with our findings at 7.5 years follow-up. Rajgopal et al compared outcomes with respect to revision for flexion instability, aseptic loosening, and septic loosening[15]. With a mean of 40.5 months follow-up, they observed higher scores for patients following revision for aseptic loosening. With respect to long term outcome following rTKA, Wilke et al showed an increase in KSS clinical, ROM and a reduction in pain at 10 years[26]. Kim et al saw an improved KSS clinical and functional score as well as an improved

Western Ontario and McMaster Universities Osteoarthritis index score[18]. Both authors, however, did not differentiate between different reasons for revision. Lee et al differentiated between septic and aseptic causes for revision. Aseptic causes included periprosthetic fractures, aseptic loosening, polyethylene wear, instability, recurrent dislocation and malalignment. They found improvements in ROM and KS, HSS and WOMAC scores at 2 years with more favorable results for the aseptic revisions[16].To our knowledge, there are currently no other authors that looked at differences between various indications with long term follow-up.

The complication- and re-revision rates found in this study were comparable to those reported in literature [19,27,28]. Kim et al showed a re-revision rate of 8% over 14.5 years and Lee et al had a re-revision rate of 3% with a mean of 5.5 years follow-up[16,18]. Although, some studies have reported much higher re-revision rates, up to 26% at 10 years[29–31]. In the present study there were 11 additional complications between 2 and 7.5 years follow up with a total re-revision rate of 8 % in this period. Between 2 and 7.5 years, only 2 aseptic and 1 septic loosening were seen. When the complications of the first 2 years were included, the re-revision rate remained 8%.

There are some limitations to the present study. Because of the subdivision in different revision groups and due to the number of patients that were lost to follow-up, the subgroups contain a relatively small sample size, with as a result a large standard deviation in the reported outcomes. Furthermore, bias cannot be excluded because the revisions were performed by different surgeons, and different TKA systems were used in time. However, all surgeons were high volume knee surgeons and the TKA systems were very comparable. Also, the choice of implant was dictated by point in time rather than reason for revision.
Due to the nature of the data collection, there were some missing data. Also, dividing the patients in different subgroups, even when more than one reason was applicable, carries a risk of selection bias. In these cases, consensus was reached between high volume knee surgeons to determine the main reason for failure.

Shared decision making is increasingly important in the field of orthopaedic surgery, and with increasing rates of revision and re-rTKA, knowledge of long-term results is needed more and more. Not only is it necessary to adequately inform our patients in the outpatient clinic, but it can also help in the decision-making process of the surgeon when a rTKA is being contemplated.

Conclusion

Reason for revision is associated with outcome at 7.5 years postoperative with severe stiffness rendering less favourable outcomes. rTKA shows an improvement in clinical outcome at 7.5 years postoperative with respect to VAS pain, VAS satisfaction and KSS clinical, compared to baseline. No further improvement was found at 7.5 years compared to the results seen at 2 years. The complication rate between 2 and 7.5 years was low, with a re-revision rate of 8%.

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Chapter 4

Improved clinical outcomes after revision arthroplasty with a hinged implant for severely stiff total knee arthroplasty

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Abstract

Background: Management of the severely stiff total knee arthroplasty (TKA) is challenging, with the outcome of revision arthroplasty being inferior compared to the outcome for other indications. The aim of this study was to analyse the outcome after revision TKA with hinged-type implants for severely stiff TKA [range of motion (ROM)≤70°] at 2 years.

Methods: A cohort of 38 patients with a hinged-type revision TKA (Waldemar Link or RT-Plus) and preoperative ROM≤70° were selected from a prospectively collected database. ROM, visual analogue scale (VAS) for pain and satisfaction and Knee Society Score (KSS) were obtained preoperatively and at 3 months, 1 year and 2 years. Pre- and postoperative outcome were compared at 2 years.

Results: There was a significant increase in ROM and KSS. VAS pain scores did not differ significantly. The median ROM at 2 years was 90° (range 50°-125°) with a median gain of 45° (range 5°-105°). Median VAS pain was 28.5 (range 0-96) points and median VAS satisfaction was 72 (range 0-100) points at 2 years. Twelve patients suffered a complication. Recurrent stiff knee was the most frequently reported complication (n=5).

Conclusions: Hinged-type revision TKA following a severely stiff TKA renders a significant, although moderate, clinical improvement at 2 years.

Level of evidence: Retrospective case series. Level IV.

Introduction

Stiffness following Total Knee Arthroplasty (TKA) is a challenging problem in orthopaedic surgery. When looking at revision Total Knee Arthroplasty (TKA), it has been shown that patients who were revised for severely stiff TKA have the worst outcome directly postoperative and remain worse at 2 years with respect to range of motion (ROM), pain and satisfaction score, and Knee Society Score (KSS) when compared to other indications (revision for septic loosening, aseptic loosening, component malposition or instability) [15]. Analysis of the outcome and treatment of severely stiff TKAs has proven to be challenging, mostly due to the fact that the aetiology is largely unknown and fairly diverse. Furthermore, comparing results reported in literature is complicated by variable definitions of stiffness that are being used[5, 16, 24].

Management of a severely stiff total knee arthroplasty consists of physiotherapy, manipulation under anaesthesia (MUA), arthroscopic debridement, or open debridement [1, 3, 4, 8, 11, 22]. Revision arthroplasty is most commonly reserved for the correction of technical errors in the severely stiff TKA, such as malrotation, malpositioning and instability [8, 11, 18].

In an attempt to further improve the outcome, a series of patients with severely stiff TKA was treated with a hinged-type rTKA. Hereby, a more extensive soft tissue release was enabled without the risk of causing instability[17]. Many authors have looked at the results of rTKA using a condylar implant on the outcome of severely stiff TKA[5, 7–9, 13, 19, 21]. According to Cohen et al, rTKA, although being a viable option for some patients, still does not offer a solution for all patients suffering from a severely stiff TKA. Farid et al are the only ones that partly looked at the effect of radical adhesiolysis and rTKA using a hinged-type TKA[9]. The aim of this study was to analyse the outcome of revision for severely stiff TKA using a hinged-type TKA system. It was hypothesized that revision of severely stiff TKA using a hinged-type implant leads to a significant increase in ROM, VAS satisfaction, and KSS scores, and a significant decrease in pain at 2 years follow-up.

Materials and methods

Patients were retrospectively selected from a prospectively collected data set, as previously described by Van Kempen et al [15]. Patients were selected from the database for the present analysis when they had received a hinged-type rTKA because of a severely stiff TKA in the period between June 2004 and December 2012. All cases were primary TKA following osteoarthritis.

In this study, a severely stiff TKA was defined as a ROM <70°, according to the International Consensus of the Definition and Classification of Fibrosis [14]. All revisions were performed by two experienced orthopaedic knee surgeons at our institution. Patients with a revision due to periprosthetic joint infection or with a follow-up of less than one year were excluded from the analysis.
The used hinged implants were the Waldemar Link Endo-Modell® (Link, Hamburg, Germany) (n=7) or the RT-Plus (Smith & Nephew, Memphis, TN, USA) (n=31). Both implants were rotating hinge TKA. Choice of implants was based on the surgeon's preference. All patients in the database were evaluated preoperatively (pre-revision), perioperative, at 3 months, and at 1 and 2 years postoperatively. All evaluations were done during routine follow-up visits.
During all procedures, a rigorous debridement of fibrous tissue and extensive release of the joint capsule was performed. Six tissue cultures were routinely taken to evaluate for periprosthetic joint infection.
In total, the data of 38 patients were available for analysis (figure 1, table 1). In all patients, a detailed and personalized work-up was performed to identify the cause of stiffness. This workup contained a standard antero-posterior, lateral, and patellar skyline, and a standing full-leg radiograph to assess alignment. Depending on patient characteristics, additional tests were performed. When malpositioning or aseptic loosening was suspected, a CT scan was performed to determine the rotation of the components and to assess bone loss. Malrotation was measured according to Berger et al. and Victor et al.[2, 23]. The presence of an infection was evaluated according to the Musculoskeletal Infection Society (MSIS) criteria [20], including blood samples (CRP, ESR and WBC) and/or an aspirate of the joint fluid (culture and WBC count/differentiation). Additional stress radiographs were performed in case of suspected instability.

Table 1. Patient demographics

Age (years) (mean (range))	64 (40-85)
Gender (male: female)	12:26
Side (right: left)	24:14
Pre-op ROM (median (range))	50° (5°-70°)
Underlying indication:	
Malposition	15
Aseptic loosening	7
Instability	2
Stiffness e.c.i.	14

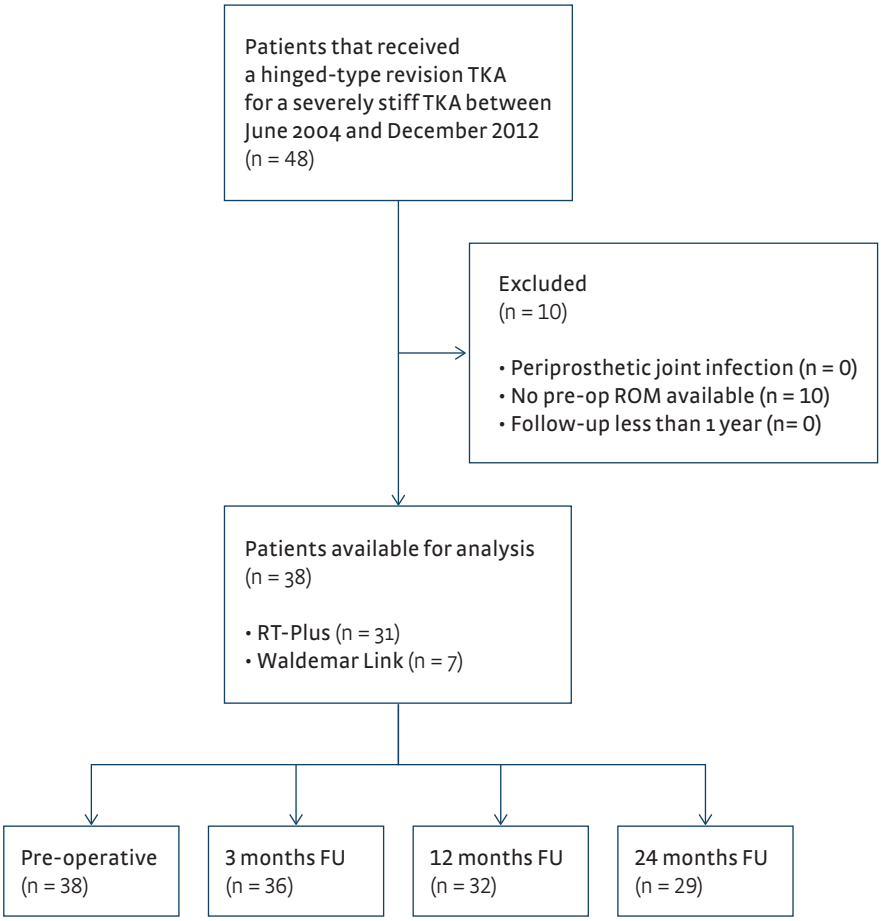

Figure 1. Flow chart.

Outcome

The outcome measurements that were collected in this database consisted of the Knee Society Scoring System (KSS) (assessed by orthopaedic surgeon or resident in the outpatient clinic) and 100-mm visual analogue scales (VAS) for both pain and satisfaction (scored by the patients; 0 is no pain and 100 the worst pain imaginable, 0 is very dissatisfied and 100 very satisfied respectively).Complications were defined as any type of adverse events related to functioning of the revision implant, warranting significant additional (non)surgical treatment.

Approval of this study was given by the hospital's investigational review board. The Medical Ethical Review Board granted a waiver for this study (ID:2003/173).

Statistical analysis

Descriptive statistics (median (range)) were used to quantify clinical outcome. Wilcoxon's signed rank tests were used to compare the preoperative with post-operative values at 2 years. Statistical analysis was performed using STATA 13 (StataCorp, College Station, TX, USA). The level of statistical significance was set at $p < 0.05$.

Results

In 14 of the 38 patients, analysis yielded no underlying reason for arthrofibrosis. Malpositioning was the most common concurrent finding, followed by loosening and instability (Table 1).

The range of motion significantly increased from a median of 50° (5°- 70°) pre-operatively to a median of 90° (50°-125°) at 2 years ($p<0.0001$) (Table 2). At 2 years, for 9 patients no data was available as these patients terminated routine follow-up. Six out of the remaining 29 patients had a ROM of less than 70°, six had a ROM of 70°-89° and 17 showed a ROM of ≥90°. The KSS clinical and KSS functional showed a significant increase at 2 years postoperative, VAS pain did not improve significantly at 2 years (Table 3).
VAS satisfaction was fairly constant (Table 3). Additionally, patients were asked if they would undergo the same procedure again. At 2 years, this question was answered positively by 23 out of 29 patients (79%).

Table 2. Gain in ROM (degrees), from the KSS. *Values are median (range)*

Follow up	Gain in ROM
3 months postoperative	40° (15°-120°) [N=36]
1 year postoperative	40° (10°-90°) [N=32]
2 years postoperative	45° (5°-105°) [N=29]

Table 3. Outcomes, *values are median (range)*

Outcomes		Preop (N=38)	3 months (N=36)	12 months (N=32)	24 months (N=29)	p-value*
KSS	ROM	50° (5°-70°)	90° (50°-125°)	90° (30°-125°)	90° (50°-125°)	<0.0001
	Clinical	43 (4-89)	65 (32-100)	72 (25-97)	76 (10-100)	<0.001
	Function	30 (5-70)	50 (5-100)	70 (30-100)	60 (5-100)	<0.05
VAS	Pain	62.5 (0-100)	33 (0-100)	23 (0-81)	28.5 (0-96)	n.s.†
	Satisfaction	NA	74 (3-100)	78.5 (6-100)	72 (0-100)	NA
Question	Yes : No	NA	27:7**	25:7	23:6	NA

* *p*-values are at 2 years postoperative, compared to pre-operative
** Not all patient answered the question at 3 months
† not significant

Twelve of 38 patients suffered a complication (Table 4). Recurrent stiff knee was the most frequent complication (five patients, one of which also had a pulmonary embolism). This was treated with MUA in one patient and with a lateral release in one other patient. The other three patients had late postoperative recurrent stiff knee, for which an expectative treatment was chosen. One patient had persistent pain without satisfactory explanation, for which the patient was referred to our pain clinic. Aseptic loosening occurred in two patients, one case of tibial aseptic loosening and one case of femoral aseptic loosening. Prosthetic joint infection was seen in one patient, eventually resulting in amputation after earlier unsuccessful debridement, antibiotics and implant retention (DAIR), implant removal and re-implantation. One patient died within 1 year of the operation, unrelated to the operation or a complication thereof.

Table 4. Complications

Complication	No cases	Treatment
Osteonecrosis tibia	1	ORIF† + solid bone graft (20 months)
Early infection	1	DAIR††, explantation, re-implantation. Eventually amputation (5 years)
Extension lag (40°)	1	Arthrodesis (3 years)
Recurrent arthrofibrosis	5	MUA in 1 patient (5 months), lateral release in 1 patient (6 months)
Pulmonary embolism *	1	Antithrombotic therapy
Aseptic loosening tibial component	1	Re-revision (1.5 year)
Aseptic loosening femoral component	1	Re-revision (2.5 year)
Persistent pain	1	Pain clinic

†*Open Reduction with Internal Fixation*
††*Debridement, Antibiotics and Implant Retention*
* Additional complication with recurrent arthrofibrosis in same patient

Discussion

The most important finding of this study was that a hinged implant significantly improves ROM and KSS clinical and functional scores in patients with a severely stiff knee arthroplasty at two years postoperative. With respect to VAS pain, no significant improvement was seen, due to the large spread in reported pain. The present study presents the largest cohort following a hinged-type rTKA for severely stiff TKA.

Knee flexion is essential for mobility, both for recreational activities as for activities of daily living (ADL). A decrease in knee ROM can therefore limit a patient's ability to perform ADL tasks. When looking at ROM related to ADL, patients require an average of 83° knee flexion to climb stairs foot over foot. To sit in a chair without using one's hands requires, on average, 93° knee flexion. Tying one's shoes while seated requires an average of 106° flexion [10]. Riding a bicycle requires, on average, 100°-110° of knee flexion (90° with modifications to the bike).
So even a mild increase in knee flexion can make the difference between walking and being able to ride a bike, which is very important for mobility and quality of life.
Therefore, even while the effects of a revision with a hinged TKA seem moderate, these results are relevant to our patients.

With respect to the question if the patient would undergo the same procedure again, we looked in more detail at the patients who changed their answer from 'Yes' to 'No' somewhere during the follow-up period to see if this was related to complications. Seven patients changed their answer in the follow-up period from 'Yes' to 'No': of them, 1 patient had unexplained pain and three patients showed recurrent stiffness. The other three patients reported unmet expectations with respect to ROM and improvement in ADL. This shows that counseling on expectations remains an important part of the consultation in patients with a severely stiff knee following TKA.

The gain in ROM found in this study is consistent with the findings reported by other authors, given the right timing of intervention[5, 7, 10, 12, 21]. So although a thorough excision of the fibrous tissue is performed, revision arthroplasty using a hinged-type TKA is not the answer for all patients with a severely stiff TKA. This underlines the importance of finding and better understanding the aetiology of arthrofibrosis. In a recent paper, Clement et al found that male gender, lung disease, diabetes, back pain, and pre-operative stiffness rendered an increased risk for developing a severely stiff TKA[6]. This is an important step in better understanding the development of arthrofibrosis and can help in counselling patients when considering a primary TKA or a revision for severely stiff TKA. Future research, however, should be directed to finding the biological basis for arthrofibrosis.

Some potential limiations have to be discussed. First, 2 different implants were used which might have influenced the outcomes. However, because the treatment of the arthrofibrosis was a radical excision of fibrous tissue and soft tissue release, the outcome was not thought to be influenced by implant design. Furthermore, both implants were a rotating hinge design. Second, there is the risk of selection bias. Typically, hinged prostheses were used in the worst cases, butselection of implant

type was done by the surgeon, not by randomisation. Third, because of the nature of data collection (during standard follow-up visits) there are some missing data. In patients with missing data, scores of the previous visit were evaluated. Of the 9 patients with missing data for ROM, 2 patients had a ROM of 85° at the previous visit, 3 patients had a ROM of 100°, 2 a ROM of 110°, and 2 a ROM of 120°. None of the patients with missing data for ROM had a recurrent severely stiff TKA at previous visits. Out of the 7 patients with missing data for patient satisfaction, 5 would undergo the same operation again at the previous visit. Most patients indicated that they terminated further follow-up due to other issues (travel distance to clinic or general health issues).

Arthrofibrosis following TKA remains challenging for both patient and surgeon, especially inrecurrent or late severely stiff TKA, where MUA and arhtrolysis are not advocated[22]. The present study shows that revision with a Hinged-type TKA is a viable option for improving ROM and clinical outcome for these patients.

Conclusion

Hinged type TKA significantly improves ROM and KSS clinical and functional scores in patients suffering from a severely stiff knee arthroplasty two years after revision surgery.

Conflict of interest

None

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Chapter 5

No association between hospital volume and early second revision rate in Revision Total Knee Arthroplasty in the Dutch Orthopedic Register

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Abstract

Background: Revision knee arthroplasty (R-KA) is rising globally. Technical difficulty of R-KA varies from liner exchange to full revision. Centralization has been shown to reduce mortality and morbidity rates. The present study aimed to evaluate the association between hospital R-KA volume and overall second revision rate, as well as revision rate for different types of revision.
Methods: The R -KAs between 2010 and 2020 with available data on the primary KA in the Dutch Orthopaedic Arthroplasty Register were included. Minor revisions were excluded. Implant data and anonymous patient characteristics were obtained from the Dutch Orthopaedic Arthroplasty Register. Survival analyses and competing risk analysis were performed per volume category (12, 13 to 24, or 25 cases/year) at 1, 3, and 5 years following R-KA. There were 8,072 R-KA cases available. Median follow-up was 3.7 years (range 0 to 13.7 years). There were a total of 1,460 second revisions (18.1%) at the end of follow-up.
Results: There were no statistically significant differences between second revision rates of the three volume groups. Adjusted hazard ratio for second revision were 0.97 (Confidence Interval (CI) 0.86 to 1.11) for hospitals with 13 to 24 cases/year and 0.94 (CI 0.83 to 1.07) with 25 cases/year compared to low volume (12 cases/year). Type of revision did not influence second revision rate.
Conclusion: Second revision rate of R-KA does not seem to be dependent on hospital volume or type of revision in the Netherlands.

Level of evidence: Level IV, Observational registry study.

Introduction

It has been documented that the number of revision knee arthroplasties (R-KA) is steadily on the rise globally[1,2]. In the Netherlands, the number of R-KAs performed almost doubled between 2010 (9.5 per 100.000) and 2019 (17.9 per 100.000)[3]. The prediction is that this trend will continue in the coming years, especially when considering that knee joint arthroplasties are being performed in an increasingly younger population with a longer life expectancy[1,2,4].

The technical difficulty of a R-KA can range from a simple insert exchange or patella component surgery to a full condylar exchange with the need to manage large bony defects. For the latter, specialized instrumentation and prostheses and extensive surgical experience are required. This surgery is also associated with an increased surgical time and longer aftercare[5]. Therefore, a full revision of a knee arthroplasty is considered as a relatively complex surgical procedure.

For demanding and uncommon surgical procedures, it has been shown that centralisation, and thereby increasing the hospital volume, has reduced mortality and morbidity rates[6]. The relation between volume and revision rate has also been described for primary unicompartmental knee arthroplasty (UKA), primary total knee arthroplasty (TKA) and total hip arthroplasty (THA)[7–9]. Recently, Jeschke et al. showed an increase of 90-day mortality in hospitals with less than 25 revision THA cases annually and higher second revision rates in hospitals with fewer than 52 revision THA cases[10]. For revision TKA, Halder et al. showed higher second revision rates for hospitals with fewer than 25 revision cases per year in Germany[11]. They focused, however, solely on aseptic revision TKA and did not discriminate between different types of revision.

The aim of the present study was to evaluate the association between hospital volume of first R-KA and the risk of a second revision. Furthermore, this study aimed to determine whether there was an association between hospital volume and second revision rate for the different types of revision (major, intermediate, or minor). Our hypothesis was that a higher volume of first R-KA in a hospital would lead to lower second revision rates for all types of revision. Because centralisation is advocated for complex and uncommon surgical procedures, this study focused on the analysis of major and intermediate complex revisions.

Patients and Methods

Procedures

Anonymous patient and implant data were obtained from the Dutch arthroplasty register (LROI). All first R-KAs between 2010 and 2020 with available data on the primary KA were included in the study population. R-KA was defined as placement, replacement or removal of one or more components of a KA. All R-KA cases (revised primary TKA as well as revised primary UKA and revised primary patellofemoral arthroplasty (PFA) to TKA) were included, as revision of primary UKA to TKA has shown comparable difficulties and outcomes to revision of a primary TKA[12]. For each procedure, data on surgical characteristics (type of implant, year of the primary operation, indication for primary KA, year of the revision operation, type of revision, and type of hospital) and patient characteristics (e.g., age, sex, BMI, ASA score, and previous surgery on the affected knee) were retrieved.

First revisions were then divided into three types; 1) minor (insert exchange, patellar component placement, and/or revision of patellar component), 2) intermediate (UKA to TKA, PFA to TKA, solitary tibial or femoral component revision, with or without insert exchange and/or patellar component), and 3) major (revision of a total TKP where tibial, femoral, and/or patellar components are revised to a total condylar-, hinged- or tumor prosthesis). Later on, minor revisions were excluded as the focus of the current study was on intermediate and major revisions.
Procedures were also excluded when the type of revision was unknown or when patient data were incorrect (e.g. unlikely high or low age, or placement of patellar component listed following UKA). (Figure 1)
Four volume categories were defined; ≤12, 13-24, 25-51,or ≥52, based on the classification described by Jeschke et al. [10]. Only 2 hospitals performed over 52 R-KA, resulting in low case-load in the ≥52 category. Therefore, the top two categories were merged. The volume categories defined for this study were ≤12, 13-24, or ≥25 cases per year. The study was conducted and reported according to STROBE guidelines.

Statistics

A competing risk analysis was performed to analyze the cumulative incidence of second revision at 1, 3, and 5 years with second revision for any reason as end point (failure) and mortality considered to be a competing event. Survival time was defined as the time at risk between the first revision and second revision.

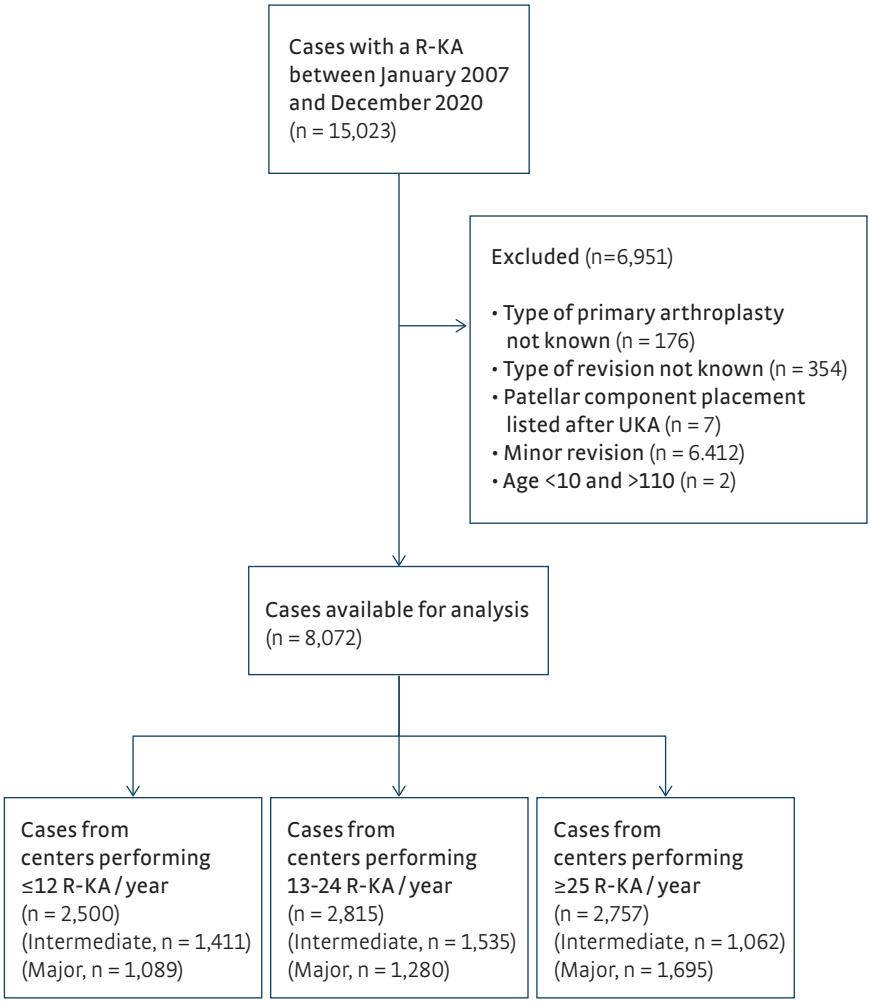


Figure 1. Data selection.

To evaluate the hazard ratio (HR) on second revision for different volume groups, a multivariable Cox regression analysis was performed, stratified for the three volume groups. Age at revision surgery, type of hospital (general hospital, university hospital, private clinic), type of first revision (intermediate, major), type of primary KA (PFA, UKA, TKA), gender, BMI, and ASA score were identified as potential confounders with a directed acyclic graph (Appendix A, Fig. 3). HRs were adjusted for these confounders. The level of statistical significance was set on $p < 0.05$.

R (The R Foundation for Statistical Computing, version 1.3.1093, Vienna, Austria) was used for all statistical analyses[13], using the packages "survminer"[14], "survival"[15], "rms"[16], "table1"[17], "cmprsk"[18].

Ethics, funding, and potential conflicts of interest

As the study was based on anonymous registry data, ethical approval was not required according to the Dutch Medical Research Involving Human Subjects Act. This study received no funding and the authors declare no conflicts of interest regarding this study.

Results

In total, 88 Dutch hospitals performed 15,023 first R-KA procedures between January 2010 and December 2020. 8,072 cases were available for analysis. Baseline characteristics are listed in Table 1.

In the vast majority of primary KA cases, indication for arthroplasty was primary osteoarthritis (94.7%). Other indications (e.g. posttraumatic and secondary OA) did not differ significantly between the volume groups (Table 1).

Median follow-up after R-KA was 3.7 years for all volume groups. There were a total of 1,460 second revisions (18.1%) at end of follow-up. Number of deaths following first revision were comparable for all volume groups. There were 150 deaths (6%) in centers with ≤12 R-KA/yr). For centers with 13-24 and ≥25 R-KA/yr this was 171 (6%) and 145 (5%) deaths respectively. It was found that higher volume centers had a higher case-load of major revisions, compared to lower volume centers, with 58.6% major revisions for centers with ≥25 R-KA/yr, as opposed to 43.6% (13-24 R-KA/yr) and 41.9%(≤12 R-KA/yr).

There were no statistically significant differences between the second revision rates of the three volume groups. When adjusted for the identified potential confounders (type of primary prosthesis, age at revision surgery, type of hospital, type of revision, gender, and ASA score), revision rates did not differ statistically. Adjusted HRs for second revision were 0.97 (CI 0.86 – 1.11) for hospitals with 13-24 cases/year (crude HR: 0.97 (CI 0.85 – 1.1)), and 0.94 (CI 0.83 – 1.07) for hospitals with ≥25 cases/year (crude HR: 1.05 (CI 0.93 – 1.19)) compared to low volume (≤12 cases/year) hospitals.

Cumulative incidence of second revision, adjusted for the abovementioned confounders, is depicted in Figure 2 and Table 2.

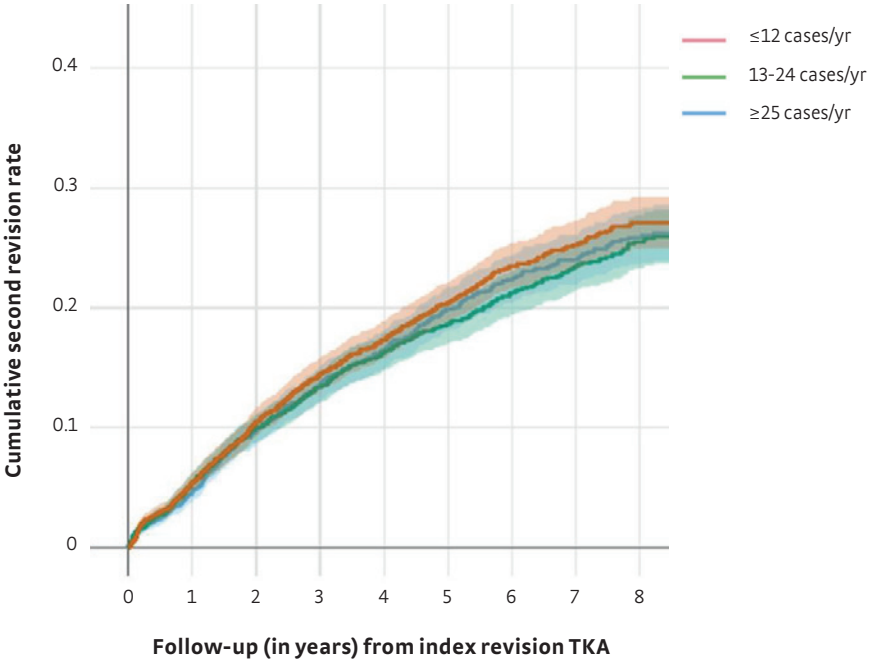
Table 1. Baseline characteristics by volume groups.

	≤ 12 revisions (n=2,500)	13-24 revisions (n=2,815)	≥25 revisions (n=2,757)	Overall (n=8,072)
Gender				
Male	836 (33.4%)	957 (34.0%)	951 (34.5%)	2,744 (34.0%)
Female	1,664 (66.6%)	1,855 (65.9%)	1,800 (65.3%)	5,319 (65.9%)
Missing	0 (0%)	3 (0.1%)	6 (0.2%)	9 (0.1%)
Age at first revision				
Mean (SD)	66.4 (9.46)	66.4 (9.39)	65.4 (9.46)	66.1 (9.45)
Missing	1 (0.1%)	3 (0.1%)	2 (0.1%)	6 (0.1%)
BMI				
Mean (SD)	30.1 (5.23)	30.1 (5.21)	30.2 (5.23)	30.2 (5.22)
Missing	642 (25.7%)	737 (26.2%)	745 (27.0%)	2,124 (26.3%)
ASA classification				
I	290 (11.6%)	374 (13.3%)	376 (13.6 %)	1,040 (12.9%)
II	1,603 (64.1%)	1,769 (62.8%)	1,841 (66.8%)	5,213 (64.6%)
III-IV	571 (22.8%)	584 (20.7%)	474 (17.2%)	1,629 (20.2%)
Missing	36 (1.4%)	88 (3.1%)	66 (2.4%)	190 (2.4%)
Primary prosthesis				
Patellofemoral	73 (2.9%)	96 (3.4%)	73 (2.6%)	242 (3.0%)
Unicompartmental	798 (31.9%)	712 (25.3%)	534 (19.4%)	2,044 (25.3%)
Total	1,629 (65.2%)	2,007 (71.3%)	2,150 (78.0%)	5,786 (71.7%)
Indication primary				
Osteoarthritis	2357 (94.3%)	2689 (95.5%)	2597 (94.2%)	7643 (94.7%)
Rheumatoid arthritis	38 (1.5%)	21 (0.7%)	26 (0.9%)	85 (1.1%)
Early posttraumatic	29 (1.2%)	37 (1.3%)	38 (1.4%)	104 (1.3%)
Late posttraumatic	42 (1.7%)	49 (1.7%)	59 (2.1%)	150 (1.9%)
Osteonecrosis	15 (0.6%)	11 (0.4%)	9 (0.3%)	35 (0.4%)
Tumor	3 (0.1%)	0 (0%)	0 (0%)	3 (<0.1%)
Inflammatory arthritis	0 (0%)	0 (0%)	2 (0.1%)	2 (<0.1%)
Other	16 (0.6%)	8 (0.3%)	26 (0.9%)	50 (0.6%)
Type of revision				
Intermediate	1,411 (56.4%)	1,535 (54.5%)	1,062 (38.5%)	4,008 (49.7%)
Major	1,089 (43.6%)	1,280 (45.5%)	1,695 (61.5%)	4,064 (50.3%)
Type of hospital				
General hospital	2,078 (83.1%)	2,495 (88.6%)	2,442 (88.6%)	7,015 (86.9%)
University hospital	194 (7.8%)	75 (2.7%)	22 (0.8%)	291 (2.7%)
Private clinic	228 (9.1%)	245 (8.7%)	293 (10.6%)	766 (12.2%)

Table 2. Cumulative incidence of second revision at 1, 3, 5, and 8 years *

Volume group	Cumulative incidence of second revision % (confidence interval)			
	1 yr	3 yrs	5 yrs	8 yrs
≤12 cases/yr	4.1 (3.3 – 4.9)	13.1 (12.4 - 14.7)	19.9 (18.5 – 21.8)	26.6 (24.2 – 29.1)
13-24 cases/yr	5.2 (4.5 - 6.2)	13.5 (12.2 - 15.0)	19.1 (17.5 – 21.0)	27.0 (24.7 - 29.5)
≥25 cases/yr	4.6 (3.8 – 5.4)	13.7 (12.4 – 15.2)	20.1 (18.4 – 21.9)	27.5 (25.2 -29.9)

** Values are adjusted for type of primary prosthesis, age at revision surgery, type of hospital, type of revision, gender, and ASA score*



Volume group	Cases at risk during follow-up						
	0 yr	1 yr	2 yrs	3 yrs	4 yrs	5 yrs	8 yrs
≤12 cases/yr	2500	2178	1796	1470	1182	902	382
13-24 cases/yr	2815	2378	1908	1556	1244	981	410
≥25 cases/yr	2757	2394	1981	1633	1397	1077	353

Figure 2. Cumulative incidence of second revision for each volume group. Values are adjusted for type of primary prosthesis, age at revision surgery, type of hospital, type of revision, gender, and ASA score.

The reason for second revision was often multifactorial. The reasons for second revision in this study were infection (531 cases), instability (298 cases), aseptic loosening (134 cases), malalignment (67 cases), patellar pain (97 cases), arthrofibrosis (34 cases), or periprosthetic fracture (11 cases). The remaining cases did not have a predominant indication.

Discussion

The main finding is that, based on the data of the Dutch arthroplasty register (LROI), there is no significant correlation between case volume of a hospital and survival of a revision KA in The Netherlands. This was not in line with our hypothesis.
Comparing current literature to this study is complicated, as the selected study population and follow-up time vary. Roof et al. looked at surgeon volume rather than hospital volume and described a significantly lower second revision rate in 308 knees for surgeons performing >19 rTKA annually [19]. Furthermore, Halder et al. found evidence of increased risk for second revision in aseptic rTKA at one year in hospitals performing <12 cases annually compared to hospitals performing >52 cases annually[11]. Using the Scottish Arthroplasty Project, Yapp et al. showed a significant risk reduction of second revision in hospital case volume >20 cases/year [20].
Contrary to the hypothesis, there was no association between volume and second revision in this study. A possible explanation could be that revisions of UKA and a PFA, as well as revisions of TKA were taken into account. However, a sensitivity analysis was performed, excluding all UKA and PFA, which again showed no significant differences in survival of the R-KA (appendix B).

The second revision rates found in this study seem to be high (approximately 20% at 5 year follow-up). When looking at second revision rates in recent literature, the reported rates differ between 6.3% and 20%. Again, comparison is difficult due to varying case-mix, single center vs national database, and differences in follow-up period. Yapp et al. found a second revision rate of 10.8% in the Scottish national registry, with a median follow-up of 6.2 years. They defined revision as permanent removal or exchange of knee arthroplasty components, with the exclusion of secondary patellar resurfacing. [20]. Aseptic second revision rate in the paper of Roof et al. ranged from 7.1% in high volume surgeons to 19% for low volume surgeons [19]. Haughton et al. reported 6.3% second revisions in 192 cases in a single center study at a median follow-up of 6.3 years [21]. Halder et al. looked at revisions due to aseptic loosening in the German national register and found a second revision rate ranging from 7.4% for high volume centers to 9.4% for low volume centers at one year follow-up [11]. This study showed a mean second revision rate of 4.6%, 13.4%, and

19.7% at 1, 3, and 5 years respectively. These results align reasonably well with current literature, taking into account the various exclusion criteria. Most previous studies chose to exclude secondary patellar resurfacing and/or solitary insert exchange [11,20,21], which aligns with the exclusion of minor revisions in this study.

Furthermore, this study showed a higher case-load of major revisions for high volume centers compared to lower volume centres. A possible explanation for this is that higher volume centers in The Netherlands act as referral centers for difficult revision cases. In these centers, the availability of surgeon's experience, specific prostheses, and specific instruments may result in a higher case-load of major revisions.
Interestingly, higher volume centers showed a caseload with a relatively lower average ASA classification. This can be explained by the presence of a high volume orthopedic referral clinic.
Treatment of a failing R-KA is dependent on both case- and surgeon-related factors. There are cases where a first revision is a minor revision (insert exchange or additional placement of a patellar component) and a subsequent revision is needed, which is often more complex. With increasing complexity, there is a chance that the patient will be referred to a higher volume revision center. Also, it could be argued that the indication for and type of revision is based on the surgeons skill level and hospital setting. For instance, the threshold for revising a UKA is much lower than for a fully cemented rotating hinge with patellar component. It is likely that a more extensive R-KA (e.g. hinged- or tumor prosthesis) will be undertaken at a lower threshold in high volume centers. It is possible that the higher volume hospitals treat more complex cases and nevertheless have similar outcomes as low revision centers. These aspects are also not registered in the database and are therefore not known.

In contrast to current literature, this study has evaluated the effect of volume of R-KA on second revision rate a broader spectrum of cases. Inclusion of revision of UKA, PFA and septic revision makes this study more representative of everyday practice.
There are limitations to the current study. Because the LROI has been established in 2007, there is a limited follow-up for patients that were included more recently. Also, because primary operations were not registered centrally before 2007, only registered revisions of primary procedures performed after 2007 could be included resulting in a limited follow-up time of the revision cases. Therefore, there will be a relatively higher percentage of failures due to infection, as infection is the most common reason for early failure [22,23]. With longer follow-up, there will be relatively more revisions due to aseptic loosening.
In The Netherlands, R-KA is performed in all types of hospitals (general, university, and private), all with different numbers of surgeons operating these cases. So the volume of R-KA in a center does not equal caseload per surgeon (which cannot be discerned from the register data), this may obscure the results.

In trying to interpret the data we feel it is reassuring that low volume centers have the same second revision rate as higher volume centers. But these data are not detailed enough to conclude that there is no benefit in centralization of revisions. Whereas second revision rate is a good technical outcome measure, it is not a complete measure of the quality of care for R-KA patients. Based on the findings of this study, a strong argument in favor of a policy change with further centralization cannot be made. However, experience with, and availability of specific materials are a reason to refer major revision cases to high volume centers. Furthermore, patient satisfaction is largely dependent on functional outcome and pain following R-KA. These data should be further explored, when determining the standard of care in R-KA in the Netherlands.

Conclusion

Second revision rate is not associated with hospital volume in the Netherlands or with type of revision (intermediate or major).

Appendix A

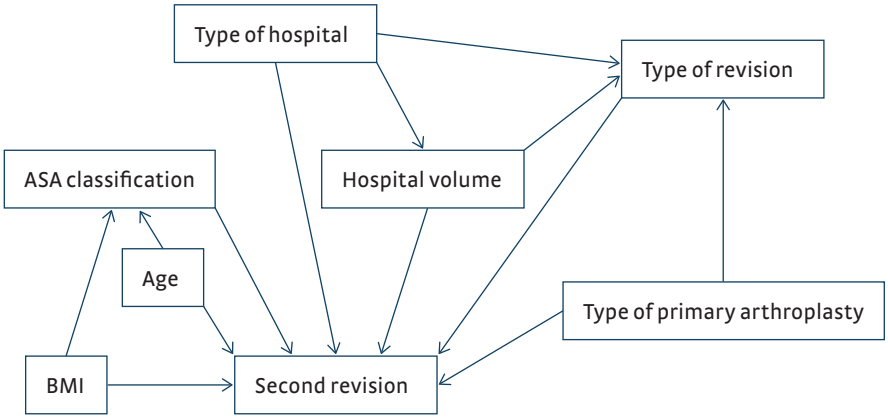


Figure 3. Directed acyclic graph used in this study.

Appendix B

Sensitivity analysis excluding PFA and UKA revisions.

Cox regression analysis showed a crude Hazard Ratio for second revision of 0.889 (CI 0.770 – 1.027) for the hospitals with 13-24 cases / year and 0.990 (CI 0.863 – 1.137) for hospitals performing ≥25 cases / year, when compared to the low volume (≤12 cases / year) hospitals. Also when corrected for type of primary prosthesis, age at revision surgery, type of hospital, type of revision, gender, and ASA score, revision rates did not statistically differ. Adjusted Hazard ratios for second revision were 0.837 (CI 0.632 – 1.111) for hospitals with 13-24 cases / year and 0.951 (CI 0.635 – 1.424) for hospitals with ≥25 cases / year compared to low volume (≤12 cases / year) hospitals.

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Chapter 6

Arthrodesis of the Knee following failed Arthroplasty

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Knee Surg Sports Traumatol Arthrosc. 2014 Aug;22(8):1940-1948

Abstract

Background: Primary stability in arthrodesis of the knee can be achieved by external fixation, intramedullary nailing or plate fixation. Each method has different features and results. We present a practical algorithm for arthrodesis of the knee following a failed (infected) arthroplasty, based on our own results and a literature review.
Methods: Between 2004 and 2010, patients were included with an indication for arthrodesis after failed (revision) arthroplasty of the knee. Patients were analyzed with respect to indication, fusion method and bone contact. Endpoint was solid fusion.
Results: Twenty-six arthrodeses were performed. Eighteen patients were treated because of an infected arthroplasty. In total, ten external fixators, ten intramedullary nails and six plate fixations were applied; solid fusion was achieved in 3/10, 8/10 and 3/6, respectively.
Conclusions: There is no definite answer as to which method is superior in performing an arthrodesis of the knee. Intramedullary nailing achieved the best fusion rates, but was used most in cases without—or cured—infection. Our data and the contemporary literature suggest that external fixation can be abandoned as standard fusion method, but can be of use following persisting infection. The Ilizarov circular external fixator, however, seems to render high fusion rates. Good patient selection and appropriate individual treatment are the key to a successful arthrodesis. Based upon these findings, a practical algorithm was developed.

Level of evidence: Retrospective case series, Level IV.

Introduction

Before the era of the total knee arthroplasty (TKA), the most common indications for arthrodesis (AD) of the knee were tuberculosis, advanced primary arthrosis and rheumatoid arthritis. Arthrodesis was usually performed using the "Charnley" clamps, which achieved solid fusion in 98.8% of the cases [18,23] After introduction of the TKA, its good long term results in combination with the ageing population led to broader indications for, and increase of the amount of implanted TKA's worldwide [26]. Consequently, the amount of failed TKA's increased, mainly because of deep infection, despite infection prevention improvements (antibiotics and laminar flow in operating rooms) [5,16]. The incidence of postoperative infections following primary TKA varies between 0.6% and 15% [23].

Aforementioned developments also led to a more frequent indication for arthrodesis of the knee [1], while arthrodesis provides moderate recovery of mobility and significant pain reduction in patients with failed (revision) TKA [1,5]. Because of poor stability and the substantial increase in bone-loss after removal of a TKA, the solid fusion rate using de conventional technique by Charnley was markedly lower in comparison to the primary arthrodeses (64% versus 99% respectively) [18]. Therefore, other techniques have been developed: Intramedullary nail fixation, external fixation and plate fixation. The fusion rates following failed TKA for these techniques range from 66% to 100%, with the worst rates being achieved by the external fixator [5,18].

In order to analyze the results of the different techniques we retrospectively reviewed the results of arthrodesis following failed TKA, with or without deep infection. Moreover, a review of the scarce literature is performed. Based on these findings, we propose a practical algorithm.

Material en methods

Patients were included retrospectively when they had a failed primary or rTKA with an indication for arthrodesis, performed in the period between january 2004 and march 2012. Data were acquired by review of retained patient record and x-rays by two different authors (PvR, JvdP). In a few cases, a temporary external fixator was placed for stabilization of the knee-joint after removal of the prosthesis in infection treatment. This was not seen as an attempted arthrodesis. In the data analysis, deep infections were compared to the group with other indications. Furthermore, we differentiated between the amount of bone-contact at time of arthrodesis. The outcome of this study was radiologic fusion.

Fixation methods

The methods used were the intramedullary (IM) nail ("Witchita nail", Stryker, Kalamazoo, Michigan, VS, Fig. 1a), bilateral plate fixation (Locking Compression Plate, Synthes, Solothurn, Switzerland, Fig. 1b) or a monoplane external fixator (Orthofix, Verona, Italy, fig 1c).

In case of infection, both surgical and antibiotic treatment was performed according to a strict algorithm by Zimmerli et. al [33]. After extensive debridement in an infection with a difficult-to-treat bacterium and/or an indication for a muscle flap and/or indication for arthrodesis, a temporary external fixator was applied. When there was no difficult to treat bacterium and no indication for muscle flap or arthrodesis, a temporary cemented spacer was placed.

In most cases, if an external fixator was applied for treatment of a prosthetic joint infection (PJI) with eventually indication for arthrodesis, the external fixator was used as method for arthrodesis after treatment of infection by applying compression. For the arthrodeses following (revision) TKA without signs of infection, the method of preference was the intramedullary nail.

Follow-up treatment of the external fixator and plate arthrodesis consisted of 10-15 kg partial weight bearing during 6 weeks, whereas the intramedullary nail immediately allowed full weight bearing postoperatively.

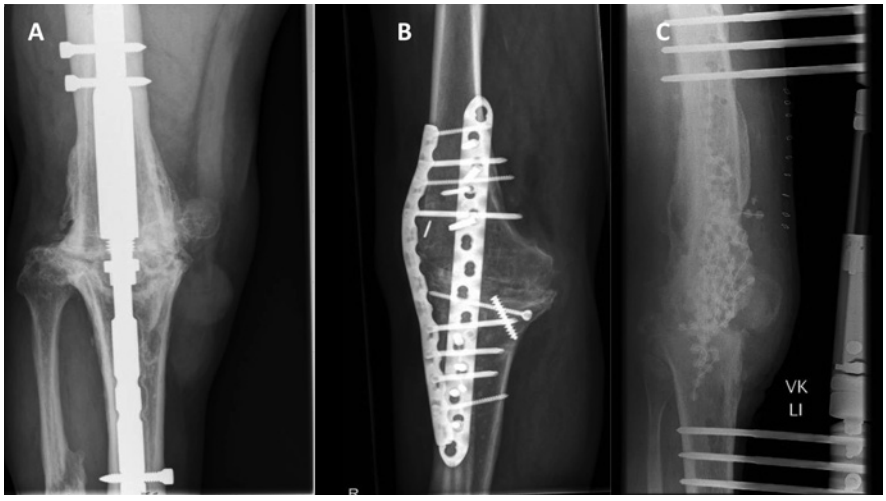


Figure 1. Used methods for arthrodesis. **A.** Intramedullary "Witchita "nail. **B.** Bilateral locking compressing plates. **C.** Monoplane external fixator.

Bone contact

Immediate postoperative (anterior-posterior and lateral) x-rays following arthrodesis were assessed for bone contact and bone loss. Lines were drawn along bone contact surface and the entire arthrodesis surface and subsequently compared. For this assessment, a classification according to Klinger [12, 27] was modified, in which the amount of bone contact following arthrodesis was divided in:

1. Good bone contact (>¾ surface contact)
2. Moderate bone contact (¾ to ¼ surface contact)
3. Poor bone contact (<¼ surface contact)

In this classification, invariably the x-ray with the least surface contact was selected. Bone loss was evaluated by measuring the distance between the plane of arthrodesis and the fibular head and between plane and top of the medial epicondyle.

Approval from our institutional Review Board was obtained. According to the Dutch law, signed informed consent was not obligatory for this study.

Literature search

A pubmed-search was performed using the following terms:
((“arthrodesis”[MeSH Terms] OR “arthrodesis”[All Fields]) AND “the knee”[All Fields] OR “Total Knee arthroplasty”[MeSH Terms]) AND “humans”[MeSH Terms]
Limits: (1) Clinical Trial, (2) Comparative Study, (3) Controlled clinical trial, (4) Journal Article, (5) Review, (6) Humans and (7) English language.
Only articles in the period between 1-1-2000 and 31-12-2011 were taken into account

In total 127 articles were found using these terms. Of these studies, 21 did not concern the knee joint, 59 did not discuss arthrodesis, 18 did not discuss arthrodesis following failed TKA and 16 were discarded for other reasons.
This resulted in a total of 12 articles that were used in writing this paper, five of which were reviews. The remaining articles were found among the references of these 12 papers [1, 3, 5, 6, 8, 10, 12, 13, 15, 18-25 27-31, 33]..

Results

The average age of the patients was 66 years and the male:female ratio was 10:10. 20 arthrodeses were performed, 12 of which following primary TKA, seven following rTKA and one following unicompartimental knee arthroplasty. The indications for arthrodesis were PJI (16 AD's), severe arthrofibrosis (two AD's) and aseptic loosening (two AD's).

The fusion rates for the 20 cases were 3/9 for the external fixator, 6/8 for the intramedullary nail and 1/3 for the plate fixation. Out of 10 failed arthrodeses, six underwent a re-arthrodesis due a to non-union. In two patients, an upper-leg amputation was performed due to persisting infection and in one patient solid fusion was achieved after re-operation. In one case, follow-up is still ongoing.
Of the six re-arthrodeses, one was performed using an external fixator, two using an intramedullary nail and three using plate fixation. One plate failed due to persisting infection and resulted in an upper-leg amputation. The external fixator failed due to aseptic non-union.

The overall fusion rates, including the re-arthrodeses were 3/10 for the external fixator, 8/10 for the intramedullary nail and 3/6 for the plate fixation. The results are summarized in table 1 and figure 2. An overview of the patients is given in table 2 and the results are discussed in more detail below.

External fixator

In nine of the twenty patients, the external fixator was used. eight patients following PJI and one patient following aseptic loosening. Therefore, it was the method of preference following PJI. Bone contact was good in six and moderate in three patients. In six patients, treatment failed, three of which showed moderate bone contact.
In four failed cases, there was non-union without indications for relapsing infection In three of these cases a re-arthrodesis was performed, in the fourth case follow up is ongoing.
In the remaining two patients with a failed external fixator, there was a persisting infection for which one patient underwent an amputation after three months. The other patient received a re-arthrodesis after proper treatment of the infection.

Intramedullary nail

Intramedullary fixation was used in eight out of twenty patients and seemed to be preferred following rTKA. Indications were PJI in five patients, arthrofibrosis in two and aseptic loosening in one patient. Surgery was performed in two-stage procedures following PJI, with a mean duration of 8 weeks to reimplantation and in one-stage

following other indications. In the two-stage procedures, a temporary external fixator was used for four weeks, following a cast for four weeks. Bone contact was good in six and moderate in two patients. In six patients, fusion was achieved in an average of 16 months. With the other two cases, there was a non-union after six and 10 months. One patient had good bone-contact, however an infection persisted after three failed rTKA and the leg was eventually amputated after seven months. The other patient had moderate bone-contact and underwent tightening of the intramedullary nail in combination with patella-autografting, after 11 months. Thereafter, solid fusion was achieved in four months.

Plate fixation

In three of twenty patients, arthrodesis was performed using plate fixation, these were all cases following treated PJI. Bone contact was good in one and moderate in two patients. The patient with good bone contact achieved fusion after 12 months. In the patients with moderate bon-contact, one patient had a persisting infection with non-union after seven months, in the other patient the plate broke without signs of persisting infection or non-union after eight months (fig. 2). The failed plate-fixations were treated with re-arthrodesis (see below).

Re-arthrodeses

In six of twenty patients, a re-arthrodesis was performed.

One patient with a persisting infection of the plate fixation following a PJI, was treated with an external fixator with moderate bone-contact. Again, there was a non-union after 5 months without signs of persisting infection (knee aspirate with negative cultures).

In two patients, intramedullary fixation was chosen for re-arthrodesis. One patient with failed external fixation received an IM nail with moderate bone contact after 10 months. Thereafter, fusion was achieved after 9 months. The other patient had a broken plate and aseptic non-union. An IM nail with good bone-contact was placed after seven months with improving consolidation after again seven months.

Three times, plate fixation was used, all three following failed external fixation and with good bone-contact. In two cases, solid fusion was achieved and in one patient an upper-leg amputation was performed after eight months, due to a relapsing infection and non-union.

Table 1. Arthrodeses, sorted by outcome, indication and bone contact.

Fusion-method	M:V	Indication		Bone contact		TKA		Overall Fusion rate	Re-AD	Aberrant outcome
		PJI	Other	Good	moderate	Primary	Revision			
External fixator (n=10)	5:5	8/10	2/10 †	6/10	4/10	10/10*	0/10	3/10	1/10	Amputation: 1/10 Re-AD: 4/10
Intramedullar nail (n=10)	4:6	5/10	5/10 †	7/10	3/10	4/10	6/10	8/10	2/10	Amputation: 1/10 2nd surgery: 1/10
Plate fixation (n=6)	4:2	3/6	3/6 †	4/6	2/6	5/6	1/6	3/6	3/6	Amputation: 1/6 Re-AD: 2/6

**1 hemi knee arthroplasty*
† Among which the revision arthrodeses

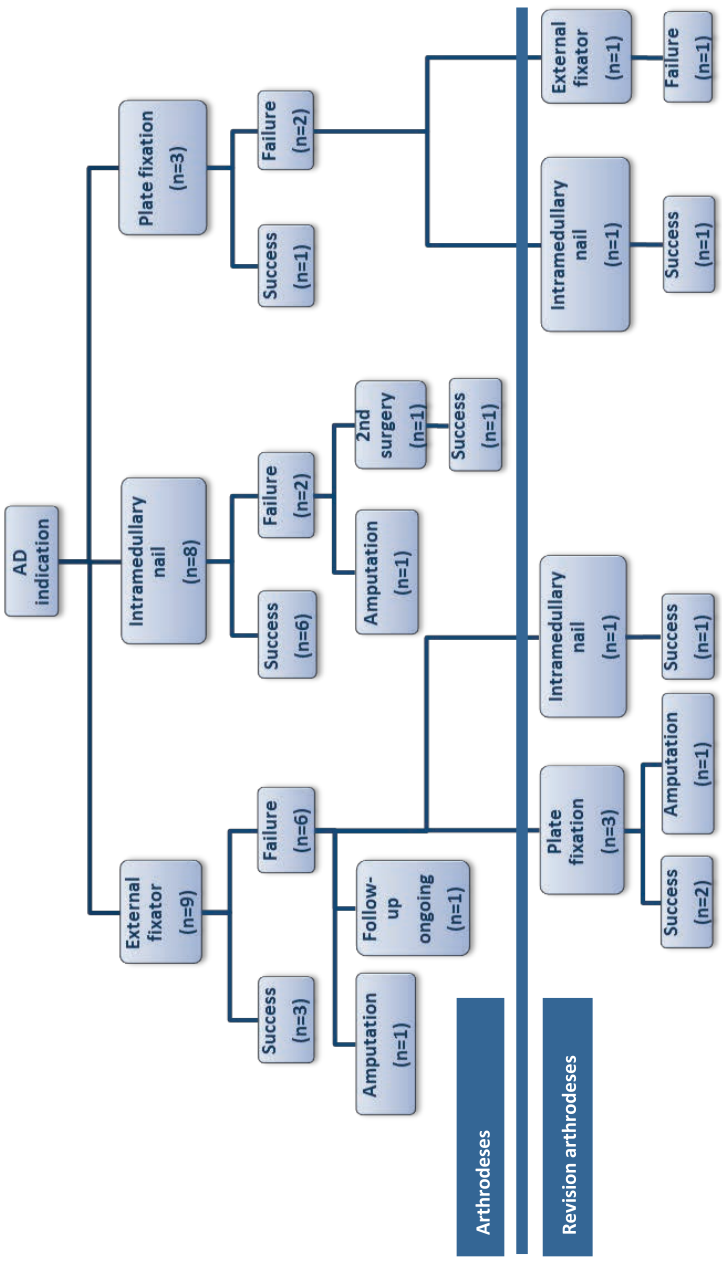


Figure 2. Flow-chart with outcome sorted by arthrodesis method.

Bone contact and defect

Good bone contact was associated with a higher degree of fusion (12/17) compared to moderate bone contact (3/9). The rate of moderate to good bone contact was found to be comparable in the three groups.
The bone defect was found to be comparable with the plate arthrodesis and the external fixator. The intramedullary nail was used in cases with the largest bone defects.

Discussion

The fusion rates found in our study, mostly match the contemporary literature [1, 18, 23, 31]. However, we had a lower success rate for the plate fixation compared to the literature, possibly due to the small number of patients included in this study. Furthermore, all three plate fixations were preceded by a PJI –however treated-. It therefore seems that plate fixation following PJI is not the preferred treatment. However, neither of the two failing plate fixations was treated in a two-stage procedure, due to normal infection parameters and absence of wound healing disorders. Following the certain indications (for instance arthrofibrosis and aseptic loosening), as a revision method and/or following a proper two-stage procedure, plate fixation seems to offer good results. Further investigation is warranted to confirm these hypotheses.

With the external fixators, there seems to have been selection bias. The worst cases, usually with (still) persisting infection, were often treated with an external fixator. This could have led to a lower fusion rate in this group. Another factor that could lead to lower fusion rates is a greater degree of bone loss. It was seen, however, that the intramedullary nail was used more frequently in cases with more extensive bone loss (e.g. following revision arthroplasty). The mean bone defect with the external fixation was found to be less than in intramedullary nailing.

External fixator

Theoretically, an advantage of the external fixator is that, following infection, the infection can be treated with antibiotics (after debridement), without a foreign body present. Afterwards, a new debridement can be done with compression of the external fixator. Furthermore, the probability of developing or persisting infection appears to be lower in comparison to other methods, with only two out of eight infections persisting after treatment. Both our and reported fusion rates, however, are low. In our series, three out of nine external fixators were successful, compared to a success rate of 38-70% reported in the literature [5, 18, 27, 31]. This is most probably

due to decreased bone contact and less adequate compression. Also, in using the monoplane external fixator, anterior-posterior stability is excellent, however varus-valgus stability is not entirely secured. This could also be a reason for the lower fusion rates in our series. [5, 27, 33]. Biplanar or circular frames could therefore provide a more solid arthrodesis. Also, the mean duration to solid fusion is about 51 weeks [27]. If a circular external fixator is used, a part of these drawbacks are overcome. Contrary to the mono- and biplane external fixators, the circular fixator renders better fusion rates, allows full weight bearing directly and renders a more rigid fixation. The infection risk, furthermore, has proven to be smaller [12, 23, 28]. Spina et al. Treated 17 patients with the Ilizarov (circular) fixator, 13 of which were successful (76%). Only one patient did not endure the fixator [28]. Manzotti et al. achieved a fusion rate of 100% with the Ilizarov and Oostenbroek reported a fusion rate of 93% in a series of 15 patients [19, 23]. The most common complications were superficial pin-tract infection (55%) and non-union (32%) [8].

Intramedullary nail

There are three types of intramedullary nails. First, there are the classic, long "Kuntscher" nails. These nails have an outstanding primary stability, allow full weight bearing immediately and have a high fusion rate (83-100%) [1, 5, 18, 29]. Drawback is the risk of fracturing of the femur at insertion [18, 27]. Also, this method cannot be used in patients with active infection or a deviant orientation of femur and/or tibia and the operation duration is longer and renders more blood-loss [18, 27, 29].

Secondly, there are short modular nails (as used in this study). These consist of a femoral and tibial component with a central coupling. These nails achieve good bone-contact and allow full weight bearing immediately. Furthermore, they can be used to create good alignment in a deviant femur and/or tibia [1, 5] and the magnitude of the wound is smaller compared to the long nails. Generally, IM nails present less discomfort for the patient and better quality of life, compared to external fixators [4, 5, 18, 27, 29]. However, there is a probability of intramedullar spreading of an active infection and the operated area is larger compared to the external fixator [5, 18, 27]. Also, the options to create a fysiologic valgus of the knee are limited.

Thirdly, there is the fairly new modular nail which does not require bone-contact. The prime advantage is the possibility to treat patients with large bone defects, without creating extreme leg length differences. This way, patients with expected large leg length differences (>5cm) can also be treated. There is, however, absence of long-term results. A potential drawback is the use of cement in this fixation, which can cause serious problems for revision in case of persisting infection. Because bony fusion is not attempted, there is a probability of loosening and therefore failure in the long term. Rao et al reported fairly good results with this implant. Two out of seven patients had to be revised in one year [25]. The long term results and long term

stability of this method, remain to be determined.

Plate fixation

The advantages of plate fixation compared to external fixation are better fusion rates and ease for the patient [5, 10, 15, 18, 22, 26, 27]. Also, in large defects plate fixation can offer rigid fixation, especially when using angle stable plates [15]. Munzinger et al. Described successful AD's in 80% of their patients using unilateral plate fixation [20] and when using bilateral fixation, Nichols Kuo found fusion rates up to 100% [15, 22]. When compared to IM nails, disadvantages of plate fixation are a larger wound area and partial weight bearing following operation. Furthermore, there is a substantial risk of persisting infection following PJI [18] and plates present a lot of stress for the overlying soft tissues, which are already weakened by (sometimes numerous) previous surgeries [5]. It is to be expected that there would be more wound-healing disorders in using plate fixation. Nichols et al. described a series of 11 arthrodeses, in which only one patient showed persisting wound drainage [22]. Pritchett et al. saw three relapsing infections with persisting drainage in a series of 26 patients, for which the material had to be removed in two patients. All three patients had an infection at the time of the first arthrodesis. The article does not mention further wound-healing problems [24]. In our own series, relapsing infection with wound-healing disorders are seen in two out of seven plate fixations, which led to non-union and amputation in one patient.

It is known that, in case of PJI with indication for arthrodesis, the success rate of each method depends directly on the success of the infection treatment before surgery. Treatment of a PJI, when done according to a strict protocol [33], renders good results [7, 9, 33]. Also, two-stage revisions generally achieve better results compared to one-stage revisions [1, 13].
According to abovementioned protocol, in absence of difficult-to-treat microorganisms (rifampin- or ciproxin-resistant, enterococci, fungi), an antibiotics-loaded spacer should be placed. In case of difficult-to-treat microorganisms or badly damaged soft tissue with indication for a muscle flap, an external fixator should be placed. We think that this protocol could apply also to the choice of method for arthrodesis following PJI.
If there is an indication for arthrodesis following successful treatment of a PJI, an intramedullary nail can be used with or without a muscle flap (based on the quality of the overlying soft tissue). If the treatment of infection is unsuccessful, a (possibly) present spacer should be removed, followed by a new debridement and appliance of an external fixator for stabilization. In case of still persisting infection thereafter, a choice should be made between further treatment using an external fixator or amputation. IM nailing should not be used, because of the risk of intramedullary spreading of the infection. If there was no infection present at the time of indication

for arthrodesis and the quality of the soft tissue is good, plate fixation or IM nailing are to be preferred. When the quality of the soft tissue is bad, an IM-nail with or without a muscle flap is indicated. These steps are displayed in the algorithm (appendix 1).

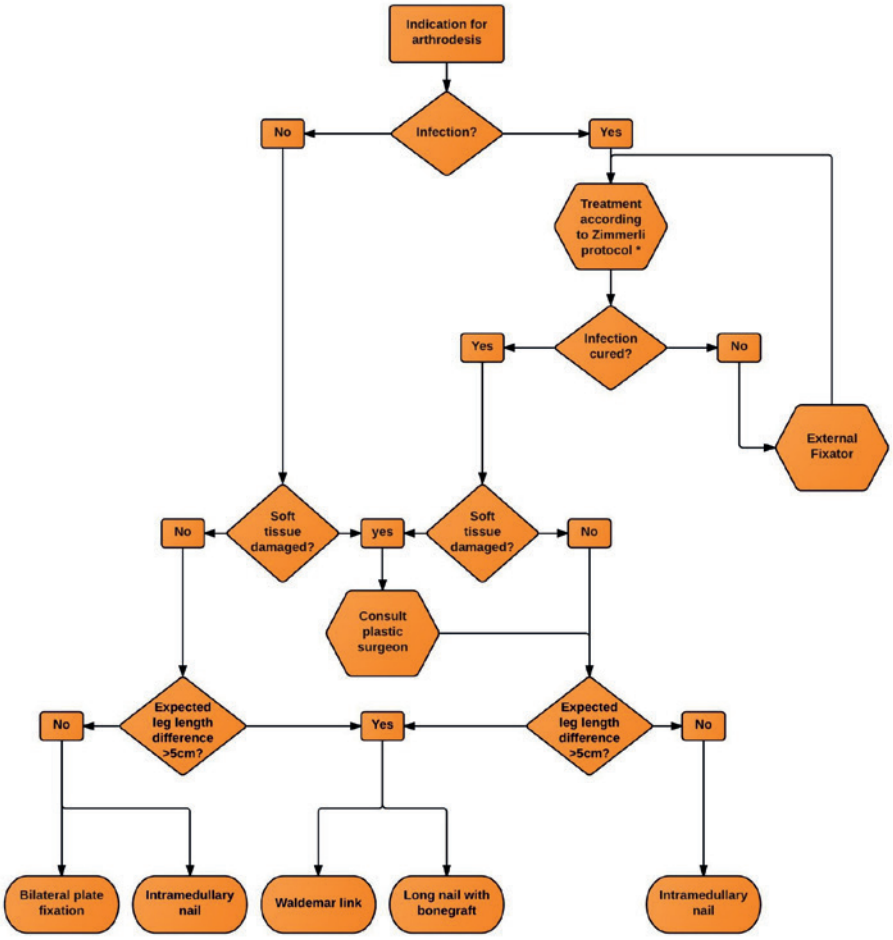
In the absence of infection, the literature favours intramedullary fixation over external fixation. In case of infection, the IM nail was thought to spread or maintain the infection. After adequate treatment, however, this risk was not seen any more [1, 5, 30]. Waldman et al. showed good results using a modular IM nail after a period with a spacer in antibiotic-impregnated cement [30]. Bargiotas achieved solid fusion in 10 out of 12 patients using an IM nail in a two-stage procedure following PJI [1]. In our series, intramedullary nails also rendered good results following PJI.

In conclusion, none of the methods for arthrodesis is superior in every case. Good patient selection and attention to specific circumstances are the key to a successful arthrodesis. We think that, based on our own data and the contemporary literature, the external fixator can be abandoned as standard method for arthrodesis of the knee after failed TKA. In case of damaged soft tissue and/or persisting infection despite extensive treatment, the external fixator can be used for stabilization during further treatment. In tenaciously persisting infections, the choice can be made to continue treatment with the external fixator. Despite the fact that the experience with monoplane external fixators is more extensive and they are easier to apply, the Ilizarov circular fixator is thought to achieve better fusion rates and should therefore be taken in consideration as standard method for external fixation [19, 28]. In case of extensive bone loss (expected leg length difference >5 cm), a modular IM nail without bone contact seems to be a good option, but lacks long term results (see before).
Progressive insight seems to indicate better results in using intramedullary nails and plate fixation, with the proper patient selection.

Conflict of interest

The authors declare that they have no conflict of interest.

Appendix 1: Protocol knee arthrodesis following failed TKA



*In case of persisting infection, the choice should be made between new debridement and continuing treatment with the external fixator or amputation.
Any wound-healing disorders after surgery are treated using the algorithm as proposed by Kovacs et al.

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Chapter 7

General discussion and future perspectives

General discussion

During the journey of a patient with knee osteoarthritis, treatment often requires a total knee arthroplasty (TKA). Although most total knee arthroplasties perform well, in some unfortunate cases, it ends with a revision of a total knee arthroplasty (rTKA) or even an above the knee amputation. This thesis focuses mainly on those cases that require a rTKA or even worse and aims to help patients and surgeons how to move on with the failed total knee implant. Although the percentage of failures is small, this step towards a rTKA is being taken by approximately 3000 patients in the Netherlands each year [1]. As outcome and survival are less optimal after a rTKA compared to primary TKA, there is certainly room for improvement. In this Discussion, various aspects of rTKA will be discussed. In the final part of this Discussion I will look forward to the future and suggest ideas of how to reduce the potential rTKA burden.

Total knee arthroplasty

When discussing a TKA in the outpatient clinic, the reason for the knee osteoarthritis is an important factor in the (shared) decision making process. For example, patients with a history of prior operations to the knee have a higher risk of complications following TKA. It is known that TKA in secondary OA cases due to a previous trauma, like tibial plateau fracture (TPF), is associated with increased risk of aseptic loosening of the tibial component [2–4]. However, the relationship between, for instance, a previous medial open wedge high tibial osteotomy (OW-HTO) and more tibial component loosening is not as evident. Literature suggests that metaphyseal stability in post tibial osteotomy cases is a recognized challenge, reflected by the increased use of tibial stems with primary TKA in these cases.

Inspiration for this approach has been found in the theory of zonal fixation, as posed by Morgan-Jones [5], which has gained widespread adoption in rTKA. Also, a recent study showed that metaphyseal fixation is key to prevent re-revision because of loosening. (ref: van Laarhoven et al, in press BJJ 2024). Although the zonal fixation theory has been developed for rTKA, it could be argued that its principles also stands in primary cases with compromised bone stock. Especially, improving the metaphyseal fixation has become a point of interest, resulting in the development of metaphyseal cones and sleeves. These cones and sleeves have shown a good survivorship in the short-to-midterm following rTKA with advanced metaphyseal bone loss [6]. The increasing number of studies on the durability of fixation with these devices even raises questions about the necessity of diaphyseal fixation in rTKA. Xie and colleagues investigated the use of metaphyseal cones with and without use of a diaphyseal stem. They found that while micromotion was increased when

omitting the use of a stem, but this seemed not clinically relevant [7]. Even in primary TKA, Martín-Hernández and colleagues have described good results of metaphyseal sleeves in post-traumatic cases. [8]. This is in line with the good survivorship of a metaphyseal sleeve in primary TKA following TPF and OW-HTO that has been shown in **Chapter 2**.

Other cases that may have a possible benefit from metaphyseal augmentation in combination with a primary TKA are patients with altered bone quality due to previous surgeries (e.g. plate fixation, tunnel widening after ACL/PCL reconstruction) or severe osteoporosis. Furthermore, increased metaphyseal fixation can be needed in primary TKA cases with severe deformities and inadequate soft tissue balance, where a more constrained prosthesis is warranted. Obesity has also been associated with increased revision rates [9–11]. In these cases in overweight patients, there might be a role for enhanced metaphyseal stability as well.
However, augmentations like revision tibial trays and stems/sleeves increase the cost of the procedure. In the light of the increasing pressure on the health care systems to provide cost-effective treatment and to avoid overtreatment, it is important to identify the right patients with an increased risk of revision to consider these metaphyseal cones and sleeves. Based on literature and our results, we conclude that routine use of a sleeve or stemmed implant after tibial plateau fracture is warranted and safe. In patients following OW-high tibial osteotomy, routine use does not seem warranted. The decision to use added metaphyseal stability is currently made by the orthopedic surgeon, based on individual experience and routines. To make a more informed decision, patient-specific benefits and risks should be explored and discussed, in more detail. Future research should therefore focus on finding the most optimal indication for the use of stems or sleeves in cases with altered bone quality in demanding primary TKA.

Revision total knee arthroplasty

Because of the strong increase in the numbers of primary TKAs in the last decades, rTKA has become more common, but many aspects of outcomes after rTKA have yet to be explored. When trying to improve revision implant longevity, function and patient satisfaction, we need to understand in detail what the current results are and why we make certain choices. As shown by van Kempen and colleagues there is a clear relation between indication for revision and short-term clinical outcomes [12]. In **Chapter 3**, we showed that this relationship between indication and outcome was maintained during long-term follow-up. Interestingly, outcomes as early as 3 months following rTKA seem predictive for the long term, regardless of reason for revision.

The most important finding in this chapter was that rTKA surgery improves function, clinical scores and ROM for almost all reasons for revision, with the exception of revision for severe stiffness (defined as range of motion <70 degrees pre-operatively). In the latter, VAS pain did not decrease significantly and KSS functional scores did not increase significantly after revision for severe stiffness. Also, VAS satisfaction was markedly lower for patients with a severely stiff knee as indication for rTKA and remarkably the score continued to decline during follow-up. For severe stiffness, pain is part of the inflammatory response in arthrofibrosis, which might account for the higher VAS pain scores in this group.
For the instability group, a satisfying explanation has not been found for the relatively low KSS functional scores. Possibly, the ligament tension in this group was altered already before primary TKA due to, for example, previous injuries to the collateral ligaments. Altered ligament tension can also occur during primary TKA by means of ligament releases. These alterations complicate achieving proper ligament balancing with the rTKA procedure. More insights and actual ligament tension measurements in native knees, primary TKA and rTKA is needed to be able to understand the pathomechanism and improve on these results.

As seen in **Chapter 3**, patients with a severely stiff TKA have overall less favorable results following rTKA. Recurrent stiffness and persisting pain after revision surgery cause patient dissatisfaction and have been a focus in the search for improvement. Focusing on this indication for revision, we found a significant, although moderate, improvement in ROM at 2 years following extensive debridement and implantation of a hinged-type rTKA for severely stiff TKAs in **Chapter 4**. However, these surgical procedures are extensive, demanding and expensive. Unfortunately, recurrent stiffness frequently occurs. The cases in our study varied widely in underlying causes and in levels of improvement of range of motion. Furthermore, pain scores did not decrease significantly. This indicates that these procedures should be further optimized to increase patient outcomes and function.
The importance of aftercare and physical therapy, as well as psychological guidance were not included in this chapter. Psychological factors as pain catastrophizing and kinesiophobia are currently recognized as adverse attributes following total knee arthroplasty [13,14]. In addition to improving technical aspects, there is a possibility that patients could be better served with a more profound understanding of the biology of arthrofibrosis. Deeper knowledge of this process could lead to a different treatment approach and possibly even help to avoid the occurrence of arthrofibrosis in primary TKA. On top of that, improvement and personalization of aftercare with respect to psychological factors could lead to a decrease in the number of (severely) stiff knees. Future research on these aspects, that are often underexposed in our daily practice, might lead to significant improvement of the patient satisfaction in these patients.

Centralization of surgery

For demanding surgical procedures it has been shown that centralization by increasing hospital volume has led to better outcomes, such as lower mortality and morbidity rates [15]. In orthopedics, this phenomenon has also been demonstrated for the treatment of prosthetic joint infection (PJI) by specialized teams [16]. Major revisions can be considered as technically challenging procedures, especially when a PJI is present. The need for specialized teams and specialized equipment in these cases are arguments for centralization of rTKA. Therefore, it was surprising that in **Chapter 5** we found no difference in survival of rTKA in high volume centers compared to centers with lower volumes using data from the Dutch arthroplasty registry (LROI). This is in contrast with Yapp and colleagues who found that increasing annual hospital case volume above 20 rTKA cases, is independently associated with a significant risk reduction for second revision [17]. A possible explanation is probably the relatively high caseload of major revisions in high volume centers and less complex revisions in the lower volume hospitals. And (repeated) liner exchanges sometimes precede a more extensive second revision, which is not always performed in the same center as the first (small) revision procedure. Data on repeated exchanges were not known in the LROI data used for our study. Secondly, a possible bias is the organization of care for infected arthroplasties in the Netherlands. Recurrent or difficult-to-treat infections are already centralized in high volume centers. These procedures regularly call for repeated surgery and second revisions, masking the effect of centralization. Moreover, as most revision surgeons in the Netherlands are fellowship-trained in high-volume centers, their performance in rTKA could be equivalent even in low-volume centers.

Further research should focus on eliminating the repeated liner exchanges from the analysis and thereby focus only on the more complex revisions. Care should be taken to adequately keeping track of location changes per individual case. Careful use of national joint registers (and more detailed record keeping) could be very helpful in this respect. Another factor we did not take into account was the surgeon volume. A high volume center can have a relatively high number of surgeons performing only a couple revision procedures each. Individual experience and exposure can be comparable to low volume centers in that respect. It could be beneficial to patient outcome to further explore the relationship between surgeon volume and outcome in rTKA.

Salvage procedures

For a small group of patients at the far end of the patient journey following knee OA treated with a TKA 'salvage procedures' are needed. These are necessary when conventional revision options are no longer possible. Among those are salvage procedures like arthrodesis of the knee (AD) or above-the-knee amputation (AKA). Fortunately, the incidence of both AD and AKA are declining (despite the increasing revision burden) [18]. Nevertheless, these salvage procedures will likely continue to be needed occasionally. Because these procedures are not performed routinely, there is a need for guidelines in these cases. Therefore, in **Chapter 6** we developed a protocol for treatment of a definitive failed rTKA. The emphasis of the study was on AD of the knee, but AKA also is a viable option. The choice for either an AD or AKA is not solely dependent on clinical factors. Patient-specific factors play an important role as well (e.g. one patient chooses an AKA to be able to keep riding in a motor sidecar, another patient wants to keep proprioception in both legs). Helping patients to familiarize with both options (through a trial brace and a visit to the revalidation department) can be very helpful in aiding the shared decision making.

Both salvage procedures are associated with a decline in quality of life. Additionally, AKA is associated with a higher mortality compared to AD[18]. On the other hand, higher pain scores and a trend for a lower quality of life are reported for AD [19]. Finally, there is the probability of failure of the AD and the need for even further surgical management.

In fact, these difficult procedures are performed most frequently following (repeatedly) failed treatment for PJI. The care for PJI is concentrated in specialized centers. Although in **Chapter 5** we did not find evidence for specialized revision centers, a case for centralization of salvage procedures can be made since beneficial outcome has been described for PJI treatment in centers with a multidisciplinary approach [20]. Microbiologists, internal medicine specialist in infectious diseases, specialized radiologists and colleagues specialized in rehabilitation surgery are essential. Furthermore, because of the rare (and declining) occurrence of these salvage indications, it would be advisable to have a really limited number of high-volume centers where these procedures are performed. This would create a situation in which knowledge and data are centralized. Given the complexity of this treatment pathway and the explicit involvement of the patient in treatment decisions, centralization seems justified.

Because of the relatively small sample size in studies regarding salvage procedures, more information will always be needed to adequately counsel patients in this difficult decision. Ideally, the flow chart proposed in **Chapter 6** would be implemented in centers that perform these procedures. The collected data on subsequent outcomes could help in more adequately manage expectations and in a more

educated decision for both surgeons and patients. The assistance of knee societies would be helpful to implement this strategy.

Shared decision making

In this discussion, informing and involving the patient in decisions about options and results is a recurrent theme. This is a prerequisite for reaching true shared decision making (SDM) after a total knee procedure with unfortunate severe clinical problems. SDM describes the deliberations that patients and clinicians do together to co-create a sensible treatment plan that best fits the patient's situation [21]. For the process of symptomatic knee osteoarthritis, in the last decade SDM has become part of the standard care in discussing treatment with a primary TKA. Transparent presentation of all options as well as unbiased information are discussed to achieve realistic expectations regarding possible benefits and the risks of possible complications. However, SDM should also play a role in subsequent treatment of complications after primary TKA and revision TKA, even if the results of the options are less well described than for primary TKA. In contrast to the salvage operations mentioned above, where patient involvement is of utmost importance and shared decision making is common, decisions on treatment of rTKA is most of the time mainly done by the surgeon. Increasing our understanding of indications for revisions and possible improvement after a revision for the individual patient should help to gain more insight into what strategies pay off in which situation. An important aspect therein is taking more time in the outpatient clinic mapping out the treatment options, even if some options are not offered at that location and/or phase of treatment. Also, patient-specific wishes should always be taken into account (e.g. the patient who refuses an arthrodesis of the knee because of the wish to be able to close the toilet door during a visit). Research on patient participation in rTKA procedures should focus on learning what information is most important for patients in decision-making in rTKA.

Limitations

There are a couple of limitations to this thesis that require addressing. Firstly, with the exception of **Chapter 2,** all studies were conducted retrospectively, however utilizing a prospectively collected database. Within this database, information regarding patient history and potential previous operations was not always consistently available. Additionally, follow-up data were missing occasionally, potentially leading to selection bias in these study types. Further, the reason for revision (**Chapter 3**) was determined by the surgeon and in cases where multiple

reasons were present, the surgeon recorded only one reason as the main reason, potentially influencing comparisons. However, for this database, the knee surgeons of the institution decided on the most important reason as a group during complication meetings, thereby making this assessment less subjective. Secondly, most studies were conducted with small sample sizes. Regrettably, this was unavoidable. Even though the studies in **Chapter 3**, **Chapter 4**, and **Chapter 6** were conducted in a high-volume referral clinic, where knee arthroplasty revisions are concentrated, severely stiff knee cases and salvage procedures are still relatively uncommon. Furthermore, rTKA and salvage procedures are highly patient-specific, rendering comparison and statistical evaluation challenging due to their heterogeneity.

Thirdly, although registry data (**Chapter 5**) often provide large sample sizes, there is a significant amount of missing data and a lack of detailed information (for instance patient history). Additionally, due to the multitude of variables in these studies, caution must be exercised to avoid confusing correlation with causality.

These points underscore the importance of comprehensive and meticulous data collection before, during, and after rTKA to be able to further enhance longevity and outcome.

Finally, the national guidelines on revision procedures may have introduced a selection bias in certain chapters, such as **Chapter 5**. Straightforward revisions are typically performed at a wide range of centers, whereas PJI's are managed mainly at specialized centers, and complex cases are often referred to dedicated facilities. This discrepancy can hamper the comparison of outcomes following revision surgery. However, despite all these limitations this thesis offers valuable insight in complex situations that can help to have clear discussions, based on outcome data, with patients about difficult decisions.

Future perspectives

The best revision TKA is the one that can be avoided. Preventing rTKA can be done by optimizing outcome and longevity of the primary TKA. In that respect, one of the main topics of discussion at the moment is about the optimal alignment and implant position in TKA. The multiple alignment and balancing techniques for primary TKA described in the literature reflect the lack of real detailed knowledge about outlining and balancing/ligament tension. These debates are leading to advanced theories on personalized approaches in TKA[21]. However, to enable these discussions, reliable data (which is currently lacking) including those on ligament balancing and alignment philosophies are needed [21].

Ideally, for all rTKA patients, a standard set of data should be collected. This approach will record what we are actually doing and achieving currently. Soft tissue balancing and subsequent peroperative adjustments to component placement, bony cuts and soft tissue releases should be logged. Consequently, it could be of interest to record also data on leg alignment (pre-, and postoperative), intended alignment strategy and the instrumentation that was used. When available, joint pressure measurements should also be registered.
After combining these elements with pre-, and postoperative range of motion, patient reported outcome measures (PROMs) and satisfaction scores, the next step will be analyzing those results and searching for parameters that can be modified to improve on outcome.
Finding a way in this vast amount of data establishes the need for (surgical) data science (SDS). SDS will evolve to analyze all measurable factors during the procedure, as well as during the rehabilitation, combining clinical data with ambulant- and patient reported data [24]. It will provide both surgeons and their patients with quantitative support to aid (shared) decision-making and link surgical choices decisions to patient outcomes [24].
Another future challenge is collecting these data on a large scale. New advancements in technology, like patient engagement apps, have the potential to provide detailed pre-, and postoperative data on baseline characteristics, while the peroperative process can be monitored by systems like Computer- and Robotic Assisted Surgery.

Computer Assisted Surgery (CAS) and Robotic Assisted Surgery (RAS) could play a big role in rTKA, as these technological developments have the potential to improve rTKA procedures by increasing the understanding of the optimal alignment and balancing in individual case. More than in revision surgery, applying these techniques in primary TKA might reduce the need for rTKA by helping 'getting it right the first time' [25]. Focusing on revision surgery, better understanding of primary TKA will also contribute to rTKA solutions. When we know what to strive for in (r)TKA placement, RAS can potentially help with the demanding challenges in rTKA (bone loss, augmentation, joint line height and orientation, patellar tracking), enabling revision surgeons to get more feedback and transparency on their procedures, and hitting their target (a painless, balanced knee with a functional range of motion) reproducibly. The importance of precision in rTKA was recently highlighted by Lee and colleagues, who concluded that achieving a balanced knee had the greatest impact on quality adjusted life years in rTKA, independent from a surgeon's volume[25].

Challenges in rTKA, especially in 1-stage revisions, are the metal artifacts in the pre-operative CT scan (for systems that rely on these), which complicates the analysis of the possibly required augmentation. Also, additional bone loss with the removal of

the primary TKA can complicate the planning in these systems. In 2-stage revisions, however, the planning of augmentation in case of severe bone loss can be done more accurately before the second surgery. Other systems that rely on intra-operative imaging can accommodate for that, but are possibly less precise in pre-operative planning.
Research (and development) in this respect should focus on ways of combining real time mapping of bone stock after removal of the prosthesis with options in intra-operative planning of augmentation. These advancements could enable the more tailor-made approach needed in rTKA. Currently, however, these technologies cannot be combined, due to the patents of different companies. Ideally, commercial parties should collaborate to create the optimal tools for rTKA.

The use of RAS in arthroplasty is currently mainly limited to primary surgery. Documented benefits mainly describe higher accuracy and reproducibility, but this has not led to better outcomes in literature so far [26–28]. Although the execution is very precise, pre-operative planning and per-operative alignment are still surgeon dependent. In other words, if the surgeon makes poor choices, this will be executed quite precise, but the clinical outcome will not improve. Also, the high initial costs in RAS have raised questions about routine use of these techniques. However, the potential of recording peri-operative data can help to improve the knowledge on primary and revision TKA. Preferably, this should at first be done by high-volume surgeons who have overcome the learning curve of these devices . This will require, however, that surgeons are open to evaluation of their decision making process during knee arthroplasty.

Last but not least, another equally important aspect of analyzing outcome is of course the patients' perspective. Future research should not focus on the technical aspects of knee arthroplasty alone. Patient expectations, psychological, physical and physiological differences between patients also have an impact on rehabilitation and outcome following (revision) arthroplasty. With the development of patient engagement platforms, real-time insight in patient-reported outcomes and satisfaction can be obtained. Rehabilitation can be monitored and support can be offered in case of divergent scores. A better understanding of these aspects could also lead to more tailor-made psychological support and physical therapy. More research should be done to measure patient commitment to exercises and to follow patients during rehabilitation after their rTKA.

It is my belief that improving patient outcome as well as surgical performance is by integrating surgical and patient data on a large scale and this is the future of orthopedic surgery.

Conclusion

The aim of this thesis was to explore the need for -and the options in- a more patient-specific approach to rTKA. From our studies, we can conclude that rTKA usually is performed while two or more modes of failure are present. This indicates that it is a highly heterogeneous group and that there is indeed a need for a more personalized approach.

When revision surgery is needed, patients should be counseled on the fact that reason for revision is associated with outcome, and the worst outcome is seen in revision for severe stiffness. However, extensive tissue releases with revision to a hinged-type TKA can improve ROM and outcome even for the most of these patients. In contrast to other fields in orthopedic surgery, we did not find an association between second revision rate and hospital volume in the Netherlands. Furthermore, PJI (and salvage procedures like arthrodesis or amputation) require a multidisciplinary approach and therefor centralization is advised.

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7

Chapter 8

Summary

Summary

Revision of a total knee arthroplasty (TKA), arthrodesis of the knee joint or even above the knee amputation can be the end of a (usually long) journey of a patient with osteoarthritis (OA) of the knee. Because of the rising incidence of revision TKA (rTKA) due to the younger age at which a primary TKA is being performed and the increasing demands of level of activity in the elderly, there is a growing need for improving the outcome of TKA and rTKA.
In this thesis, different aspects of rTKA are evaluated, from primary TKA to salvage procedures. The aim of the thesis was to explore possible options in improving patient outcome for rTKA.

Improving the outcome in rTKA starts with improving the outcome in primary TKAs. Therefore, in **Chapter 2**, we studied the influence of previous operations on outcome and survival of primary TKA. It is known that previous high tibial osteotomy (HTO) and tibial plateau fractures (TPF) may cause problems in subsequent TKA due to compromised metaphyseal bone stock. Higher rates of loosening of the tibial component have been described. In post-HTO and TPF cases, a more durable fixation could be achieved by adding tibial sleeves to the primary TKA implant. We therefore selected a cohort of 28 patients with a TKA following HTO (11 patients), and following TPF (17 patients). These patients were evaluated radiologically and clinically. We found that, with no revision for aseptic loosening, using tibial sleeves in primary TKA seems a safe and reliable method for improved fixation of the tibial component in metaphyseal bone with altered bone structure at short and mid-term follow-up.

Although most total knee arthroplasties perform well, in some unfortunate cases, a revision of a total knee arthroplasty (rTKA) is needed. The main modes of failure of a primary TKA are aseptic loosening, component malposition, knee instability, septic loosening, patellar instability and stiffness. There is limited information about long-term clinical outcomes following rTKA in relation to the indication for revision. In **Chapter 3**, the relationship between clinical outcome and reason for revision was evaluated. A cohort of 129 patients with a total system rTKA was selected. Range of motion (ROM), visual analogue scale (VAS) for pain and satisfaction, and clinical and functional Knee Society Score (KSS) were obtained preoperatively, at 3 months, 1, 2, 5, and 7.5 years. We found that patients revised for severe stiffness had significantly worse outcome and deteriorated slightly at longer follow-up. Outcome at 3 months seemed to be predictive for long term outcome.

Based on the findings in **Chapter 3**, it was understood that an important aspect in rTKA is improving on the management of severely stiff TKA. It was hypothesized that

extensive tissue release and implantation of a hinged-type rTKA implant would improve outcome for patients with a severely stiff TKA. In **Chapter 4**, the outcome after rTKA with hinged-type implants for severely stiff TKA (ROM ≤ 70°) at 2 years was evaluated in a cohort of 38 patients. ROM, VAS for pain and satisfaction and KSS were obtained preoperatively and at 3 months, 1 year and 2 years. Pre- and postoperative outcome were compared at 2 years. We saw a significant increase in ROM and KSS. VAS pain scores did not differ significantly. The median ROM at 2 years was 90° (range 50°-125°) with a median gain of 45°(range 5°-105°). Median VAS pain was 28.5 (range 0-96) points and median VAS satisfaction was 72 (range 0-100) points at 2 years and 5 patients had a recurrent stiff knee. We concluded that revision with a hinged-type rTKA following a severely stiff total knee arthroplasty renders a significant, although moderate, clinical improvement at 2 years.

Because of the increase in rTKA globally, there is an increase of technically challenging procedures as well. Centralization has not only been shown to reduce mortality and morbidity for complex surgical procedures, but also for primary TKA, and treatment of prosthetic joint infections (PJI). Therefore, in **Chapter 5** we aimed to evaluate the association between hospital rTKA volume and overall second revision rate, as well as revision rate for different types of revision. 8,072 rTKAs between 2010 and 2020 with available data on the primary knee arthroplasty in the Dutch orthopedic arthroplasty register (LROI) were included. Minor revisions (insert exchange or patella surgery) were excluded. Hospitals were divided in different volume groups (≤12 cases/year, 13-14 cases/year, and ≥25 cases/year). We found that there were no statistically significant differences between second revision rates of the three volume groups. We therefore concluded that second revision rate of rTKA does not seem to be dependent on hospital volume or type of revision in the Netherlands.

Even with improving long-term results of rTKA, salvage procedures will remain to be necessary. Depending on the mode of failure, condition of the soft tissue, and patient preferences, arthrodesis of the knee or even amputation can present an acceptable solution.
Primary stability in arthrodesis of the knee can be achieved by external fixation, intramedullary nailing or plate fixation. Each method has different features and results. In **Chapter 6**, we aimed to develop a practical algorithm for arthrodesis of the knee following a failed (infected) arthroplasty. Therefore 26 patients with an indication for arthrodesis after failed (revision) arthroplasty of the knee between 2004 and 2010 were studied. Patients were analysed with respect to indication, fusion method and bone contact. End-point was solid fusion. In total, ten external fixators, ten intramedullary nails and six plate fixations were applied; solid fusion was achieved in 3/10, 8/10 and 3/6, respectively.

We concluded that there is no superior method in performing an arthrodesis of the knee. Good patient selection and appropriate individual treatment are the key to a successful arthrodesis. Based upon our findings, we have developed a practical algorithm.

With this thesis, we explored various aspects of rTKA procedures and how to improve on the longevity and outcome of knee arthroplasty in different stages of a patients' journey from knee OA to primary TKA, rTKA, or even an arthrodesis of amputation. There are still many aspects of TKA and rTKA that are not understood well enough. In **Chapter 7**, we have laid out our ideas for the direction of future research.

Chapter 9

Summary in Dutch / Nederlandse samenvatting

Summary in Dutch / Nederlandse samenvatting

Revisie van een totale knieprothese (TKP), arthrodese van de knie en zelfs een bovenbeenamputatie kunnen het eindpunt zijn van een (meestal lange) reis van een patiënt met knie-artrose. De steeds jongere leeftijd waarop een TKP wordt uitgevoerd, gecombineerd met de toenemende eisen die ouderen stellen aan hun activiteitenniveau, leidt tot het steeds meer toepassen van revisie knieprotheses (rTKP). Hierdoor is er een groeiende behoefte aan verbetering van de uitkomsten van TKP en rTKP. In dit proefschrift worden verschillende aspecten van rTKP geëvalueerd, van verbeteren van de primaire TKP tot de meer extreme ingrepen bij revisie. Het doel van dit proefschrift is om opties te verkennen om de patiëntuitkomsten voor rTKP te verbeteren.

Verbetering van de uitkomsten bij rTKP begint met de verbetering van de resultaten bij de primaire TKP. Daarom hebben we in **Hoofdstuk 2** de invloed van eerdere operaties op de resultaten en levensduur van primaire TKP bestudeerd. Het is bekend dat eerdere tibiakop osteotomie (TKO) en tibiaplateaufracturen (TPF) problemen kunnen veroorzaken bij een daaropvolgende TKP vanwege aangetaste botkwaliteit van het dragende deel (metafyse) van het onderbeen. Hogere percentages met loslating van de tibiacomponent zijn daarbij beschreven. In gevallen na eerdere TKO en TPF zou een duurzamere fixatie kunnen worden bereikt met tibiale sleeves. We selecteerden daarom een groep van 28 patiënten met een TKP en een sleeve na TKO (11 patiënten) en na TPF (17 patiënten). Deze patiënten werden zowel radiologisch als klinisch geëvalueerd. We vonden dat, aangezien er geen revisie voor aseptische loslating noodzakelijk was, het gebruik van sleeves bij primaire TKP een veilige en betrouwbare methode lijkt voor fixatie van de tibiacomponent in metafysair bot met veranderde botstructuur op korte en middellange termijn.

Hoewel de meeste totale knieprothesen goed functioneren, is in sommige gevallen helaas een revisie van een totale knieprothese (rTKP) nodig. De meest voorkomende redenen voor het niet slagen van een primaire TKP zijn aseptische loslating, componentmalpositie, knie-instabiliteit, septische loslating, patella-instabiliteit en stijfheid van de knie. Er is beperkte informatie over de klinische lange termijn resultaten na rTKP in relatie tot de indicatie voor revisie. In **Hoofdstuk 3** wordt de relatie tussen klinische uitkomst en reden voor revisie geëvalueerd. Een groep van 129 patiënten met een totale revisie van een TKP werd geselecteerd. Bewegingsbereik (ROM), visueel analoge schaal (VAS) voor pijn en tevredenheid, en de klinische en functionele Knee Society Score (KSS) werden preoperatief, op 3 maanden, en op 1, 2, 5 en 7,5 jaar verzameld. We vonden dat patiënten die werden gereviseerd voor ernstige stijfheid (ROM ≤ 70°). significant slechtere uitkomsten hadden, en zelfs nog iets verslechterden op langere termijn. Uitkomsten na 3 maanden leken voorspellend voor de lange termijn uitkomsten.

Op basis van de bevindingen in **Hoofdstuk 3** wordt duidelijk dat een belangrijk aspect bij rTKP het verbeteren van de behandeling van ernstige stijfheid bij TKP is. Er werd verondersteld dat uitgebreid losmaken van het omringende weefsel en implantatie van een scharnierend rTKP-implantaat de uitkomsten voor patiënten met een ernstig stijve TKP zou verbeteren. In **Hoofdstuk 4** wordt de uitkomst na rTKP met een implantaat met interne scharnier voor de ernstig stijve TKP op 2 jaar geëvalueerd in een groep van 38 patiënten. ROM, VAS voor pijn en tevredenheid en KSS werden preoperatief en op 3 maanden, 1 jaar en 2 jaar verzameld. Pre- en postoperatieve uitkomsten werden vergeleken op 2 jaar. We zagen een significante toename in ROM en KSS. VAS-pijnscores verschilden niet significant.
De gemiddelde ROM op 2 jaar was 90° (bereik 50°-125°) met een gemiddelde toename van 45° (bereik 5°-105°). De gemiddelde VAS-pijn was 28,5 (bereik 0-96) punten en de gemiddelde VAS-tevredenheid was 72 (bereik 0-100) punten op 2 jaar. Helaas hadden 5 patiënten na operatie nog steeds een stijve knie. We concludeerden dat revisie met een scharnierende rTKP na een ernstig stijve totale knieprothese een significante, maar matige, klinische verbetering oplevert op 2 jaar.

Vanwege de toename van rTKP wereldwijd, is er ook een toename van technisch uitdagende procedures. Voor zowel complexe chirurgische procedures, als voor primaire TKP en de behandeling van prothese-infecties (PJI) is aangetoond dat met centralisatie een negatieve uitkomst en ook de kans op overlijden verminderen. Daarom hebben we in **Hoofdstuk 5** geprobeerd het verband tussen het ziekenhuis-volume van rTKP en het totale revisiepercentage te evalueren, evenals het revisie-percentage voor verschillende soorten revisies. Er werden 8.072 r-TKP's tussen 2010 en 2020 met beschikbare gegevens over de primaire knieprothese in het Nederlandse Landelijke Register Orthopedische Interventies (LROI) meegenomen. Kleine revisies (insertwissel of patella-operatie) werden buiten beschouwing gelaten. Ziekenhuizen werden ingedeeld in verschillende volumegroepen (≤12 gevallen/jaar, 13-14 gevallen/jaar en ≥25 gevallen/jaar). We zagen dat er geen statistisch significante verschillen waren tussen de revisiepercentages van de drie volumegroepen. We concludeerden daarom dat in Nederland het revisiepercentage van rTKP niet afhankelijk lijkt te zijn van het ziekenhuisvolume of het type revisie.

Zelfs met verbetering van de lange termijn resultaten van rTKP, zullen noodprocedures noodzakelijk blijven. Afhankelijk van de faalmechanisme, de toestand van de weke delen en de voorkeuren van de patiënt, kunnen arthrodese (verstijving) van de knie of zelfs bovenbeenamputatie acceptabele oplossingen zijn. Primaire stabiliteit bij arthrodese van de knie kan worden bereikt door externe fixatie, intramedullaire pen, of plaatfixatie. Elke methode heeft verschillende eigenschappen en resultaten. In **Hoofdstuk 6** hebben we getracht een praktisch algoritme te ontwikkelen voor

arthrodese van de knie na een niet geslaagde (vaak geïnfecteerde) prothese. Daarom werden zesentwintig patiënten met een indicatie voor arthrodese na onsuccesvolle rTKP tussen 2004 en 2010 bestudeerd. Patiënten werden geanalyseerd met betrekking tot indicatie, fusie methode en bereikt botcontact. Eindpunt was solide fusie. In totaal werden tien externe fixatoren, tien intramedullaire pennen en zes plaatfixaties toegepast; solide fusie werd bereikt bij respectievelijk 3/10, 8/10 en 3/6 patiënten. We concludeerden dat er geen superieure methode is voor het uitvoeren van een arthrodese van de knie. Goede patiëntselectie en passende individuele behandeling zijn de sleutel tot een succesvolle arthrodese. Op basis van onze bevindingen hebben we een praktisch algoritme ontwikkeld.

Met dit proefschrift zijn verschillende aspecten van rTKP-procedures onderzocht en werd bestudeerd hoe de duurzaamheid en uitkomst van knieprothesen kunnen worden verbeterd in verschillende stadia van de reis van een patiënt met knie-artrose naar primaire TKP, rTKP, of zelfs een arthrodese of amputatie. Er zijn nog veel aspecten van TKP en rTKP die niet goed genoeg worden begrepen. In **Hoofdstuk 7** hebben we onze ideeën uiteengezet voor de richting van toekomstig onderzoek.

Appendices

I Data management
II PhD Portfolio
III Dankwoord
IV List of publications
V Curriculum Vitae
VI Theses SMK

Data management

This thesis is based on the results of research involving human participants (or existing data from published papers), which were conducted in accordance with relevant national and international legislation and regulations, guidelines, and codes of conduct.

Ethics and privacy

This thesis is based on the results of human studies, which were conducted in accordance with the principles of the Declaration of Helsinki.

For **Chapter 2**, **Chapter 5**, and **Chapter 6**, ethical approval was not required according to the Dutch Medical Research Involving Human Subjects Act. For **Chapter 2** and **Chapter 6**, the studies were based on patient record data, without added procedures for the subjects, and **Chapter 5** was based on anonymous registry data.

For **Chapter 3**, **Chapter 4**, **Chapter 5, and Chapter 6** the Sint Maartenskliniek institutional review board approved the studies. The medical ethics committee on Research Involving Human Subjects region Arnhem-Nijmegen granted a waiver for the studies in **Chapter 3 and 4,** under the same number (no. 2003/173).

For **Chapter 2**, written informed consent was given by all participants for the collection, processing, and sharing of their data for future research. For **Chapter 3** and **Chapter 4** patients were informed about the prospective database and that their data could be used for scientific research (opt-out procedure). For **Chapter 5**, all orthopedic patients who will be operated on are informed that their data will be transferred to the national implant register (LROI). The privacy of the participants was warranted by the use of pseudonymization.

Funding

None of the studies received any funding.

Data collection and storage

Data from **Chapter 2** was obtained from, and logged in the Electronic Patient Records of the Rijnstate Hospital. The data were then pseudonymized and stored on a secure drive at the Rijnstate Hospital in Arnhem.

Data from **Chapter 3** and **Chapter 4** were collected from a prospective database at the Sint Maartenskliniek in Nijmegen. Relevant data was selected and datasets were stored pseudonymized on a secured server of the Sint Maartenskliniek, Nijmegen, with limited access only for local study team members.

For **Chapter 5,** anonymous patient and implant data were obtained from the Dutch arthroplasty register (LROI). The dataset and analysis scripts is stored at the secured server of the Sint Maartenksliniek, with limited access only for local study team

members. Data were also stored at the LROI on a secure server. These secure storage options ensure the availability, integrity and confidentiality of the data.

Data for **Chapter 6** was collected from the Electronic Patient Records of the Sint Maartenskliniek. A pseudonymized dataset was created and stored on a secured server of the Sint Maartenskliniek, with limited access only for local study team members.

Data sharing

Although the datasets of **Chapters 2** through **5** could be suitable for reuse, the absence of permission to share (**Chapters 3-5**) and/or ownership of the data (**Chapter 2**) prevent publication of the datasets. Moreover, the data from **Chapters 2** through **4** are so traceable to specific identities that anonymity cannot be guaranteed. The data are therefore stored within the institutes (Rijnstate for **Chapter 2**) and St. Maartenskliniek for **Chapters 3-5**) in a secure and sustainable location. Data can be requested by contacting the secretariat of the Research department of Sint Maartenskliniek (**Chapters 3** through **5**).
Data were made reusable by adding sufficient documentation according to local standard operating procedures for archiving.
The data of **Chapter 6** is not suitable for reuse and will be archived for at least 15 years after termination of the study.

PhD Portfolio

Training activities	Hours
- Courses	
- Basiscursus Regelgeving en Organisatie voor Klinisch onderzoekers (BROK)	42,00
(2021)	10,00
- Herregistratie Basiscursus Regelgeving en Organisatie voor Klinisch onderzoekers (BROK) (2024)	20,00
- Radboudumc – Scientific integrity (2024)	
Courses followed during orthopedic surgery resident training (2013-2020)	
- 2016-2019: Centraal examen orthopedie 1-2-3	288,00
- 2016: Total knee Arthroplasty, NVA arthroscopie cursus knie basis.	
- 2017: Masterclass revision TKA (Sint Maartenskliniek, Nijmegen)	
- 2018: Ligament Balancing course Smith & Nephew (Londen), Masterclass revision TKA Zimmer-Biomet (Amsterdam), Basic course osteotomies around the knee (ViaSana, Mill)	
- 2019: GECO AGREG GRAAL course Anterior cruciate ligament reconstruction Pro-Motion (Parijs). Instructional course ROSA knee system Zimmer-Biomet (Wemmel)	
Oral presentations	
- 2012: 31e, jaarlijkse bijeenkomst van de European Bone and Joint Infection Society, Montreux (Zwitserland). *Arthrodesis of the knee following failed arthroplasty.*	10,00
- 2014: Symposium voor revalidatie-artsen regio Nijmegen, St. Maartenskliniek te Nijmegen. *Salvage procedures following failed total knee transplant; arthrodesis vs amputation.*	10,00
- 2019: European Knee Society congress, Valencia (Spanje). *Improved clinical outcomes after revision arthroplasty with a hinged implant for severely stiff total knee arthroplasty*	10,00
- 2022: Refereermiddag voor orthopedisch chirurgen in opleiding van de ROGO Oost (Radboud UMC). *Jonge klare in een ZBC, goed idee of niet?*	10,00
- 2022: Knee expert meeting. Stryker hoofdkantoor (Amsterdam). *The impact of MAKO on my practice.*	10,00
Poster presentation	
2019: European Knee Society congress, Valencia (Spanje). *Long Term Outcome following Revision TKA is associated with reason for revision.*	5,00
Teaching activities	
Patient education sessions concerning hip- and knee osteoarthritis	
- 2022-2024: 4 sessions (Horst, Wijchen, Horst, Uden).	10,00
- 2023: series of 5 sessions at the Hiltho in Horst	12,00
- 2023-2024: Lecture and hands on training about revalidation after total hip arthroplasty for Physical therapists in training (Nederweert).	8,00
Total	**445,00**

Dankwoord

Het allermooiste aan het afronden van een proefschrift is dat je ineens gaat bedenken hoeveel bijzondere en mooie mensen er in je leven zijn. Ik wil iedereen bedanken voor de hulp en ondersteuning de laatste jaren. In het bijzonder wil ik hieronder een paar mensen persoonlijk bedanken.

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Posterus referit sui!

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Lieve, lieve **Saar**. Waar te beginnen? Jij bent mijn rots in de branding! Ik heb het je lang niet altijd makkelijk gemaakt. Eerst moest een opleiding en beginnende carrière nagejaagd en dan ook nog 'even' promoveren. Zonder jouw steun en liefde was ik nooit gekomen waar ik nu ben, laat staan dat ik het voor elkaar had kunnen krijgen dit proefschrift af te schrijven. Bedankt dat je mijn flauwe grapjes nog altijd niet beu bent. Ninakupenda, Mpenzi wangu! Ik kijk uit naar nog vele jaren met ons gezinnetje te genieten!

List of publications

van Rensch PJH, Belt M, Spekenbrink-Spooren A, van Hellemondt GG, Schreurs BW, Heesterbeek PJC. No association between hospital volume and early second revision rate in Revision Total Knee Arthroplasty in the Dutch Orthopaedic Register Submitted to: J Arthroplasty 2023

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Curriculum Vitae

Paul van Rensch was born on May 18, 1984, in Venray, the Netherlands, and spent his childhood in America, the Netherlands. He graduated in 2002 from the Dendron College in Horst, after which he moved to Nijmegen to study Biology. After earning his bachelor's degree, he completed a minor research internship at the Department of Tissue Engineering at the Nijmegen Centre for Molecular Life Sciences (NCMLS), resulting in his first peer-reviewed publication.

In 2005, he started medical school. He attended an orthopedic internship at the Sint Maartenskliniek in Nijmegen, where he developed an interest in orthopedic surgery as a specialty. The foundation for this thesis was also laid there. After completing an overseas internship in Public Health at the Rubya Hospital in Tanzania in 2011, he finished his medical training in 2012 and began working as a resident (not in training in orthopedic surgery, first at the Sint Maartenskliniek in Nijmegen and then in 2013 at the Elkerliek Hospital in Helmond. In 2014, he started his career as an orthopedic resident in training. He completed his general surgery rotation at the Gelre Hospital in Apeldoorn and his orthopedic rotations at the Sint Maartenskliniek, Radboud University Hospital in Nijmegen, and the Rijnstate Hospital in Arnhem between 2015 and 2020. In his last year of training, he did a rotation abroad with Prof. Dr. Vandenneucker at the University of Leuven, focusing on knee pathology.

After completing his training as an orthopedic surgeon, he worked as an orthopedic fellow in knee pathology at the Rijnstate Hospital in Arnhem in 2020. Since May 2021, he has been a staff member at CortoClinics in Nederweert, where he performs robotic arm-assisted total hip and total knee arthroplasty.

In his free time, Paul enjoys climbing, running, woodworking, and having outdoor adventures with family and friends. Paul lives with Saar Terra, and together they have three sons, Tuur, Joep, and Freek.

Theses SMK

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