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Doctoral thesis

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Thesis for the Degree of Philosophiae Doctor
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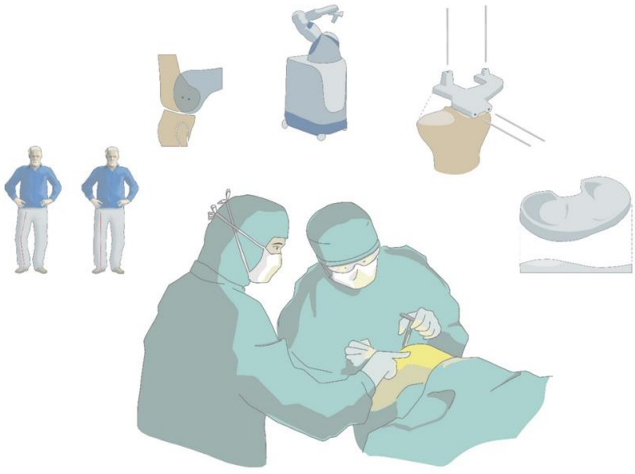

PhD Thesis

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Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology

Norsk sammendrag

Moderne totalproteser i kneleddet- Design og kirurgiske teknikker

Inngrepet totalprotese i kneleddet har gjennomgått en evolusjon de siste tiårene. Fra å være en kirurgisk prosedyre for de få, er det nå et av de mest utførte inngrepene i verden. Fra å være et inngrep som krevde to ukers innleggelse på sykehus, eller mere, varer sykehusinnleggelsen nå kun 1-2 døgn. Totalprotese utføres nå til og med som dagkirurgi enkelte steder. Selv om det er et inngrep med stor suksess hos de fleste, er omtrent 20% av pasientene ikke fornøyd av forskjellige årsaker. Utviklingen til nå har vært drevet av nye kirurgiske teknikker, både når det gjelder posisjonering av protesen, pasient spesifikke posisjonsguider (PSPG), computernavigering, robot kirurgi og nye protesetyper. En av disse protese typene er den såkalte medial pivot designen (MP). Mens eldre designs (cruciate retaining, CR) i noen tilfeller beveger seg på en såkalt paradoksal måte i kneleddet, altså at utsiden av lårbensdelen glir fremover istedenfor bakover når man bøyer kneet, så er disse protesene designet for å gjenskape kneets naturlige bevegelser under dagligdagse aktiviteter. Når vi undersøker ortopediske implantater ønsker vi gjerne å studere den såkalte migrasjonen, altså bevegelsen over tid mellom implantat og knokkel. Migrasjon, et mål på stabiliteten av protesen, måles ofte med radiostereometrisk analyse (RSA), en svært eksakt metode. Økt migrasjon av et implantat er ofte forløper til løsning av protesen. Dette fører igjen gjerne til revisjon, altså utskifting, av protesen. Revisjon er ofte et smertefullt inngrep, rehabiliteringstiden er lang, og resultatet er ofte dårlig for pasienten. Overlevelse av proteser måles ofte i store registerdatabaser, og kan si oss hvor mange implantater som ikke er reviderte over en gitt tidsperiode. Stabilitet og overlevelse av proteser er derfor viktige mål når vi innfører nye kirurgiske teknikker eller nye implantat design.

Målet med dette forskningsarbeidet var todelt; å studere stabiliteten til en CR protese når vi bruker PSPG som representant for moderne teknikk, og å studere overlevelse, revisjonsrisiko, årsaker til revisjonsoperasjon og stabiliteten til den såkalte MP design.

I artikkel I benyttet vi RSA til å studere stabiliteten til Vanguard® CR protesen ved bruk av to forskjellige kirurgiske teknikker; konvensjonell teknikk og PSPG. RSA er ansett å

være en metode med høy presisjon ved evaluering av risiko for senere proteseløsning. I artikkel II, som er en registerstudie som inkluderer store datasett fra de australske (AOANJRR) og norske leddregistrene (NAR), sammenliknet vi overlevelse av proteser med MP design med de tre mest brukte CR protesene i begge land. Vi undersøkte også revisjonsrisiko og revisjonsårsaker for de forskjellige MP implantater. I artikkel III undersøkte vi stabiliteten til GMK® Sphere protesen med RSA teknikk.

Konklusjon

Vi kan så langt ikke konkludere hvorvidt PSPG påvirker stabiliteten ved totalprotese i kneledd, selv om vi finner den kontinuerlige migrasjonen bekymringsverdig. Noen av MP implantatene hadde dårligere overlevelse og høyere revisjonsrisiko på grunn av malalignment og instabilitet sammenliknet med CR. Stabilitetsmålingen av GMK® Sphere tillater oss ikke å komme med noen endelig konklusjon vedrørende risiko for mekanisk løsning på lang sikt. Videre oppfølgning av PSPG teknikk og MP design anbefales derfor.

Kandidat: Frank-David Øhrn

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Hovedveileder: Stephan Maximillian Röhrl

Biveileder: Øystein Bjerkestrand Lian

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Contents

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Last, but not least, my sons Aleksander, Henrik and Johannes, for making me so proud and for giving so much meaning to my life!

My wife, Bente, for all your love, and your tremendous patience during all these years!

Kristiansund, Norway

20 November 2021

Acronyms and abbreviations

ACL - Anterior Cruciate Ligament

AOANJRR - Australian Orthopaedic Association National Joint Replacement Registry

ASA - American Society of Anaesthesiologists

BCR TKA - Bicruciate Retaining Total Knee Arthroplasty

BMI - Body Mass Index

CAD model – Computer Aided Design model

CAS – Computer-Assisted Surgery

CI - Confidence Interval

CIRRO - Center for Implant and Radiostereometric Research Oslo

CN - Condition Number

CONSORT - Consolidated Standards of Reporting Trials

CR - Cruciate Retaining

EF - Extension Facet

EQ-5D - EuroQol-5 Dimension

FF - Flexion Facet

FJS – Forgotten Joint Score

GMK® Sphere-Global Medacta Knee® Sphere

KOOS - Knee Injury and Osteoarthritis Outcome Score

LCL - Lateral Collateral Ligament

MCL - Medial Collateral Ligament

ME - Mean Error of Rigid Body Fitting

MP - Medial Pivot

MTPM - Maximum Total Point Motion

MRK^{TM} - Medial Rotation Knee

NAR - Norwegian Arthroplasty Register

NJR - National Joint Registry

OA - Osteoarthritis

PCL - Posterior Cruciate Ligament

PSPG - Patient Specific Positioning Guides

PS - Posterior Stabilized

QoL - Quality of Life

RATKA - Robotic-Arm Assisted Total Knee Arthroplasty

ROM - Range of Motion

RSA - Roentgen Stereophotogrammetric Analysis - Radiostereometric Analysis

SD - Standard Deviation

Sport/rec - Sport and Recreational Function

Spt - Symptoms

STROBE - STrengthening the Reporting of OBservational studies in Epidemiology

TKA - Total Knee Arthroplasty

"If conclusions are to be of any value they must be definite and one cannot draw definite conclusions from less than, say fifty cases followed up for at least five years. However, few surgeons will ever see fifty patients requiring arthroplasty of the knee, let alone operate on them, even in five years." L. G. P. Shiers, 1954[203]

"We never settle for being the best. We always strive to be better"

Dr Charles Olson, Medical Director of Cardiology

Thesis summary

Total knee arthroplasty (TKA) has undergone an evolution in recent decades. From being a surgical procedure for the few, it is now one of the most frequently performed surgeries worldwide. From being a procedure requiring a fortnight-long hospital stay, or more, the length of stay is now only one or two days. TKA is now even performed as day care surgery in some hospitals. Although it is a highly successful procedure in most patients, approximately 20% of patients are still not satisfied for various reasons. Developments until now have been driven by new surgical techniques, in terms of implant alignment, patient-specific positioning guides, computer-navigated surgery, robotic arm surgery and new prosthesis designs. One of these new designs is the so-called medial pivot (MP) prosthesis. Whereas older designs (cruciate retaining, CR) move in a paradoxical manner, i.e. the lateral femur slides forwards on the tibia instead of backwards during flexion, these implants are especially constructed to replicate the native knee motion during the patient´s everyday activity. When studying orthopaedic implants, we often want to study the migration of the implant. Migration, a measure of the stability of a prosthesis, is often measured by radiostereometric analysis (RSA), a very accurate and precise method. Migration of an implant often proceeds loosening of the implants, which often results in revision surgery. Revision surgery is painful and time consuming for patients, and the results are often poor. Survivorship is measured in large registry databases, and tells us how many implants were not revised over a given timespan. Stability and survivorship are therefore very important measures when introducing new surgical techniques or new implant designs.

The aim of this thesis was twofold: to assess the migration of a CR design utilizing the patient-specific positioning guides (PSPG) technique as representative of modern surgical techniques, and to assess the survivorship, migration, risks and reasons for revision of the MP design.

In Paper I, we used RSA to study the migration of the Vanguard® CR prosthesis using two different surgical methods: the conventional and the PSPG methods. RSA is considered to be a highly accurate and precise method for evaluating risk of later loosening of implants. Paper II, a registry study using large datasets from the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and the

Norwegian Arthroplasty Register (NAR), compared the survivorship of the MP design with the three most used CR knee prostheses in both countries. We also investigated reasons for revision of the different MP implants. In Paper III, we investigated the early stability of the Global Medacta Knee® (GMK®) Sphere total knee arthroplasty with RSA.

Conclusion

We cannot yet conclude whether the surgical tool of PSPG influences the stability of TKA or not, although we find the continuous migration a cause for concern. Some of the MP implants had a poorer survivorship and higher risk of revision due to malalignment and instability compared with CR controls. The early stability of the GMK® Sphere does not allow for a final conclusion on the risk of mechanical loosening in the long term. Further follow-up of the PSPG technique and the MP design is therefore warranted.

Papers in the thesis

Paper I

Ohrn FD, Van Leeuwen J, Tsukanaka M, et al. A 2-year RSA study of the Vanguard® CR total knee system: A randomized controlled trial comparing patient-specific positioning guides with conventional technique. Acta Orthop. 2018:1-7.

Paper II

Øhrn FD, Gøthesen Ø, Låstad Lygre SH, et al. Decreased Survival of Medial Pivot Designs Compared with Cruciate-retaining Designs in TKA Without Patellar Resurfacing. Clin Orthop Relat Res. 2020;478(6):1207-18.

Paper III

Øhrn FD, Lian ØB, Tsukanaka M, et al. Early migration of a medially stabilized total knee arthroplasty: a radiostereometric analysis study up to two years. Bone Jt Open. 2021; 2(9):737-44.

Introduction

Brief history of knee arthroplasty

In 1861, Themistocles Gluck presented his knee arthroplasty made of ivory. This was not successful due to the high risk of infection. [58] At the same time, Ferguson performed a resection arthroplasty of the first knee and Verneuil suggested interposition of soft tissue to replace the joint. [34, 203] Various attempts at interposing different tissues or materials were suggested, until Shiers presented his hinged primary TKA in 1954 (Figure 1). [203]

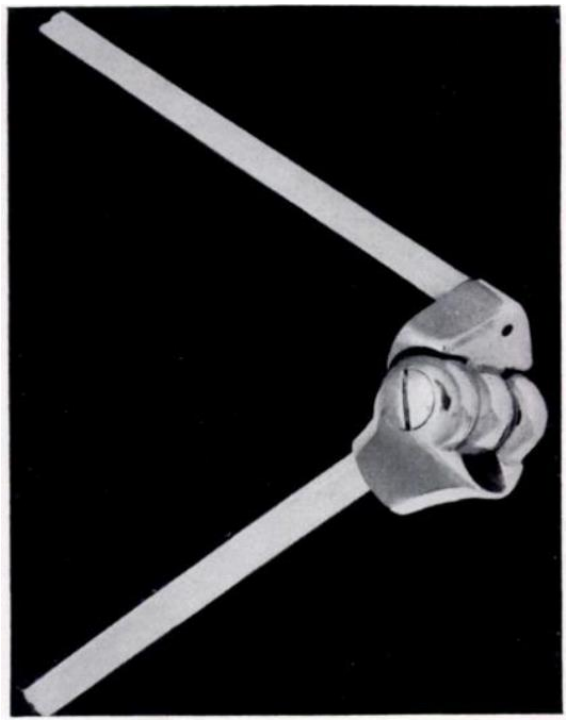

Figure 1: Shiers, L. G. (1954). "Arthroplasty of the knee; preliminary report of new method." J Bone Joint Surg Br 36-b(4): 553-560. Courtesy of Bone and Joint Journal. https://online.boneandjoint.org.uk/doi/epdf/10.1302/0301-620X.36B4.553

With the discovery of high density polyethylene and bone cement in the mid and late 60s, the evolution took further steps. [34] In the early 1970s, the total condylar knee prosthesis of Insall and the Freeman-Swanson knee prosthesis were introduced as the prototypes of

modern knee arthroplasty. [34, 183] Since then, there have been numerous smaller or larger changes in design, but it is beyond the scope of this thesis to discuss this in detail. The MP category was introduced with the Medial Rotation Knee (MRK™, MRK; MatOrtho, UK) in 1994. Later on, computer navigation and Patient-specific positioning guides (PSPG) evolved. [65, 175, 200]

Epidemiology of OA

Osteoarthritis (OA) of the knees is the most common joint disorder. Symptomatic disease affects 10% of men and 13% of women past 60 years of age. [239] OA affects approximately 4% of the world's population and knee OA accounts for a significant part of this. [227] The incidence of knee arthroplasty varies around the world. In Norway it is highest among women in the age group 70-79, where around 650 surgeries/100000 are performed. [151] The highest proportion in Australia is patients aged 65-74. The percentage of women is 56%. [140] Millions of TKAs are performed worldwide every year. [91, 112] Despite this, projection studies from the USA, UK, Australia and Germany suggest a vast increase in both primary TKAs and revision TKAs towards 2035-2050. [33, 79, 109]

Aetiology of OA

The aetiology of knee OA is multifactorial and caused by both biological and mechanical factors. Yet it is not fully understood. Knee OA can be subdivided into primary and secondary, based on whether the cause is known or not. [4, 110] Several risk factors have been identified. High body mass index (BMI) is a risk factor that is heavily associated with OA in the knees and other weight-bearing joints. [50] In fact, a BMI > 30 triples the risk of knee OA. [226] Others are limb malalignment, meniscal tears, previous knee trauma, female gender, and older age.[19, 42, 50, 229] There is also a strong genetic association, especially through the mother of female children. [229]

MicroRNA (miRNA), Long non-coding RNA (LncRNA) are types of non-coding RNA (Riblonucleic Acid). Together with exosomes, a kind of vesicles with double plasmalemma structure, they are expected to be an important way to explain the pathogenesis, early diagnosis, and possibly treatment of OA in the future. [233]

Diagnosis of OA

Symptomatic OA is generally defined by the presence of pain, swelling, aching, or stiffness in a joint with radiographic OA. [239] In more advanced knee OA, there might be reduced range of motion (ROM), instability and malalignment. [238]

Native knee anatomy and kinematics

It is beyond the scope of this thesis to describe the anatomy and kinematics of the native knee in detail. It is, however, important to be familiar with the anatomy and kinematics to understand the function of a knee with a TKA. In order to improve patient satisfaction after TKA, it has been hypothesized that the kinematics should be as close to the native knee as possible. [6]

The knee joint consists of the medial tibio-femoral, the lateral tibio-femoral and the patello-femoral joints. [74] In addition to this, there is the proximal tibiofibular joint, but that is not relevant in TKA. Important anatomical structures of the knee joint in the setting of TKA are the lateral and medial menisci, the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), patella, medial and lateral tibial and femoral condyles, the medial collateral ligament (MCL) and the lateral collateral ligament (LCL). Few structures in the knee bear one function alone, they usually act in synergy with each other. [129] The ACL is the primary restraint against anterior translation of the tibia, while the PCL is the primary restraint against posterior translation. The PCL is also important in restricting external rotation. [74, 129] The MCL and LCL act primarily against valgus and varus stress respectively, but also against internal and external rotation. [74] Each of the femoral condyles consists of two circular arcs of different radii. The medial tibial condyle is concave, whereas the lateral condyle is almost flat. The medial and lateral menisci compensate for the lack of congruency between femur and tibia. [74] Both menisci deform and move with the femoral condyle during flexion and extension, the lateral more than the medial. [74] The articular surfaces of the femoral and tibial condyles can be subdivided into flexion facet (FF) and extension facet (EF). [83] In the medial part, the FF is engaged between 30 degrees to full flexion. During this motion, there is mostly rotation around the FF circle. Between -5 and 10 degrees the EF is engaged, and between this they both are. There is no rollback on the medial side. [172] In contrast to the medial side, the lateral femur rolls and slides backwards about 20 mm during flexion (Figure 2). [172] From 120

degrees to maximum flexion both condyles roll back onto the posterior horn of the meniscus so that the tibio-femoral joint subluxes. [49]

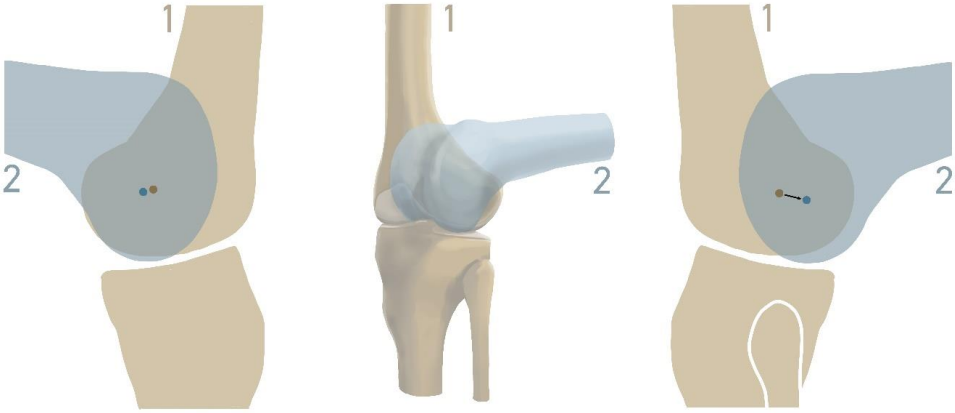

Figure 2: Knee joint during extension (1) and flexion (2). To the left, medial view showing almost no antero-posterior translation, to the right lateral view showing extensive translation. Drawn by Alf Hellevik. Courtesy of Hellevik Studio.

A native knee joint has six degrees of freedom, internal-external, varus-valgus and flexion-extension rotations, and anterior-posterior, medial-lateral and proximal-distal translations. [74] In the sagittal plane the condyles move by rolling and sliding. [74]

Indications of TKA

OA is by far the most frequent indication of TKA and ranges from 92-98% between NAR, AOANJRR and the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man (NJR). [140, 150, 151] Other known indications are rheumatoid and other inflammatory forms of arthritis, osteonecrosis and sequelae after meniscal tears, ligament ruptures, fractures and infection. [140, 151] There exists no international consensus on the indication for TKA, yet most authors agree that the indication is stronger with increasing degree of radiological findings and increasing symptoms, although the degree of OA and radiological findings do not always correspond. [2, 51] According to the British Orthopaedic Association (BOA) and the National Institute for Health and Care Excellence (NICE), patients with OA and symptoms that have a substantial impact on their quality of life and are refractory to non-surgical treatment such as physiotherapy, self-management

programmes, education, NSAIDs, etc. can be referred to surgery. The symptoms should preferably have persisted for more than three months despite such measures having been taken. The patients should also receive detailed information, and arguments for and against surgery. They should also be informed of other possible procedures such as unicondylar knee arthroplasty (UKA), high tibial osteotomy (HTO) or distal femoral osteotomy (DFO), which in some cases can be an alternative. [141, 149]

Just as important as whom to operate on is whom not to operate on. Studies suggest that patients with low preoperative pain and high levels of physical activity, or high scores on fatigue and preoperative pain in combination are probably not the best candidates for TKA. [53, 111] Preoperative psychological factors are also shown to play an important role in postoperative satisfaction after TKA. [206]

Classical TKA surgical technique

The classical surgical technique of TKA usually involves the medial parapatellar approach, measured resection, mechanical alignment (MA) and intramedullary referencing of the femur and intramedullary or extramedullary referencing of the tibia. For referencing the tibia, intramedullary and extramedullary referencing have been shown to yield equal results in precision of the tibial cuts and thus placement of the tibial tray. Most manufacturers deliver both systems. [236] On the femoral side, intramedullary referencing is preferred in most cases, although there also exist extramedullary referencing guides for the femur. [8] Starting on the femoral or tibial side usually depends on the surgeon's preference. After the incision, the ACL is resected. The entry point in the femur is found just in front of the PCL insertion site. A femoral rod is then placed in the canal and the distal cutting guide can be attached in valgus in order to restore mechanical axis. An alignment rod is then used to aim for the femoral head to ensure that this has been achieved. The distal cut is then performed and is usually around 9 mm in depth. [143, 154, 159] The correct sizing of the implant and rotation of the femoral cutting block is very important. Femoral sizing is achieved by either posterior or anterior referencing. Posterior referenced implants have a constant posterior cut, whereas the anterior cut changes according to the size of the implant. Hence too small implants will give so-called notching. The opposite is true of anterior referencing, where too small implants will lead to flexion instability. [202] Correct rotation is usually achieved by using a combination of

Whiteside's line, the posterior condylar axis and the transepicondylar axis (TEA). [202] The cutting block is usually set to 3° external rotation from the posterior condylar axis by default. This usually gives rotation parallel to the TEA. [202] Because there is a great deal of variety in the orientation of the posterior condylar axis, there are options for adjusting the external rotation in order to align the orientation of the femoral implant with the TEA. [202] The 4-in-1 cutting block is utilized for the femoral cuts. [143, 154, 159]

On the tibial side, the choice is between internal or external referencing. In the external referencing technique, the manufacturers provide an extramedullary guide with a malleolar clamp. This can be adjusted so that the alignment intersects the centre of the ankle joint, or slightly medially, in coronal plane. [143, 153, 154, 159] The second metatarsal is also a possible reference of mechanical axis, as this usually is aligned with the centre of the ankle. [159] In the sagittal plane, the guide can be slid in order to align the guide with the mechanical axis of the tibia. The manufacturers usually provide several options regarding the slope. The rotation of the assembly is also important, but somewhat controversial. The manufacturers usually recommend to set the rotation to the medial third of the tibial tubercle. [143, 154, 159] Some also advocate the central third of the tubercle. [45] The depth of resection is set by the stylus. This depends on the depth of the erosions, but the aim is usually to resect the minimum of what is needed to make room for the implant. After the cuts are made, the surgeon uses provisional inserts, femoral and tibial implants and tests flexion, extension and stability. In many cases there is a need for secondary cuts or soft tissue balancing.

Contemporary design of TKA

Primary TKAs can be subdivided according to constraint (CR, PS, MP, fully stabilized, hinged), bearing (fixed or mobile), fixation (cemented, cementless or hybrid) or modularity (modular or non-modular). [140] There is also debate as to whether to perform concomitant patella resurfacing by default or not. Traditionally in the Scandinavian countries this is infrequent, although there are differences between the countries. Norway has a frequency increasing up to 8.1% of primary TKAs and concomitant patella resurfacing in 2019, [151] whereas the figure for Sweden is 2.8% [157]. The AOANJRR and NJR reported 68.6% and 43% respectively in 2019. [140] An alternative to TKA can in certain circumstances be UKA.

Modern TKAs are usually modular implants consisting of a polyethylene insert (PE), and metal alloy femoral and tibial components. The insert is attached to the tibial component through a locking mechanism. Thus, the articulation is between the femoral component and the PE insert.

What defines a contemporary TKA design? There is no clear definition, because it will of course change as time goes by. In contemporary design there is usually a focus on the knee kinematics, ROM, increased modularity, deeper and longer patella groove with a thin anterior flange of the femoral component. [54, 131, 225] Some, but not all, have asymmetrical tibial trays. Better conformity between the femur and insert is also prioritized. [54] In principle there are four different contemporary femoral sagittal designs: multi radius or J-curve, single radius, gradually reducing radius or MP design. [135] Examples are second generation MP implants such as the GMK® Sphere (Medacta International, Switzerland), SAIPH® Knee System (Matortho, UK) and the Evolution® MP (MicroPort Orthopaedics, USA), second generation bicruciate retaining designs such as the JOURNEY™ II BCS (Smith & Nephew, Memphis, TN, USA) and ATTUNE® CR (DePuy Synthes, Warsaw, Indiana) and the Persona® Knee System (Zimmer-Biomet, Warsaw, Indiana, United States), to mention some of them. [160]

It is too comprehensive and beyond the scope of this thesis to discuss all of these different subgroups in detail. The most important ones are, however, discussed below.

Cruciate retaining designs

Figure 3: Triathlon® CR. Copyright © Stryker. Courtesy of Stryker Norway

CR TKA (Figure 3) is a non-constraint design, also known as minimally stabilized. These implants are generally non-conforming. [90] They have a flat or sometimes dished insert. [140] It is the working horse of the TKAs, especially in Europe and Australia, whereas in the USA, PS implants are more common as primary implant. [90, 140, 151, 157]

Contemporary CR design often tries to mimic the native knee with increased conformity between the insert and the femur, either with a single radius of the femoral condyle, such as the Triathlon® CR (Stryker, Mahwah, NJ, USA) (Figure 3), or a gradually reducing femoral radius that allows a smooth transition during knee flexion, such as the ATTUNE® CR. [26, 55, 139] Earlier designs had a J- curved design from the introduction of the total condylar knee, yet several well documented implants still in use, like the NexGen® CR (ZimmerBiomet, Warsaw, IN, USA), the Vanguard® CR (Vanguard® Complete Knee System, Zimmer Biomet, Warsaw, IN, USA), PFC® Sigma® (DePuy Orthopaedics Inc, Warsaw, IN, USA) and GENESIS II TKA system (Smith & Nephew; Memphis, TN), utilize this design. [80] Also the modern Persona® TKA that was recently released to the market uses this femoral design. [22] Fluoroscopy studies have suggested that CR implants may have a paradoxical femoral anterior translation during flexion, as opposed to the femoral rollback of the native knee. [38] These polyethylene inserts therefore now often come with an anterior lip to prevent this. [90]

Posterior stabilized designs

Figure 4: Triathlon® PS TKA. Copyright © Stryker. By courtesy of Stryker Norway.

In posterior stabilized (PS) TKAs (Figure 4) the PCL is either deficient or resected. It is considered å more constraining alternative than CR prostheses. PS implants usually have a cam and post articulation, where the tibial post engaged in the femoral cam forces the femur backwards during flexion, resembling the native knee femoral rollback. [34] The cam and post mechanism does not provide any valgus or varus constraint. [90] PS implants are widely used as a primary TKA design in the USA. [90, 157] Studies have shown better postoperative ROM and equal PROMs in knees with PS compared to CR TKAs. [88, 222] They are however known to have an overall poorer survivorship than CR implants in the registries. This could partly be explained by the fact that in parts of the world it is reserved for more complicated surgeries. Yet a study from the AOANJRR suggests as much as 45% higher risk of revision of PS implants compared to CR implants in high volume clinics that prefer either of the two as primary implants. [223]

Medial pivot designs

Native knee kinematics were studied intensively by Iwaki, Pinskerova and Freeman. [49, 83, 172] MP TKAs are constructed to mimic native knee kinematics. In order to achieve this, they have ball-on-socket articulation medially, whereas the lateral part of the PE insert is rather flat (Figure 5). [95] This facilitates the lateral femoral rollback and virtual absence of

medial translation. The first MP design knees used commercially were the MRK™ (1994, and the Advance® MP (1998, Wright Medical Group, USA). [5, 145, 148] Second generation MP implants include the SAIPH® (2009), Evolution® MP (2010) and GMK® Sphere (2011). [146, 147, 162] Other modern implants such as the Persona® have so-called medial congruent inserts that are optional for the surgeon. [153] Some have advocated the combination of MP implants and kinematic alignment, but further evaluations have to be made before concluding on this matter. [180]

These implants are in regular use in England, and are implanted in increasing numbers in Australia. [140, 150] Together with the PS and minimally stabilized (CR) design, they now constitute their own primary design category in the AOANJRR. [140] Although the whole idea behind the MP designs is appealing, there have been varied results previously. One of these implants, the Advance® MP, has been particularly followed up in the AOANJRR due to poor results. [140] Most studies on these implants have been on their kinematics or clinical performance. [10, 54, 210, 228] Because of the increased usage around the world despite the lack of long-term follow-up, especially on second generation MP TKAs, there is an obvious knowledge gap in the literature.

Figure 5: GMK® Sphere insert showing deep and congruent medial part and flat lateral part. Courtesy of Medacta International ASA. All rights reserved.

Bicruciate retaining arthroplasty

In bicruciate retaining total knee arthroplasty (BCR TKA), the ACL is retained in order to better mimic native knee kinematics. Although earlier BCR TKA designs seemed promising in terms of survivorship, the results of second generation implants are more heterogeneous. [21]

Bearing

The inserts of modern TKAs are manufactured from PE. Ultrahigh molecular weight polyethylene (UHMWPE) is long PE particles well suited for TKAs because of their strength and resistance to abrasion. This is vital because wear of PE particles is a common reason for implant loosening. UHMWPE is used in production of both conventional PE and highly cross-linked polyethylene (HXLPE). Irradiation produces more crosslinks in the PE, and although first generation HXLPE was more resistant to wear than conventional PE, it was more fragile and thus prone to crack formation. [57] In second generation HXLPE, the strength is reinforced by means of sequential annealing and addition of anti-oxidants. [231] Recent studies therefore suggest that PE wear as a reason for loosening might be a smaller problem in the future.

Most implants have fixed bearing, i.e. the PE insert is irreversibly attached to the tibial component and the locking mechanism has to be destroyed to separate them. [140] However, several manufacturers provide mobile bearing TKAs. The bearing will move with the femur throughout the flexion and extension with both translation and rotation of the insert. There are several types of movement between the insert and the tibial tray: rotation, anteroposterior translation, and associated rotations. [34] Potential advantages are improved patella tracking, reduced wear, and minimalization of cutting forces. [34] They are, however, known for a higher revision rate due to trapping of soft tissue and dislocation. [34] A large registry study including patients from NAR and AOANJRR revealed a higher revision rate for LCS Complete PFC Sigma and Duo-fix, all with a rotating mobile bearing, due to loosening. [59]

Custom-made TKA

Recently, several manufacturers have started offering custom- made TKAs to individual patients. No studies have yet proven the superiority of these implants. They also face

problems that could probably be solved in the future with robotics and artificial intelligence. [152, 225]

Fixation

Figure 6: Copyright © Stryker. Courtesy of Stryker Norway

There are basically three types of fixation; cemented, cementless (Figure 6) and hybrid fixation. For CR implants in general, hybrid fixation has the lowest cumulative revision percentage followed by cemented fixation. For PS implants, cemented fixation has the lowest cumulative revision percentage. [140]

The type of cement used can be important to implant survivorship. The history of Boneloc® (Biomet, Warsaw, IN) is well known to most orthopaedic surgeons. Introduced in the early 90s, this new cement was said to be less toxic and easy to handle. [36, 87] Sadly, this cement caused early loosening and numerous revisions of hip and knee prostheses. [68, 136, 179, 208] The different cement types currently used in Norway are however all well documented. [223]

Contemporary techniques of total knee arthroplasty

Surgical approaches

The most widely used and the gold standard approach to TKA is still the medial parapatellar approach. Other approaches currently used are the midvastus, medial midvastus, subvastus, mini-parapatellar and quadriceps-sparing approaches. There is diversity in the literature with respect to superiority of any of these approaches. [150, 235] One review article could not find any difference in clinical scores, yet better ROM with the subvastus approach. [24] Another review article found better clinical scores when using the mini-midvastus approach. [116] A large recent registry-based study covering more than 875 000 patients found little difference in PROMs between the different approaches. There was, however, a nearly 20% reduction in risk of revision of the medial midvastus approach compared to the medial parapatellar approach. [20]

Patient-specific positioning guides

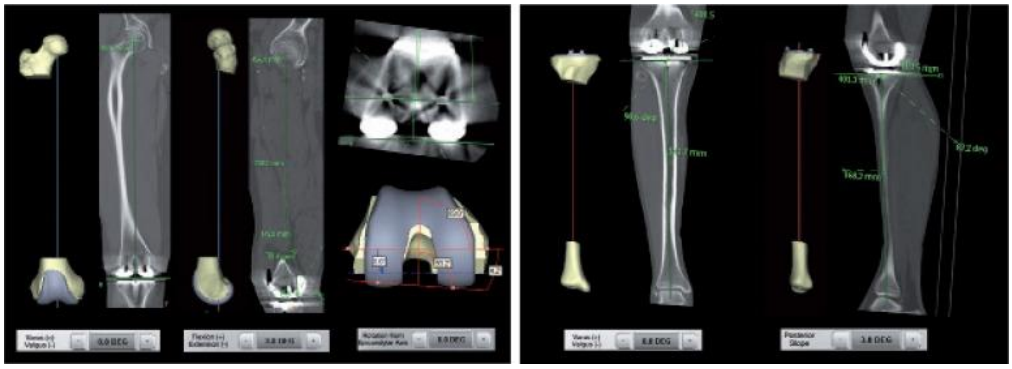

Figure 7: Acta Orthop. 2015 Apr; 86(2): 201–207. Published online 2015 Mar 25.
https://dx.doi.org/10.3109%2F17453674.2014.985154

PSPG (Figure 7 and Figure *8*) or patient-specific instrumentation represent a technique that has been on the market for some years now. Possible advantages with this system are more accurate bone cuts and thus more accurate implant and limb alignment. It also allows for both kinematic alignment (KA) and mechanical alignment (MA). As a

consequence it might give better patient satisfaction. It is also possible to use when intramedullary guiding cannot be used, for instance after previous femoral shaft fractures, etc. [124] The PSPG system used in Paper I was the Signature™ Personalized Patient Care (ZimmerBiomet, Warsaw, IN, USA). The PSPG requires a preoperative MRI or CT scan. The DICOM images are then uploaded by the surgeon to a server, after which the images are processed by engineers and digital planning takes place. The surgeon can decide the coronal, sagittal and rotational alignment, as well as implant sizes, and plan for neutral or kinematic limb alignment. Based on the digital planning, 3D printed PSPGs are sent to the surgeon. These guides are then fixed with pins during surgery, and represent the alignment of the cutting block and thus the final implants. Some PSPGs are delivered with cutting slots in which the surgeon can cut through, while for others the surgeon has to use standard cutting blocks once the pins are placed in their designated position.

The past decade has seen intensive research on the PSPG technique. Although one very small study from 2008 advised strongly against the method due to malalignment in four patients, it is now in regular use. [107, 108] The PSPG system has been shown to have no significant learning curve with regard to alignment. [30] Although some authors highlight the accuracy of the method, others claim that it is not very accurate and requires recuts or abandonment of the method in a significant number of procedures [105, 219, 230] Yet it is indicated that for overall neutral alignment and time consumed, it is superior to both computer-assisted surgery (CAS) and the conventional technique. [119] The best alignment using PSPG is probably achieved with MRI-based, rather than CT-based, PSPG. [192]

So far the system has failed to yield more patient satisfaction than the conventional technique. [132, 191, 218] Another question remains: does PSPG improve or diminish stability in TKA? To investigate this question we performed an RSA study.

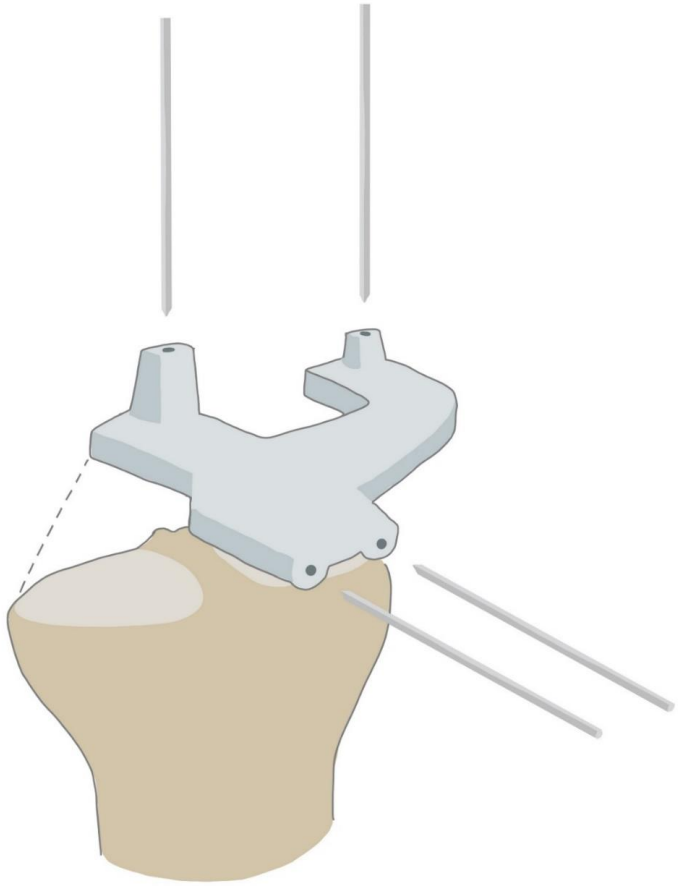

Figure 8: Patient Specific Positioning Guides (PSPG). Drawn by Alf Hellevik. Courtesy of Hellevik Studio.

Computer-assisted surgery

In CAS, the device has an interface that allows implementation of data of the patient anatomy, and provides feedback on the placement of implants and limb alignment. It is not able, however, to receive programming to perform tasks. [201]

Known systems: Stryker CT-free navigation (Navigation System II; Stryker, Mahwah, New Jersey), OrthoPilot CT-free navigation (OrthoPilot version 4.2; B. Braun Aesculap, Tuttlingen, Germany), and VectorVision CT-based navigation (VectorVision version 1.6; BrainLAB, Munich, Germany). Possible complications are pin site infection and fracture.

[201] Computer-assisted surgery can be a valuable tool when dealing with abnormal anatomy, fracture sequelae and malalignment. [60] Computer-assisted surgery can also be combined with augmented reality devices. [99]

Robotic-assisted surgery

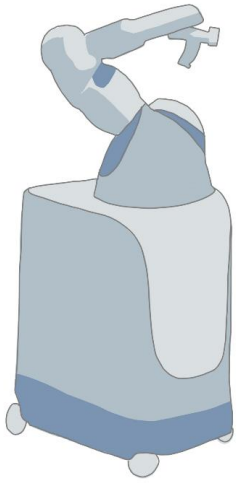

Figure 9: Robotic-arm assisted surgery. Drawn by Alf Hellevik. Courtesy of Hellevik Studio

Robotic-arm assisted TKA (RATKA) (Figure 9) represents a different phase in the development of the technology than CAS. The possibilities in planning are more comprehensive. [201] Most large TKA manufacturers are now developing their own robotic systems. The systems differ with respect to how they take control during surgery and are thus categorized as either active, passive, or semi-active designs. They also differ with respect to the surgeon's freedom in choice of implants, the so-called open and closed systems. [207] There exist both image-based and image-free systems. [9] Image-based systems typically use preoperative CT or MRI scans to plan surgery and after an initial mapping procedure of the bony anatomy during surgery, these images are correlated to the patient`s 3D anatomy. [64, 85] Unlike CAS, robotic systems can therefore provide haptic i.e. tactile, auditory or visual restraints for surgical resection. [9] Well-known robotic systems for TKA include the Mako® (Robotic Arm Interactive Orthopedic System (Rio); Mako Stryker, Fort Lauderdale, FL), Navio® (Smith & Nephew, Memphis, TN, USA) and the Rosa® (ROSA® Knee System, ZimmerBiomet, Warsaw, IN).

Anticipated benefits of the robotic systems, except for the above-mentioned real-time haptic feedback, are the possibility for the surgeon to plan surgery in detail in advance, accuracy in implant placement, limb alignment accuracy, patient safety, short learning curve, soft tissue preservation and balancing and as a result higher clinical performance. [9, 103, 123, 212] Several authors have reported decreased pain, improved early functional recovery, reduced length of stay, improved accuracy and better alignment compared to the conventional technique. [64, 96, 97, 117, 205] A few review articles have concluded that there is evidence that image-based robotic-assisted TKA improves knee bone cut accuracy and precision, limb alignment, implant positioning, soft tissue balancing and protection, learning curve and ability to correct deformities. There is, however, a need for longer-term follow-up regarding survivorship and the role it will play in different alignment philosophies. [9, 103, 237] Although short- to mid-term patient satisfaction is promising, we also need longer studies to establish whether the patient-reported outcome is superior to the conventional technique in a long-term perspective. [103]

Alignment

Malalignment of the components, and varus alignment of the tibial component in particular, is said to be an important failure mechanism for TKAs. This typically applies to knees in preoperative varus. [15] Bellemans found that a large part of the population has a constitutional malalignment, and raised the question that restoration of MA to neutral in these cases may not be desirable (Figure 10). [14] A recent review article actually found that kinematic alignment (KA) yielded equal or better clinical results without catastrophic failures. The follow-up time was, however, rather short. [115] It has also been suggested to combine KA and an MP design, but the evidence to support this at present is rather scarce. [180] 2 RSA studies relevant to coronal alignment were recently published. Hasan et al. assessed pooled data from 7 RSA studies including 476 TKAs. [66]They concluded that for patients with preoperative malalignment, postoperative coronal alignment or malalignment did not affect the tibial migration at 2 years. In the study of Van Hamersveld et al., they followed 85 TKAs for a median of 11 years, and found that postoperative malalignment, especially coronal varus, led to a higher tibial migration. [214] Matching the constitutional alignment did not preclude higher migration. Thus, because of diversity in the literature, larger scale clinical and RSA studies should be commenced

on this matter, as KA is considered controversial. MA is still the gold standard. [1] KA can be achieved either by a calipered technique with standard surgical instruments, CAS, PSPG or a combination of these. [133] It is beyond the scope of this thesis to describe the KA technique in detail. The method is, however, fully described and can be read elsewhere. [13, 133] There are also other alignment options including anatomic and functional alignment. [11]

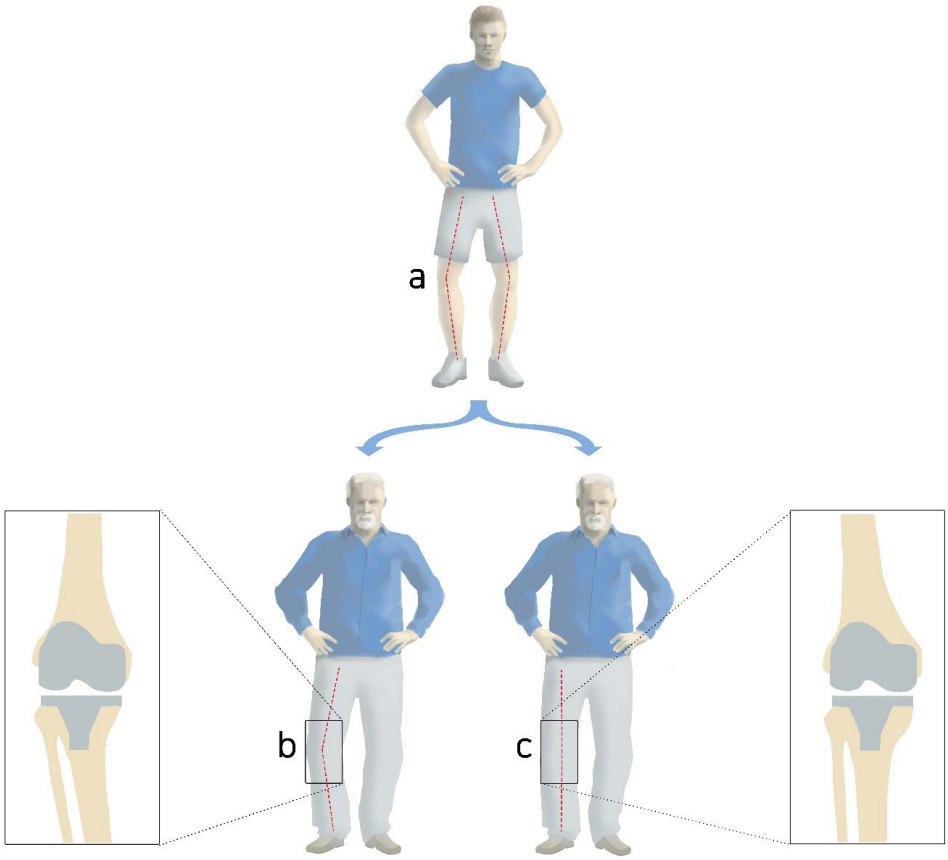

Figure 10: Drawn by Alf Hellevik. Courtesy of Hellevik Studios. Patient with congenital varus (a) that later develops OA. TKA with either kinematic alignment (b) or mechanical alignment (c).

Reasons for revision of total primary arthroplasty

There is a distinction between early failures and late failures. Early failures are often due to infection, malalignment including malrotation, instability, pain and suboptimal surgery. Failures due to the specific cement used, for instance Boneloc®, or poor implant design can also be the reason. [137, 171] Aseptic loosening is usually a late failure and typically takes more than a decade to become clinically relevant. [187]

Major overall modes of failure are loosening, instability and infection, whereas the main reasons for early failures are infection and instability. PE wear is more seldom now due to improved polyethylene. Stiffness and pain is also an important reason for suboptimal clinical result and subsequent revision. [75, 173, 193] Cumulative reasons for revision are, according to the AOANJRR, in descending order: infection, loosening, patella reasons, pain, instability, fracture and malalignment. [140] In Norway, reasons for revision in 2019 were deep infection, instability, pain, loosening of tibial component and malalignment in descending order. Other reasons are fracture and loosening of femoral component. [151]

Risk factors for revision

There are several known risk factors for revision. There is an increasing risk of revision with decreasing age at primary surgery. This applies to both early and late revisions. Women have a slightly higher risk of revision. The risk of American Society of Anaesthesiologists (ASA) class 3 and 4 patients is higher than for ASA class1 and 2 and there is a higher risk of revision with increasing BMI. This is probably because of increased risk of infection with increasing ASA class and BMI. [140] Patients with rheumatoid arthritis have increased risk of revision before nine months due to increased risk of infection. After that, the revision rate is lower. [140] The different kinds of revision indication predict the result of the revision surgery. For instance, revision for aseptic loosening yields good clinical results. Revisions for malposition of components, septic loosening and instability yield more pain and higher complication rates. Results for stiffness are less favourable. [217]

Thesis aims

Overall aim

The aim of this thesis was twofold: to assess the migration of a CR design utilizing the patient-specific positioning guides (PSPG) technique as representative of modern surgical techniques, and to assess the survivorship, migration, risks and reasons for revision of the MP design.

Paper I

The aim of this study was to compare the stability of the cemented Vanguard® CR Total Knee with PSPG and conventional technique.

Paper II

The aim of this study was to assess the survivorship, risks and reasons for revision of MP implants compared to CR implants.

Paper III

The aim in this study was to assess the early migration of the GMK® Sphere using RSA.

Materials and Methods

	Paper I	Paper II	Paper III
Study design	RCT	Register study	Single group
Inclusion period	2011-2013	2005-2017	2016-2018
Follow-up time	2 years	0-12 years?	2 years
Sample size	22	77180	31
Statistics	Linear MM Wilcoxon signed-rank test Mann–Whitney U test Fisher's exact test	Chi-square test Student´s T-Test Kaplan-Meier Cox Regression	Paired Student's t-test Wilcoxon signed-rank test
Randomization	Yes	No	No
Control group	Yes	Yes	No
Primary outcome	MTPM	Survival MP vs. CR	MTPM
Secondary outcomes	KOOS HKA CT RSA (Tx/Rx) Point motion	Survival misc. MPs Indications revision Risk of revision (HR)	RSA (translation/rotation), point motion, wear KOOS FJS ROM HKA CT (Berger)
RSA	Yes	No	Yes
Age	50-80	Not applicable	50-75
Exclusion		Cementless tibias Patella resurfacing	• Preoperative flexion contracture more than 15° • Preoperative limited ROM (flexion <110°) • <50 and >75 at the time of surgery • Use of walking aids because of other musculoskeletal and neuromuscular problems • Preoperative diagnosis other than OA and avascular necrosis (e.g. rheumatoid arthritis, tumours) • Revision arthroplasty • Obesity with BMI >35 • Impaired collateral ligaments • Postoperative revision surgery due to deep wound infection
Inclusion	Knee OA	MP and 3 most used CR TKAs in NAR and AOANJRR 2005-2017	Knee OA

Table 1 Materials and methods used in the different papers. Knee Injury and Osteoarthritis Outcome Score (KOOS), Forgotten Joint Score Knee (FJS), maximum total point motion (MTPM)

	Paper I	Paper II	Paper III
Prostheses	Vanguard® CR	GMK® Sphere Evolution® MP Advance® MP SAIPH® MRK™ Triathlon® CR NexGen CR Legion PFC Sigma	GMK® Sphere
Fixation	Refobacin BCR	Misc. cements (tibia)	Refobacin BCR
Polyethylene	HXLPE (ArCom)	Misc.	HXLPE (Vitamin E, UHMWPE)

Table 2 Materials and methods used in the different papers, continued

Randomization

Randomized controlled trials (RCTs) have long been considered the gold standard of medical research, and are almost at the top of the evidence-based medicine pyramid (Figure 11), only surpassed by systematic reviews and meta-analyses. [89, 130] In RCTs, patients with a given condition, for instance knee OA, are recruited into the study, and randomly divided into two or more interventional groups receiving different treatment. We usually compare a new treatment with a well-known treatment. In orthopaedics we can compare a new surgical technique or a contemporary TKA with an established technique or a well-documented TKA, such as the NexGen CR. By randomizing, we then minimize the effect of possible confounders, and create as equal groups as possible. [186] It is possible to blind participants, care providers and those assessing outcomes in order to reduce the bias. [195] This is often challenging within surgical specialities. Block randomization is also possible, for instance to ensure an equal gender distribution and that surgeons operate on an equal number of patients in each group.

Figure 11: American Diabetes Association Validity of Meta-analysis in Diabetes: Meta-analysis Is an Indispensable Tool in Evidence Synthesis, Sherita Hill Golden, Diabetes Care 2013 Oct; 36(10): 3368-3373. Copyright and all rights reserved. Material from this publication has been used with the permission of the American Diabetes Association.

Paper I

The patients were block randomized with variable block sizes, by the online service of the Unit for Applied Clinical Research at the Faculty of Medicine of the Norwegian University of Science and Technology, Trondheim, Norway (NTNU). WebCRF - Collecting Clinical Data was used. Patients were randomized to either conventional technique or PSPG.

Clinical scoring - PROMs

Clinical performance is measured by using patient-reported outcome measures (PROMs). Because patients and surgeons often have different views on whether the TKA was a success or not, PROMS are important measures to evaluate patient satisfaction. Some of the PROMS are generic, others are joint specific.

WOMAC

The Western Ontario and McMaster Universities Arthritis Index (WOMAC) is a widely used outcome measure for OA. [32] It consists of 24 items and the three subscales pain, stiffness and physical function, but there are different versions using five- point Likert scales, the visual analogue scale (VAS) or an 11-point numerical rating scale. Although this PROM is widely used, it is not freely available, hence we did not use the WOMAC score in our thesis.[32]

Knee Injury and Osteoarthritis Outcome Score

The Knee Injury and Osteoarthritis Outcome Score (KOOS) was first introduced in the late 90s. [185] The KOOS score has five subscales: pain, other symptoms, function in daily living (ADL), function in sport and recreation (Sport/Rec), and knee-related quality of life (QOL). It can be used to measure improvement in conservative treatment including physiotherapy, and surgery over time. It has been validated for different surgical interventions, such as anterior cruciate ligament reconstruction, meniscectomy and total knee replacement. The KOOS score is a self-administered 42-item questionnaire that is widely used. It can be used for short- and long-term follow-up of several different types of knee injuries and OA. The score is a percentage score where 0 is the worst case and 100 is best possible result. An improvement of 8-10 points has been suggested to be the MPCI (minimal perceptible clinical improvement). [184] The KOOS score, however, has a higher ceiling and floor effect than other PROMs. [72]

Forgotten Joint Score Knee

The Forgotten Joint Score Knee (FJS) was introduced in 2012, and is a 12-item score. [12] It measures the joint awareness of artificial joints, or the patient's ability to forget the artificial joint in everyday life. It has proven to have a lower ceiling effect than WOMAC and KOOS scores. [12, 72]

Knee Society Score

The Knee Society Score was introduced in 1989. It consists of a knee score and a function score that rates the ability to walk and climb stairs. [81] It has now been revised, and the objective knee score, filled in by the health professional, includes a VAS score of pain walking on level ground and on stairs or inclines, as well as an assessment of alignment,

ligament stability, and ROM, along with deductions for flexion contracture or extensor lag. It is also self-administered as patients report their satisfaction, functional activities, and expectations. [198] Of the PROMs mentioned in this thesis, and among the commonly studied PROMs, this is the only one that has an objective section completed by the surgeon. [176]

Generic PROMs

EuroQol-5 Dimension (EQ-5D) is a general health or health-related quality-of-life score (HRQoL). [204] EQ-5D is not specific to the knee joint and should therefore be used together with a joint specific PROM. The Patient-Reported Outcomes Measurement Information System 10 (PROMIS-10) is a ten-item questionnaire that assesses generic HRQoL compared with normal values for the general population.[71] The PROMIS-10 Global Health tool has superior responsiveness to change compared to the EQ5D in TKA, and thus might be significant for future clinical and research use. [204]

VAS

The visual analogue scale (VAS) can be used to measure pain in TKA patients (VAS-P). VAS is typically a 100-point scale with anchor words at each end, e.g. no pain and the worst possible pain. The patient is asked to mark on this scale how much pain they are experiencing at the moment. Alternatively one can use the numeric rating scale (NRS) from 0-10. [101] One study reported the mean and average highest postoperative VAS-P after TKA to be 43 mm and 61 mm respectively. [35]

Radiology

Knee OA is characterized by loss of joint cartilage, subchondral bone remodelling, formation of osteophytes, and inflammation. [29] Plain X-rays remain the gold standard of diagnosing OA. [110] In 1957, Kellgren and Lawrence published a four-grade radiological classification system for OA (Figure 12). [100] Today, this system still is the most widely used radiological system for clinical classification of OA.[110] It has been criticized for the fact that grade 3 contains all degrees of joint space narrowing regardless of the extent. It is also not suitable for grading the rare but known condition atrophic phenotype of knee OA characterized by definite joint space narrowing without concomitant osteophyte formation. [69] The Ahlbäck grading system is another system well suited for grading knee

OA. [73] MRI is also widely used, especially in research, because of its ability to visualize cartilage morphology and composition. Currently, radiologists are developing more advanced hybrid PET/MRI techniques for research purposes, but plain radiographs remain the mainstay of clinical use. [70]

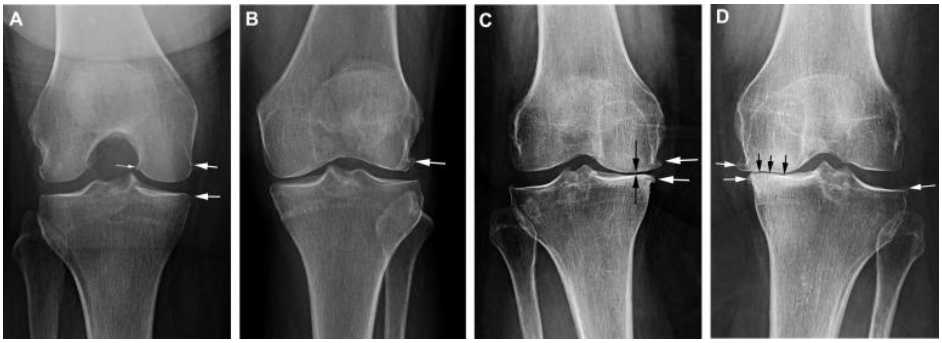

Figure 12: The Kellgren-Lawrence classification is a composite scale of OA severity taking into account primarily the radiographic OA features of marginal osteophytes and joint space narrowing in the AP radiograph. A. Kellgren-Lawrence grade 1. Minimal, equivocal osteophytes are observed at the medial joint margins (large arrows) B. Kellgren-Lawrence grade 2 is characterized by presence of at least one definite marginal osteophyte (arrow) without evidence of joint space narrowing. C. Kellgren-Lawrence grade 3 knees exhibit signs of definite joint space narrowing (black arrows) and marginal osteophytes (white arrows). The amount of joint space narrowing is not taken into account. D. Kellgren-Lawrence grade 4 is defined by bone-to-bone contact and complete obliteration of the joint space (black arrows). Note definite marginal osteophytes in addition (white arrows). Imaging for osteoarthritis, D. Hayashi, F.W. Roemer and A. Guermazi, Annals of Physical and Rehabilitation Medicine, 2016-06-01, Volume 59, Issue 3, Pages 161-169, Copyright © 2015 Elsevier Masson SAS.
https://www.sciencedirect.com/science/article/pii/S1877065715005849?via%3Dihub

Alignment

Coronal alignment of the knee is usually defined by the hip-knee-ankle (HKA) angle, and is measured as the angle between the mechanical axes of the tibia and femur. [127] A perfect neutral alignment is defined as 180°. The mechanical axis line runs from the centre of the femoral head to the middle of the ankle, and in a neutrally aligned knee it passes through the centre of the knee. Mechanical axis deviations are defined as the distance from the centre of the knee to the mechanical axis line. Degrees of varus and valgus are defined as deviations from 180°, with negative and positive signs respectively. A neutral constitutional HKA is defined by Bellemans et al. to be within ±3°. [14] A large proportion of the population has, however, either constitutional varus or valgus, defined as more than

3° deviation from 180°. According to Bellemans, 32% of men and 17% of women have constitutional varus knees. [14]

Joint line orientation is also important in the coronal alignment. Femoral mechanical angle (FMA) is the angle between the mechanical axis of the femur and the line between the most distal parts of the femoral condyles. Tibial mechanical angle (TMA) is the angle between the tibial mechanical axis and the tangent of the tibial plateau. Mean joint line orientation is approximately 3° varus, and thus TMA and FMA 3° varus and valgus respectively, but with great individual variation. [128]

The joint line convergence angle (JLCA) is defined as the angle between the joint lines of the femur and tibia. The sum of FMA, TMA and JLCA equals HKA. [128]

When constitutionally malaligned knees develop OA, the malalignment usually, but not always, tends to increase. [118] MacDessi et al. recently introduced a classification system called CPAK (Coronal Plane Alignment of the Knee) in order to better identify patients that may benefit from kinematic alignment TKA as opposed to mechanical alignment TKA. [118] It is beyond the scope of this thesis to describe this classification system in detail.

Implant alignment

There are several coronal alignment strategies in TKA. The classical alignment strategy is mechanical alignment (MA). It has been pointed out that malaligned implants have a higher risk of revision due to mechanical loosening, although not all studies support this conclusion. [167, 181] In MA the aim is of course to achieve neutral alignment. As with native knees, a valgus or varus knee is classified as such if there is more than ± 3° deviation from this on HKA radiographs. The tibial component alignment angle is the medial angle between the mechanical axis of the tibia and the tibial tray. Ideally this should be 90°; if it is more or less, the component is said to be in valgus or varus respectively (Figure 13). The femoral component alignment angle is the medial angle between the anatomical axis of the femur and the femoral component. If this medial angle is more than 90°, the femoral component is said to be in valgus. [209]

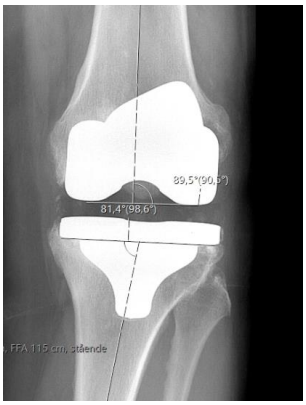

Figure 13: Tibia in varus

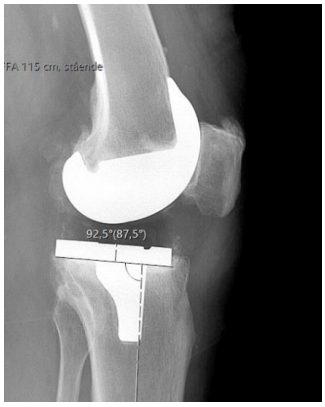

Figure 14: Tibia with reduced slope

The ideal tibial sagittal slope is between 0° and 7° for most implants. This is achieved by a combination of built-in PE slope and the tibial cut. (Figure 14).[62, 209] Axial or rotational alignment of the implant components cannot be assessed based on plain X-ray images, and CT scans are therefore utilized. [174] Femoral rotation is usually calculated in degrees of deviation of the prosthetic posterior condylar line from the surgical epicondylar axis (SEA), the latter defined as the axis connecting the lateral epicondylar prominence and the medial sulcus of the medial epicondyle. [16, 17] This should be neutral or have slight external rotation. Alternatively, the rotation can be calculated as the axis between the SEA and the line connecting the femoral pegs. [37] Regardless of method used, internal rotation may cause pain and problems with the patellofemoral joint. [104] Tibial rotation is

somewhat more controversial. It can be calculated by the Berger method, although several other methods are also in use. [16, 37, 189] In this method, the angle formed by the line from the geometric centre of the implant to the tip of the tibial tubercle, and the anteroposterior tibial component axis, is measured. The angle measured should, according to Berger, be subtracted by 18°. Positive or negative value implies internal or external rotation respectively. [16] How many degrees of malrotation in tibial and femoral components are tolerated is, however, still debated, and no clear cut-off values have been established. [37, 166, 174]

Registry studies

There are numerous prosthesis registries around the world. The Swedish Knee Arthroplasty Register (SKAR) was established in 1975 [182] and The Swedish Hip Arthroplasty Register in 1979. [221] Within some years all the Scandinavian countries and Finland had their own arthroplasty registries. [151] In 1999 the AOANJRR, and in 2002 the NJR, were established. [221] These registries are high quality registries with high completeness. [43, 140] They produce large databases available for research, recording data such as type of implant, age, gender, ASA classification and revision arthroplasties. Registry studies are observational studies by nature, and most often retrospective cohort studies. [78] Their greatest weakness as such is the bias caused by possible differences in baseline data and risk of confounders. We can correct for this, but only for confounders that are known; possible confounders are for instance gender, age and preoperative diagnosis. In orthopaedic registry studies one usual outcome measure is the survivorship of the implant, with revision as the hard endpoint. Another weakness is that most registry studies only report revised implants as failures. Many patients with pain or failed implants are not revised for various reasons. Some authors have therefore advocated publishing PROMs data. [232] Many national registries now include such data or have plans to do so. [140, 151] The survivorship analysis is usually based on the assumption of non-informative censoring, i.e. potential dropouts are non-related to the study. To account for possible informative censoring, i.e. dropouts related to the study, for instance death, one can perform a sensitivity analysis with death or other reasons for revision as competing risk factors. This can be done using the method of Fine and Gray. [46] It is also advised to control for emigration. The strength of the registry studies is the large number of patients

included, thus reducing random error. The studies are also cheap to perform compared to RCTs because all the data have already been gathered. Recently, a new study design has evolved, namely registry-based randomized controlled trials. These studies combine the strength of RCTs with patients allocated to treatment at random with the benefit of the large number of patients in registry studies. [240]

Radiostereometric Analysis

The history RSA started with Selvik in 1974. [199] RSA is an abbreviation for radiostereometry, radiostereometric analysis or roentgen stereophotogrammetric analysis, as these three terms are regarded as synonyms. [211] It is a method with reported high accuracy and precision in measuring translations and rotations of the implant assessed. With RSA we usually study implant migration over time. This is again predictive of implant loosening, either generally on an implant design level, or for the individual patient. [138, 187]

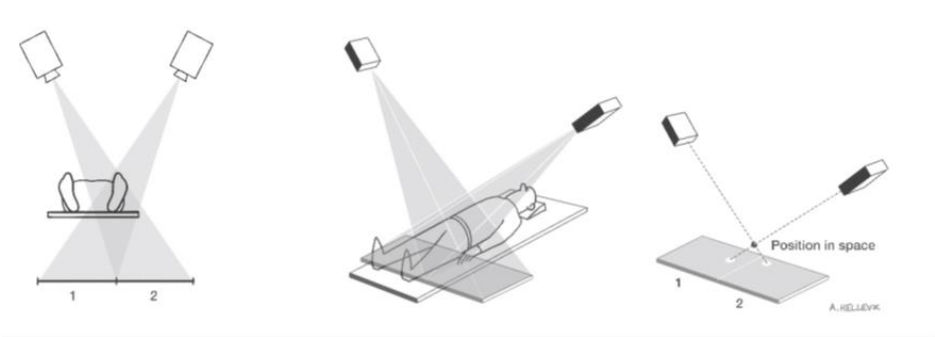

Figure 15: Drawn by Alf Hellevik. Courtesy of Hellevik Studios.

The RSA setup usually consists of a calibration cage that is either uniplanar or biplanar. For RSA of TKAs, biplanar cages are usually, but not always, used (Figure 15). In the calibration cage there are both fiducial (bottom) and control markers (top) in order to make a coordinate system within each scene. The X-ray tubes are arranged at fixed angles to each other, and with biplanar cages usually at 90 degrees. The X-rays are taken simultaneously and thus there is no motion between the images taken. During surgery tantalum markers are implanted in the tibia scattered around the implant in a non-collinear fashion. It is important that we can see at least three or four of these markers throughout the entire follow-up of the same patient. It is therefore advisable to implant 6-9 markers

during surgery. [211] Together these tantalum markers form a so called rigid body, to which the migration of the implant is referenced. The condition number (CN) is a measure of the geometry of these markers. A collinear distribution gives a high CN and makes the rotations particularly unpredictable. In clinical RSA studies of the knee the CN is usually below 100, and a figure above 120 is not accepted in larger joints such as knee, shoulder or hip. [163] Mean Error of rigid body fitting (ME) is a measure of the migration of the individual markers in the rigid body. If the ME is above 0.35 mm, the marker is considered to have migrated and is not accepted. [163] There are special software programmes to perform the actual RSA analysis. We used the RSAcore (versions 3.40 and 4.1, Leiden, The Netherlands) Software in our studies.

During an RSA study, postoperative follow-up moments at 6 weeks or 12 weeks, 12 months and 24 months are recommended. [163, 170] The images can be taken supine or standing with weight bearing. Some studies use inducible micromotion, i.e. images with and without weight bearing. Most studies investigate all six degrees of freedom, i.e. x-y-z translation and rotation, and so- called maximum total point motion (MTPM). MTPM is a vector defined by the point in the implant that moves the most from one follow-up moment to the next. The actual points the vector is referencing can change from time to time, but the MTPM is considered an important measure for later loosening. [171, 187] Migration of the tibia is seldom a general subsidence. Instead there is usually a combination of subsidence, lift-off and tilting. It is therefore interesting to follow the migration of the feature points of the computer-aided design (CAD) model. These are predefined points in the model, such as medial, lateral and posterior. By following the translation of these feature points we can study the way in which the implant migrates, for instance with medial subsidence or lateral lift off, or we can estimate the risk of future loosening of the individual implant based on certain predefined thresholds (Figure 16). [63]

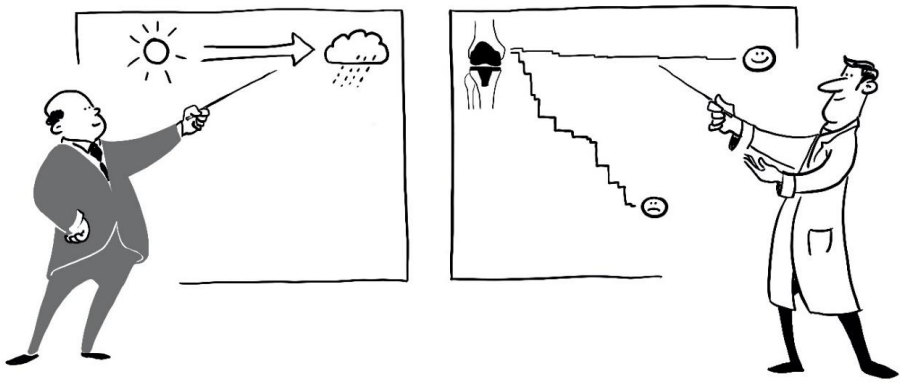

Figure 16: Drawn by Alf Hellevik. Courtesy of Hellevik Studios.

Provided tantalum markers have been implanted and a postoperative RSA image taken, we can also use RSA in a clinical setting in order to investigate implant loosening. It has been shown that implants tested with RSA have lower ten-year revision rates that those without. [67] In later years, other methods have emerged for studying the migration of implants and implant loosening. Computer tomography motion analysis (CTMA) and image motion analysis (IMA) are interesting and promising methods with reported acceptable accuracy and precision. [25] In addition, these methods will probably allow more centres to perform migration studies without the need to invest in costly RSA equipment. [188] RSA can also be used dynamically with a fluoroscopy examination in order to evaluate the in vivo kinematics of the implants. [31, 82]

Statistics

Paired Student's t-test

This test is used when comparing means in two normally distributed datasets. The paired T-test is utilized if there is high correlation between the datasets, otherwise the independent T-test is used. The significance level (p-value) is often set to an alpha of 0.05. In order to perform a sample size, we usually set the power to 80%, although some authors prefer 90%. [61]

Wilcoxon signed-rank test/Mann-Whitney U-test

These tests compare medians in two samples of non-normally distributed datasets. The former compares dependent samples, the latter independent samples. [168]

Categorical data

Fisher's exact tests and the Chi-squared test are used to test the association between binominal categorical data. [168]

Survival data

In order to assess the survivorship of implants over time, the Kaplan-Meier approach is often used. [177] With this method, every revision is recorded and the survival function is calculated as the cumulative probability that an implant will survive over time. In this way a confidence interval (CI) can also be calculated. The cumulative percent revision is the complement to this, and is also meaningful. [140] In order to compare the survivorship or revision risk of two or more different implants, we use a type of regression analysis called Cox regression. This analysis takes time into account for a revision to occur, and the hazard ratios (HR) can be calculated. The Cox model is based on the proportional hazards assumption. [177] In other words, the hazard of two given implants is proportional at any time point.

Mixed model analysis

For longitudinal data with repeated measurements over time, we can use the linear mixed model analysis. This model takes into account differences either between or within different cases over time, and is robust to differences in loss to follow-up between groups. [113]

Paper I

Figure 17: Vanguard® CR. Courtesy of ZimmerBiomet Inc. All rights reserved

This study was part of a multicentre trial recruiting patients from three hospitals. [218] Inclusion criteria were symptomatic knee OA with the need for TKA. Contra-indications were: marked bone loss, non-cooperative subjects, neurological and muscular disorders, severe vascular insufficiency of the affected limb, severe instability or deformity of the ligaments, rheumatoid arthritis, other systemic diseases and known metal allergy.

Aim

The aim of this study was to compare the stability of the cemented Vanguard® CR Total Knee (Figure 17) with PSPG and conventional technique.

Study design

RCT

Control group

Patients with Conventional surgery

Study group

Patients with patient-specific positioning guides (PSPG)

Primary outcome

MTPM at two years

Secondary outcomes

KOOS score, segmental translations and rotations. Fictive point motion.

Time of surgery

2011-2013

Patients

One hundred and fifteen patients were recruited in the larger trial, 40 of these at Ullevaal Hospital OUS. Eighteen were allocated to PSPG, 22 to conventional technique. Because of miscellaneous reasons such as withdrawn consent, inadequate RSA pictures or no beads, high CN, etc., only 21 patients (7 PSPG vs. 13 conventional) were available for RSA analysis.

RSA

MB-RSA performed postoperatively, at 3, 12 and 24 months. Calculation of segmental translations and rotations as well as fictive points in the tibial tray.

Radiology

Front and side view, CT scans and HKA images.

Statistics

Linear mixed model to evaluate differences in MTPM, translations, rotations and point motion between the groups over two years. Wilcoxon signed-rank test to evaluate difference in KOOS scores from preoperative to two years. Mann-Whitney U test used to evaluate differences in KOOS scores between high-risk and low-risk (independent) groups. Fisher's exact test was used to detect potential associations between categorical independent variables.

Paper II

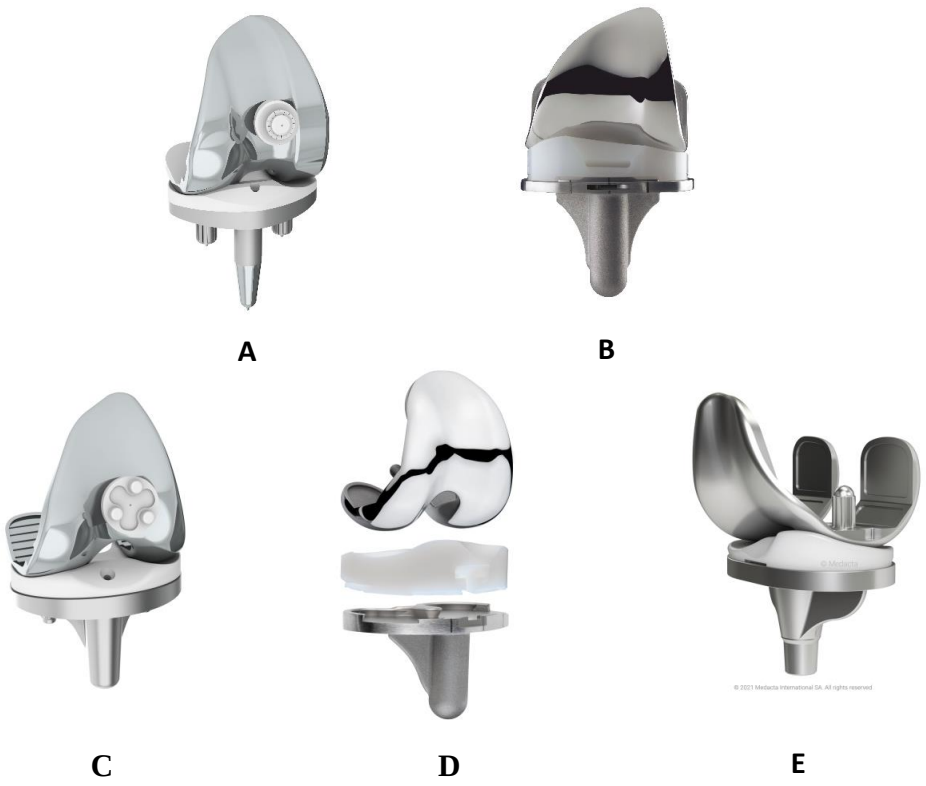

Figure 18: MP implants from Paper II in order of release to the market; A) MRK™, Courtesy of MatOrtho Limited, All Rights Reserved, B) Advance® MP, courtesy of MicroPort Orthopedics Inc., All Rights Reserved, C) SAIPH®, courtesy of MatOrtho Limited, All Rights Reserved D) Evolution® MP, Courtesy of MicroPort Orthopedics Inc., All Rights Reserved and E) GMK® Sphere, Courtesy of Medacta International ASA., All Rights Reserved

This was a registry study where data on TKAs from the NAR and AOANJRR were retrieved. The three most used CR TKAs in the period and all MP implants from those registries were included. Primary patella resurfaced TKAs and uncemented tibias were

excluded, but not uncemented femurs. Four Advance® 1 MP implants were also excluded.

Aim

The aim of this study was to assess the survivorship, risks and reasons for revision of MP implants compared to CR implants.

Study design

Registry study (observational study)

Control group

The three most used CR TKAs in Norway (NexGen® CR, Triathlon® CR and Legion® CR) and Australia (PFC® Sigma®, NexGen® CR and Triathlon® CR).

Study group

MP implants (Figure 18) used in Norway (Evolution® MP, Advance® MP and GMK® Sphere) and Australia (MRK™, SAIPH®, Evolution® MP, Advance® MP and GMK® Sphere)

Patients

A total of 6310 MP implants (NAR 298 vs. AOANJRR 6012) and 70 870 CR implants (NAR 16 316 vs. 54 554 AOANJRR)

Research questions:

1. Is there any difference in the survival rate between Medial Pivot and Cruciate-retaining TKAs?
2. Is there any difference in survival between the different Medial Pivot implants?
3. What are the main reasons for revision of Medial Pivot TKAs?

Time of surgery

2005-2017

Statistics

Chi-squared test to compare gender and preoperative diagnosis, two-tailed T-test for age differences. Kaplan-Meier estimates of implant survival. Cox regression for causes of revision and HR.

Paper III

Figure 19: GMK® Sphere tibia and insert. Frontal and side view. Courtesy of Medacta International ASA. All rights reserved.

Patients with knee OA in need of surgery were included. Exclusion criteria were preoperative flexion contracture, preoperative limited range of motion, < 50 or > 75 years of age at the time of surgery, use of walking aids because of other musculoskeletal and neuromuscular problems, preoperative diagnosis other than osteoarthritis and avascular necrosis, revision arthroplasty, BMI >35, impaired collateral ligaments and postoperative revision surgery due to deep wound infection.

Aim

Our aim in this study was to assess early migration of the GMK® Sphere using RSA.

Study design:

Single group study

Study group

GMK® Sphere (Figure 19)

Control group

Not applicable

Primary outcome

MTPM

Secondary outcomes

Segmental translations and rotations, fictive point motion, KOOS score, FJS-12, polyethylene wear, knee flexion

RSA

Postoperative and at 3, 12 and 24 months

Radiology

Frontal and side view, HKA images and CT scans

Patients

Thirty-one patients were recruited and underwent surgery. Twenty-three patients were available for RSA analysis at two years.

Time of surgery

2016-2018

Statistics

Paired T-test for power analysis, Wilcoxon signed-rank test for evaluation of KOOS, FJS-12 and wear.

Summary of the results

Paper I

In this study we investigated the migration of TKA implants (Vanguard® CR) inserted with PSPG or conventional technique.

Baseline data

The PSPG and conventional groups consisted of eight vs. 14 patients, two vs. seven male gender and five vs. four right knees respectively. Baseline data means (SD, range) were for body weight (kg) 87 (12, 70-100) vs. 84 (18, 60-105), BMI (kg/m2) 30 (4.8, 22-35) vs. 28 (4.2, 22-36), age (years) 60 (5.1, 50-68) vs. 65 (7.9) (53-77), operation time (min) 111 (8.9, 95-125) vs. 121 (37, 68-228) and postoperative HKA (degrees) 178 (5.7, 171-186) vs. 181 (4.8, 172-188) for the PSPG and conventional groups respectively.

Major findings

There was a difference in mean MTPM between the groups, but this difference was not significant ($p=0.1$). In the point motion analysis we found a generally higher mean subsidence in PSPG group, but the p values were well above the significance level. We could see an improvement in the KOOS scores for all five subscales from preoperative to two years ($p<0.001$). We did not find any difference between the two groups in clinical scores. The patients were otherwise divided into a high- and low-risk group based on certain threshold criteria. These groups were further investigated, but we could not find any correlation with gender or malalignment.

Impact

The clinical results for the implant showed a good and significant improvement in both groups as expected. There was no significant difference in migration between the groups. The absolute value of the difference does, however, increase over time, and this could be a cause for concern in the long term.

Time	MTPM		Difference*
	Conventional	PSPG	
3 months	0.7 (0.4-1.0)	0.8 (0.5-1.2)	0.1 (0.1-0.2)
12 months	0.9 (0.5-1.2)	1.0 (0.6-1.4)	0.2 (0.1-0.2)
24 months	0.8 (0.5-1.1)	1.5 (1.1-1.9)	0.7 (0.6-0.8)

Table 3 MTPM in mm (95% CI). *Difference in MTPM between the groups

Paper II

In this registry study we used data from NAR and AOANJRR to study the survivorship and reasons for revision of MP implants, compared to CR implants.

Baseline data

The mean ages in the study and control groups were comparable (p=0.8), but the percentage of men was significantly lower in the study group of both countries (p<0.001). The percentage of knee OA as primary diagnosis was significantly lower in Norway (92%) than in Australia (99%), with a p-value of <0.001.

Major findings

There was an increased risk for revision of any cause for MP designs in Australia (HR 1.4, 95% CI 1.2-1.7), but not in Norway (HR 1.5, 95% CI 0.9-2.4). The nine-year survival rates of MP implants (95% CI) were 94.8 % (94.3-96.3) and 92.2% (89-95.4) for Australia and Norway respectively.

Stratified by brands, we could find differences in HRs (95% CI). In Australia, the Advance® MP (HR 1.7, 1.2-2.6, p<0.004) and GMK® Sphere (HR 2.0, 1.5-2.6, p<0.001) had a higher all-cause revision than CR implants. For the Evolution® MP (HR 1.4, 1.0-1.9, p = 0.06), the MRK^{TM} (HR 0.7, 0.4-1.5, p = 0.4) and the SAIPH® (HR 0.9, 0.5-1.5, p = 0.7), no such difference could be found. The major reasons for revision of the MP implants in Norway were loosening (28%), instability (28%), pain (11%), whereas in Australia they were infection (27%), pain (19%), patella erosion (13%) and loosening (12%). The HRs (95% CI) due to revision for instability, malalignment and patella erosion were 1.9 (1.1-3.4), 4.9 (1.9-12.5) and 2.2 (1.4-3.6).

Impact

We found higher HR of some MP implants than the most frequently used CR implants in Australia. Surgeons using these implants should be especially aware of the risks of instability, patella erosion and malalignment during surgery.

Paper III

In this study we assessed the migration of the GMK® Sphere.

Baseline data

The male vs. female and right vs. left ratios were 21/10 and 17/14 respectively. Six smokers were included. The mean (95% CI) BMI (kg/m^2), age (years), operation time (min) and length of stay (days) were 29 (27-30), 63 (61-66), 118 (114-124) and 4.0 (3.6-4.39) respectively.

Major findings

The median clinical scores improved significantly from preoperative (KOOS) and three months (FJS) to two years with p values of <0.001 and 0.002 respectively. The KOOS subscales of pain and quality of life had a ceiling effect of 38%. Flexion of the knees did not improve significantly from preoperative to two years (p=0.25), yet mean preoperative flexion was rather high (123 degrees, 95% CI 118-128).

The RSA analysis of the implant (MTPM, 95% CI) showed a migration of 1.0 (0.8-1.2), 1.3 (0.9-1.7) and 1.4 (0.8-2.0) mm at 3, 12 and 24 months respectively. The segmental rotations and translations were all within the precision of the investigation.

Five implants were regarded as high-risk implants based on well-known thresholds. One of these underwent revision due to aseptic loosening.

Impact

This study revealed excellent clinical results of the GMK® Sphere, yet a somewhat higher migration than expected. There are still no known RSA thresholds for MP implants. We therefore have to wait for the five-year results to conclude on the safety of the implant.

Methodological considerations

Randomized controlled trials

RCTs usually follow the Consolidated Standards of Reporting Trials (CONSORT statement). [195] In RCTs, the random assignment is made in order to prevent bias due to non-comparability between groups caused by for instance gender, BMI, smoking habits, etc. Because the interventions take place after the random assignment, we can detect causality. Results in the two groups can be compared statistically, and conclusions can be drawn with a rather high degree of certainty if the observed difference is an actual difference. [195] These statistical inferences are usually based on a power analysis. Paper I was an RCT comparing PSPG with conventional technique. This study was part of a larger trial investigating clinical and radiological differences between these two techniques. Because it was not powered to RSA, and especially because of a large number of dropouts due to technical issues, only 22 patients were investigated with RSA. The mean MTPM in the PSPG group had a higher mean at 12 and 24 months than in the conventional group, although this was not significant (p=0.1). The lack of significance could be due to a statistical type 2 error, but it could also mean that there is no difference. Because the study is underpowered, there is little we can do but wait and repeat the RSA later. The increase in mean difference in MTPM between the two time points is, however, a cause of concern.

There are several potential biases in RCTs, based on performance, selection, detection or attrition. [122] We took several measures to reduce the potential bias. Most importantly, the study was single blinded, and all the patients underwent a preoperative MRI scan, despite the lack of need for this in the conventional group. Being a surgical trial, it was not feasible to perform further blinding. To prevent selection bias, the patients were randomized by block randomization with variable block sizes, by the online service of the NTNU (Norwegian University of Science and Technology). We did not, however, perform an intention-to-treat analysis, because there were no crossovers. More patients in the PSPG group than the conventional group withdrew consent; it is therefore possible that the study is prone to attrition bias.

Registry studies

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) was introduced in order to improve scientific reporting of the three main types of observational studies: cohort, case-control and cross-sectional studies. [220] Paper II is an observational cohort study adhering to the STROBE guidelines. In cohort studies temporality of events can be established, and as such they provide the highest level of evidence that can be obtained from registry data. Registry studies, due to the large number of patients and surgeons participating, have high generalizability. Because of this, and the length of follow-up, they are well suited for detecting the occurrence of rare events, such as implant revision. [78] In order to perform a registry study on the MP implants, it was relevant to contact the AOANJRR, because there is increased usage of MP TKAs in Australia. This means that the number of patients was also sufficient to assess the survivorship of different brands. We chose to compare the MP group with the three most used CR implants in Norway and Australia. Some of the co-authors had done this in a previous study. [59] In this way, we ensured that the implants in the control group were well-known to the surgeons. In both countries CR is the working horse of TKAs, whereas PS implants are reserved for more complicated cases. [140, 151] In addition, in both countries there has been a tradition of preserving the patella. However, in Australia there was an increasing tendency of patellar resurfacing during the relevant timeframe. We therefor chose to exclude the TKAs with patella resurfacing, although we are aware that this reduces the external validity in some countries.

The Cox model is based on the proportional hazards assumption. In some of our curves, we found that this did not apply. In those cases we performed a Cox regression analysis after the crossing with starting point as the time of the crossing.

In registry studies, it is possible to calculate the crude risk estimates. Confounders are factors that affect both the dependent and independent variables in a study. [224] Because there might have been an imbalance of confounders in the different groups, we performed an adjusted calculation to increase the validity of the results. Identified confounders were age, sex and preoperative diagnosis. As in all observational studies, residual confounding could, however, theoretically be a problem. [177] When comparing results from different registries, there might be various ways of reporting different revisions. We were therefore

cautious when merging the data. We also used the Australian hierarchy of revision when calculating the hazard ratios. [140]

Kaplan-Meier estimates and Cox regressions are based on non-informative and independent censoring respectively. This is not compatible with competing events that preclude the event studied, such as death. [178] We therefore investigated the effect of death as a competing risk, using the method of Fine and Gray. [46]

RSA

RSA is a method of high accuracy and precision. As a consequence of this, combined with the costs and tedious analyses, the sample sizes of RSA studies are usually small, and 15-25 patients is often considered enough. [211]In order to draw conclusion on the general outcome of a prosthesis design, however, Derbyshire recommended at least 50 patients. [39]This is because of the anticipated wide CI of such a small sample size. The accuracy of a method describes the closeness of the calculated and the true value, and thus in RSA the accuracy is measured by a method with significantly higher resolution than RSA. [163] In our studies we did not perform a phantom study with respect to accuracy. The precision of a method measures the ability to achieve the same value repeatedly, regardless of whether the value is true or not. Precision is measured by double RSA examinations. The bias is the mean difference and is usually close to zero, and the error is usually described as ±1.96 x SD. [163] The precision of MTPM in Paper I was 0.74, and in Paper III 0.77. The precision is also often reported as the SD, especially if the migrations are not normally distributed. The SDs of Paper I and Paper III were 0.21 and 0.39 respectively. We also performed a phantom study with respect to Paper 3 (data not published). With 12 repeated examinations, we found a precision (SD) of 0.42, thus the precision was actually slightly lower than the clinical data suggested. We assumed this was due to the low number of examinations in the phantom study (n=12). The absolute values of transversal and internal rotation were large. There was a rather low precision in those rotations. We attribute this to the shape of the implant rather than actual excessive rotations. There exist in principle two statical RSA methods. In marker-based RSA, markers are provided on the implant by the manufacturer. In model-based RSA (MBRSA), we use digital models and fit them on the contours of the implants in each scene. Marker-based RSA is the most precise method, yet MBRSA gives a precision of

0.1 mm for translations and 0.2 degrees for rotations, and is thus applicable to most studies. [77, 92, 170] For rotations it might have been better to use marker-based RSA in Paper III, because of the shape of the implant.

The digital models can either be CAD models, or reversed engineering (RE) models. RE models generally give higher accuracy, but for most studies CAD models are sufficient. [93] In our studies, we considered the accuracy and precision provided by MBRSA and CAD models to be sufficient.

There are numerous cages for RSA studies delivered by different manufacturers. Some are especially designed for hip (uniplanar) and knee (biplanar) examinations. In Paper I we used a uniplanar cage, designed for RSA of the hip. Biplanar cages are known to give a higher accuracy and precision, [28] yet we believe that the precision in this study was sufficient. In Paper III we used a biplanar calibration cage.

In vivo PE wear analysis can be performed as either linear wear or volumetric wear. [52] As we do not possess software for volumetric wear, we calculated linear wear in Paper III. The best way to do this is of course to use weight bearing RSA images in order to calculate the minimum joint space width, but this is not always feasible in a busy clinic. It has been shown that one can use supine images when excluding unstable knees. [216] We measured the linear wear in the medial part, which previous studies have shown to be greatest. [52]

RSA is a method often used as a surrogate investigation for aseptic loosening of an implant in individual or groups of patients. The best known individual threshold for implant loosening is probably from the study of Ryd. He set the threshold of an increase in the MTPM to be either 0.2 mm at any time after 12 months (SCM criteria), or 0.2 mm/two years after that (MCM criteria). Gudnason et al. presented individual thresholds using peripheral point motion and transversal rotation. [63] With regard to implant survival at group level, Pijls et al. presented an article in 2012 discussing mean MTPM thresholds at 12 months. They introduced the categories “acceptable”, “at risk” and “unacceptable”. [171] They later advocated the use of the same thresholds as early as six months postoperatively. [170] With respect to interpretation of the use of different thresholds on

implant level and individual patients, an expert group set up by the International Radiostereometry Society is currently evaluating these criteria.

Single group studies

Single group studies have some of the shortcomings of RCTs, in that they are smaller studies, and often one or two surgeons performing the operation. This gives lower external validity than the registry studies. In addition, an obvious weakness is the lack of controls. This reduces the generalizability of the study to other surgeons or centres. However, these studies are early and smaller safety studies when introducing a new implant, and can be compared to phase 2 studies when introducing a new medication to the market. In addition, as stated above, in RSA research there are well-known thresholds for migration of the implants. It has been argued that RSA studies should be performed before an implant is introduced to the market, as part of a "phased" or "stepwise" introduction. [121, 134, 169] However, RSA research is costly. In our case the study was also performed in a low-volume clinic. This is the reason why Paper III was a single group study.

Funding and ethical considerations

We have come a long way since the famous words of Hippocrates “Primum non nocere”, “first do no harm”. [56] What it means is simply that we have an obligation to our patients of both non-maleficence and beneficence, but the former has to be in the context of patient autonomy and beneficence. [56] Still, these words are relevant today, both in clinical practice and medical research.

The Nuremberg code is a document on medical research following the Nuremberg trials after World War 2. [158] In this code informed consent is vital. Whereas the Nuremberg code is especially concerned with healthy subjects, the Helsinki Declaration, launched by the World Medical Association in 1964, also applies to research on patients. This declaration emphasizes the fragility of the consent when the researcher is also the patient´s treating physician. There is also a special focus on research on vulnerable groups. The Helsinki Declaration also discusses non-maleficence and beneficence, although it uses the terms risks, burdens and benefits. [164] The Declaration of Geneva is of course highly relevant for all medical doctors, both in clinical work and research. [161] Another important ethical framework for publishing research is the International Committee of Medical Journal Editors (ICJME) and their “Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals”. [144]

All the papers in this thesis adhered to the Helsinki and Geneva declarations, as well as the ICJME. Paper I, being an RCT, adhered to the CONSORT statement. [142] Paper II, being an observational study, adhered to the STROBE checklist. [155] Paper III was not an RCT. Apart from that, this study also adhered to the CONSORT statement. [142, 195]

Papers I and III were preapproved by the Regional Ethical Committee of Western Norway with approval numbers 2010/2056 and 2014/1075, and registered at clinicaltrials.gov with unique protocol ID numbers NCT01696552 and 424444-1 respectively. All patients voluntarily signed a written consent before inclusion in those studies.

In Paper II, which is a registry study, written consent from each patient was required for the collection of Norwegian data according to a licence issued by the Norwegian Data Inspectorate on 15 September 2014 (ref. No: 03/00058-20/CGN). As such this study was preapproved and needed no further evaluation from the Regional Ethical Committee. The

use of Australian data in Paper II was approved by the Commonwealth of Australia as a Declaration of Quality Assurance Activity under section 124X of the Health Insurance Act of 1973. [59]

When we perform research, we have an ethical obligation to present and publish our research regardless of our findings. Paper I and II were presented at the annual autumn congress of the Norwegian Orthopaedic Federation in 2017 and 2019 respectively. Paper II was also presented at the 8th Annual International Congress of Arthroplasty Registries in Leiden, the Netherlands, in 2019. Paper III was presented at the International Radiostereometry Society`s biannual congress in Oslo in 2021. All three papers were published in international peer-reviewed journals with open access and were thus available for everyone.

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Discussion

Paper I

The main finding of Paper I was a continuous migration of the mean MTPM of the PSPG group between one and two years. In the conventional group, the initial migration during the first year then ceased, and the implants stabilized. Although the absolute difference in MTPM between the two groups increased, the difference was not significant. Because of the limited number of patients, we focused on estimated values, not p-values. The study by Ryd et al. found that MTPM at one to two years could be used to predict individual prostheses at risk of later loosening with a power of 85%. [187] In the study by Pijls et al., the authors defined some MTPM thresholds based on RSA at one year, the association between early migration and late revisions for aseptic loosening, and introduced the categories "acceptable", "at risk" and "unacceptable". [171] In the study of Gudnason et al., the authors could predict early loosening with a focus on peripheral subsidence and lift-off, or transversal rotation at two years follow-up. [63] We therefore chose, based on these previous seminal papers, to divide the implants into high-risk and low-risk implants with respect to later aseptic loosening. Five implants were identified as at risk. Only one of these had inferior clinical scores, but this patient had postoperative hematoma that was evacuated and belonged to the conventional group. However, we know from the study by Ryd that although loosening is a process that starts almost immediately, clinical signs of loosening can take as much as a decade to become apparent. [187] As of November 2021 there have still been no revisions for aseptic loosening in either of the groups.

A limitation of Paper I is of course that it is underpowered. This could lead to a statistical type 2 error, i.e. there could in theory be a difference in migration between the two methods despite the p-value of > 0.05. We can only wait and see whether this migration ceases or increases as time goes by. There have been several other studies on the Vanguard® CR implant, several of which have found excellent results on survivorship. [41, 44, 48, 106, 194] None of these articles looked at the PSPG technique separately. To our knowledge, there is only one other RSA article on the Vanguard® CR TKA. [3] In this study, the implant was found to be in the same risk category of Pijls et al. ("at risk") as in

our study. Being in the "at risk" category of Pijls et al., there could be an increased revision risk due to aseptic loosening at five and ten years with this implant. [171] However, in the AOANJRR and NJR annual reports of 2021, the Vanguard® CR had a cumulative percent revision at 10 years (95% CI) of 4.6 (4.1-5.2) and 2.98 (2.78-3.20) respectively. [140, 150] In a study from the Finnish arthroplasty registry, they found that the Vanguard® had an HR of 1.4 when compared to the NexGen CR. [126] The Vanguard® CR tibial tray consists of two different versions, namely the I-beam tray and the cruciate finned tray. The latter tray, which was used in Paper I, had a significantly higher revision rate than the reference in the 2018 report of the SKAR. [156] This increased all-cause revision rate was not found in the 2020 report, however. [157]

There could be several reasons for a theoretical increased migration of the PSPG group. In the original multi-centre study, it was found that there were differences in the frontal femoral and tibial component angles, as well as the tibial component angle in the sagittal plane. [218] Malrotation and malalignment of the tibia or femur has been shown to have an impact on the survival of the implants. [98] However, in the original multi-centre study, the number of outliers was equal in both groups. [218] The learning curve could be an issue, but the method was well established in the department before inclusion of patients.

Conclusion

The knees operated with PSPG technique showed increased migration compared to the conventional group. Although the difference was not statistically significant, this is worrying and warrants longer follow-up.

Paper II

In this study, we raised three questions: 1) Is there any difference in the survival rate between MP and CR TKAs? 2) Is there any difference in survival between the different MP Implants? and 3) What are the main reasons for revision of MP TKAs?

The main finding was that there was decreased survivorship of primary cemented MP TKAs without concomitant patella resurfacing as a group, compared with the three most used cemented CR TKAs. We also found that by brand, the GMK® Sphere and Advance® MP had inferior survival, whereas the other MP TKAs had survival on the same level as CR TKAs.

Preceding our study, numerous articles were published on results of the MP category, but there were no larger registry studies. A small registry study assessed the ten-year survivorship of the Advance® MP. [23] There were a couple of review articles, also mainly focusing on the Advance® MP. [47, 234] Some smaller clinical studies showed excellent results of the MP category. [7, 94, 95, 120] When compared with PS TKAs, MP implants have been shown to yield higher PROMs scores. [76, 190] Being rather rare events, the causes of revision and survivorship are best studied in large-scale registry studies. There is thus a knowledge gap in the literature. In our study we were able to show an overall higher risk of revision of MP implants when compared to the three most used CR implants in Australia. We were also able to stratify this by brand, and showed that the Advance® MP and the GMK® Sphere had a lower survivorship than the CR TKAs. Whereas the Evolution® MP showed a trend (p=0.06), the MRK™ and SAIPH® did not. In our study, the MP category had a nearly five-fold risk of revision caused by malalignment (HR 4.9, p<0.001). Risk of revision for instability (HR=1.9, p=0.03) and patellar erosion (HR=2.2, p=0.001) were also significantly higher.

There could be several reasons for these findings. MP implants are actually posterior cruciate-sacrificing implants. This could imply that some surgeons reserve these implants for more complicated surgeries, and use them as standard PS implants with post and cam mechanism. Also, lacking the stability of the PCL, it is imperative to achieve stability medially. If the surgeon does not succeed in this, instability is unavoidable. It is also possible to overtighten the medial construct and thus force the implant into a valgus malalignment. Theoretically, MP implants that build their stability medially should not be suitable for patients with preoperative valgus deformity. Although the small study of Iwakiri et al. showed that this is not the case, the debate on that issue is not settled. [84]

The study had some limitations. The advantage of an observational study that captures large volumes of implants is also a disadvantage because observational studies can be prone to selection bias. For instance, some surgeons recruiting patients might reserve the MP implants for more active patients, other more technically demanding cases than the average patient receiving a CR TKA. Also, we do not know anything about the surgeon volume. It is therefore possible that the problems we see with MP implants are related to learning curve issues rather than problems caused by the implants themselves. In addition,

we do not have any information on patients with a suboptimal or loose TKA that are not revised. If the difficulty level of revising the implants is regarded differently, this could of course affect the risk of revision of the implant. However, we do not regard it as likely that it is more difficult to revise MP implants than CR implants.

Conclusion

In this study we found lower survivorship in the MP category than the CR controls. There was a higher risk of revision due to malalignment, instability and patellar erosion in Australia and aseptic loosening in Norway. Stratified by brand, the Advance® MP and the GMK® Sphere had a statistically higher risk of revision than CR controls.

Paper III

The main finding in this study was that the mean implant migration (MTPM) before 12 months was rather high, but that subsequently migration subsided. Of the translations and rotations, internal rotation had the highest absolute value. This is not surprising considering that this specific rotation had the lowest precision of all. According to the study of Pijls et al., this implant is in the "at risk" category. [171] In that study, the authors found that no implants in the "acceptable" category at 12 months RSA had a higher revision rate than 5% due to mechanical loosening at ten years follow-up. Likewise, all the implants in the "unacceptable" category had a higher revision rate than 5%. For the "at risk" category one cannot draw any firm conclusion. One may say that the MP design is a more constraining implant. Although one study from 2018 did not find any migration difference between PS implants and CR implants, the study of van Hamersveld et al. found that PS implants probably have a higher migration than CR implants before settling. [170, 215] However, MP implants are not true PS implants; they do not have a cam and post mechanism. Yet they are more constrained than CR implants, and their stability relies solely on the collateral ligaments and the conformity and tightness of the medial construct. In theory, they may therefore have the same natural migration pattern as PS implants do. Based on the aforementioned criteria of Ryd and Gudnason, we were able to identify a total of five implants at risk of early loosening.[63, 187] One of the patients was revised for premature mechanical loosening at 32 months. Postoperative radiology showed that this patient had a valgus of six degrees, despite having a preoperative neutral mechanical axis. We therefore believe that the loosening was due to surgical problems

rather than true aseptic loosening. With the exception of one other patient, the rest of the high risk implants all had excellent clinical scores. Still, we know that it might take a decade before the clinical appearance of a loose implant. [187] There could be other reasons for the somewhat high initial migration of this implant. The cement used could theoretically have played a role here, but we think not because the Refobacin BCR is a well-known bone cement with excellent results on survivorship. [18, 165, 213] In the study, we did not use a tourniquet. This should not be a problem because several studies have stated that this is safe with respect to migration of the implant. [40, 114, 125] Clinically the implant performed excellently, with generally high ROM and PROMs scores. There was also a significant ceiling effect of some of the KOOS subscales. The wear measured was very low. The wear shifted from negative to positive from 12 to 24 months. We attribute this to a wide interquartile range based on the low number of participants in the wear analysis (n=14).

Several studies have reported on the mid- to long-term survivorship of MP implants. The survival analysis of Karachalios et al. reported a cumulative success rate of the Advance® MP as high as 97.3% at 15 years. [94] Some authors find similar survivorship for MP implants compared to CR or PS controls. [27, 86] Studies on the GMK® Sphere usually focus on kinematics, not survivorship. The GMK® Sphere is reported to have kinematics comparable to the design rationale. [102, 196, 197] As for survivorship and revision rate, our recently published registry study showed inferior survivorship compared to CR controls. [241] The AOANJRR and the NJR have published data showing that the GMK® Sphere has a cumulative percent revision at five years of 3.3 and 2.98 respectively. [140, 150]

Our study had several limitations. Firstly, it was not an RCT. We have therefore not compared it to well-known implants with excellent long-term survivorship. However, in RSA there are known thresholds of migration that we relate the results to. Secondly, a limited number of patients was included. One should therefore be cautious about drawing conclusions on the clinical performance. The study was only powered with respect to the primary outcome, and for this there was a sufficient number of patients at all time points. Thirdly, the wear measurements were performed with supine RSA radiographs, and we thus had to exclude some of the patients due to minor clinical instability. [216] The strengths of the study were first of all that it is the first ever RSA study on the MP category in

general and GMK® Sphere in particular, to the best of our knowledge. It therefore fills a significant gap in the literature. Secondly, we performed an analysis of MTPM, all six degrees of freedom and adhered to the ISO standard. [163] Thirdly, we analysed feature points and were able to compare the results with known thresholds of migration. [63]

Conclusion

The mean migration of the implant was higher than anticipated from postoperative to 12 months and then seemed to stabilize. Based on previous studies on RSA thresholds, it is too early to draw a conclusion on the long-term survivorship of this implant. Further RSA follow-up is therefore indicated.

Conclusion

Paper I

The knees operated with PSPG technique showed increased migration compared to the conventional group. Although the difference was not statistically significant, this is worrying and warrants longer follow-up.

Paper II

In this study we found lower survivorship in the MP category than in the CR controls. There was a higher HR with respect to revision due to malalignment, instability and patellar erosion in Australia and aseptic loosening in Norway. Stratified by brand, the Advance® MP and the GMK® Sphere had a statistically higher HR than CR controls.

Paper III

The mean migration of the implant was higher than anticipated from postoperative to 12 months and then seemed to stabilize. Based on previous studies on RSA thresholds, it is too early to draw a conclusion on the long-term survivorship of this implant. Further RSA follow-up is therefore indicated.

Overall conclusion

We cannot yet conclude whether the surgical tool of PSPG influences the stability of TKA or not, although we find the continuous migration a cause for concern. Some of the MP implants had a poorer survivorship and higher risk of revision due to malalignment and instability compared with CR controls. The early stability of the GMK® Sphere does not allow for a final conclusion on the risk of mechanical loosening in the long term. Further follow-up of the PSPG technique and the MP design is therefore warranted.

Future perspectives

"If conclusions are to be of any value they must be definite and one cannot draw definite conclusions from less than, say fifty cases followed up for at least five years. However, few surgeons will ever see fifty patients requiring arthroplasty of the knee, let alone operate on them, even in five years." L. G. P. Shiers

Many years have passed since the famous words of L. G. P. Shiers in 1954. Today we are fortunate enough to be able to help many more patients with much more advanced techniques and implants. Yet, as shown in this thesis, there are still numerous knowledge gaps to be filled. The ongoing debate about alignment continues. A possible scenario in near future is the combination of MP implants, customized implants, kinematic alignment, PSPG or robotic surgery (Figure 20).

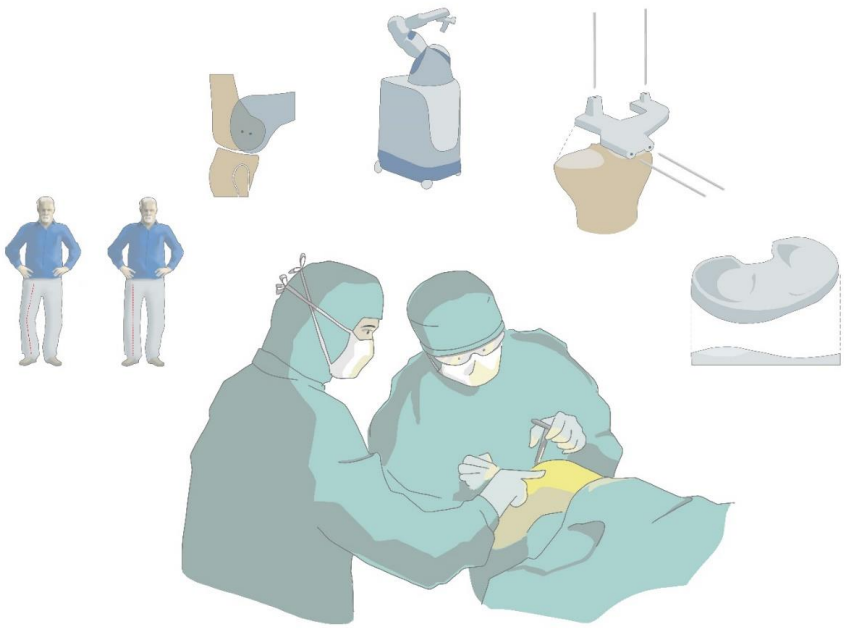

Figure 20: Future perspectives of TKA surgery with an emphasis on alignment, robotic surgery, PSPG and design. Drawn by Alf Hellevik. Courtesy of Hellevik Studios.

"We never settle for being the best. We always strive to be better"

Dr Charles Olson, Medical Director of Cardiology

We must never settle for the best, but always strive to be better. In order to achieve this, larger trials and longer follow-up studies should be conducted, with respect to survivorship of individual designs or the method in use. At present, the cost of robotic surgery is too high for this to be adopted in every clinic performing TKAs, but this is likely to change. The new technology certainly provides many opportunities with respect to accuracy of the cuts as well as real-time feedback with respect to alignment, regardless of alignment philosophy, and soft tissue balancing. Together with better tools for picking the right TKA candidates, this is likely to increase patient satisfaction due to better function and less pain.

In the somewhat more distant future, there might be a shift in materials utilized in the TKA implants. In the distant future implants might only be scaffolds for bone and cartilage cells. Gene therapy or other biological treatments for OA in the knee are also likely to be developed, although in a longer-term perspective.

As for my own research perspective, I will continue the work of documenting MP implants through an already ongoing five-year RSA study on the GMK® Sphere, and perform other observational studies on MP implants. The precision of new CTMA technology is also now being evaluated in an ongoing migration study on cementless GMK® Sphere, and I consider myself fortunate to be taking part in this project as well.

There are many possibilities for future research; the greatest obstacle is our own imagination.

"Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world." Albert Einstein

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Papers in the thesis

I

A 2-year RSA study of the Vanguard CR total knee system: A randomized controlled trial comparing patient-specific positioning guides with conventional technique

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Background and purpose — There is some concern regarding the revision rate of the Vanguard CR TKA in 1 registry, and the literature is ambiguous about the efficacy of patient-specific positioning guides (PSPGs). The objective of this study was to investigate the stability of the cemented Vanguard CR Total Knee using 2 different surgical techniques. Our hypothesis was that there is no difference in migration when implanting the Vanguard CR with either PSPGs or conventional technique. We hereby present a randomized controlled trial of 2-year follow-up with radiostereometric analysis (RSA).

Patients and methods — 40 TKAs were performed between 2011 and 2013 with either PSPGs or the conventional technique and 22 of these were investigated with RSA.

Results — The PSPG (8 knees) and the conventional (14 knees) groups had a mean maximum total point motion (MTPM) (95% CI) of 0.83 (0.48–1.18) vs. 0.70 (0.43–0.97) mm, 1.03 (0.60–1.43) vs. 0.86 (0.53–1.19), and 1.46 (1.07–1.85) vs. 0.80 (0.52–1.43) at 3, 12, and 24 months respectively ($p = 0.1$). 5 implants had either an MTPM > 1.6 mm at 12 months and/or a migration of more than 0.2 mm between 1- and 2-year follow-ups. 2 of these also had a peripheral subsidence of more than 0.6 mm at 2 years.

Interpretation — 5 implants (3 in the PSPG group) were found to be at risk of later aseptic loosening. The PSPG group continuously migrated between 12 and 24 months. The conventional group had an initial high migration between postoperative and 3 months, but seemed more stable after 1 year. Although the difference was not statistically significant, we think the migration in the PSPG group is of some concern.

Not all patients are satisfied after total knee arthroplasty (TKA); in several studies up to 25% of patients have persistent pain and dysfunction (Baker et al. 2007, Beswick et al. 2012, Howells et al. 2016). Many revisions are caused because of aseptic loosening of the implant. Younger patients undergoing TKA (Kurtz et al. 2009, Ravi et al. 2012) show a higher revision rate (Civinini et al. 2017). Thus, patient dissatisfaction, aseptic loosening, and demographic changes are good reasons to try to improve prosthesis designs and surgical precision. At the same time, all changes in clinical practice or choice of implant should follow the principle of stepwise introduction (Malchau 2000, Nelissen et al. 2011, Pijls and Nelissen 2016).

The Vanguard Cruciate Retaining (CR) Total Knee (Vanguard Complete Knee System, Zimmer Biomet Inc., Warsaw, IN, USA) was introduced in 2003. In some registries (AOANJRR , NJR) the prosthesis has showed promising results. Yet in another (SKAR), the Vanguard CR had a significantly higher relative risk of revision compared with other implants.

The implant can be inserted by conventional surgical technique or with patient-specific positioning guides (PSPGs). PSPGs are customized and manufactured from preoperative CT or MRI data to improve postoperative alignment (van Leeuwen et al. 2015). The literature is still ambiguous regarding the efficacy of PSPGs (Boonen et al. 2012, Nunley et al. 2012, An et al. 2017). Altered surgical technique or alignment might influence the early stability of the implants.

The hypothesis of this study was that the cemented Vanguard CR TKA is a stable implant using PSPGs. Therefore we investigated the stability of the cemented Vanguard CR Total Knee using 2 different surgical techniques.

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Patients and methods

This study was part of a randomized controlled multicentre trial (RCT) in Oslo and Skien, Norway, which compared clinical and radiological but no radiostereometric analysis (RSA) results of the PSPG technique (Signature Personalized Patient Care System; Zimmer Biomet) with the conventional technique for TKA. The exclusion criteria were published in that study (van Leeuwen et al. 2018). All surgeries and investigations in the RSA cohort were performed at Ullevål Hospital, Oslo, Norway.

40 patients participated in the RSA study at Ullevål Hospital, but only 22 were included in the RSA analyses (Figure 1). These were operated between December 2011 and December 2013. A Vanguard Cruciate Retaining (CR) TKA was performed in all patients (Cemented Vanguard Complete Knee System; Zimmer Biomet Inc., Warsaw, IN): 8 with the PSPG technique and 14 with the conventional surgical method.

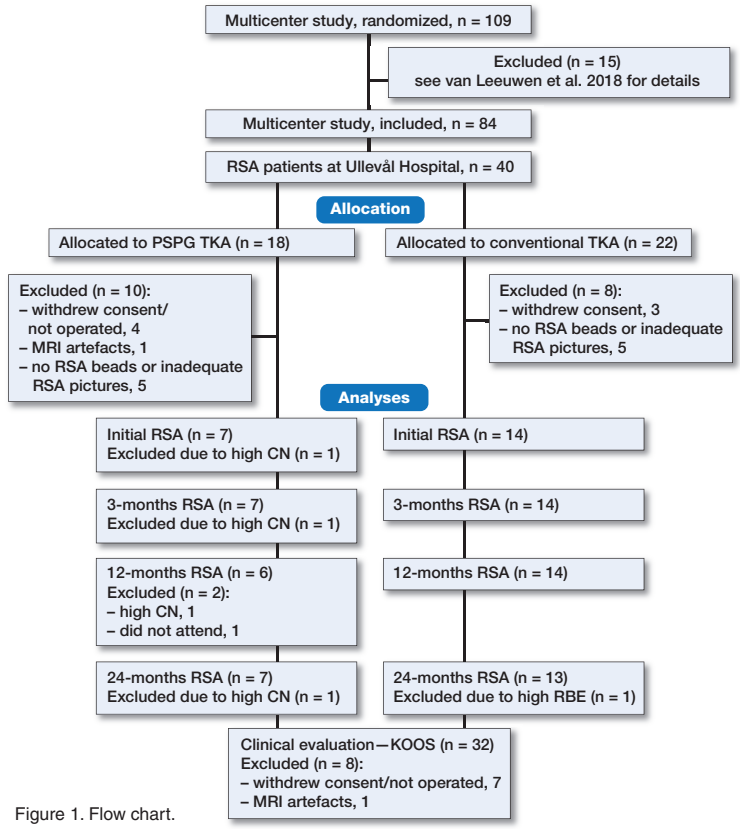

Figure 1. Flow chart.

Design

This study was designed as a single blinded RCT of patients receiving TKA for symptomatic osteoarthritis of the knee.

Patients

The participants were assigned to either the conventional or PSPG technique according to the protocol of the multicentre RCT with block randomization obtained by variable block sizes (van Leeuwen et al. 2018). In the original RCT the sample size was calculated for the frontal mechanical axis and the secondary outcome KOOS score. That study was terminated when the total number of patients was sufficient according to the primary outcome measure, hence the suboptimal number of patients in the RSA study (Figure 1). The surgeries were performed by 2 experienced surgeons. 7 patients withdrew their consent or were not operated for various reasons after randomization, 1 had MRI artefacts that precluded manufacturing of PSPGs, and 10 did not have beads inserted or had inadequate RSA pictures, thus only 22 had RSA in this study. At 2 of the time points there were only 20 patients included in these analyses. 1 patient had a high condition number (CN) and was excluded at all time points, 1 did not show up at 12 months, and 1 had high rigid body error (RBE) at 24 months.

Intervention

We used a standard midline incision and medial parapatellar capsulotomy in all patients. A tourniquet was used in all cases. For details of the operative procedure see van Leeuwen (2018). Both surgical techniques (conventional and PSPG) for this implant were well established in the department prior to the inclusion of RSA patients, so we assumed that there was no learning curve.

During surgery 6 to 8 1.0 mm tantalum markers (RSA Biomedical, Umeå, Sweden) were inserted in the tibia. All patients followed the same standardized postoperative rehabilitation protocol.

Evaluation

Implant migration was evaluated using RSA. The first examination took place within a week postoperatively, then after 3, 12, and 24 months. They were all performed in the supine position by the same radiographers at each time point. We used calibration cage number 43 (RSA Biomedical, Umeå, Sweden) and ceiling mounted X-ray tubes (Proteus XR/A, GE Healthcare and Canon Triathlon T3).

Figure 2. Fictive points of the tibial implant (the posterior fictive point is hidden behind the stem).

Table 1. Baseline characteristics of conventional vs. PSPG patients. Values are mean (SD) (range) unless otherwise specified

Factor	Conventional	PSPG
Number of patients	14	8
Left/right, n	10/4	3/5
Men/women ratio, n	7/7	2/6
Age	65 (7.9) (53–77)	60 (5.1) (50–68)
BMI	28 (4.2) (22–36)	30 (4.8) (22–35)
Body weight (kg)	84 (18) (60–105)	87 (12) (70–100)
Operation time (min)	121 (37) (68–228)	111 (8.9) (95–125)
Postoperative HKA (°)	181 (4.8) (172–188)	178 (5.7) (171–186)

MB-RSA 3.40 (RSAcore, Leiden, The Netherlands) software was used for the migration analysis. The migration was described both as segment motion of all 6 degrees of freedom (translations and rotations) and maximum total point motion (MTPM), the latter being primary outcome. In addition, we analyzed the point motion from fictive points added to the computer aided design (CAD) model of the tibial component. We had the following 7 fictive points: stem tip, anterior, posterior, posteromedial, posterolateral, medial, and lateral (Figure 2). All these points were reported for X, Y, and Z translations. As we performed double examinations, the 2 RSA pictures were run against all the others, making a total of 4 motions for each patient at each time point. The average of these 4-point motions represented the motion of the individual implant at each time point. The movements of the 13 left knees were converted to right knees for stability analysis (Valstar et al. 2005).

Our upper limit for CN was 100, and for RBE 0.50 mm. 1 patient exceeded 0.5 mm RBE at 2 years and was excluded from the RSA examination at this time point. The rest had RBE of less than 0.35mm. Precision was assessed by double RSA examinations of all patients at all time points, and reported as absolute mean difference of double examinations ± 1.96 x standard deviation (SD).

For clinical assessment we used the Knee injury and Osteoarthritis Outcome Score (KOOS) (Roos et al. 1998). All complications were registered.

Statistics

We used linear mixed models to evaluate differences in MTPM, translations, rotations, and point motions within groups (PSPG vs. conventional) over the entire follow-up period and to control for repeated measurements. The fixed effects were time, group, and time-by-group interaction. The model included a random slope. As the KOOS scores were not normally distributed, the Wilcoxon signed-rank test was used to evaluate difference from preoperative to 2 years. Further, patients were divided into high- and low-risk group according their migration data (Ryd et al. 1995, Pijls et al. 2012). To estimate differences in KOOS scores between these 2 independent groups we used the Mann–Whitney U test. Fisher's exact test was used to detect associations between categorical independent variables.

The results are reported as means or proportions with 95% confidence intervals (CI), if not stated otherwise.

All statistical calculations were performed using the IBM SPSS Statistics version 23 (IBM Corp, Armonk, NY, USA).

Ethics, registration, funding, and potential conflicts of interest

The study was approved by the Regional Committee for Medical and Health Research Ethics, West-Norway (REC West, approval number 2010/2056) and the institutional review board at Oslo University Hospital (2011/7613), and registered at clinicaltrials.gov (NCT01696552). All patients were included with written consent. No financial funding from companies has been received for this study, and the authors declare that there are no conflicts of interest.

Results

Demographics

See Table 1 for baseline characteristics.

RSA

The mean MTPM, and relevant point motions, translations, and rotations are shown in Tables 2 and 3 (see Supplementary data) and Figures 3–6. The PSPG group had an increasing migration pattern compared with the conventional group. The results from the linear mixed model analysis showed a statistically significant change in MTPM within ($p < 0.001$), but not between the 2 groups after 2 years ($p = 0.1$) (Table 4). Generally in the point motions analysis, we found a larger subsidence in the PSPG than the conventional group, but no statistical significance could be found (Table 3, see Supplementary data, Figure 4).

On an individual basis 4 implants had more than 1.6 mm migration at 12 months, but 1 of these was excluded due to an RBE > 0.5 mm at 2 years (Figure 5). 4 implants had more

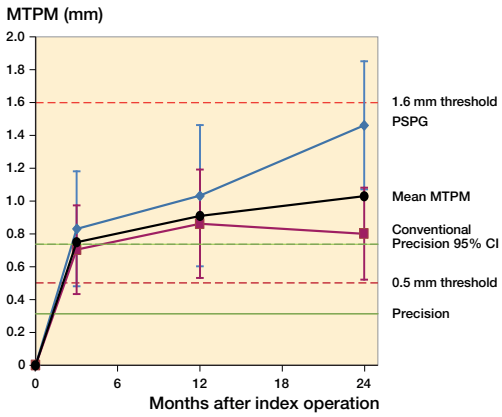

Figure 3. Mean MTPM over time for the whole cohort and for the PSPG and conventional groups with thresholds (Pijls et al. 2012).

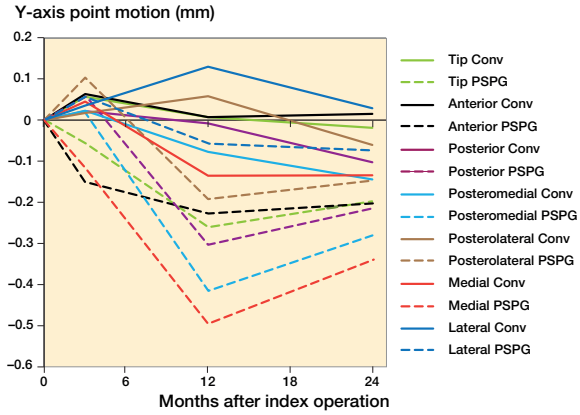

Figure 4. Y (axial, lift-off, subsidence) point motions stratified in PSPG (dashed lines) vs. conventional.

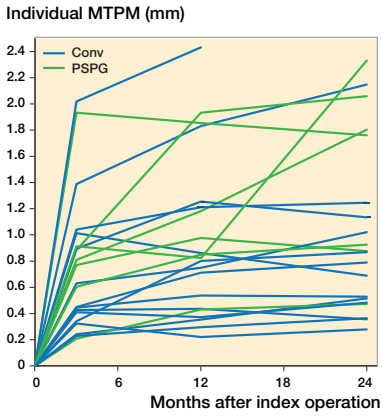

Figure 5. Individual time profiles of MTPM in the two subgroups (n = 21). Conventional marked with blue lines, PSPGs with green lines.

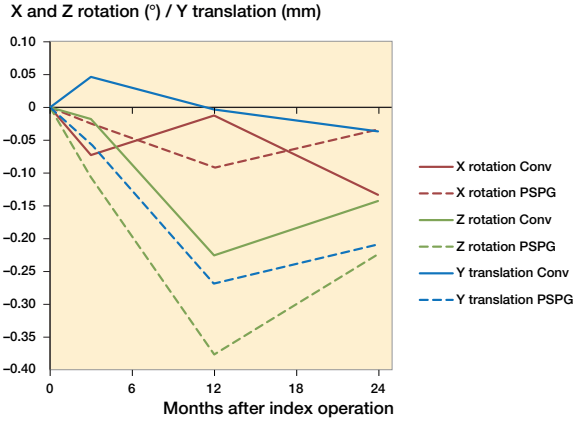

Figure 6. X and Z rotation in degrees and Y translation in mms (PSPG vs. conventional).

than 0.2 mm migration between 1- and 2-year follow-ups. Of the 3 remaining patients with MTPM > 1.6 mm at 1 year, 2 had migration of more than 0.2 mm between 1 and 2 years, hence 5 patients had either >1.6 mm at 1 year, or > 0.2 mm migration between 1 and 2 years. 2 of these patients also met the criteria for distal or proximal peripheral translation. No other implants met these criteria. None of the implants met the criteria of transversal rotation (Gudnason et al. 2017). In 3 of these 5 high-risk patients the PSPG method had been used.

The precisions of our RSA examinations were the following: 0.31 mm for MTPM (95% CI 0.00–0.74), 0.01 mm for X translation (95% CI –0.12 to 0.14), 0.01 mm for Y translation (95% CI –0.07 to 0.08), 0.03mm for Z translation (95% CI –0.25 to 0.32), 0.05° for X rotation (95% CI –0.28 to 0.37), 0.04° for Y rotation (95% CI –0.65 to 0.72), and 0.00° for Z rotation (95% CI –0.14 to 0.15).

Clinical results

We found a statistically significant improvement of all the KOOS subscales from preoperative through 2 years in the whole cohort. We could not see any difference in clinical performance for implants with migration at risk or PSPG and conventional groups (Mann–Whitney U test) (Figure 7, see Supplementary data).

Neither could we demonstrate any other subgroup to explain the inferior stability of the high-risk group (Table 5, see Supplementary data).

Table 4. Results of the linear mixed model analysis of MTPM at 2 years after randomization into PSPGs and conventional subgroups

Parameter	Coefficient	p-value	95 % CI
Intercept	–0.13	0.2	–0.32 to 0.07
Time	0.30	< 0.001	0.18 to 0.42
Randomization	–0.18	0.3	–0.50 to 0.14
Time x Randomization	0.16	0.1	–0.04 to 0.36

Among the patients with high-risk migration we found 1 with inferior clinical scoring. This person was in the conventional group and had a postoperative hematoma with no need for further surgery. Postoperative radiographs showed an HKA-angle of 172° (varus).

Complications

5 complications occurred: 1 deep hematoma that was evacuated, 1 stiff knee requiring mobilization under anaesthesia, 2 superficial hematomas, and 1 superficial infection. The latter was in the PSPG group, the others in the conventional group. None of the complications required reoperation. Except for the aforementioned high-risk patient, they had good clinical scores after 2 years.

Discussion

Our main finding was that the implants in the PSPG group had continuous migration between 12 and 24 months. The implants in the conventional group showed migration between postoperatively and 3 months; thereafter the mean migration abated and the implant stabilized. The difference in MTPM and subsidence between the two groups, however, was not statistically significant.

Several studies have discussed threshold levels for increased risk of aseptic loosening. Ryd et al. (1995) showed that the process of loosening probably starts directly after the operation and that a migration of more than 0.2 mm after 1 year gives a high risk of revision. Pijls et al. (2012) showed that more than 1.6 mm migration at 12 months gives an "unacceptable" risk of later revision. Gudnason et al. (2017) recently suggested a transversal rotation of more than 0.8°, or peripheral distal or proximal translation of more than 0.6 mm or 0.9 mm respectively at 2 years as a threshold. 5 of the 22 implants in our study met 1 or more of these criteria for high-risk implants. We could not identify any other factor than surgical technique that could explain why these knees performed worse than the rest, such as obesity, age, postoperative valgus or varus. However, due to the limited numbers of observations, emphasis should be given to the estimated values rather than p-values. All the high-risk patients, except for 1, also performed well clinically, with no symptoms of early loosening after 2 years. It is important to stress that although implants for individual patients met the criteria for "unacceptable risk" according to Pijls et al. (2012), it does not mean that the specific implant is loose. The meta-analysis of Pijls focused on mean MTPM with 12 months' observation time, mainly because not all studies reported 2-year results, or migration in all degrees of freedom. The discussion concerning which criteria to follow therefore continues. In our study, as many as 5 of 22 patients were at risk of later loosening based on several studies (Ryd et al. 1995, Pijls et al. 2012), but following the recent study by Gudnason et al. (2017), only 2 implants were at risk of aseptic loosening, 1 in each group. Also, in that study the authors concluded that MTPM after 1 and 2 years is inferior to transversal rotation, peripheral subsidence, and lift-off in predicting late aseptic loosening.

A limitation of our study is the sample size. Ideally, we would have liked between 25 and 30 participants in each group, yet several other RSA studies have suboptimal sample sizes for various reasons (Hansson et al. 2005, Molt and Toksvig-Larsen 2014, Henricson and Nilsson 2016, Meinardi et al. 2016). RSA research is costly and tedious work, and it is not always possible to recruit enough patients. As the cohort was part of a larger RCT assessing clinical and radiological outcome of 2 different surgical methods, the RSA study was not powered as an RCT. This may be a possible reason why we could not find a statistically significant difference in MTPM between the 2 groups. In addition, in the larger RCT, a statistically significant difference was found in the position of the tibia in the frontal and sagittal planes (van Leeuwen et al. 2018). As the surgical techniques were well established in the department, we assume there was no learning curve. Longer follow-up of both groups is needed, especially with a focus on the continuous migration of the PSPG group.

One strength of our study is that we used fictive points in our RSA model. We could therefore show with which pattern the implant was migrating. Many studies include only MTPM and the segmental micromotions, their absolute values are often smaller than the peripheral point motions, and they do not tell us exactly how the implant migrates. Thus we could also evaluate the implant with respect to Gudnason's data (Gudnason et al. 2017).

The long-term results of the implant we used diverge in the literature. Some registries show excellent results after 5- and 10-year follow-up (AOANJRR , NJR), the latter with only a few hundred patients reaching 10 years, and with no information regarding surgical technique. Several clinical studies also show excellent results (Kievit et al. 2014, Schroer et al. 2014, Faris et al. 2015, Emerson et al. 2016, Flament et al. 2016). To our knowledge, there is only 1 other study that has assessed the Cemented Vanguard CR with RSA (Schotanus et al. 2017). They found a mean MTPM for this implant of 0.7 mm at 12 months and 0.8 mm after 24 months. Although slightly lower migration than our data suggest, it leaves the implant in the same risk category according to Pijls et al.(2012). However, they did not use PSPGs. Another register found the implant to

perform worse compared with other implants (SKAR). This effect is not present when a patellar button is implanted during primary surgery. As long-term data are still lacking, especially on the Signature System (PSPG), and only 1 RSA study shows early follow-up data on the implant, our study adds knowledge for users of this implant.

In summary we found that the cemented Vanguard CR had a higher initial mean migration than expected at 12 months, but from 12–24 months the conventional group stabilized. The PSPG group also had continuous migration at this point. None of the implants in our study rotated more than recommended, and only 2 implants had a total peripheral subsidence above that recommended, 1 in each group. Although the PSPG group did not have a statistically different MTPM from the conventional group, we think that the findings of the migration pattern of this technique are of some concern and call for longer follow-up.

Supplementary data

Tables 2, 3, and 5 and Figure 7 are available in the online version of this article, http://dx.doi.org/ 10.1080/17453674.2018.1470866

FDØ analysed parts of the data and wrote the manuscript. MT analysed parts of the data and critically reviewed the manuscript. JvL and SMR designed the study and critically reviewed the manuscript.

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Decreased Survival of Medial Pivot Designs Compared with Cruciate-retaining Designs in TKA Without Patellar Resurfacing

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Abstract

Background The medial pivot TKA design was introduced in the 1990s. These are fixed-bearing, medial-conforming implants with virtually no translation in the medial part of the knee, in contrast to the flat lateral part of the insert allowing for translation similar to the native knee during flexion and extension. Most primary TKAs performed in

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Each author certifies that his institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
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Norway and Australia are cruciate-retaining. All of the medial pivot implants in our study are cruciate-sacrificing but without a post-cam mechanism. The medial pivot implant design was developed to more closely mimic native knee motion, in the hope of improving function, and not primarily as a more constrained knee for difficult cases. In the past 10 to 12 years, a second-generation medial-pivot design has emerged, but there are no larger registry studies on the survival of these implants. Both cruciate-retaining and medial pivot designs are reported in the Australian and Norwegian registries, allowing for large-scale, comparative survivorship studies.

Questions/purposes (1) Is there any difference in survival between the medial pivot design and the three most commonly used cruciate-retaining TKA designs? (2) Is there any difference in survival among the different medial pivot implant designs? (3) What are the main indications for revision of medial pivot TKAs?

Methods Registry data from the Australian Orthopaedic Association National Joint Replacement Registry and Norwegian Arthroplasty Register from 2005 until the end of 2017 were used to compare the five different brands of medial pivot TKA designs (total primary TKAs assessed: 6310). In Australia, the study group of medial pivot implants represented 9% (6012 of 72,477) of the total number of cemented/hybrid TKAs without patellar resurfacing; 345 had cementless femoral components. In Norway, the study group represented 1% (298 of 47,820) of the total number of TKAs with cemented tibias without patellar resurfacing; all had cemented femoral components. The control group consisted of the three most commonly used cruciate-retaining TKA designs (n = 70,870; Australia n = 54,554; Norway n = 16,316). All TKAs used a fixed-bearing, cemented tibial component and did not involve patella resurfacing. Kaplan-Meier survival analysis was assessed to estimate survivorship. We compared the groups by calculating the hazard ratios (HR) using Cox regression adjusted for age, gender and preoperative diagnosis with 95% CI. To answer our third question, we calculated the percentage of each revision indication from the total number of revisions in each group, and used a Cox regression analysis to compare revision causes and HRs. Analyses were performed separately by each registry. Accounting for competing risks (Fine and Gray) did not alter our findings [12].

Results After controlling for potential confounding variables such as gender, age and preoperative diagnosis, we found an increased revision risk for the medial pivot compared with cruciate-retaining TKA designs in Australia (HR 1.4 [95% CI 1.2 to 1.7]; $p < 0.001$), but not in Norway (HR 1.5 [95% CI 0.9 to 2.4]; $p = 0.1$). Two brands of the medial pivot design reported to the AOANJRR showed an increased risk of revision compared with cruciate-retaining designs: the Advance® II MP (HR 1.7 [95% CI 1.2 to 2.6]; $p = 0.004$) and the GMK® Sphere (HR 2.0 [95% CI 1.5 to 2.6]; $p < 0.001$), whereas the MRK™ (HR 0.7 [95% CI 0.4 to 1.5]; $p = 0.4$), the Evolution® MP (HR 1.4 [95% CI 1.0 to 1.9]; $p = 0.06$) and the SAIPH® (HR 0.9 [95% CI 0.5 to 1.5]; $p = 0.7$) showed no difference. The most common reasons for revision of medial pivot implants in Australia were infection (27%), pain alone (19%), patellar erosion (13%), loosening/lysis (12%); in Norway the primary indications were loosening/lysis (28%), instability (28%), malalignment (11%) and pain alone (11%).

Conclusions The medial pivot TKA design as a group had a higher revision rate than cruciate-retaining fixed-bearing controls in TKA performed without patellar component resurfacing. By brand, the Advance II MP and the GMK Sphere had inferior survivorship, whereas the MRK, the SAIPH and the Evolution MP had no differences in survivorship compared with cruciate-retaining controls. In Australia, TKAs with the medial pivot design without patella resurfacing had a higher rate of revisions for instability, malalignment, and patella erosion. In Norway, there was an increased risk of revision for lysis and loosening compared with the cruciate-retaining design. Several of these implants had short follow-up in this study. Further registry studies with longer follow up are therefore necessary.

Level of Evidence Level III, therapeutic study.

Introduction

TKA is a generally effective way to treat gonarthritis. Still, not all patients achieve the desired result of decreased pain and increased function, and in some studies, as many as 20% are dissatisfied [3, 4]. Implants also perform differently with respect to survivorship, and the prosthesis design may contribute to these variations. Although there are a variety of prosthetic designs, primary TKA implants can be broadly classified into cruciate-retaining and posterior-stabilized implants [6]. Studies suggest that after TKA, there may be paradoxical motion of the lateral femoral condyle, and instead of femoral rollback during flexion, as occurs in the native knee [20], there may be anterior femoral translation [10]. This may lead to a sensation of instability, reduced quadriceps strength, and reduced flexion range of the knee [8-10, 35].

In the 1990s, the medial pivot design was introduced [19]. The medial pivot design tries to mimic the in vivo kinematics of the native knee. These fixed bearing implants have a medial conforming articulation, similar to a ball and socket. In the lateral compartment, the tibial insert is flat, and together with laxity of the lateral collateral ligament, theoretically allows natural femoral rollback during knee flexion. All the medial pivot implants in our study are also cruciate-sacrificing but without a post-cam mechanism [25, 27-29, 42]. The first TKA with a medial pivot design was the Medial Rotation Knee (MRK™, MatOrtho, Surrey, UK)

which was introduced in 1994, followed by the Advance® Medial-Pivot Knee in 1998 (Wright Medical Group Inc, Memphis, TN, USA) [1, 25]. A second generation of prostheses further developed the medial pivot theme, including the Evolution® Medial-Pivot Knee (MicroPort Orthopedics Inc, Arlington, TN, USA [42]), the SAIPH® Knee System (MatOrtho [28]) and the GMK® Sphere (Medacta International AG, Castel San Pietro, Switzerland [29]). As medial pivot implants have increased in popularity, the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) now classifies them in a separate medial pivot design category, and they accounted for 7% of the primary TKAs in Australia in 2017 [18].

Despite the growth in use of the medial pivot design, there is little knowledge of the longevity of these implants as a group or of different brands. Most studies are smaller clinical studies on the longevity of the Advance MP [21, 24, 36], or smaller clinical or fluoroscopic studies on the different implants' function [19, 35, 38]. To our knowledge, there have been no larger registry studies that address the survival of medial pivot implants before this study.

We used the databases of the AOANJRR and Norwegian Arthroplasty Register (NAR) to ask the following questions: (1) Is there any difference in survival between the medial pivot design and the three most commonly used cruciate-retaining TKA designs? (2) Is there any difference in survival among the different medial pivot implant designs? (3) What are the main indications for revision of medial pivot TKAs?

Patients and Methods

Study Design and Setting

This study derived its data from two national registries, the NAR and AOANJRR. From those, we identified all medial pivot TKAs from 2005 until the end of 2017. We compared these with a control group of the three most commonly used cruciate-retaining designs of TKA in Norway and Australia. The NAR began registering TKA data in 1994 [14, 15] and the AOANJRR began registering data 1999. Both registries have a completeness of 99% and 98%, respectively [11, 18]. Emigration from both countries was negligible in the elderly [2, 30].

Participants

Datasets from Australia and Norway from 2005 through 2017 (Fig. 1) were merged by creating common endpoints using the Australian hierarchy of revision diagnoses [18]. In Australia, the study group of implants (medial pivot) included the Evolution MP, the MRK, the SAIPH, the GMK Sphere, the Advance MP II, which represented 9% (6012 of 72,477) of the total number of TKAs with cemented tibias without patella resurfacing; 345 had cementless femoral components. In Norway, only the Advance MP II, Evolution MP, and GMK Sphere were used during this period and represented 1% (298 of 47,820) of the total number of TKAs with cemented tibias without patella resurfacing, all with cemented femoral components. We thus included only fixed-bearing prostheses with cemented tibial components in TKA without patella resurfacing. The control group consisted of the three most commonly used fixed-bearing, cruciate-retaining TKA implants with a cemented tibial component in each country. This comparison group was chosen as fixation with or without cement for the femoral component yields equivalent survival [18]. The medial pivot design was primarily developed to mimic native knee motion to improve function, and not as a constrained knee for difficult cases. This is, however, likely the case for many of the posterior-stabilized TKA designs used in the registries (10% and 23% of the total number of primary TKAs in Norway and Australia respectively) [14, 18]. The control group therefore consisted of cemented tibia and uncemented or cemented femoral components from NexGen® CR (Zimmer Biomet, Warsaw, IN, USA), Triathlon® Total Knee System (Stryker, Mahwah, NJ, USA) and Legion Total Knee System (Smith and Nephew, Memphis, TN, USA) from Norway (n = 16,316) and NexGen® CR, PFC® Sigma® (DePuy Orthopaedics Inc, Warsaw, IN, USA), and Triathlon® Total Knee System from Australia (n = 54,554). Patellar resurfacing is rarely performed in Norway, but the survival of both medial pivot and cruciate-retaining TKA designs has been shown to improve with patellar resurfacing [18]. In Sweden, about 2% of TKAs have the patella resurfaced [33], and The National Joint Registry of England and Wales reported 42% of their TKAs have resurfaced patellae [26]. In addition, for the medial pivot as a group reported in the AOANJRR, 47% (6740 of 14,421) of the TKAs did not have a resurfaced patella. In fact, 2017 was the only year in our study period (2005-2017) that patellar resurfaced TKAS outnumbered un-resurfaced patellar TKAs [18]. To minimize confounding because of the changing proportion of patellar component use over time, we therefore excluded all patients with patella resurfacing.

Variables, Outcome Measures, Data sources, and Bias

Our primary study endpoint for our first question was to determine if there was a difference in survival between the medial pivot design and the three most commonly used cruciate-retaining TKA designs. We investigated this by assessing the Kaplan-Meier estimates of survivorship, and compared the groups by calculating the hazard ratios using Cox regression. We used this approach for our second

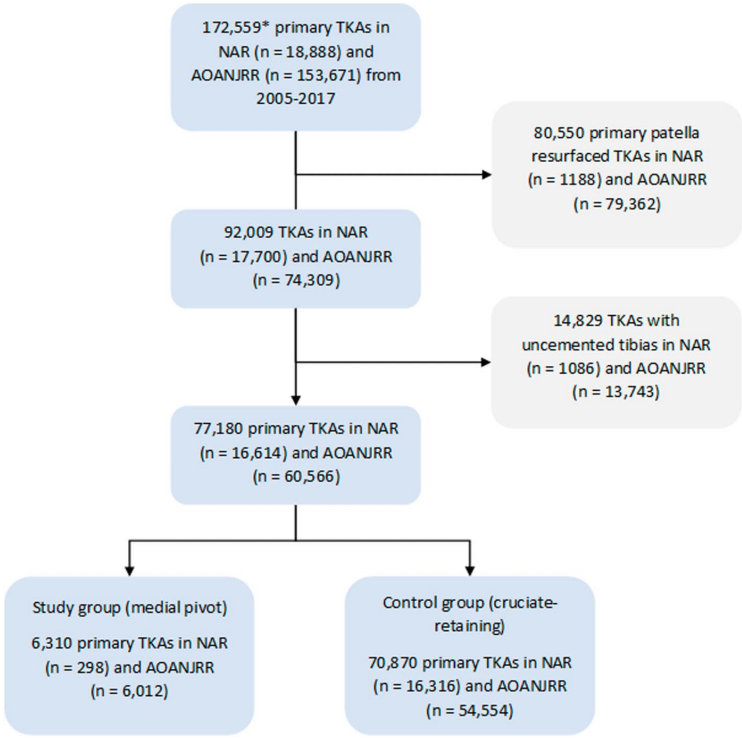

Fig. 1 This flowchart shows the patients who were included in the study; NAR = the Norwegian Arthroplasty Register, AOANJRR = the Australian Orthopaedic Association National Joint Replacement Registry. *Three most used cruciate-retaining and all-medial pivot TKAs.

question as well. For our third question, we calculated the percentage of each revision indication of the total number of revisions in each group for both nations. In addition, we calculated hazard ratios of the different revision causes, based on the Australian hierarchy of revisions [18]. To limit bias, we adjusted for gender, age, and preoperative diagnosis.

Demographics, Description of Study Population

The proportion of men in the study group was almost identical between the two databases (48% in the NAR versus 49% in the AOANJRR) (Table 1), whereas in the control group, there was a difference in the proportion of men between the databases (40% in the NAR versus 44% in the AOANJRR; $p < 0.001$). The mean ages in the study group (NAR, 68 years; AOANJRR, 68 years) and control group (NAR, 69 years; AOANJRR, 69 years) were comparable. The proportion of patients with a preoperative diagnosis of osteoarthritis differed between the countries (study group NAR 92% versus AOANJRR 99%; $p < 0.001$; control group NAR 92% versus AOANJRR 99%; $p < 0.001$).

As the Advance MP I was reported in the AOANJRR as having an unfavorable result [18], we reviewed all of the catalog numbers of this implant in both countries; only four such tibial implants were used in Australia from 2005 to 2017.The remaining Advance MP implants in Australia and all implants in Norway were Advance® MP II implants (Table 2). Advance MP I was thus excluded from further analyses.

Statistical Analysis, Study Size

We used the chi-square test to compare dichotomous data (that is, gender and preoperative diagnosis) and a two-sided t-test for continuous distributed data (age differences). P values < 0.05 were regarded as statistically significant. Kaplan-Meier estimates of implant failure are clinically meaningful and straightforward to interpret for clinicians, and recommended by the Nordic Arthroplasty Register Association (NARA) study group [32] and used by the NAR

Table 1. Demographics of the study and control groups

Variable	Study group: medial pivot designs			Control group: cruciate-retaining designs		
	Norway (n = 298)	Australia (n = 6012)	p value	Norway (n = 16,316)	Australia (n = 54,554)	p value
Men (%)	48	48	0.9	40	43	< 0.001
Age (years), mean ± SD	68 ± 10	68 ± 9	0.6	69 ± 10	69 ± 9	0.8
Diagnosis (%)						
Osteoarthritis	92	99	< 0.001	92	99	< 0.001
Other	8	2		9	1	

[14]. The AOANJRR uses the complement to this, the cumulative percent revision [18]. In the AOANJRR, Kaplan-Meier estimates were made for 9-year survival stratified by group and country, and 3-year and 9-year survival by medial pivot brand. Survival tables and curves were constructed. A Cox regression analysis of the groups, stratified by country with revision for any cause, and analysis for competing risk from death using the methods of Fine and Gray [12], was also performed. We also performed Cox regression analyses to investigate causes of revision and HR in Norway and Australia. Whenever crossing curves were displayed, we performed individual Cox regression analyses before and after they intersected to test whether the assumption of proportional hazards could be applied. Cox regression analyses of the main reasons for revision of medial pivot and cruciate-retaining implants in Norway and Australia were also performed. The Advance MP is under special follow-up in the AOANJRR, so we also constructed plots and Cox regression analyses of the study group without this implant. Many medial pivot implant revisions in Australia were performed for patella erosion or pain alone. For this reason, we performed a sensitivity analysis for Australia excluding all revisions for these two diagnoses whenever the revision involved a secondary patella insertion only or patella insertion and exchange of the insert. For Australia, we also performed Cox regression analyses of the individual medial pivot implants, with the cruciate-retaining group as a control. Such an analysis was not possible for the implants reported in the NAR because of the low number of cruciate-retaining implants. All Cox regression analyses and Kaplan-Meier estimates are given with 95% CIs, the former always adjusted for age, gender, and preoperative diagnosis. SPSS® Statistics version 25 (IBM Corp, Armonk, NY, USA) and R version 3.5.3 (The R Foundation for Statistical Computing, Vienna, Austria) was used for the statistical analyses.

Results

Is There Any Difference in the Survival Rate Between Medial Pivot and Cruciate-retaining TKAs?

The medial pivot group had poorer survivorship than the cruciate-retaining group in Australia. After controlling for potential confounding variables such as age, gender and preoperative diagnosis, we found an increased HR for revision for any cause for medial pivot designs compared with cruciate-retaining TKAs in Australia (HR 1.4 [95% CI 1.2 to 1.7]; $p < 0.001$) but not in Norway (HR 1.5 [95% CI 0.9 to 2.4]; $p = 0.1$) (Table 3). The Fine and Gray analysis with death as the competing risk was identical [12]. In Australia, the Kaplan-Meier 9-year survival with revision for any cause was 94.8% (95% CI 93.4 to 96.3) for the medial pivot designs and 96.4% (95% CI 96.2 to 96.6) for cruciate-retaining TKAs (Fig. 2). In Norway, the corresponding survival for the medial pivot designs was 92.2%

Table 2. Number of implants by group and by brand in Norway and Australia

Medial pivot designs			Cruciate-retaining designs		
Medial pivot brands (n)	Norway	Australia	Cruciate-retaining brands (n)	Norway	Australia
GMK® Sphere	31	2122	Triathlon® CR	2519	25,604
Advance® MP	0	4	Legion® CR	2703	
Advance® II MP	216	492	NexGen® CR	11,094	19,378
MRK™	0	425	PFC® Sigma®		9572
SAIPH®	0	834	Total cruciate-retaining	16,316	54,554
Evolution® MP	51	2135			
Total medial pivot	298	6012			

Table 3. Cox HR revision for any cause (HR1) and lysis or loosening (HR2) comparing the control (ref.) and study groups in Norway and Australia

Group	Implant type	Total (n)	Revised for aseptic loosening n (%)	Median follow-up (years)	Kaplan-Meier 9-year all cause (95% CI)	p value[a]	At risk (n)	Kaplan-Meier 9-year loosening (95% CI)	p value[a]	At risk (n)	Cox HR1 (95% CI)	Cox HR2 (95% CI)
Norway												
Control[b]	Cruciate-retaining	16,316	43 (0.3)	2.7	94.5 (93.8 to 95.2)	0.1	418	99.5 (99.3 to 99.7)	0.001	2158	1 (ref.)	1 (ref.)
Study[c]	Medial pivot	298	5 (1.7)	5.0	92.2 (89.0 to 95.4)		7	97.7 (95.7 to 99.7)		195	1.5 (0.9 to 2.4)	4.7 (1.8 to 12.0)
Australia												
Control[d]	Cruciate-retaining	54,554	242 (0.4)	4.4	96.4 (96.2 to 96.6)	< 0.001	4186	99.4 (99.3 to 99.5)	0.3	4186	1 (ref.)	1 (ref.)
Study[e]	Medial pivot	6012	22 (0.4)	1.9	94.8 (93.4 to 96.3)		158	99.4 (98.3 to 99.5)		158	1.4 (1.2 to 1.7)	1.32 (0.8 to 2.2)

Both had 95% CIs and were adjusted for sex, age, and preoperative diagnosis.
[a]p values are based on Cox regression analyses.
[b]NexGen, Triathlon and Legend Study.
[c]GMK® Sphere, Advance® II MP and Evolution® MP. Control.
[d]NexGen® CR, Triathlon ® CR and PFC® Sigma®. Study.
[e]Advance® II MP, Evolution® MP, SAIPH®, MRK™ and GMK® Sphere.

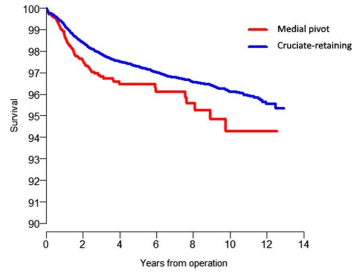

Fig. 2 This graph shows survival functions of the medial pivot and cruciate-retaining designs in Australia. Curves end when 20 patients are left at risk.

(95% CI 89.0 to 95.4) and for the cruciate-retaining it was 94.5% (95% CI 93.8 to 95.2) (Fig. 3). The Kaplan-Meier survival curves of Norway crossed at 1.7 years (Fig. 4A). The HR before this time point (0.5 [95% CI 0.1 to 2.1]; p = 0.4) and after (2.1 [95% CI 1.2 to 4.0]; p = 0.02) was therefore calculated (Fig. 4B).

Is There Any Difference in Survival Between the Different Medial Pivot Implants?

There were prosthesis-specific differences in revision rates (Table 4). In Australia, the Advance MP II had a higher all-cause revision than cruciate-retaining implants (HR 1.7 [95% CI 1.2 to 2.6]; p < 0.004) (Fig. 5A). The same was true for the GMK Sphere (HR 2.0 [95% CI 1.5 to 2.6]; p < 0.001) (Fig. 5B). There was no difference in the HRs of the Evolution MP (1.4 [95% CI 1.0 to 1.9]; p = 0.06) (Fig. 5C), the MRK (0.7 [95% CI 0.4 to 1.5]; p = 0.4) (Fig. 5D), and the SAIPH (0.9 [95% CI 0.5 to 1.5]; p = 0.7) (Fig. 5E). The Kaplan-Meier plot of the medial pivot in the AOANJRR, excluding the Advance MP II, showed an HR of 1.4 (95% CI 1.1 to 1.7; p < 0.001) (Fig. 6).

What Are the Main Reasons for Revision of Medial Pivot TKA?

In Norway, the most frequent reasons for revision in the medial pivot group were lysis or loosening (28%, five of 18), instability (28%, five of 18), malalignment (11%, two of 18) and pain alone (11%, two of 18), while in Australia, they were infection (27%, 39 of 142), pain alone (19%, 27 of 142), patella erosion (13%, 19 of 142) and loosening (12%, 17 of 142) (Table 5). By comparison, the reasons for revision in Norway for the cruciate-retaining group were infection (34%, 176 of 519), instability (19%, 97 of 519), malalignment (13%, 70 of 519), and pain alone (12%, 64 of 519). In Australia, pain alone (30%, 393 of 1324), infection (25%,

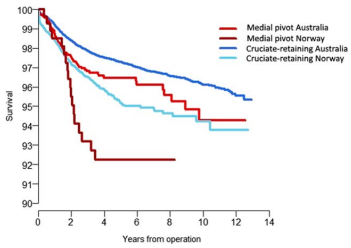

Fig. 3 This graph shows the survival function of the medial pivot and cruciate-retaining designs in Norway and Australia. Curves end when 20 patients are left at risk.

333 of 1324), lysis or loosening (15%, 199 of 1324) and patella erosion (10%, 130 of 1324) were the most frequent reasons for revision in the control group. The sensitivity analysis did not affect the HR for Australia (HR 1.5 [95% CI 1.2 to 1.9]; $p < 0.001$) (Fig. 7). Stratified by the reasons for revision, for Australia, we found there was an increased risk of revision in the medial pivot group for malalignment (HR 4.9 [95% CI 1.9 to 12.5]; $p < 0.001$), instability (HR 1.9 [95% CI 1.1 to 3.4]; $p = 0.03$), and patella erosion (HR 2.2 [95% CI 1.4 to 3.6]; $p < 0.001$) (Table 6). In Norway, there was an increased risk for loosening or lysis (HR 4.7 [95% CI 1.8 to 12.0]; $p < 0.001$) (Table 3).

Discussion

Despite the increased usage of medial pivot implants as documented in international registries, no registry studies on this design as a group have been published to our knowledge. We therefore performed this large registry study to compare the survival of medial pivot TKAs with the most-used cruciate-retaining implants in Norway and Australia. Our main finding was that there was decreased Kaplan-Meier survival of the medial pivot designs compared with cruciate-retaining designs, although differences between individual brands existed.

Limitations

Our study has several limitations. First, because it was a national registry study, we cannot rule out selection bias, with the medial pivot design potentially chosen for a more active patient group. There were differences in gender distribution and preoperative diagnosis, but the Cox regression analysis adjusted for these differences. Second, although we adjusted for the preoperative diagnosis, we did not have any information about the severity of osteoarthritis or extent of preoperative malalignment. In the AOANJRR [18], more than 23% of all TKAs were posterior-stabilized designs, which are often preferred for more difficult procedures [33]. Theoretically, the medial pivot could be used as a substitute for posterior-stabilized designs in such cases, and this might partly explain the difference in HR. Third, we did not adjust for hospital or surgeon volume. Because medial pivots are newer implants, there might be more of a learning curve than with the cruciate-retaining design. Fourth, there was an uneven distribution of prosthesis types between the countries. The difference between the Advance MP I and II was the locking mechanism of the tibial insert [13]. In Norway, almost all medial pivot implants were the Advance MP II.

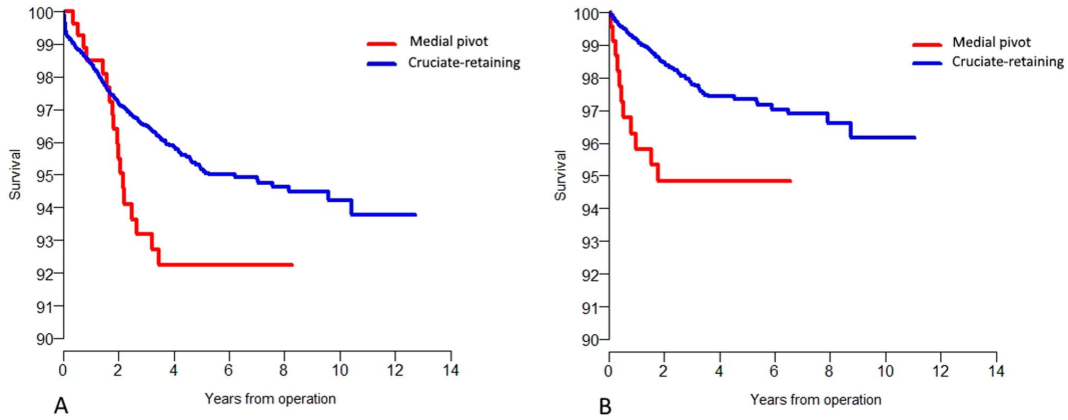

Fig. 4 **A-B** These graphs show (**A**) the survival function of the medial pivot and cruciate-retaining designs in Norway and (**B**) after crossing of the curves at 1.68 years. Curves end when 20 patients are left at risk

Table 4. Cox regression analyses comparing medial pivot brands to cruciate-retaining controls in Australia

Medial pivot brand	Cox HR[a] (95% CI)	p value	Cox HR[b] (95% CI)	p value	Kaplan-Meier[e] 3 years (95% CI)	Left at risk	Kaplan-Meier[e] 9 years (95% CI)	Left at risk	Median follow-up
Advance® II MP	1.7[d] (1.2 to 2.6)	0.004	1.2[d] (0.4 to 3.8)	0.7	96.2 (94.4 to 97.9)	413	93.5 (90.9 to 96.0)	202	7.9
MRK™	0.7[d] (0.4 to 1.5)	0.4	1.2[d] (0.3 to 4.9)	0.8	97.9 (96.5 to 99.4)	305	97.9 (96.5 to 99.4)	20	5.4
Evolution® MP	1.4[d] (1.0 to 1.9)	0.06	1.9[d] (0.9 to 4.1)	0.09	97.2 (96.2 to 98.1)	226			1.7
GMK® Sphere	2.0[d] (1.5 to 2.6)	< 0.001	1.6[d] (0.6 to 3.8)	0.3	95.9 (94.8 to 97.1)	289			1.5
SAIPH®	0.9[d] (0.5 to 1.5)	0.7			97.9 (96.7 to 99.1)	323			2.3

Hazard ratio by [a]revision for any cause and [b]lysis or loosening of medial pivot brands compared to minimally dtabilized (NexGen® CR, Triathlon® CR and PFC® Sigma®) ([d]reference HR = 1) controls in Australia. [e]Kaplan-Meier survival estimates for 3 and 9 years when 20 or more implants were left at risk.

As stated earlier, the Advance® MP I was reported to have an inferior performance in the AOANJRR [18], so if similar performance plagues the Advance MP II, this could affect the survival and HR of the medial pivot group in Norway. The lack of findings in the Norwegian data could, of course, be partly explained by the small number of medial pivoting implants. Fifth, this study considered only survivorship and did not include patient-reported outcome measures, which may be a more sensitive method of determining outcome differences and patient satisfaction. This was simply because we did not have this information. Furthermore, like most revision studies, the study does not account for those who may be candidates for revision, but who have too many comorbidities to undergo surgery or are awaiting surgery. Sixth, we only included TKAs with un-resurfaced patellae. This could affect the external

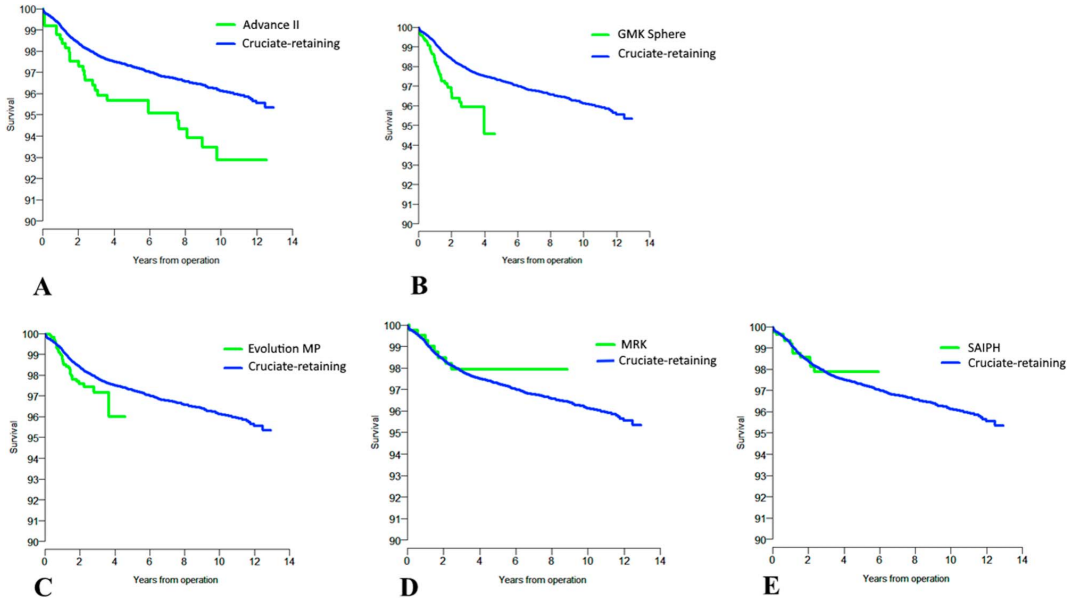

Fig. 5 These graphs show the survival function of the (**A**) Advance® II MP, (**B**) the GMK® Sphere, (**C**) the Evolution® MP, (**D**) the MRK™, and (**E**) the SAIPH® versus cruciate-retaining in Australia. Curves end when 20 patients are left at risk.

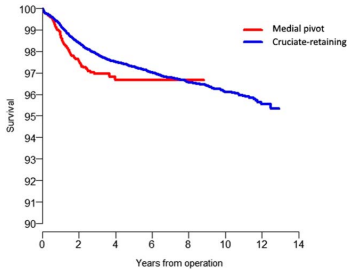

Fig. 6 This graph shows the survival function of the MP = medial pivot design, excluding the Advance® MP, versus cruciate-retaining design in Australia. Curves end when 20 patients are left at risk.

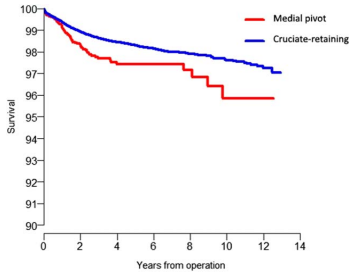

Fig. 7 This graph shows the sensitivity analysis for Australia. All revisions for "pain alone" and "patella erosion" and minor revision surgery for "patella only" or "patella/insert" combined were excluded before the Cox regression analysis. Curves end when 20 patients are left at risk.

validity of the study, but only in countries where resurfacing is done more or less by default for reasons stated earlier [14, 18, 33]. One study recently implied that postoperative retropatellar pressure is low in medial pivot implants [17], yet our study showed there is an increased risk for revision due to patellar erosion.

Is There Any Difference in the Survival Rate Between Medial Pivot and Cruciate-retaining TKAs?

Medial pivot implants have a higher revision risk than cruciate-retaining implants do in Australia for primary cemented TKAs without patella resurfacing. We found no such difference in Norway, and the confidence intervals were very wide. To our knowledge, there have been no larger registry or clinical studies on the medial pivot design TKA as a group. There was one smaller registry study [5], and one review article [13], but they assessed only the Advance MP and in a limited number of patients. Both studies concluded with excellent survival results. Furthermore, one other review article assessed medial pivot implants [44], but this also included primarily studies on the Advance MP. They compared the medial pivot design with non-medial stabilized design and were "unable to reach a clear conclusion in the clinical performance of medial stabilized knee replacement construct" [44]. Only three studies included in this review were not on the Advance MP, and only one was a high-quality study on the MRK™ [19]. Our study is to date the most comprehensive study on the matter, and therefore, we think it adds substantial knowledge to the field of interest; however, the results should be treated with caution because the follow-up period for most of the implants was short.

Table 5. Reason for revision of medial pivot and cruciate-retaining implants in Norway and Australia following the hierarchy of the AOANJRR

	Medial pivot		Cruciate-retaining	
Revision diagnosis	**Norway n = 298**	**Australia n = 6012**	**Norway n = 16,316**	**Australia n = 54,554**
Not revised (n)	280	5870	15,797	53,230
Total number revised (%)	18 (6)	142 (2)	519 (3)	1324 (2)
Infection	1 (6)	39 (27)	176 (34)	333 (25)
Malalignment	2 (11)	6 (4)	70 (13)	17 (1)
Loosening or lysis	5 (28)	17 (12)	43 (8)	199 (15)
Instability	5 (28)	13 (9)	97 (19)	97 (7)
Pain alone	2 (11)	27 (19)	64 (12)	393 (30)
Patella erosion[a]	0 (0)	19 (13)	3 (1)	130 (10)
Other[b]	3 (16)	21 (15)	66 (13)	155 (12)

Numbers in parentheses are the percentage of all revisions in each category.
[a]Patella erosion or progression of disease.
[b]Other means the remaining reasons for revision are not listed here; AOANJRR = Australian Orthopaedic Association National Joint Replacement Registry.

Is There Any Difference in Survival Between the Different Medial Pivot Implants?

In the analysis of individual implants, the Advance MP II and the GMK Sphere had a higher revision risk than the other implants, the latter at only 3 years of follow-up. The Evolution MP, the SAIPH, and the MRK, in contrast, have survival results similar to the three most-used cruciate-retaining implants in Australia. The SAIPH and the MRK had some revisions within the first 2 years of implantation, but no further revisions in the time frame studied, in contrast to the Advance MP II, the GMK Sphere and the Evolution MP. The latter three continue to have documented revision surgery after 2 years postoperatively (Fig. 5). The Advance MP I has

Table 6. Cox regression hazard ratios (95% CIs) of various causes of revision for medial pivot versus cruciate-retaining controls in Norway and Australia

	Norway[a]			Australia[a]		
Cause for revision	Cruciate retaining	Medial pivot	p value	Cruciate retaining	Medial pivot	p value
Number	16,316	298		54,554	6012	
Infection	0.3 (0.0 to 1.9)		0.2	1.3 (0.9 to 1.8)		0.1
Malalignment	1.0 (0.3 to 4.3)		1.0	4.9 (1.9 to 12.5)		< 0.001
Instability	2.1 (0.9 to 5.2)		0.1	1.9 (1.1 to 3.4)		0.03
Pain alone	1.4 (0.3 to 5.6)		0.7	1.0 (0.7 to 1.5)		1.0
Patellar erosion[b]	[c]		[c]	2.2 (1.4 to 3.6)		0.001

[a]Cruciate-retaining controls have HR = 1 for the various revision causes.
[b]Patellar erosion or disease progression.
[c]No operations for this indication were performed in Norway.

been shown to have a higher-than-anticipated revision rate [18], and we therefore excluded the Advance MP II from the Cox regression analysis. This did not affect the relative risk of the medial pivot as a group. One explanation for this could be that the total number of Advance MP II implants accounted for only 8% of the medial pivot implants used between 2005 and 2017, and thus had a relatively low impact on the overall results. There have been numerous studies on these individual implants. Some have suggested the in vivo kinematics of their design are like the native knee [38, 39], but some of the studies included very few patients [23, 37]. Smaller survivorship studies also show they have good-to-excellent survivorship [22] and patient satisfaction [34], but others report they do not have better functional results than other designs [43]. The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man (NJR) report excellent results of the MRK, and good results of the Advance MP. In their report they did not discriminate between Advance MP I and II [26]. Despite numerous studies on the design, ours is the first to document inferior results with the Advance MP II and the GMK Sphere. It therefore highlights a gap in the documentation on the different medial pivot implants because we do not know the reason why they perform differently. Further studies are thus necessary.

What Are the Main Reasons for Revision of Medial Pivot TKA?

The main reasons for revision in absolute numbers, in the medial pivot group in Norway were lysis or loosening, instability, malalignment, and pain alone. The total number of revisions was, however, very small. In Australia, the main reasons in absolute numbers were infection, pain alone, patella erosion, and loosening/lysis. Infection, loosening/lysis, and pain alone are frequent reasons for revision of cruciate-retaining implants in the AOANJRR as well. In terms of Kaplan-Meier survival, only patella erosion as a revision indication showed poorer survival. All of these are frequent and well-known reasons for TKA revision [14, 18, 31], although the main indications differ in other reports [40]. However, we documented a near fivefold risk of revision for malalignment, and a doubled risk of revision for instability in Australia for medial pivot designs compared with cruciate-retaining implants. Some reports indicate that medial pivot design improve patellofemoral biomechanics [1, 17, 42], possibly due to the lack of medial translation and the lateral femoral rollback [39]. However, other studies fail to report this [7]. We excluded all primary resurfaced patellar implants from our study, and therefore performed a sensitivity analysis to examine whether there was a change in the HR when we excluded secondary patella insertions combined with patella erosion or pain alone as revision indications. This did not affect the HR. We do not think that the status of the patella in terms of resurfacing affected the relative risk of revision for malalignment and instability. Therefore, it is likely that this finding applies for all medial pivot design TKA procedures, regardless of resurfacing. Although all the medial pivot implants in the study were cruciate-sacrificing, they still have no post-cam mechanism and are dependent on the medial femoral condyle resting snugly in the congruent insert for appropriate kinematics. If this is not achieved, instability might partially explain the higher revision risk due to patella erosion and subsequent increased forces on the patella. The medial congruency of these implants could in theory also lead to loosening [16, 41].

Conclusions

This large registry study that captured data from two countries between 2005 and 2017 showed that the medial pivot TKA design as a group had a higher revision rate than cruciate-retaining fixed-bearing controls in TKA

performed without patellar component resurfacing. By brand, the Advance II MP and the GMK Sphere had inferior survivorship, whereas the MRK, SAIPH and the Evolution MP had no differences in survivorship compared with cruciate-retaining controls. In Australia, TKAs with the medial pivot design without patella resurfacing had a higher rate of revisions for instability, malalignment, and patella erosion. In Norway, there was an increased risk of lysis and loosening compared with those with the cruciate-retaining design. Several of these implants had short follow-up in this study. Further registry studies with longer follow up are therefore necessary.

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III

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KNEE

Early migration of a medially stabilized total knee arthroplasty

A RADIOSTEREOMETRIC ANALYSIS STUDY UP TO TWO YEARS

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Aims

Medial pivot (MP) total knee arthroplasties (TKAs) were designed to mimic native knee kinematics with their deep medial congruent fitting of the tibia to the femur almost like a ball-on-socket, and a flat lateral part. GMK Sphere is a novel MP implant. Our primary aim was to study the migration pattern of the tibial tray of this TKA.

Methods

A total of 31 patients were recruited to this single-group radiostereometric analysis (RSA) study and received a medial pivot GMK Sphere TKA. The distributions of male patients versus female patients and right versus left knees were 21:10 and 17:14, respectively. Mean BMI was 29 kg/m² (95% confidence interval (CI) 27 to 30) and mean age at surgery was 63 years (95% CI 61 to 66). Maximum total point motions (MTPMs), medial, proximal, and anterior translations and transversal, internal, and varus rotations were calculated at three, 12, and 24 months. Patient-reported outcome measure data were also retrieved.

Results

MTPMs at three, 12, and 24 months were 1.0 mm (95% CI 0.8 to 1.2), 1.3 mm (95% CI 0.9 to 1.7), and 1.4 mm (0.8 to 2.0), respectively. The Forgotten Joint Score was 79 (95% CI 39 to 95) and Knee Injury and Osteoarthritis Outcome Score obtained at two years was 94 (95% CI 81 to 100), 86 (95% CI 75 to 93), 94 (95% CI 88 to 100), 69 (95% CI 48 to 88), and 81 (95% CI59 to 100) for Pain, Symptoms, Activities of Daily Living, Sport & Recreation, and Quality of Life, respectively.

Conclusion

In conclusion, we found that the mean increase in MTPM was lower than 0.2 mm between 12 and 24 months and thus apparently stable. Yet the GMK Sphere had higher migration at one and two years than anticipated. Based on current RSA data, we therefore cannot conclude on the long-term performance of the implant, pending further assessment.

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Keywords: TKA, Knee arthroplasty, Medial pivot, Medially stabilized, RSA, Contemporary knee designs, Contemporary knee arthroplasties, GMK Sphere

Introduction

Total knee arthroplasty (TKA) is a very common procedure for treating osteoarthritis of the knees in most countries, and incidence is expected to continue rising.[1,2] However, not all patients are satisfied after a TKA.[3] Several new implants have therefore been introduced to the market in recent decades, to meet patients' increasing functional demands. The medial pivot (MP) category was introduced in the 1990s to mimic the kinematics of the native knee.[4] The native knee is tight in the medial compartment, with a concave medial tibial plateau, and a circular medial femoral condyle fitting almost like a ball-on-socket. The lateral tibial plateau is rather flat. This, in addition to the laxity of the lateral collateral ligament (unlike the tightness of the medial collateral ligament), facilitates medial pivoting, lateral sliding, and a rolling motion of the joint during flexion and extension.[5,6] The first generation

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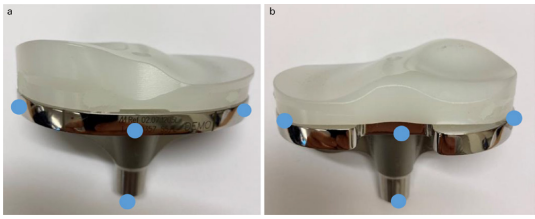

Fig. 1

a) Global Medacta Knee Sphere (GMK Sphere, anterior view) displaying the congruent medial and flat lateral parts of the insert designed to mimic the native knee motion during flexion and extension. Blue dots indicate position of feature points. b) The posterior view of the same implant displaying the congruent medial and flat lateral parts of the insert designed to mimic the native knee motion during flexion and extension.

Table I. Inclusion and exclusion criteria of the study.

Inclusion criteria
Patients with knee osteoarthritis
Exclusion criteria
Preoperative flexion contracture more than 15°
Preoperative limited range of motion under anaesthetics (less than 110°)
Less than 50 or more than 75 years of age at the time of surgery
Use of walking aids because of other musculoskeletal and neuromuscular problems
Preoperative diagnosis other than osteoarthritis and avascular necrosis (e.g. rheumatoid arthritis, tumours)
Revision arthroplasty
Obesity with BMI > 35
Impaired collateral ligaments
Postoperative revision surgery due to deep wound infection

of MPs consisted of The Medial Rotation Knee (1994, MRK; MatOrtho, UK) and the Advance Medial-Pivot Knee (1998, Wright Medical Group, USA).[7–9] A second generation was later introduced with the SAIPH Knee System (2009, Matortho), Evolution Medial-Pivot Knee (2010, MicroPort Orthopaedics, USA), and the Global Medacta Knee Sphere (GMK Sphere) (2011, Medacta International, Switzerland)[10–12] (Figures 1a and 1b). The latter uses an ultra high molecular weight polyethylene (UHMWPE) insert,[13] made from Granular-UHMWPE-Ruhrchemie (GUR) 1020 and sterilized with ethylene oxide (EtO).[14] Several smaller studies have shown good clinical results in terms of function, kinematics, and longevity of these implants.[15–18] Our primary aim was to assess the migration pattern of the tibial tray of the GMK Sphere using radiostereometric analysis (RSA), and to compare this with previously known limits of safe migration patterns with respect to aseptic loosening. Secondary aims included wear, alignment, and clinical performance.

Methods

A single series of 31 consecutive patients was recruited at Oslo University Hospital, Ullevaal, Oslo, Norway. The study protocol is shown in Table I and Figure 2. All patients received a cemented GMK Sphere TKA using Refobacin Bone Cement R (Zimmer Biomet, USA). One of two experienced surgeons performed all surgeries between April 2016 and February 2018. All patients underwent the same operative procedure and postoperative protocol including a medial parapatellar approach, without tourniquets. During surgery, five to eight tantalum 1 mm beads (RSA Biomedical, Sweden) were inserted in tibial bone with a fair geometrical spread.

Clinical evaluation. Baseline data such as age, sex, and BMI were retrieved. For clinical assessment, we used the Knee Injury and Osteoarthritis Outcome Score (KOOS)[19] at baseline and all timepoints. The Forgotten Joint Score 12 (FJS-12)[20] was retrieved at three and 24 months postoperatively. Degrees of flexion and valgus/varus alignment were recorded postoperatively using a manual goniometer. All complications were accounted for.

Conventional radiology. All patients had preoperative plain standing radiographs, including the hip-knee-ankle (HKA) exposures. These were repeated at three months postoperatively, together with a CT scan of the artificial joint. Valgus and varus knee angles were defined as positive and negative values respectively. Tibial tray rotation was evaluated using Berger's method.[21]

RSA. Supine RSA radiographs were taken postoperatively within a week and thus before discharge, and at three, 12, and 24 months using fixed ceiling-mounted x-ray tubes (Proteus XR/A, GE Healthcare, USA and Canon Triathlon T3, Japan) and knee cage number 10 (UmRSA; RSA Biomedical). All patients had double RSA examinations once for precision purposes. All RSA images were analyzed using RSAcore (v. 4.1, the Netherlands) Model Based RSA software. The first author analyzed all images and migration was reported for translations and rotations in all planes, feature point motions, as well as maximum total point motion (MTPM). Left-sided RSA knees were converted to right-sided by multiplying the segmental x-translations and y-z-rotations by a factor of -1,[22,23] while x-, y-, and z-translations and rotations were reported with signed values and categorized as medial, proximal, and anterior translations and transversal, internal, and varus rotations, respectively.

Our upper limits for condition number (CN) and mean error (ME) were 120 and 0.35 respectively.[22,23] Computer-aided design models (CAD) of both femoral and tibial components for all sizes were obtained from the manufacturer. They were implemented in the RSAcore software with the feature points positioned as anteriorly, medially, laterally, posteriorly, tip (all tibia model), and centre of the medial condyle (femoral model only) (Figures 1a and 1b). Feature point translations of the tibia were calculated. The change in sagittal distance of the centre of the femoral condyle and medial tibia feature points over time was calculated in terms of wear of the polyethylene of the

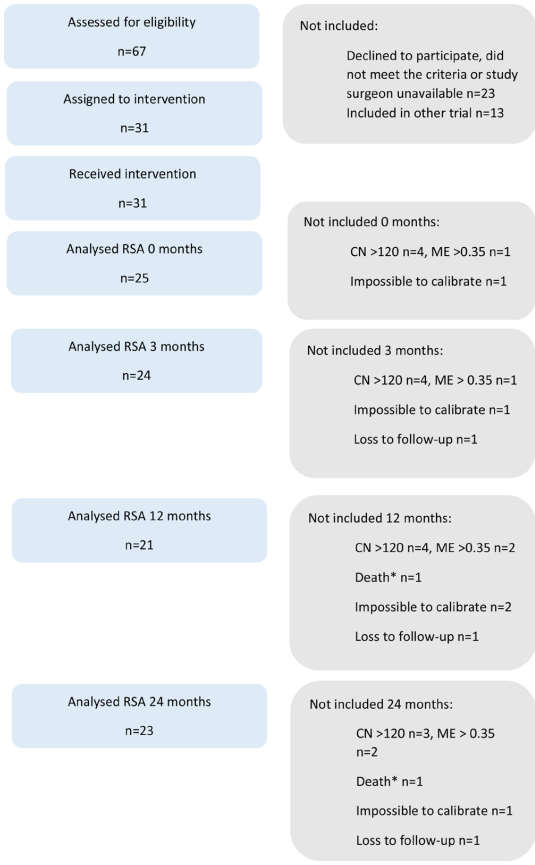

Fig. 2

Flow chart of the study. *Unrelated to the study; this patient already had condition number (CN) > 120. ME, mean error; RSA, radiostereometric analysis.

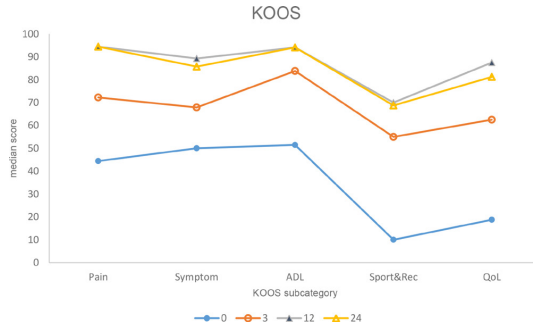

Fig. 3

Median Knee injury and Osteoarthritis Outcome Score (KOOS) from baseline to 24 months. ADL, activities of daily living, QoL, quality of life.

medial part of the insert. As the RSA radiographs were performed in supine position, only implants regarded as stable in the mediolateral direction, i.e. < 5° movement in any position, were included in this analysis.[24]

Statistical analysis. We used SPSS for Windows v. 25 (IBM, USA) for statistical analysis. Data were normally distributed unless otherwise stated and presented with means and 95% confidence intervals (CIs). When appropriate, a paired *t*-test was used, presenting p-values with a significance level < 0.05. Non-normally distributed data were presented with median and interquartile range (IQR), and p-values calculated using the Wilcoxon signed-rank test.

We regarded a within-group change of 0.2 mm in MTPM from 12 to 24 months as clinically relevant.[25] With an α of 0.05 and a power of 80% and the assumption of a standard deviation (SD) of 0.3, we calculated that we needed a minimum of 20 patients.[26] To account for loss to follow-up and the exclusion of some patients, we originally included 30 patients. One patient died unrelated to the study within one year, so one extra patient was included.

Precision of the RSA analyses was reported as SDs of the absolute mean of the difference of repeated measurements with 95% CI and thus reported as SD 1.96.[23]

Table II. Demographic data.

Variable	Total
Total, patients (knees)	31 (31)
Sex, M:F	21:10
Side, R:L	17:14
Smokers, n	6
Mean BMI, kg/m² (95% CI)	29 (27 to 30)
Mean age, yrs (95% CI)	63 (61 to 66)
Mean operation time, mins (95% CI)*	118 (114 to 124)
Mean LOS, days (95% CI)	4.0 (3.6 to 4.3)

*Data missing for one patient.
CI, confidence interval; LOS, length of stay.

Results

Clinical evaluation. Table II shows patient demographics. KOOS improved from preoperatively to two years and FJS-12 from three months to two years (Table III and Figure 3). KOOS scores of patients identified as high-risk, based on the RSA analyses, are shown in Table IV. There was no difference in flexion of the knees from preoperatively to two years (Table V).

Conventional radiology. Mean preoperative and postoperative HKA angles were -6° (95% CI -8.5 to -3) and -1° (95% CI -2.3 to -0.25) respectively (p < 0.001, paired *t*-test). Mean postoperative tibial rotation using the Berger technique[21] was 15.1° (5% CI 12.0 to 18.1).

RSA. Precision calculated by repeated RSA examinations is displayed in Table VI. The mean difference and SD of MTPM were 0.01 and 0.39 respectively. Because not all of these were suitable for analysis, the total number of double examinations was only 14. The mean CN and ME

Table III. Patient-reported outcome measures.

PROM	Preop median (IQR)	3-mth median (IQR)	1-yr median (IQR)	2-yr median (IQR)	Ceiling effect %*	p-value†
KOOS						
Pain	44 (33 to 56)	72 (64 to 97)	94 (74 to 100)	94 (816 to 100)	38	< 0.001
Symptoms	50 (46 to 64)	68 (57 to 84)	89 (6 to 93)	86 (75 to 93)	3	< 0.001
ADL	52 (34 to 59)	84 (64 to 96)	94 (82 to 100)	94 (88 to 100)	8	< 0.001
Sport&Rec	10 (5 to 26)	55 (36 to 75)	70 (55 to 82)	69 (48 to 88)	3	< 0.001
QoL	189 (13 to 31)	63 (47 to 78)	88 (63 to 97)	81 (59 to 100)	38	< 0.001
FJS-12	N/A	60 (27 to 83)	N/A	79 (39 to 95)	10%	0.002

*Ceiling effect at two years.
†Wilcoxon signed-rank test comparing change from preoperative to two years.
ADL, activities of daily living; FJS, Forgotten Joint Score; IQR, interquartile range; KOOS, Knee injury and Osteoarthritis Outcome Score; N/A, not applicable.

Table IV. Clinical and radiological data of high-risk patients. preoperative and postoperative hip-knee-ankle angle and CT rotation (Berger) > 18° means that the implant is internally rotated. Varus and valgus knee hip-knee-ankle angles defined as negative and positive values, respectively.

Patient	Pain	Symptoms	ADL	Sport & Recreation	QoL	Preop HKA, °	Postop HKA, °	CT rotation, °
10	64	54	87	60	44	0.1	6.2	29.6
11	47	39	51	5	38	-7.4	-1.8	11.6
20	100	100	97	90	10	-9.7	-1.7	23.1
25	89	100	92	83	100	12.4	1.6	14.3
28	100	89	100	95	100	-7.2	1.6	9.4
38	100	75	100	90	100	-6.0	-2.7	3.6

ADL, activities of daily living; HKA, hip-knee-ankle angle; QoL, quality of life.

Table V. Flexion from preoperatively to two years.

Variable	n	Preop mean, ° (95% CI)	3mth mean, ° (95% CI)	1-yr mean, ° (95% CI)	2-yr mean, ° (95% CI)	p-value*
Flexion	29	123 (118 to 128)	115 (109 to 120)	122 (119 to 127)	120 (117 to 124)	0.250

*Paired *t*-test comparing change from preoperative to two years.
CI, confidence interval.

Table VI. Migration, rotation, and wear of GMK Sphere.

Variable	3mths	1 yr	2 yrs	Precision
Mean MTPM, mm (95% CI)	1.00 (0.78 to 1.21)	1.30 (0.94 to 1.67)	1.40 (0.84 to 1.96)	0.01 (0 to 0.77)
Translation, mm (95% CI)				
Medial	0.01 (-0.08 to 0.09)	0.04 (-0.13 to 0.21)	0.05 (-0.14 to 0.24)	0.01 (-0.18 to 0.20)
Proximal	-0.03(-0.10 to 0.04)	-0.03(-0.16 to 0.1)	-0.10(-0.34 to 0.13)	0.03 (-0.07 to 0.13)
Anterior	0.04 (-0.16 to 0.23)	-0.01(-0.24 to 0.21)	0.06 (-0.11 to 0.22)	0.00 (-0.41 to 0.41)
Rotation,°(95% CI)				
Transversal	0.09 (-0.19 to 0.38)	-0.10(-0.33 to 0.12)	-0.32(-0.80 to 0.15)	0.04 (-0.97 to 1.04)
Internal	-0.37 (-0.71 to 0.02)	0.04 (-0.57 to 0.66)	-0.39(-0.81 to 0.03)	0.06 (-1.19 to 1.3)
Varus	0.09 (-0.08 to 0.26)	0.09 (-0.21 to 0.39)	0.16 (-0.45 to 0.78)	0.01 (-0.24 to 0.27)
Median wear, mm (IQR)	0.03 (-0.23 to 0.21)	-0.13(-0.48 to 0.25)	0.09 (-0.10 to 0.55)	0.116*

*Wilcoxon signed-rank test comparing change in wear from three to 24 months.
CI, confidence interval; IQR, interquartile range; MTPM, maximum total point motion.

for all examinations were 63.8 and 0.15. Segmental rotations and translations and mean and individual MTPMs are seen in Table VI and Figure 4 respectively. The mean MTPM increased the most before three months and towards one year. Subsequently, it seems stable. Otherwise, segmental mean translations and rotations all seem to be within the range of their respective precisions. The wear data are also shown in Table VI.

Four of the patients had a higher than anticipated migration or transversal rotation (Table VII).

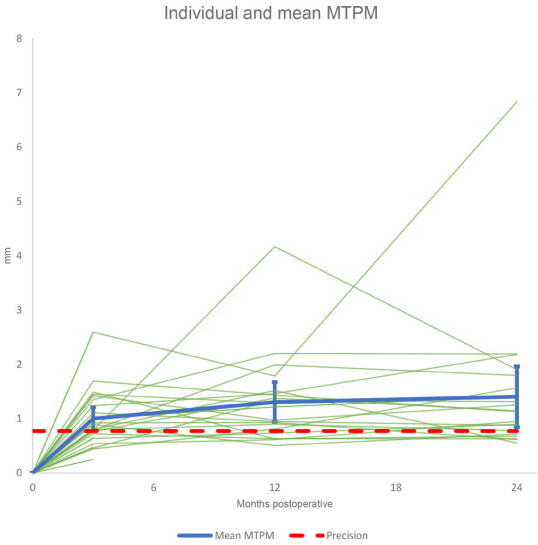

Fig. 4

Individual and mean maximum total point motions (MTPMs) with error bars showing 95% confidence intervals.

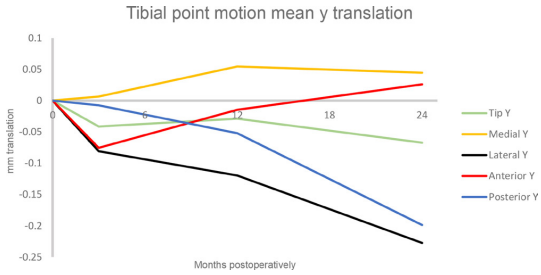

Fig. 5

Peripheral distal and proximal sagittal translations of the different feature points over time.

Table VII. High-risk patients qualifying based on Ryd et al[25] or Gudnason et al.[27]

Thresholds	10*	11	20	25	28	38
> 0.2 mm 12 to 24 months†	X		X	X		X
Transversal rotation 24 months‡	X					
Peripheral distal translation > 0.6 mm‡	X	X	X		X	X
Peripheral proximal translation > 0.9 mm‡	X				X	

*Revised after 32 months.
†Based on Ryd et al.
‡Based on Gudnason et al.

Sagittal point movement of the tibial tray is depicted in Figure 5. An analysis of the peripheral distal or proximal translations did not reveal any specific migration pattern. However, we identified five implants with peripheral distal or proximal translation above 0.6 mm or 0.9 mm respectively (Table VII).[27]

Adverse events. One death occurred within one year, not study-related. One patient was revised due to aseptic loosening.

Discussion

Our main finding is that this implant migrated initially and then stabilized after three to 12 months. This concurs with the literature on early migration of cemented implants.[25] A MTPM of 1.3 mm at 12 months puts the implant in the "at risk" category of Pijls et al.[28] In our study, based on the one-year MTPM results, we cannot state whether there is a higher or lower risk of revision due to aseptic loosening of 5% at ten years.[28] However, several implants with good long-term survivorship also fall into this category.[29,30]

Segmental motion, measuring the movement of the centre of the implant, often underestimates real migration. Peripheral feature points (Figure 1) give a better impression of the real implant movement as the dominant failure mechanism for tibial baseplates is tilting (rotation) rather than general subsidence.[31] Furthermore, we could identify some individual high-risk implants based on previous studies by Ryd et al,[25] using the strict continuous migration criteria, and by Gudnason et al,[27] using the transversal rotation or proximal or distal peripheral translation of the feature points of the tibial tray. One of these implants was revised due to aseptic loosening of the tibial tray 32 months after surgery (Patient 10). The postoperative HKA angle of this patient revealed a valgus alignment of 6°. We therefore attribute the failure to surgical reasons rather than implant-related reasons. Another characteristic feature of the patients with high-risk implants was inferior clinical scores (Patient 11). This implant was well aligned in the coronal plane but was 7° externally rotated on the CT scan. This would probably not cause any clinical problems.[32] The other patients had excellent KOOS scores at two years, implying no symptoms of aseptic loosening. Nevertheless, we know from the literature that symptoms of loose implants can take up to ten years to become apparent.[25]

It has been debated whether the use of a tourniquet is important for good fixation of implants. Several RSA studies have, however, proven that this is not the case.[33–35] Another explanation of the somewhat high MTPM could be the cement used in the study. Refobacin Bone Cement R has been used for several years at our hospital, and several studies including registry and RSA studies suggest that this cement gives good fixation and long-term survivorship.[36–38] The GMK Sphere has a shorter but wider wing of the keel than for instance the NexGen CR (Zimmer Biomet) and the Triathlon CR (Stryker, USA), both known for their excellent survivorship.[39] In theory, this could increase the rotation of the implant. We found that the mean internal and transversal rotation of the

implant is lower than the precision measured by double examinations, so we conclude that for that rotation it is unlikely.

It has been stated that the combination of early and continuous migration defines a specific migration pattern of each implant.[40] Most cemented implants seem to have a migration pattern with a lower mean MTPM than the GMK Sphere.[41] A recent study by van Hamersveld et al[42] shows, however, that PS implants have a migration pattern with a higher mean MTPM than CR implants. MP implants are actually constrained implants medially. No authors have studied their natural migration pattern, but they may have a higher initial migration before stabilizing. If so, this could partly explain the somewhat higher migration found in the current data.

Several studies indicate good mid- to long-term results of medial pivot implants.[16,43] One review article found similar or even better survivorship of the Advance MP, compared to other TKAs.[44] Another article found no difference in survivorship at 13 years between MP and central mobile-bearing TKAs.[45] In a recent review article, Cacciola et al[46] found that primary MP implants in general provide overall mid-term survivorship comparable to standard cruciate-retaining and posterior-stabilized implants, according to the available data, and yield better high-end function than standard implants.

Most studies on the GMK Sphere focus on the implant's kinematics,[47,48] rather than survival. We did, however, publish a registry study in 2020 on implants from the Norwegian Arthroplasty Registry and the Australian Orthopaedic Association National Joint Arthroplasty Registry (AOANJRR).[49] In that study we found a hazard ratio (HR) of 2.0 (95% CI 1.5 to 2.6; $p < 0.001$) for revision of any cause of the GMK Sphere compared to the three most used minimally stabilized TKAs in the AOANJRR. There was also a higher HR for revision of the MP category due to malalignment, instability, and patella erosion in the AOANJRR, but we could not stratify this by brand.

Although our study is not powered to evaluate clinical results, the scores on the FJS[50] and KOOS[30,51] are consistent with other TKAs. The polyethylene wear over two years was not clinically relevant ($p = 0.116$, Wilcoxon signed-rank test).

According to the registries, the GMK Sphere has a cumulative five-year all-cause revision rate of 3.5% (95% CI 3.0 to 4.0) and 3.1% (95% CI 2.1 to 4.6) in the AOANJRR[52] and the National Joint Registry[53] respectively. This is higher than the < 3% revision thresholds set by the registries,[28] and could be supported by our findings.

We did not find any static RSA studies on any implant from the MP design nor the GMK Sphere. Since this design has been on the market for over two decades, this is somewhat surprising. We agree with previous scholars that there should have been a phased or stepwise introduction of novel implants to the market.[40,54,55] This study therefore fills a significant gap of knowledge in the literature.

One weakness is the number of patients included, as the small number does not account for the random distribution in the baseline data in the general population. This could affect the external validity of the study. RSA studies are costly, yet provide high precision.[22] Our power calculation shows that the number of implants is sufficient to study the migration of the implant over time, as do several other previously published RSA studies.[22,26] Although we had some dropouts, the final number of patients was sufficient with respect to the power calculation at all timepoints. Because our RSA radiographs were taken in supine position, and thus without weightbearing, we could only use the images in patients with knees regarded as stable in the mediolateral direction to assess polyethylene wear. The study by van Ijsseldijk et al[24] suggests that this could be done, as they found no difference in wear between non-weightbearing examinations of stable knees and weightbearing examinations.

This study has several strengths. Firstly, we assessed both the MTMP and all six degrees of freedom, which complies with the ISO standard.[23] Secondly, because of the feature points in the CAD models, we could study the peripheral point motions of the implants. We could thus identify implants at risk of mechanical loosening that would otherwise be regarded as stable. Thirdly, all the surgeries were performed by two experienced surgeons only. Given that this is a novel implant, with an anticipated learning curve, we believe this is a strength. Fourthly, numerous RSA studies have been published from this hospital.[56–58] The staff are therefore experienced in using RSA technology.

In our study, one of 31 patients showed a clear migration pattern for mechanical loosening and was revised. This was probably due to non-implant-specific technical difficulties during the primary surgery, and we believe that the malalignment of the implant was a possible reason for early loosening.[59]

In conclusion, we found that the mean increase in MTPM was lower than 0.2 mm between 12 and 24 months and thus seems stable. However, the GMK Sphere had a higher total migration at one and two years than anticipated. Based on current RSA data, we therefore cannot conclude on the long-term performance of the implant, pending further assessment.

Take home message

- The GMK Sphere showed good clinical scores, but had a higher short-term migration than anticipated.
- Based on the radiostereometric analysis data we cannot conclude on the long-term performance yet, pending further assessment.

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Appendix

Bergen 15 May 2007

Norwegian KOOS, version LK1.0

The KOOS form was translated into Norwegian in the following way.

Translation done at The Norwegian Arthroplasty Register (NAR)

- KOOS was translated from the Swedish version by two researchers in orthopedics. The choice of using the Swedish version was based on the assumption that cultural differences between the two neighbour countries would be minimal due to similarities in language and lifestyle.
- The translation was checked by two bilingual orthopedic surgeons (Swedes with permanent address in Norway).
- The form was tested on knee arthroplasty patients to clarify potential misinterpretations.

Translation done by The Norwegian National Knee Ligament Registry (NKLR)

- A translation from the English version was done by an orthopedic researcher.
- Another translation from the Swedish version was done by a former researcher at the Norwegian School of Sport Sciences who is bilingual in Norwegian and Swedish.
- The translations were compared, and due to only minor differences in the use of synonyms, the NKLR chose a wording as close to the Swedish translation as possible. This is due to the fact that the creators of the KOOS form are Swedish, even though the first form was made in English.

Finally the NAR and the NKLR versions were compared, minor adjustments were done, and the translators agreed upon a common translation. The final validated Norwegian version is named KOOS Norwegian version LK1.0

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KOOS – SPØRRESKJEMA FOR KNEPASIENTER

DATO: _____/_____/_____ FØDELSENR (11 siffer): _____

NAVN: _____

Veiledning: Dette spørreskjemaet inneholder spørsmål om hvordan du opplever kneet ditt. Informasjonen vil hjelpe oss til å følge med i hvordan du har det og fungerer i ditt daglige liv. Besvar spørsmålene ved å krysse av for det alternativ du synes passer best for deg (kun ett kryss ved hvert spørsmål). Hvis du er usikker, kryss likevel av for det alternativet som føles mest riktig.

Symptom

Tenk på de **symptomene** du har hatt fra kneet ditt den **siste uken** når du besvarer disse spørsmålene**.**

S1. Har kneet vært hovent?

Aldri	Sjelden	I blant	Ofte	Alltid
☐	☐	☐	☐	☐

S2. Har du følt knirking, hørt klikking eller andre lyder fra kneet?

Aldri	Sjelden	I blant	Ofte	Alltid
☐	☐	☐	☐	☐

S3. Har kneet haket seg opp eller låst seg?

Aldri	Sjelden	I blant	Ofte	Alltid
☐	☐	☐	☐	☐

S4. Har du kunnet rette kneet helt ut?

Alltid	Ofte	Iblant	Sjelden	Aldri
☐	☐	☐	☐	☐

S5. Har du kunnet bøye kneet helt?

Alltid	Ofte	I blant	Sjelden	Aldri
☐	☐	☐	☐	☐

Stivhet

De neste spørsmålene handler om **leddstivhet**. Leddstivhet innebærer vanskeligheter med å komme i gang eller økt motstand når du bøyer eller strekker kneet. Marker graden av leddstivhet du har opplevd i kneet ditt den **siste uken**.

S6. Hvor stivt er kneet ditt når du nettopp har våknet om morgenen?

Ikke noe	Litt	Moderat	Betydelig	Ekstremt
☐	☐	☐	☐	☐

S7. Hvor stivt er kneet ditt **senere på dagen** etter å ha sittet, ligget eller hvilt?

Ikke noe	Litt	Moderat	Betydelig	Ekstremt
☐	☐	☐	☐	☐

Smerte

P1. Hvor ofte har du vondt i kneet?

Aldri	Månedlig	Ukentlig	Daglig	Hele tiden
☐	☐	☐	☐	☐

Hvilken grad av smerte har du hatt i kneet ditt den **siste uken** ved følgende aktiviteter?

P2. Snu/vende på belastet kne

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

P3. Rette kneet helt ut

Ingen	Lett	Moderate	Betydelig	Svært stor
☐	☐	☐	☐	☐

P4. Bøye kneet helt

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

P5. Gå på flatt underlag

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

P6. Gå opp eller ned trapper

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

P7. Om natten i sengen (smerter som forstyrrer søvnen)

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

P8. Sittende eller liggende

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

P9. Stående

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

Funksjon I hverdagen

De neste spørsmål handler om din fysiske funksjon. **Angi graden av vanskeligheter du har opplevd den siste uken ved følgende aktiviteter på grunn av dine kneproblemer**.

A1. Gå ned trapper

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A2. Gå opp trapper

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

Angi graden av **vanskeligheter** du har opplevd ved hver aktivitet den **siste uken**.

A3. Reise deg fra sittende stilling

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A4. Stå stille

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A5. Bøye deg, f.eks. for å plukke opp en gjenstand fra gulvet

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A6. Gå på flatt underlag

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A7. Gå inn/ut av bil

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A8. Handle/gjøre innkjøp

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A9. Ta på sokker/strømper

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A10. Stå opp fra sengen

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A11. Ta av sokker/strømper

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A12. Ligge i sengen (snu deg, holde kneet i samme stilling i lengre tid)

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A13. Gå inn og ut av badekar/dusj

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A14. Sitte

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A15. Sette deg og reise deg fra toalettet

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

Angi graden av **vanskeligheter** du har opplevd ved hver aktivitet den **siste uken.**

A16. Gjøre tungt husarbeid (måke snø, vaske gulv, støvsuge osv.)

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

A17. Gjøre lett husarbeid (lage mat, tørke støv osv.)

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

Funksjon, sport og fritid

De neste spørsmålene handler om din fysiske funksjon. Angi graden av vanskeligheter du har opplevd **den siste uken** ved følgende aktiviteter på grunn av dine kneproblemer.

SP1. Sitte på huk

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

SP2. Løpe

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

SP3. Hoppe

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

SP4. Snu/vende på belastet kne

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

SP5. Stå på kne

Ingen	Lett	Moderat	Betydelig	Svært stor
☐	☐	☐	☐	☐

Livskvalitet

Q1. Hvor ofte gjør ditt kneproblem seg bemerket?

Aldri	Månedlig	Ukentlig	Daglig	Alltid
☐	☐	☐	☐	☐

Q2. Har du forandret levesett for å unngå å overbelaste kneet?

Ingenting	Noe	Moderat	Betydelig	Fullstendig
☐	☐	☐	☐	☐

Q3. I hvor stor grad kan du stole på kneet ditt?

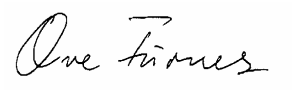
Fullstendigl	I stor grad	Moderat	Til en viss grad	Ikke i det hele tatt
☐	☐	☐	☐	☐

Q4. Generelt sett, hvor store problemer har du med kneet ditt?

Ingen	Lette	Moderate	Betydelige	Svært store
☐	☐	☐	☐	☐

Takk for at du tok deg tid og besvarte samtlige spørsmål!

Until otherwise is decided it is recommended that future revisions of the Norwegian KOOS form are done by The Norwegian Arthroplasty Register. If someone find that any questions from the questionnaire is difficult to understand or difficult to answer, we will be thankful to receive information on this.



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FJS-12 skår

Forgotten Joint Score (FJS), Norwegian version

De 12 spørsmålene nedenfor dreier seg om i hvilken grad du legger merke til det kunstige hofteleddet ditt i hverdagen. Kryss av ett svar for hvert spørsmål.

Legger du merke til det kunstige leddet…

1. …når du ligger i sengen om natten?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

2. …når du sitter på/i en stol i mer enn 1 time?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

3. …når du går i mer enn 15 minutter?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

4. …når du tar et bad eller en dusj?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

5. …når du reiser med bil?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

6. …når du går opp en trapp?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

7. …når du går på ujevnt underlag?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

8. …når du reiser deg opp fra en lav sittestilling?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

9. …når du står i lengre perioder?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

10. …når du gjør husarbeid eller hagearbeid?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

11. …når du går på tur?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

12. …når du driver med treningsaktiviteten som du liker best?

Aldri	Nesten aldri	Sjelden	Av og til	Som oftest
☐	☐	☐	☐	☐

Skåring:

Alle svarene summeres (aldri - 0 poeng, nesten aldri - 1 poeng, sjelden - 2 poeng, av og til - tre poeng, som oftest - 4 poeng). Summen divideres deretter på antall besvarte spørsmål. Gjennomsnittsverdien multipliseres med 25 for å oppnå en skår mellom 0 og 100. Til slutt subtraheres skåren fra 100, for å endre retningen slik at høy score indikerer en høy grad av å "glemme" det kunstige leddet, det vil si lav grad av å legge merke til det.

Total skår = 100 - ((Sum av spørsmålene / antall besvarte spørsmål) x 25)

Dersom mer enn 4 svar mangler, bør ikke total skår beregnes/ brukes.

Forgotten Joint Score Questionnaire (H. Behrend et al 2011). Oversatt av VP. Moen et al, Helse Bergen HF, 2014

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