On Patellofemoral Joint Replacement

Clinical, Radiological, and Numerical Studies

Hans-Peter W. van Jonbergen

The printing and distribution of this thesis was financially supported by:
Arthrex Nederland BV, Astra Tech Benelux BV, Bauerfeind Benelux BV,
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De Orthopedische Schoenmakerij, DePuy Johnson & Johnson Medical BV,
Deventer Orthopedie Techniek, Deventer Ziekenhuis, Link Nederland,
Mathys Orthopaedics BV, Nederlandse Orthopaedische Vereniging,
Otto Bock Benelux BV, Reumafonds, Smith & Nephew BV, Synthes BV.

Cover: Furtwängler Glacier 2004
Cover and layout by: In Zicht Grafisch Ontwerp, www.promotie-inzicht.nl
Printed by: Ipskamp Drukkers, www.ppi.nl

ISBN: 978-90-9025917-8

On Patellofemoral Joint Replacement

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Een wetenschappelijke proeve op het gebied van
de Medische Wetenschappen

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. mr. S.C.J.J. Kortmann,
volgens besluit van het college van decanen
in het openbaar te verdedigen op
donderdag 14 april 2011
om 15.30 uur precies

door

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geboren op 1 juli 1967
te Laren (N-H)

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'Because it's there.'

George Leigh Mallory, 1923

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Introduction and aims

Background

The three compartments of the knee joint allow for seven possible patterns of osteoarthritis. Isolated patellofemoral, isolated medial femorotibial, and combined medial femorotibial and patellofemoral osteoarthritis have been identified as the most common patterns in patients with knee complaints (McAlindon et al. 1992, Davies et al. 2002). The reported radiological prevalence of isolated patellofemoral osteoarthritis varies between 4% and 24%, the prevalence of clinically important isolated patellofemoral osteoarthritis is not known (Barrett, Jr. et al. 1990, McAlindon et al. 1992, Davies et al. 2002). Three etiological groups of patellofemoral osteoarthritis are recognised: posttraumatic patellofemoral osteoarthritis, patellofemoral osteoarthritis with a history of patellofemoral instability, and primary patellofemoral osteoarthritis (Argenson et al. 1995).

Mild isolated patellofemoral osteoarthritis is significantly associated with pain, stiffness, and functional limitation (Hunter et al. 2003, Duncan et al. 2009). The diagnosis is based on a typical history of anterior knee pain after prolonged sitting or upon rising from a chair, and pain when descending and ascending stairs. The pain is characteristically less severe when walking on level ground. Clinical findings are not specific, and include quadriceps wasting, pain, and crepitus emanating from the anterior compartment (Iwano et al. 1990, Donell and Glasgow 2007). Findings of patellofemoral instability are common. The radiological findings include patellofemoral joint space narrowing and osteophyte formation on lateral and axial (skyline) knee radiographs, chondral lesions and subchondral changes on magnetic resonance imaging (MRI) studies, and increased uptake on technetium-99m bone scans (Boegard et al. 1998, Leadbetter et al. 2005, McDonnell et al. 2009).

Initially, patients with isolated patellofemoral osteoarthritis can be treated with a nonoperative approach, such as activity modification, weight loss, oral and intra-articular medications, and physical therapy, although it is unclear which specific conservative treatment should be recommended (Donell and Glasgow 2007). A multitude of operative treatment modalities have been used in patients with disabling complaints unresponsive to non-surgical treatment (Saleh et al. 2005, Grelsamer and Stein 2006). These modalities include partial lateral facetectomy, distal realignment procedures, lateral retinacular release, patellectomy, and partial or total knee replacement. Primary total knee replacement with or without

patellar resurfacing leads to predictable and durable good results; however, 7 to 19% of patients have reported anterior knee pain after total knee replacement for isolated patellofemoral osteoarthritis (Laskin and Van Steijn 1999, Parvizi et al. 2001, Mont et al. 2002, Meding et al. 2007). Moreover, total knee replacement is probably too aggressive of a treatment for what is, in effect, a disease confined to one compartment.

Patellofemoral joint replacement was introduced in 1948 as an alternative to patellectomy, which led to poor cosmetic and functional outcomes (McKeever 1955). Several prosthetic designs have been used with varying results. Many of the failures resulted from a combination of poor patient selection and the geometric properties of the trochlear component (Lonner 2008). Identifying the proper indications and contra-indications, together with design improvements, has led to results that are comparable to those achieved after primary total knee replacement, albeit with a significantly less intrusive surgical procedure (Leadbetter et al. 2005, Leadbetter et al. 2006).

The development of painful femorotibial osteoarthritis is the most important non-prosthesis-related reason for conversion to total knee replacement (Kooijman et al. 2003). Predictive factors have yet to be identified, and the question remains how to improve the selection criteria. Obviously, unicompartmental joint replacement will always be associated with the risk of developing osteoarthritis in other compartments. Although conversion to total knee replacement for failed patellofemoral joint replacement improves the clinical outcome, it is not known if these results are comparable to those achieved after primary total knee replacement (Lonner et al. 2006). Furthermore, the results of conversion may be compromised by loss of bone behind the anterior flange of the femoral component and by technical difficulties during conversion, as this is a known issue with revision of total knee replacements (van Loon et al. 1999, Huff and Sculco 2007).

Despite numerous studies in recent years, the issue of whether or not to resurface the patella during primary total knee replacement remains unresolved (Calvisi et al. 2009). According to the 2009 Annual Report of the Swedish Knee Arthroplasty Register, patellar resurfacing is used in less than 10% of TKA cases in Sweden, 70% of cases in Denmark, 5% in Norway, and 45% of cases in Australia (The Swedish Knee Arthroplasty Register 2009). Other strategies to reduce the

prevalence of anterior knee pain after total knee replacement include electrocautery of the patellar rim, patelloplasty, and selective resurfacing (Barrack and Burak 2001, Saoud 2004, McPherson 2006). In contrast, there have been no published reports on the outcome of patellofemoral joint replacement without patellar resurfacing.

Aims of the thesis

The aims of this thesis are as follows:

- To clarify the role of nonoperative and operative treatment modalities in isolated patellofemoral osteoarthritis;
- To evaluate the long-term outcomes of a patellofemoral prosthesis, and to identify the different failure mechanisms;
- To investigate whether prior patellofemoral joint replacement has an effect on the clinical outcome of later conversion to total knee replacement for femorotibial osteoarthritis;
- To evaluate the possible loss of distal femoral bone after patellofemoral joint replacement;
- To investigate the efficacy of circumpatellar electrocautery in total knee replacement.

Outline of the thesis

In **Chapter 2**, we present a systematic review on nonoperative and operative treatment options for isolated patellofemoral osteoarthritis. We assessed the quality of included studies with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach (Atkins et al. 2004). In addition to describing the overall methodological quality of the studies (high, moderate, low or very low), we provide a strong or weak recommendation for or against the use of specific interventions.

Chapter 3 describes the long-term outcomes of the Richards II patellofemoral prosthesis used in Deventer from 1976 onwards (Slingenberg and Driessen 1982, Werkman 1991). We investigated whether preoperative diagnosis influenced long-term implant survival, and correlated surgical outcomes with age, sex, and

body mass index (BMI). We also identified the main modes of failure of the Richards II patellofemoral prosthesis.

In **Chapter 4**, we assess the clinical results of conversion of patellofemoral joint replacement to total knee replacement for painful femorotibial osteoarthritis. We investigated, in a matched case-control study, whether these results were comparable to those achieved after primary total knee replacement for femorotibial osteoarthritis.

In **Chapters 5 and 6**, we present radiological and numerical data regarding the possible loss of bone behind the anterior flange of the femoral component of a patellofemoral prosthesis. Dual-energy X-ray absorptiometry (DXA) measurements were performed in patients undergoing patellofemoral joint replacement, and finite element analysis was employed to evaluate the likelihood of stress shielding.

In **Chapter 7**, we present the results of a postal questionnaire that we used in The Netherlands to assess the use of circumpatellar electrocautery in total knee replacement. Electrocautery of the patellar rim is employed by some orthopaedic surgeons to reduce the prevalence of anterior knee pain after total knee replacement.

In **Chapter 8**, we studied the clinical efficacy of circumpatellar electrocautery in primary total knee replacement without patellar resurfacing with respect to the prevalence of anterior knee pain and standardised clinical and patient-reported outcomes.

Finally, **Chapter 9** summarises the studies described in this thesis with a general discussion and final conclusions.

2

Isolated patellofemoral osteoarthritis: A systematic review of treatment options using the GRADE approach

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Acta Orthop 2010; 81: 199-205.

Abstract

Background and purpose: The optimal treatment for isolated patellofemoral osteoarthritis is unclear at present. We systematically reviewed the highest level of available evidence on the nonoperative and operative treatment of isolated patellofemoral osteoarthritis to develop an evidenced-based discussion of treatment options.

Methods: A systematic computerized database search (Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, MEDLINE (PubMed), and EMBASE) was performed in March 2009. The quality of the studies was assessed independently by two authors using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach.

Results: We extracted data from 44 articles. The best available evidence for treatment of isolated patellofemoral osteoarthritis is sparse and of generally low methodological quality. Nonoperative treatment using physiotherapy (GRADE: high quality, weak recommendation for use), taping (GRADE: moderate quality, weak recommendation for use), or injection therapy (GRADE: very low quality, weak recommendation for use) may result in short-term relief. Joint-preserving surgical treatment may result in insufficient, unpredictable, or only short-term improvement (GRADE: low quality, weak recommendation against use). Total knee replacement with patellar resurfacing results in predictable and good, durable results (GRADE: low quality, weak recommendation for use). Outcome after patellofemoral arthroplasty in selected patients is good to excellent (GRADE: low quality, weak recommendation for use).

Interpretation: Methodologically good quality comparative studies, preferably using a patient-relevant outcome instrument, are needed to establish the optimal treatment strategy for patients with isolated patellofemoral osteoarthritis.

Introduction

A multitude of nonoperative and operative treatment options have been described for isolated patellofemoral osteoarthritis in the literature, but the optimal treatment is unclear at present. To develop an evidenced-based discussion of treatment options in isolated patellofemoral osteoarthritis, we reviewed the highest level of available evidence on the nonoperative and operative treatment of isolated patellofemoral osteoarthritis.

Materials and methods

With use of the evidence-based cycle, we formulated 3 focused clinical questions with well-articulated Patient/Population (P), Intervention (I), Comparison (C), and Outcome (O) (PICO) elements (Poolman et al. 2007a). The questions were as follows.

1. In patients with isolated patellofemoral osteoarthritis (P), is physical therapy (I) better than no physical therapy (C) when assessed with a validated outcome measure (O)?
2. In patients with isolated patellofemoral osteoarthritis (P), is operative treatment (I) better than nonoperative treatment (C) when assessed with a validated outcome measure (O)?
3. In patients with isolated patellofemoral osteoarthritis (P), is patellofemoral arthroplasty (I) better than other operative treatment options (C) when assessed with a validated outcome measure (O)?

Criteria for eligibility

We searched for studies that fulfilled certain inclusion criteria. Publications in the English, French, Dutch, or German language that describe the clinical outcome of nonoperative or operative treatments for isolated patellofemoral osteoarthritis in 10 or more patients were included. Publications reporting the results of treatment of patellofemoral pain syndrome without osteoarthritis were excluded, as were studies with incompletely described patient populations, insufficient descriptions of treatment, and studies lacking the use of validated or commonly used outcome measures.

Study identification

Using the following search terms with Boolean operators ([femoropatell* OR femoropatell* OR patell*] AND [osteoarthritis OR arthritis OR arthrosis]), we conducted the following searches:

1. Computerized database searches of:
   a. the Cochrane Database of Systematic Reviews (2009, Issue 1);
   b. the Cochrane Central Register of Controlled Trials (2009, Issue 1);
   c. MEDLINE (PubMed) (1966 to 6 March 2009) using the "clinical queries" feature with a "broad search" for "therapy";
   d. EMBASE (1966 to 7 March 2009) using a search strategy with "Include sub-terms/derivatives" and "Record limits: Humans".
2. Reviews of the bibliographies of eligible articles.

The systematic search was performed in March 2009 with adherence to the QUOROM statement and the MOOSE guidelines (Moher et al. 1999, Stroup et al. 2000). The search was performed in duplicate by one of the authors (HPWvJ) and a librarian. Authors of eligible studies were not contacted with regard to possible unpublished results.

Evaluation of methodological quality

The quality of the studies included was assessed independently by two authors (HPWvJ, RWP) using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach (www.gradeworkinggroup.org) (Atkins et al. 2004, Petrisor et al. 2006, Guyatt et al. 2008). Apart from describing the methodological quality of the studies (high, moderate, low or very low), a strong or weak recommendation was given for or against the use of an intervention. A strong recommendation for using an intervention was given when the benefits clearly outweighed the risks for most if not all patients, with high-quality evidence supporting that recommendation. However, a strong recommendation against use may also be supported by studies of low-grade quality, such as case series that show serious adverse effects of the intervention (Poolman et al. 2007b). A weak recommendation for or against use of an intervention was given where the risks and benefits were more closely balanced or were more uncertain because of the low methodological quality of the supporting studies.

Data abstraction

Relevant data regarding study design, study population, intervention, and outcome measures were extracted from the text, figures, and tables of the articles included.

Results

44 studies, all of which were published as full journal articles, met the eligibility criteria and were included in this review (**Figure** and **Table**).

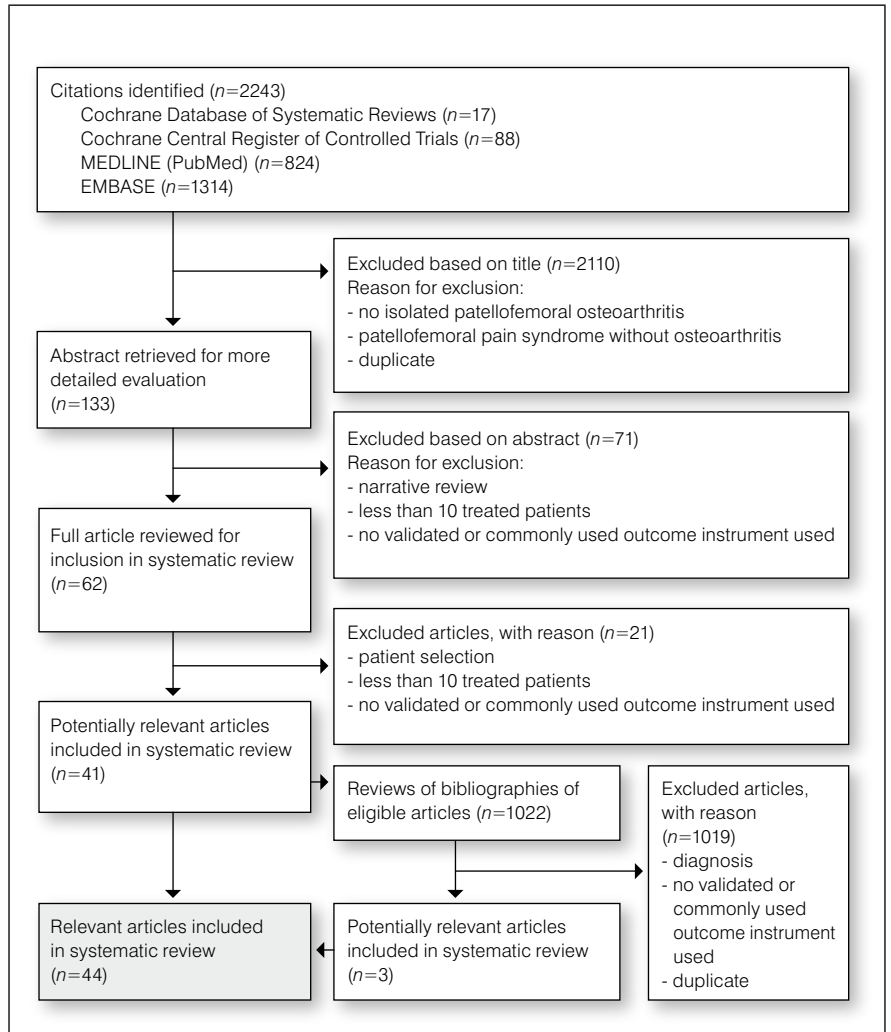

Figure QUOROM flow diagram of included studies.

Table GRADE evidence profile: nonoperative and operative treatment for isolated patellofemoral osteoarthritis.

Quality assessment							Summary of findings				Recommendation
							Number of patients		Effect	Quality	
Number of studies	Design	Limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Treatment	Control	Absolute (95% CI) [a]		
Nonoperative treatment: Physiotherapy versus no physiotherapy											
1	Randomized trial	No serious limitations	Only one study	No serious indirectness	No serious imprecision	Undetected	40	43	Knee pain at 5 months (−6.4 mm; 95% CI −15.3 to 2.4; p=0.16) Increased quadriceps strength at 5 months (+11.7 Nm; 95% CI 4.5 to 19.0; p=0.002) WOMAC at 5 months (−0.6; 95% CI −3.7 to 2.4; p=0.68)	⊕⊕⊕⊕ HIGH	Weak for
Nonoperative treatment: Taping											
1	Randomized crossover trial	Serious (-1) [b]	Only one study	No serious indirectness	No serious imprecision	Undetected	14	(14)	Neutral vs. medial taping: knee pain at 4 days (15.5 mm; 95% CI 2.4 to 28.6; p=0.023) Neutral vs. lateral taping: knee pain at 4 days (-8.0mm; 95%CI −22.5 to 6.5, p=0.26)	⊕⊕⊕○ MODERATE	Weak for
Nonoperative treatment: Intra-articular injection											
1	Observational	Serious (-1) [c]	Only one study	No serious indirectness	No serious imprecision	Undetected	25	-		⊕○○○ VERY LOW	Weak for
Operative treatment: Arthroscopy											
2	Randomized trial	No serious limitations	No serious inconsistency	Some uncertainty about directness (-1) [d]	No serious imprecision	Undetected	196	135	KSPS at 24 months (placebo 51.6±23.7; lavage 53.7±23,7; debridement 51.4±23.2; p=0.64 and p=0.96) [e] WOMAC at 24 months (−23±605; 95% CI −208 to 161; p=0.22)	⊕⊕⊕○ MODERATE	Strong against
Operative treatment: Chondroplasty, resection arthroplasty, and lateral facetectomy											
5	Observational	No serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	155	-		⊕⊕○○ LOW	Weak for
Operative treatment: Extensor mechanism alignment and lateral release											
7	Observational	No serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	224	-		⊕⊕○○ LOW	Weak against
Operative treatment: Patellectomy											
0											
Operative treatment: Total knee arthroplasty											
6	Matched case control, observational	No serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	271	-		⊕⊕○○ LOW	Weak for
Operative treatment: Patellofemoral arthroplasty											
24	Systematic review, observational	No serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	2938	-		⊕⊕○○ LOW	Weak for

a 95% CI = 95% confidence interval.
b patients not blinded, short follow-up.
c pilot study, important heterogeneity in diagnosis.
d not specifically limited to isolated patellofemoral osteoarthritis.
e KSPS = Knee Specific Pain Score.

Results relating to the 3 focused, patient-oriented clinical questions developed using PICO were as follows. One randomized controlled trial described the short-term outcome of physical therapy compared with no physical therapy (Quilty et al. 2003). We were unable to identify studies that directly compared the results of operative and nonoperative treatments. Also, no comparative studies were retrieved that directly compared the results of patellofemoral arthroplasty with the results of other operative treatment options.

Due to the heterogeneity of the study designs and outcome measures, a meta-analysis was not performed. The following review of the literature is therefore descriptive.

Highest available evidence

1. Nonoperative treatment:
   a. Physical therapy versus no physical therapy: 1 randomized controlled trial (83 patients) (Quilty et al. 2003)
   b. Taping: 1 randomized cross-over trial (14 patients) (Cushnaghan et al. 1994)
   c. Intra-articular injection: 1 prospective case series (25 patients) (Clarke et al. 2005)
2. Nonoperative versus operative treatment:
   a. No comparative studies identified
3. Operative treatment:
   a. Arthroscopy: 2 randomized controlled trials (165 and 168 patients) were included based on indirect evidence (Moseley et al. 2002, Kirkley et al. 2008)
   b. Chondroplasty, resection-arthroplasty, and lateral facetectomy: 1 prospective case series (50 patients) (Becker et al. 2008), and 4 retrospective case series (11-63 patients) (Beltran 1987, Yercan et al. 2005, Spak and Teitge 2006, Paulos et al. 2008)
   c. Extensor mechanism alignment and lateral release: 2 prospective case series (35 and 50 patients) (Becker et al. 2008, Alemdaroglu et al. 2008), 2 retrospective comparative studies (12 and 48 patients) (Weaver et al. 1991, Jacquot et al. 2004), and 3 retrospective case series (14-50 patients) (Aderinto and Cobb 2002, Kohn et al. 2004, Carofino and Fulkerson 2008)
   d. Patellectomy: no studies met the inclusion criteria
   e. Total knee arthroplasty: 2 matched case-control studies (94 and 54 patients) of total knee arthroplasty for isolated patellofemoral osteoarthritis compared with total knee arthroplasty for tri-compartmental osteoarthritis (Laskin and Van Steijn 1999, Meding et al. 2007), 1 prospective case series (24 patients) (Parvizi et al. 2001), and 3 retrospective case series (25-47 patients) (Mont et al. 2002, Dejour et al. 2004, Dalury 2005)
   f. Patellofemoral arthroplasty: 3 systematic reviews of case series (538-812 patients) (Leadbetter et al. 2005, Leadbetter et al. 2006, Becher et al. 2008), 5 prospective case series (15-240 patients) (Arnbjornsson and Ryd 1998, Tauro et al. 2001, Merchant 2004, Ackroyd and Chir 2005, Ackroyd et al. 2007), and 16 retrospective case series (12-65 patients) (Arciero and Toomey 1988, Cartier et al. 1990, Argenson et al. 1995, Krajca-Radcliffe and Coker 1996, Mertl et al. 1997, Fink et al. 1999, de Cloedt et al. 1999, de Winter et al. 2001, Smith et al. 2002, Kooijman et al. 2003, Board et al. 2004, Cartier et al. 2005, Argenson et al. 2005, Merchant 2005, Sisto and Sarin 2006, Gadeyne et al. 2008).

The available evidence together with background information from systematic reviews and other relevant sources was used for the following discussion of treatment options.

Nonoperative treatment options

Physiotherapy

Initially, patients with isolated patellofemoral osteoarthritis can be treated using a nonoperative approach such as activity modification, weight loss, and physiotherapy. One randomized controlled trial described the short-term outcome of a commonly used physiotherapy package (patellar taping, functional exercises, quadriceps strengthening exercises, postural advice, and education) compared with no physical therapy (Quilty et al. 2003). The physiotherapy intervention was delivered by a single physiotherapist in nine 30-minute sessions over 10 weeks, with advice to continue thereafter. The treatment group had a small reduction in pain and a substantial increase in the quadriceps strength of the index knee 10 weeks after treatment compared with the no-treatment group. After 12 months, no differences in patient-relevant outcome measures were noted between groups (Quilty et al. 2003). According to GRADE, the quality of this evidence is high, with a weak recommendation for use of the intervention.

Taping

A randomized crossover trial using visual analog scale ratings for pain demonstrated a 25% reduction in knee pain when the patella was taped medially. However, each tape (medial, lateral, or neutral) was applied for only 4 days, with

3 days of no treatment between tape positions (Cushnaghan et al. 1994). According to GRADE, the quality of the evidence is moderate, with a weak recommendation for use of this intervention.

Intra-articular injections / visco-supplementation

The clinical effect of intra-articular visco-supplementation with hylan G-F 20 (Synvisc; Genzyme Corporation, Cambridge, MA) was assessed in a non-randomized clinical trial with use of a patient-relevant outcome instrument. Pain upon stair climbing improved 4 weeks after the initial injection and the improvement was maintained to 26 and 52 weeks (Clarke et al. 2005). According to GRADE, the evidence is of very low quality, with a weak recommendation for use of this intervention.

Operative treatment options

Arthroscopy

We did not identify any studies describing the results of arthroscopic debridement of articular cartilage for patients with *isolated* patellofemoral osteoarthritis. However, we did include 2 methodologically sound randomized controlled trials, although they describe the results of arthroscopy in osteoarthritis of the knee, and were not specifically limited to isolated patellofemoral osteoarthritis (Moseley et al. 2002, Kirkley et al. 2008). No differences in outcome were found between surgical placebo treatment and arthroscopy, and between arthroscopy combined with physiotherapy as opposed to nonoperative treatment with physiotherapy only. Although these papers do not strictly describe the results of arthroscopic treatment for isolated patellofemoral osteoarthritis, indirect evidence is given. Based on these high-quality studies, arthroscopy is not recommended for osteoarthritis of the knee. In the case of indirect evidence, the GRADE group advises reducing the level of quality from high to moderate (Guyatt et al. 2008), with a strong recommendation against the use of this intervention.

Chondroplasty, resection-arthroplasty, and lateral facetectomy

A retrospective case series in patients younger than 55 years of age showed that the use of fresh osteochondral allografts for patellofemoral arthritis resulted in relief of the arthritic condition, improved knee function, and delayed prosthetic knee replacement (Spak and Teitge 2006). A retrospective case series describing the results of en bloc removal of articular cartilage and subchondral bone showed that 20 of the 33 operated knees were pain-free after an average of 31-months of

follow-up (Beltran 1987). Partial lateral facetectomy results in short-term improvement in pain scores with no or moderate improvement in function, as assessed with a patient-relevant outcome instrument (Yercan et al. 2005, Becker et al. 2008, Paulos et al. 2008). According to GRADE, the evidence is of low quality, with a weak recommendation for use of these interventions.

Extensor mechanism alignment and lateral release

Anterior displacement of the tibial tuberosity reduces the contact forces, but not necessarily the stress on the patellofemoral joint (Lewallen et al. 1990). Anteromedialization, which translates the contact area medially, results in relief of the lateral facet which could theoretically reduce pain. Retrospective case series evaluating the 2- to 6-year results of anteromedial transfer of the tibial tuberosity combined with lateral retinacular release have demonstrated an improvement in outcome measures with reduced pain (Weaver et al. 1991, Kohn et al. 2004, Carofino and Fulkerson 2008). Total loss of cartilage or absence of lateralization are contraindications to the Fulkerson procedure (Steimer and Kohn 2007). Compared with medialization with vastus medialis obliquus shortening, anterior displacement and lateral facetectomy both result in improved knee function (Jacquot et al. 2004). However, the number of complications associated with the Maquet anterior displacement is high (Kadambande et al. 2004). Combined partial lateral facetectomy, lateral release, and medialization of the tibial tubercle result in incomplete improvement of symptoms as assessed with a patient-relevant outcome instrument (Becker et al. 2008). In a large number of patients, isolated arthroscopic lateral retinacular release results in reduction of pain rather than resolution (Aderinto and Cobb 2002, Alemdaroglu et al. 2008). In evaluating the results, a patient-relevant outcome instrument was used. According to GRADE, the evidence is of low quality, with a weak recommendation against use of these interventions.

Total knee arthroplasty

Total knee replacement with patellar resurfacing gives satisfactory 5- to 7-year results in patients with isolated patellofemoral osteoarthritis (Laskin and Van Steijn 1999, Parvizi et al. 2001, Mont et al. 2002, Dejour et al. 2004, Dalury 2005, Meding et al. 2007). These results are similar to those achieved after total knee arthroplasty with patellar resurfacing for femorotibial osteoarthritis (Laskin and Van Steijn 1999, Meding et al. 2007). However, up to one-fifth of patients have reported anterior knee pain after total knee replacement (Laskin and Van Steijn

1999, Parvizi et al. 2001, Mont et al. 2002, Meding et al. 2007). As with total knee arthroplasty for tricompartmental osteoarthritis, it remains unclear whether patellar resurfacing results in better outcomes in isolated patellofemoral osteoarthritis (Thompson et al. 2001). Because of its relationship with patellofemoral instability, total knee arthroplasty in patients with isolated patellofemoral osteoarthritis is a technically more demanding procedure (Laskin and Van Steijn 1999, Parvizi et al. 2001, Mont et al. 2002, Saleh et al. 2005). According to GRADE, the evidence is of low quality, with a weak recommendation for use of this intervention.

Patellofemoral arthroplasty

In patellofemoral arthroplasty, the femorotibial compartments with cruciate ligaments and menisci are spared, which probably allows preservation of physiological femorotibial joint mechanics. The clinical results reported are related to prosthetic design, surgical technique, patient selection and indication, and length of follow-up, and have shown good to excellent 3- to 17-year results in two-thirds of patients to all of them (Arciero and Toomey 1988, Cartier et al. 1990, Argenson et al. 1995, Krajca-Radcliffe and Coker 1996, Mertl et al. 1997, Arnbjornsson and Ryd 1998, de Winter et al. 2001, Smith et al. 2002, Kooijman et al. 2003, Merchant 2004, Merchant 2005, Ackroyd and Chir 2005, Cartier et al. 2005, Sisto and Sarin 2006, Ackroyd et al. 2007, Gadeyne et al. 2008). Progression of femorotibial osteoarthritis, malposition of the prosthesis, and wear or loosening may result in failure of the patellofemoral arthroplasty (Leadbetter et al. 2005). Development of painful femorotibial osteoarthritis is the most important non-prosthetic-related reason for conversion to total knee arthroplasty. Conversion rates of 1 in 5 have been reported after an average of 7 to 16 years (Kooijman et al. 2003, Argenson et al. 2005). It remains unclear which patients are at risk of developing femorotibial osteoarthritis (Leadbetter et al. 2005). Recently, the results of revision to total knee arthroplasty for progression of femorotibial osteoarthritis or malposition was described (Lonner et al. 2006). Clinical outcome as assessed by the Knee Society score (KSS) improved after revision. Patellofemoral arthroplasty does not have a negative effect on the outcome of later total knee arthroplasty (van Jonbergen et al. 2009). According to GRADE, the evidence is of low quality, with a weak recommendation for use of this intervention.

Discussion

Several nonoperative and operative treatment options for isolated patellofemoral osteoarthritis have been described. At present, there are no publications describing the outcome of nonoperative treatment after 1 year. A multitude of studies of generally low methodological quality have reported the short- and long-term results of surgical management. Despite these limitations, we present the following treatment recommendations based on the best available evidence.

Nonoperative treatment using physical therapy (GRADE: high quality, weak recommendation for use), taping (GRADE: moderate quality, weak recommendation for use), or injection therapy (GRADE: very low quality, weak recommendation for use) may result in short-term relief. Joint-preserving surgical treatment may result in insufficient, unpredictable, or only short-term improvement (GRADE: low quality, weak recommendation against use). Total knee replacement with patellar resurfacing results in predictable and durable good results (GRADE: low quality, weak recommendation for use).

However, for a degenerative disease involving only one compartment, it is probably too aggressive. Outcome after patellofemoral arthroplasty in selected patients is good to excellent (GRADE: low quality, weak recommendation for use). Total knee replacement can be performed later if painful femorotibial osteoarthritis develops.

Strengths and limitations of this review

Our study is the first systematic review to use both well-articulated patient-oriented clinical questions (PICO) and an evaluation using the GRADE approach in order to obtain an evidenced-based discussion of nonoperative and operative treatment options in isolated patellofemoral osteoarthritis.

However, our study has some limitations that should be considered. First, there is always the possibility that we failed to identify some studies, although a comprehensive search strategy was used including visually searching the reference lists of all eligible articles. Secondly, our aim was to evaluate the best evidence on the treatment of patellofemoral osteoarthritis, and therefore we did not include chondromalacia in our search strategy. Because there is currently no consensus on the diagnostic criteria of patellofemoral osteoarthritis, it is possible that we included studies with important heterogeneity among the degree of osteoarthritis and clinical complaints.

Limitations of primary research

This systematic review shows that the current best available evidence for treatment of isolated patellofemoral osteoarthritis is sparse and generally of low methodological quality. The lack of randomized, controlled studies may result in substantial selection bias. Also, comparison of the results of different treatments is hampered by the extensive heterogeneity among the outcome instruments used. Only 4 of the 44 studies included employed a patient-relevant outcome instrument such as the WOMAC Osteoarthritis Index in evaluating the results of treatment (Quilty et al. 2003, Clarke et al. 2005, Alemdaroglu et al. 2008, Becker et al. 2008).

Implications for future research

Methodologically good-quality studies, preferably evaluating results with a validated patient-relevant outcome measure such as the KOOS or WOMAC (Paxton and Fithian 2005), are needed to establish the optimal treatment strategy for patients with isolated patellofemoral osteoarthritis. Ideally, such studies should compare the results of commonly advocated methods of nonoperative and operative treatments.

Conclusion

The results of this systematic review show that the best available evidence for nonoperative and operative treatment options for patients with isolated patellofemoral osteoarthritis is sparse and of low methodological quality. Presently, there is no convincing evidence that one specific treatment modality is superior to another in terms of better outcomes.

3

Long-term outcomes of patellofemoral arthroplasty

van Jonbergen H P W, Werkman D M, Barnaart A F W, van Kampen A.
J Arthroplasty 2010; 25: 1066-71.

Abstract

The purpose of this study was to correlate the long-term survival of patellofemoral arthroplasty with primary diagnosis, age, sex, and body mass index. One hundred eighty-five consecutive Richards type II patellofemoral arthroplasties were performed in 161 patients with isolated patellofemoral osteoarthritis. Diagnoses included primary patellofemoral osteoarthritis, posttraumatic patellofemoral osteoarthritis, and patellofemoral osteoarthritis with a previous realignment procedure for patellar subluxation or trochlear dysplasia. Median time to follow-up was 13.3 (range, 2.0–30.6) years. Patellofemoral arthroplasty survival was 84% at 10 years and 69% at 20 years. Primary diagnosis, sex, or age at patellofemoral arthroplasty did not significantly affect the rate of revision ($p=0.35$, $p=0.24$, and $p=0.65$, respectively). The rate of revision in obese patients (body mass index >30 kg/m^2) was higher than that in nonobese patients ($p=0.02$).

Introduction

Isolated patellofemoral osteoarthritis is a relatively common degenerative disorder of the knee that occurs in 13.6 to 24% of women and 11 to 15.4% of men older than 55 to 60 years (McAlindon et al. 1992, Davies et al. 2002). Surgical treatment should be reserved for the minority of patients with incapacitating pain and functional limitations and for whom nonoperative modalities, such as weight reduction and physical therapy, have failed (Leadbetter et al. 2005, Grelsamer and Stein 2006). Several surgical approaches have been used to treat isolated patellofemoral osteoarthritis successfully, including arthroscopic debridement with or without lateral release, chondroplasty, unloading procedures with osteotomy of the tibial tuberosity, patellectomy, total knee arthroplasty, and patellofemoral replacement (Saleh et al. 2005, Grelsamer and Stein 2006, Lonner 2007).

Although total knee arthroplasty with or without patellar resurfacing gives predictably good results for isolated patellofemoral osteoarthritis (Laskin and Van Steijn 1999, Parvizi et al. 2001, Thompson et al. 2001, Mont et al. 2002), a less aggressive approach using patellofemoral arthroplasty may be more appropriate. In contrast to total knee arthroplasty, in patellofemoral arthroplasty, only the involved joint compartment is replaced and the femorotibial joint with the cruciate ligaments and menisci is spared, thereby preserving more physiologic joint motion.

Several studies have addressed the short-term and midterm results of patello-femoral arthroplasty (Vermeulen et al. 1973, Blazina et al. 1979, Arciero and Toomey 1988, Cartier et al. 1990, Argenson et al. 1995, Krajca-Radcliffe and Coker 1996, Arnbjornsson and Ryd 1998, de Winter et al. 2001, Tauro et al. 2001, Smith et al. 2002, Kooijman et al. 2003, Board et al. 2004, Merchant 2004, Ackroyd and Chir 2005, Merchant 2005, Cartier et al. 2005, Argenson et al. 2005, Sisto and Sarin 2006, Ackroyd et al. 2007). Although authors stress the importance of patient selection, no long-term outcome data regarding optimal preoperative indications or ideal patient age range are available (Leadbetter et al. 2005, Lonner 2007).

We hypothesized that patients with primary isolated patellofemoral osteoarthritis would demonstrate implant survival similar to that of patients with posttraumatic patellofemoral osteoarthritis or patellofemoral osteoarthritis with a previous realignment procedure for patellar subluxation or trochlear dysplasia. Therefore, our primary objective was to correlate survival rates for the patellofemoral prostheses

with these 3 different diagnostic groups. Secondary objectives were to correlate surgical outcomes with the age, sex, and body mass index (BMI), and to identify the main modes of failure of Richards type II patellofemoral arthroplasty.

Materials and Methods

Between December 1976 and December 2005, 185 consecutive Richards type II (Smith & Nephew, Memphis, Tennessee) patellofemoral arthroplasties were performed in 161 patients with isolated patellofemoral osteoarthritis. Patients were followed up regularly with clinical and radiological examinations. After approval from the Regional Ethics Committee (NL15032.075.06) and Institutional Review Board, informed consent was obtained from every patient before the final follow-up analysis in 2007. Thirty-five patients (41 knees) had died during follow-up; clinical and radiological data obtained before their deaths were included. Median time to demise after arthroplasty was 14.1 (range, 2.3–29.1) years. Four patients with 4 patellofemoral replacements (2%) were lost to follow-up. Therefore, information on surgical outcomes was complete for 157 patients (181 knees). Median time to follow-up was 13.3 (range, 2.0–30.6) years. Demographic data are presented in **Table 1**.

Table 1 Patient characteristics.

Characteristic	
Number of patients (knees)	157 (181)
Side (right : left)	92 : 89
Age at operation	52 (14) years
Sex (female : male)	98 : 59
Height	172 (8) cm
Weight	82 (15) kg
Body mass index	27.8 (4.7) kg/m^2
Number of previous surgeries	
Realignment procedures	25
Patelloplasties	109
Meniscectomies	24
Other	19

Continuous values are given as the mean with standard deviation in parentheses.

Patellofemoral arthroplasty was performed by 3 similarly experienced surgeons at our institution using a currently commercially available Richards type II prosthesis (Smith & Nephew). After a medial parapatellar or midline incision and medial arthrotomy, the patellofemoral joint and femorotibial compartment were assessed for degenerative disease. No degenerative changes in femorotibial compartments with articular cartilage grade 2 or higher were found in any patient. A template was used to determine size (short or long) and optimal placement of the femoral component in the trochlear groove. Alignment of the femoral component in the sagittal plane was assessed carefully to prevent distal impingement of the prosthesis against the anterior cruciate ligament. No alignment guide for rotation in the coronal plane was available; thus, optimal positioning was determined by visual alignment of the long axis of the trial component with the trochlear groove. The trochlear cartilage with subchondral bone was then removed using a small chisel; and after a central hole for the peg was created, the trial component was inserted. After resection of patellar subchondral bone with an oscillating saw and sizing of the patellar component, a rotating trial component was inserted on the medial aspect of the patella with restoration of patellar thickness. Any bone remaining on the lateral side was then beveled to prevent impingement against the lateral femoral condyle or trochlear prosthesis. Stability (patellar tilt, subluxation) and impingement (catching) were tested over a full range of motion before the definitive components were cemented in place (**Figure 1**). A short trochlear component was used in all but 1 knee. Concomitant distal realignment was performed after insertion of the prosthesis in 5 patients. One patient underwent debridement of a chondral lesion on the medial femoral condyle; and in 1 patient, hardware from a previous realignment was removed.

Initially, direct postoperative weight bearing was restricted for 2 weeks; however, since 1989, we have allowed patients immediate postoperative protected weight bearing with crutches. All patients routinely received antithrombotic prophylaxis with warfarin for 8 weeks.

Immediate postoperative radiographs (anteroposterior and lateral non-weight bearing) were reviewed to evaluate the position of the prosthesis. During follow-up, radiological evaluations included 3 radiographs: anteroposterior standing, lateral non-weight bearing, and axial patellar. The same radiologist assessed all sequential radiographs to determine the existence or progression of femorotibial osteoarthritis and loosening or wear of the prosthesis. Radiological findings were

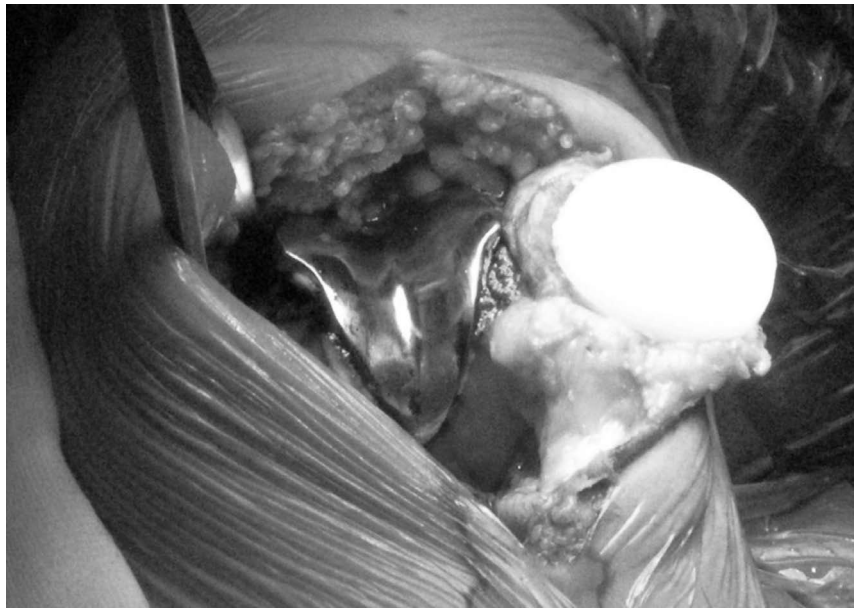

Figure 1 Intraoperative photograph showing cemented Richards type II patellofemoral prosthesis in position.

reported using the Knee Society total knee arthroplasty roentgenographic evaluation and scoring system (Ewald 1989).

To assess the primary objective, we stratified indications for surgery into 3 diagnostic groups: primary isolated patellofemoral osteoarthritis (Group I), posttraumatic patellofemoral osteoarthritis after patellar fracture or direct trauma (Group II), and patellofemoral osteoarthritis with a previous realignment procedure for patellar subluxation or trochlear dysplasia (Group III). *Further surgery* was defined as any surgical procedure after the primary patellofemoral arthroplasty, including conversion to patellofemoral arthroplasty or total knee arthroplasty. The end point for survival analysis was clinical failure of the primary arthroplasty resulting in conversion to total knee arthroplasty, revision to patellofemoral arthroplasty, or removal of the prosthesis.

We performed descriptive analysis by calculating the means and standard deviations for continuous variables and frequencies for categorical variables. The Kaplan-Meier product-limited method was used for survival analyses. A knee was censored if it had not been revised by the end of the study or at death (without prior conversion). Survival curves with 95% confidence intervals (CIs) were computed.

Conversion rates between the three different diagnostic groups were compared using the Cox proportional-hazards technique with calculation of the hazard ratio and 95% CI. A p-value < 0.05 was considered statistically significant. Similarly, the Cox proportional-hazards technique was used to compare conversion rates between patients 50 years or younger and patients older than 50 years at patellofemoral arthroplasty, between female and male patients, and between patients with BMI not exceeding 30 kg/m^2 and BMI greater than 30 kg/m^2. Because a number of patients had both knees operated upon, resulting in nonindependence among observations, the Cox proportional-hazards technique was adjusted for clustering of observations within the same patient.

We identified 3 different failure mechanisms: conversion to total knee arthroplasty for progression of femorotibial osteoarthritis, revision for malposition that resulted in catching and instability, and revision for wear and/or loosening. Survival data were computed for each of these 3 end points.

Results

No technical complications occurred during any surgery. Immediate postoperative radiographs confirmed adequate positioning of the prosthesis in 174 of 181 knees (96%; **Figure 2**). Radiologically visible component malposition, with the distal tip of the femoral component projecting into the intercondylar notch, was observed in 7 (4%) of 181 knees. Postoperatively, 11 knees in 10 patients (6%) required manipulation under anesthesia. The indication for manipulation was failure to achieve 90° of flexion by 6 weeks postoperation. Ninety-five further surgical procedures were performed on 69 knees (38%) in 67 patients (43%) during the follow-up period (**Table 2**).

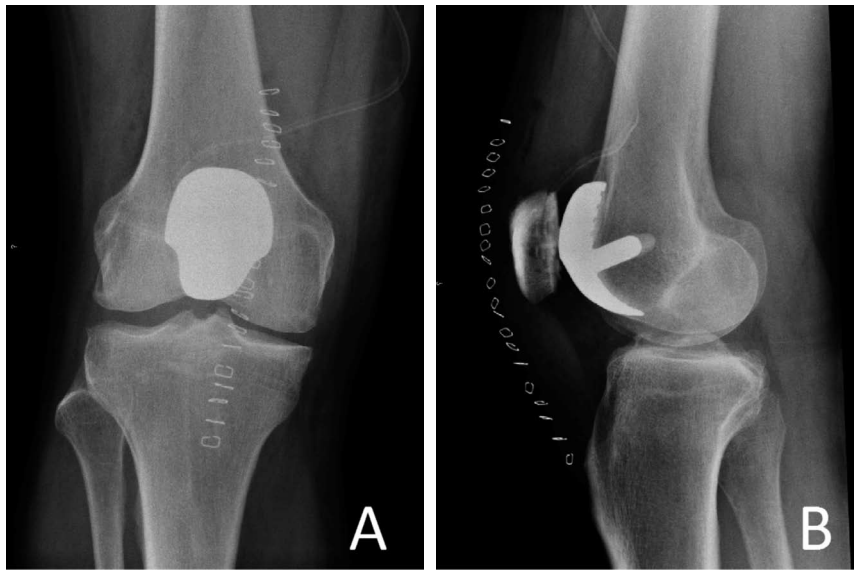

Figure 2 Direct postoperative radiograph demonstrating adequate position of the Richards type II prosthesis. (A) Anteroposterior view. (B) Lateral view.

At final follow-up, a 1mm radiolucency was seen in patellar zone 2 in 6 of the 137 unrevised knees (115 patients). No femoral or patellar component had migrated. Degenerative changes of the femorotibial compartments were observed in 61 knees (45%), with predominantly medial femorotibial involvement.

Table 2 Further surgery performed on 181 knees after primary patellofemoral arthroplasty.

Further surgical procedures	Number of procedures	Time to conversion (years)
Arthrotomy	14 (8%)	
Arthroscopy	27 (15%)	
Other	10 (6%)	
Removal of prosthesis		
Infection	1 (1%)	20.6
Malposition	2 (1%)	0.8 and 7.0
Conversion to		
Total knee arthroplasty		
Femorotibial osteoarthritis	23 (13%)	11.7 (8.0)
Patellofemoral arthroplasty		
Malposition	10 (6%)	2.2 (1.8)
Loosening	4 (2%)	8.5 (8.9)
Wear	4 (2%)	7.1 (4.3)

The values in the number of procedures column are given as absolute numbers with the percentage in parentheses. The values in the time to conversion column are given as the mean with standard deviation in parentheses.

Survivorship analysis based on clinical failure of the primary arthroplasty revealed 84% (95% CI, 78%–90%) cumulative survival at 10 years and 69% (95% CI, 59%–79%) cumulative survival at 20 years (**Figure 3**).

Survival analysis using the Cox proportional-hazards technique demonstrated that primary diagnosis as an indication for patellofemoral arthroplasty did not significantly affect the conversion rate (**Table 3**).

No significant differences in rates of conversion were noted between patients 50 years or younger and patients older than 50 years at patellofemoral arthroplasty, or between female and male patients. The rate of revision in obese patients (BMI >30 kg/m^2) was higher than that in nonobese patients (**Table 3**).

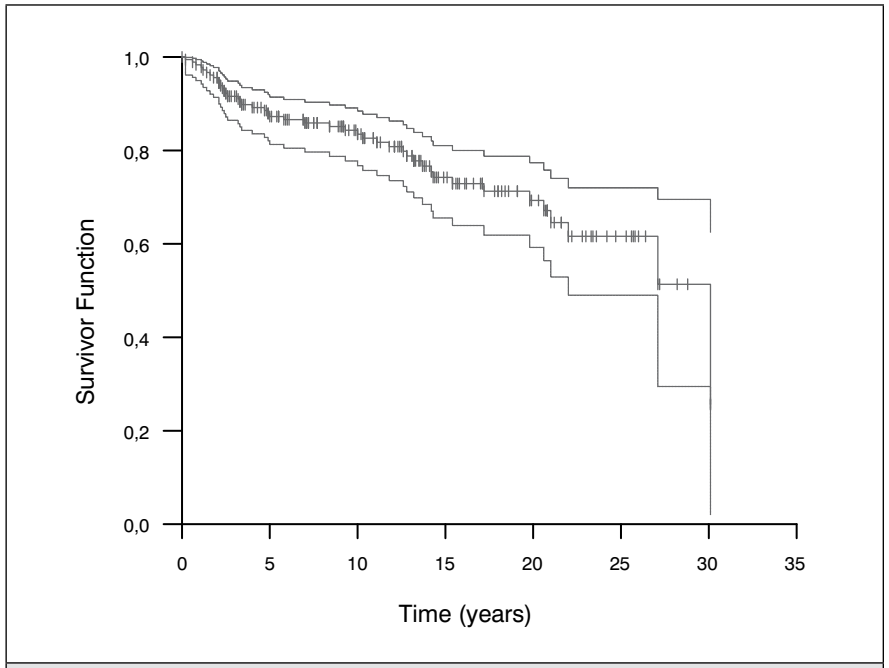

Figure 3 Kaplan-Meier curve denoting the cumulative probability of conversion for any reason, including 95% CIs.

The most common reasons for conversion in this series were progression of femorotibial osteoarthritis (13%), revision for malposition that resulted in catching and instability (7%), and loosening and/or wear of the patellar component (4%; **Table 2**). Of the 10 knees that were revised to another Richards type II patellofemoral arthroplasty for malposition, one had an additional revision for persistent instability 5 months later and was converted to a total knee replacement 2 years later. One patient (1 knee) had recurrent patellar dislocations but did not want further surgery. Results in the other 8 knees were satisfactory.

Table 3 Conversion rates to patellofemoral or total knee arthroplasty for different groups.

Covariates	Number of conversions	Time to conversion in years	Cox proportional hazards
Diagnostic group			p=0.35
Group I (n=138) §	34 (25%)	8.6 (7.8)	
Group II (n=22)	4 (18%)	9.7 (5.7)	HR 0.7 (0.2-2.2)
Group III (n=21)	6 (29%)	8.2 (10.0)	HR 1.7 (0.7-4.2)
Age			p=0.65
≤ 50 years (n=85) §	20 (24%)	8.5 (8.5)	
> 50 years (n=96)	24 (25%)	8.8 (7.3)	HR 1.2 (0.6-2.1)
Sex			p=0.24
Female (n=114) §	29 (25%)	7.1 (6.1)	
Male (n=67)	15 (22%)	11.6 (9.8)	HR 0.7 (0.3-1.3)
Body mass index			p=0.02
≤ 30 kg/m^2 (n=124) §	26 (21%)	9.4 (8.7)	
> 30 kg/m^2 (n=57)	18 (32%)	7.5 (6.1)	HR 2.1 (1.2-4.0)

The values in the number of conversions column are given as the absolute number with the percentage in parentheses. The values in the time to conversion column are given as the mean with standard deviation in parentheses. HR indicates hazard ratio, with 95% CIs in parentheses. § Indicates reference level for hazard ratios.

Discussion

Our results demonstrate an overall revision rate of 24% using the Richards type II patellofemoral arthroplasty for isolated patellofemoral osteoarthritis, with cumulative survivals of 84% and 69% after 10 and 20 years, respectively. This conversion rate is superior to the long-term follow-up conversion rates reported in the literature (Cartier et al. 2005, Argenson et al. 2005). The number of knees requiring further surgery coincides with that reported in other series (Blazina et al. 1979, Kooijman et al. 2003, Board et al. 2004). A recent review reported a reoperation rate of 24% (Leadbetter et al. 2005). Extensor malalignment with

prosthetic instability, progression of arthritis, prosthetic malposition, mechanical prosthetic related symptoms, and prosthetic type were most often correlated with revision surgery (Leadbetter et al. 2005). The number of knees requiring manipulation was high. Our postpatellofemoral arthroplasty rehabilitation protocol is similar to the protocol used after total knee arthroplasty; thus, the reason for the elevated manipulation rate is not clear.

This study had several limitations that should be noted. With a maximum follow-up of more than 30 years, the use of the same clinical scoring system for all cases was not feasible, which eliminated our ability to compare preoperative and follow-up clinical scores for the group as a whole. Furthermore, postoperative treatment protocols have changed over time; and rehabilitation regimens have become more aggressive. Another limitation is that 3 different surgeons performed the surgeries; however, the surgical procedure was standardized; and all of the surgeons who participated in the study were similarly experienced. Finally, 4 patients were lost to follow-up and were not included in the survival analysis; no worst-case scenario was used in reporting the results. We are unable to rule out the possibility that these patients had a revision in another hospital.

Several investigators have emphasized the importance of proper patient selection for patellofemoral arthroplasty (Leadbetter et al. 2005). Clear contraindications have been reported; however, the optimal indication for patellofemoral arthroplasty is less clear. Reported short-term and midterm results vary; and although most clinical researchers describe better results in patients with trochlear dysplasia or surgically corrected maltracking or instability (Arciero and Toomey 1988, Argenson et al. 1995, Argenson et al. 2005), some found better results in patients with posttraumatic patellofemoral osteoarthritis (Argenson et al. 1995). Outcomes of arthroplasty for primary isolated patellofemoral osteoarthritis were the least favorable. After a median of 13.3 years of follow-up in 181 patellofemoral arthroplasties, we found no differences in outcomes among the 3 different indications using the Cox proportional-hazards technique. Furthermore, the results from the current study demonstrate that patients who were younger than 50 years at the primary procedure do not have a higher risk of revision for any reason than do patients who were older than 50 years. This demonstrates that the ongoing concerns regarding survival after total knee arthroplasty in younger patients do not apply to patellofemoral arthroplasty (Harrysson et al. 2004, Gioe et al. 2007). A number of studies suggest higher revision rates after total knee

arthroplasty in obese patients (Amin et al. 2006). Indeed, we found a significantly higher risk of any type of conversion in obese patients (BMI > 30 kg/m^2).

Several "failure scenarios" contributed to the overall revision rate of 24% in the current study. Major sources of failure described in the literature are progression of femorotibial osteoarthritis, malposition of the prosthesis, and loosening and/or wear.

In our series, progression of femorotibial osteoarthritis accounted for more than half of the revisions. Several knees were converted to total knee arthroplasty for early progression of femorotibial osteoarthritis. Although these patients could have been misdiagnosed with isolated patellofemoral osteoarthritis, no significant degenerative changes were found on visual assessment of the femorotibial compartments at primary patellofemoral arthroplasty.

Malposition of the prosthesis with resultant instability or impingement of the prosthesis was also an important cause for revision in our study. These prosthetic-related failures have been described by several authors as patellar maltracking or implant malalignment. Reported causes include surgical prosthetic malalignment of the femoral component (flexion, rotation), prosthetic malalignment of the patellar component (rotation, lateral placement), uncorrected malalignment of the extensor apparatus, soft tissue imbalance, and design characteristics of the patellofemoral prosthesis. Some authors have reported a higher percentage of concomitant procedures addressing malalignment during implantation of the patellofemoral prosthesis, which is in sharp contrast to our series and may explain our higher early rate of revision for malposition. One author reported concomitant realignment procedures in 85% of cases (Cartier et al. 1990). High revision rates for maltracking with the Richards type II prosthesis have been reported by several authors (Blazina et al. 1979, Arciero and Toomey 1988, de Winter et al. 2001). The Richards type II prosthesis has a deep constraining trochlear groove (**Figure 4**); this geometric property could have influenced patellar tracking and contributed to the number of failures ascribed to malposition in our series. Lonner has stated that the implant's geometry should allow it to be implanted flush with the femoral cortex proximally (Lonner 2007); however, this is not possible with the Richards type II femoral component, which behaves more like an onlay prosthesis (**Figure 2**). Given the fact that the short version of the femoral component was used in all but 1 knee, the lack of sizing options could also have contributed to the

relatively high rate of revision due to malposition (Lonner 2004). In revision arthroplasty for malposition, the position of the trochlear component relative to the trochlear groove was not changed. To eliminate catching of the patellar component on the proximal extension of the prosthesis or maltracking on initiation of flexion, more bone was resected proximally to ensure a flush anatomical transition of the trochlear component to the anterior femoral cortex. Similar observations have been described by Lonner (Lonner 2004). Because the results of these revisions to patellofemoral arthroplasty were satisfactory in the majority of patients, we do not routinely perform conversion to total knee arthroplasty in cases of malposition.

Recently, the use of more contemporary trochlear designs has helped decrease the incidence of patellofemoral complications (Lonner 2004, Sisto and Sarin 2006). Newer designs with more sizing options and improved geometric properties should provide a better fit to the trochlea and distal femur.

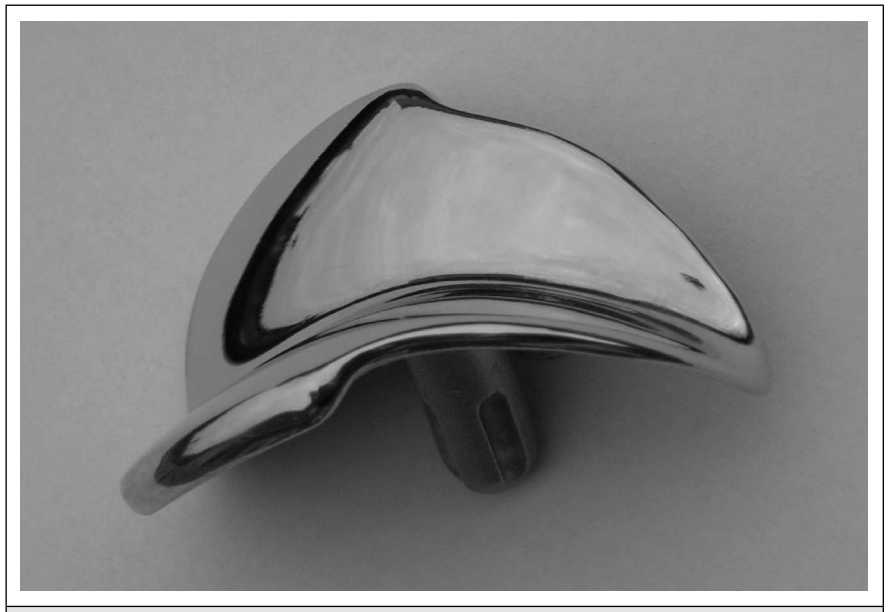

Figure 4 Photograph of the Richards type II patellofemoral prosthesis.

In our series, loosening and/or wear of one or both components as a basis for revision was observed in 8 (4%) knees. Loosening of the cemented trochlear component was not observed, which is in accordance with the literature; cases of trochlear component loosening have been reported for cementless femoral component designs (Argenson et al. 2005).

Conclusions

Long-term outcomes of patellofemoral arthroplasty using the Richards type II prosthesis are not affected by primary diagnosis, sex, or age at patellofemoral arthroplasty. The large number of patellofemoral complications that necessitate revision for malposition could have been due to the constraining geometric properties of the Richards type II prosthesis.

4

Conversion of patellofemoral arthroplasty to total knee arthroplasty: A matched case-control study of 13 patients

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Acta Orthop 2009; 80: 62-6.

Abstract

Background and purpose: The long-term outcome of patellofemoral arthroplasty is related to progression of femorotibial osteoarthritis with need for conversion to total knee arthroplasty. We investigated whether prior patellofemoral arthroplasty compromises the results of total knee arthroplasty.

Methods: 13 patients who had had 14 Richards type II patellofemoral arthroplasties converted to total knee arthroplasty because of femorotibial osteoarthritis, were individually matched to a control group of 13 patients with 14 primary total knee arthroplasties. The mean follow-up times for the patients and the control group were 5.7 (2–13) years and 5.2 (2–13) years, respectively. Clinical outcome was assessed using Knee Society score (KSS), WOMAC score, range of motion, and complications.

Results: KSS and WOMAC scores were similar in the two groups (KSS in patient and control groups: 82 and 86 (p=0.6); KSS function: 76 and 88 (p=0.5); WOMAC score: 33 and 21 (p=0.1)). Within 6 months after conversion, 3 knees had to be manipulated under anesthesia for limited motion. No patients in the control group required manipulation under anesthesia.

Interpretation: Patellofemoral arthroplasty appears not to have a negative effect on the outcome of later total knee arthroplasty.

Introduction

Patellofemoral arthroplasty is a treatment alternative for isolated patellofemoral osteoarthritis. The long-term outcome is related to malposition of the prosthesis, the progression or development of femorotibial osteoarthritis, and - to a lesser extent - wear and/or loosening of the patellar component. Several reports have described the progression of symptomatic femorotibial osteoarthritis as an important reason for conversion to total knee arthroplasty, with an overall revision rate of between 4% and 28% (Argenson et al. 2005, Leadbetter et al. 2005, Nicol et al. 2006, Ackroyd et al. 2007).

With the renewed interest in patellofemoral arthroplasty, more conversion to total knee arthroplasty due to progression of femorotibial osteoarthritis may be anticipated. Only one paper has reviewed the results of revision of a failed patellofemoral arthroplasty to a total knee arthroplasty (Lonner et al. 2006). No technical difficulties were observed, and clinical outcome as assessed by the Knee Society score (KSS) improved after revision. However, whether or not these results compare favorably with the results obtained after primary total knee arthroplasty is unknown.

We therefore performed a retrospective case-control study to compare the outcome of patients with a patellofemoral arthroplasty converted to a total knee arthroplasty with that of a matched group of patients with a primary total knee arthroplasty for femorotibial osteoarthritis.

Patients and methods

Patient selection

Patellofemoral arthroplasty has been performed at our institution since 1976. The entire cohort of 172 patients with 196 patellofemoral arthroplasties had a regular follow-up with clinical and radiographic examinations every 1 or 2 years.

Between October 1987 and March 2007, 23 Richards type II patellofemoral arthroplasties (Smith and Nephew, Memphis, TN) were revised to total knee arthroplasty in 22 patients (17 women) because of development of painful femorotibial osteoarthritis. No conversions had been done before 1987.

Seven patients had died since conversion (of causes unrelated to surgery), and only patients with at least 2 years of follow-up were included. The index group thus consisted of 14 revision total knee arthroplasties in 13 patients (10 women), with revision surgery performed between 1993 and 2005. The study was performed with retrospective data collection and review. The study protocol was approved by the institutional Review Board (NL22632.075.0818, March 2008). A control group of 14 primary total knee arthroplasties in 13 patients was selected from the cohort of primary total knee arthroplasties performed at our institution during the same time period. The underlying diagnosis was primary osteoarthritis in all patients. Only patients with at least 2 years of follow-up were included.

To prevent cohort disparity, each case was individually matched on the basis of 7 attributes: sex, age at time of total knee arthroplasty (± 5 years), date of surgery (± 1 year), type of total knee prosthesis, duration of follow-up (± 1 year), body mass index (± 2), and radiographic grade of osteoarthritis (**Table 1**). No matches were made for type and number of previous procedures. The matching process was performed blind to the clinical outcome.
Informed consent was obtained from all patients.

Clinical evaluation

Patients in both groups had regular follow-up with clinical and radiographic examinations every 1 or 2 years after surgery. All patients completed the Dutch version of the WOMAC 3.1 Osteoarthritis Index, range of motion was registered, and the KSS was used for outcome assessment (Insall et al. 1989).

Radiographic evaluation

Preoperative radiographs were assessed by a radiologist for femorotibial osteoarthritis using the Kellgren and the Ahlbäck grading systems (Kellgren and Lawrence 1957, Ahlbäck 1968). Immediate postoperative radiographs (antero-posterior and lateral non-weight bearing) were evaluated to assess the position of the prosthesis. During follow-up, the radiographic examination consisted of 2 radiographs (anteroposterior standing and lateral non-weight bearing), and all sequential radiographs were assessed by a radiologist to determine loosening or wear of the prosthesis.

Statistics

No power analysis was performed prior to this study, as all patients who had a conversion from patellofemoral to total knee arthroplasty at our institution were included. The Fisher exact probability test was used for categorical data, and the Wilcoxon signed ranks test was used to investigate differences in continuous data between groups. All p-values less than 0.05 were considered significant.

Results

Matching

No statistically significant differences with respect to age, preoperative grade of osteoarthritis, duration of follow-up, or body mass index were found between the two groups (**Table 1**).

Table 1 Demographic and radiographic data for 14 knees with a patellofemoral arthroplasty prior to conversion to total knee arthroplasties (index group) and 14 knees with primary total knee arthroplasties (control group).

	Index	Control	p-value
Sex (female : male)	10 : 3	10 : 3	
Number of knees	14	14	
Age at time of total knee arthroplasty, years (range)	67 (50-77)	68 (51-76)	0.7
Follow-up, years (range)	5.7 (2.0-13)	5.2 (2.1-13)	0.1
Body mass index, kg/m^2 (range)	29 (22-35)	29 (23-34)	0.4
Kellgren grade			0.3
1	0	0	
2	6	8	
3	6	2	
4	2	4	
Ahlbäck grade			0.6
1	11	12	
2	2	0	
3	1	2	
4	0	0	

Previous patellofemoral arthroplasty

The mean age at patellofemoral arthroplasty was 56 (35–72) years. The Richards type II patellofemoral prosthesis was used in all patients. Further surgery after patellofemoral arthroplasty was performed in 9 knees and included 16 procedures (2 knees were manipulated under anesthesia; arthrotomy for painful bony impingement or persistent pain was done in 3 knees; 9 arthroscopies were performed (femorotibial debridement, meniscectomy, diagnostic); and 1 knee had a proximal tibial osteotomy with subsequent hardware removal). The patellofemoral prostheses had been in place before conversion to total knee arthroplasty for an average of 11 (1.2–27) years.

Surgical procedure

In both groups, total knee arthroplasty was performed by several surgeons with similar experience. Before 1999, the posterior-stabilized Insall-Burstein total knee prosthesis was used (Insall-Burstein; Zimmer, Warsaw, IN), and from 1999 onwards a NexGen posterior-stabilized total knee prosthesis was used (NexGen; Zimmer). In each group, 3 Insall-Burstein prostheses and 11 NexGen prostheses were used. Operative records were available for all patients.

At conversion, both the femoral and patellar component were removed in all cases (**Figures 1** and **2**). The distal femur was prepared using standard cutting blocks with resection of the soft cancellous bone directly beneath the femoral component (**Figure 3**). Patellar thickness was restored using the standard patellar component for total knee arthroplasty. After preparation of the proximal tibia and insertion of trial components, patellofemoral stability was tested through a full range of motion before the definitive components were cemented in place. Condylar support for the femoral component was adequate in all cases; no additional metal augmentation was required for any of the knees. Identical surgical procedures and cutting blocks were used for primary total knee arthroplasty in the control group. In all cases, patellar resurfacing was performed using the standard patellar component for total knee arthroplasty.

Radiographs taken immediately postoperatively showed adequate positioning of the prosthesis in all 28 knees. Patients were allowed immediate protected weight bearing with crutches. All patients routinely received coumarine prophylactically for 8 weeks. Data for operative time and blood loss were incomplete and were therefore not included in the analysis.

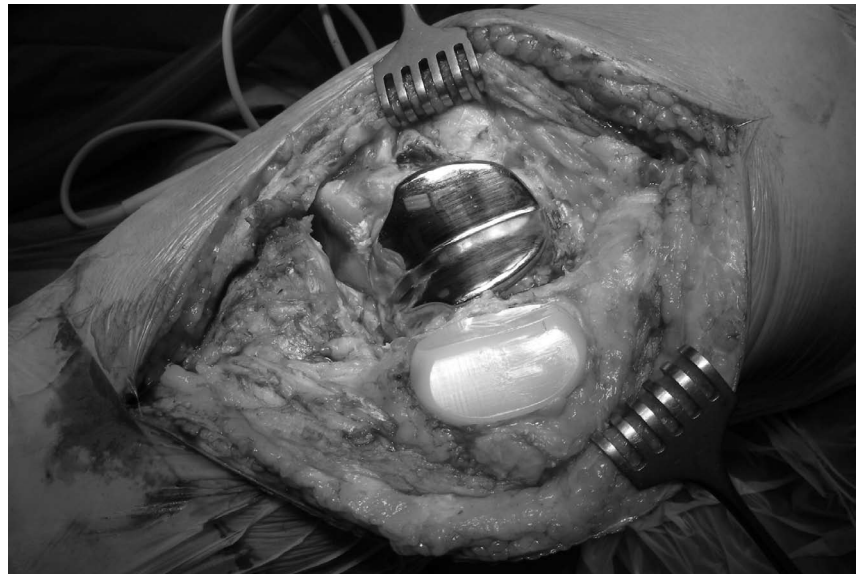

Figure 1 Patellofemoral prosthesis in situ.

Figure 2 After removal of femoral and patellar components.

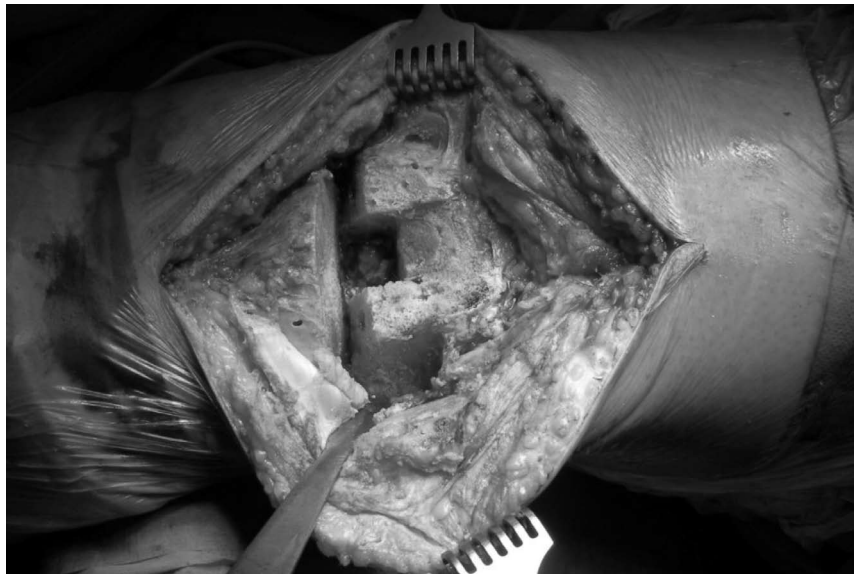

Figure 3 After preparation of distal femur and proximal tibia using the standard cutting blocks.

Complications and further surgery

Within 6 months of conversion from patellofemoral arthroplasty to total knee arthroplasty, 3 knees (in 3 patients) had to be manipulated under anesthesia for failure to achieve 90 degrees of flexion by 6 weeks postoperatively. In 2 of these patients, manipulation had also been necessary after the previous patellofemoral arthroplasty. For the 3 patients requiring manipulation, the mean time between patellofemoral arthroplasty and conversion was 15 (13–17) years. The patients had had an average of 4 previous knee operations before conversion and achieved a mean preoperative flexion of 98 (85–120) degrees.

One patient (with 3 previous procedures before conversion, including patellofemoral arthroplasty, proximal tibial osteotomy, and subsequent hardware removal) had signs of infection of the prosthesis within this time period, and received adequate operative and antibiotic treatment. To date, he has no clinical signs of infection of the total knee prosthesis. No patients had patellofemoral-related complications.

In the control group, no further surgery or manipulation under anesthesia within this time period was required or performed, and no complications were observed.

Clinical outcome

The functional outcome using KSS, WOMAC scores, and range of motion were similar in both groups (**Table 2**). Additional analysis of subscores of the KSS (pain, range of motion, and stability) and WOMAC (pain, stiffness, and function) showed no statistically significant differences between the index and control groups. Preoperative KSS and WOMAC scores were not available for the entire group, so comparison of improvement between the groups was not possible.

Table 2 Clinical outcome after total knee arthroplasty. Values are mean (SD).

	Index	Control	p-value
KSS (max. 100)	82 (19)	86 (10)	0.6
KSS function (max. 100)	76 (31)	88 (10)	0.5
WOMAC (max. 96)	33 (23)	21 (16)	0.1
Preoperative flexion (degrees)	108 (14)	110 (12)	0.7
Postoperative flexion (degrees)	117 (13)	116 (11)	0.9

Radiographic outcome

At final follow-up, none of the knees showed signs of radiographic loosening and/or wear.

Discussion

Our findings suggest that patellofemoral arthroplasty has no negative effect on the outcome of later total knee arthroplasty.

Although no statistically significant differences in KSS and WOMAC scores between the groups were found, the high number of manipulations in the patellofemoral conversion group may be an important observation. Recently, Lonner et al. (2006) assessed the conversion of patellofemoral knee replacement to total knee arthroplasty in 12 patients and found that 2 of the patients required

manipulation under anesthesia 6 weeks after conversion. In our complete cohort of patients with primary patellofemoral arthroplasty, 12 of 196 knees (6%) in 11 of 172 patients had to be manipulated under anesthesia within 6 months of arthroplasty. Several other studies have noted a need for manipulation under anesthesia for stiffness within 6 months of patellofemoral arthroplasty, with reported incidences ranging from 3% to 14% (Arciero and Toomey 1988, Argenson et al. 1995, de Winter et al. 2001, Ackroyd and Chir 2005). The reasons underlying the need for manipulation may be complex and possibly related to the primary patellofemoral disease process and surgical treatment before patellofemoral arthroplasty. The reported prevalence of stiffness after primary total knee arthroplasty varies from 1% to 5%, although it is notable that a commonly used definition of stiffness following knee arthroplasty is lacking (Kim et al. 2004, Yercan et al. 2006, Keating et al. 2007). A history of previous knee surgery and the preoperative range of motion are important predictors of the range of motion after total knee arthroplasty.

Our study has several limitations. Although progression or development of femorotibial osteoarthritis is an important reason for conversion to total knee arthroplasty, large populations need to be tracked for long periods of time to observe disease development. Also, follow-up after conversion to total knee arthroplasty should be extended to several years to reliably evaluate the results of conversion. Thus, a case-control study was designed using a cohort of patients with conversion to total knee arthroplasty. With the small number of patients available in our study, no statistically significant differences in clinical outcome using KSS and WOMAC scores were found. Furthermore, more discriminatory knee scoring systems may be necessary (Paxton and Fithian 2005). Potential differences in improvement between the two groups were not evaluated, as preoperative KSS and WOMAC scores for the entire group were not available.

To date, only 1 paper has reported the results of revision of failed patellofemoral arthroplasty to a total knee arthroplasty (Lonner et al. 2006). Conversion of patellofemoral arthroplasty to a NexGen Legacy posterior-stabilized total knee arthroplasty was performed in 12 patients for patellar maltracking or degenerative joint disease. At a mean follow-up of 3 (2–5) years, all patients had higher Knee Society clinical and functional scores. No technical difficulties were encountered during revision. No patellar components were revised, since the femoral component was accommodating to the original dome-shaped all-polyethylene

patellar components of the Lubinus, Autocentric, Low-Contact Stress or Avon patellofemoral prostheses. At our institution, however, the patellar component was revised in all cases. The Richards type II all-polyethylene patellar prosthesis has a long midline central ridge (**Figure 1**). Retaining the patellar prosthesis could have resulted in maltracking or increased wear of the polyethylene; thus, some authors have suggested that patellofemoral arthroplasty should use a universal patellar component that is compatible with total knee systems, thus obviating the need for revision of the patella (Argenson et al. 2005).

We did not experience technical problems during conversion. Removal of the trochlear component proved to be straightforward, without any substantial loss of bone. Use of the standard total knee replacement cutting blocks resulted in an optimally prepared distal femur, and therefore metal augmentation was not required in any of the patients. This was also observed by Lonner et al. (2006), who noted that condylar support in each knee was uncompromised.

5

Distal femoral bone mineral density decreases following patellofemoral arthroplasty: 1-year follow-up study of 14 patients

van Jonbergen H P W, Koster K, Labey L, Innocenti B, van Kampen A.

BMC Musculoskeletal Disorders 2010; 11: 74.

Abstract

Background: The bone mineral density (BMD) of the distal femur decreases by 16–36% within one year after total knee arthroplasty (TKA) because of the femoral component's stress-shielding effect. The aim of this prospective study was to determine the quantitative change from the baseline BMD in the distal femur 1 year after patellofemoral arthroplasty using dual-energy X-ray absorptiometry (DXA).

Methods: Between December 2007 and December 2008, 14 patients had patello-femoral arthroplasty for isolated patellofemoral osteoarthritis. Distal femoral BMD was assessed using DXA in 2 regions of interest (ROI) on the lateral view 2 weeks before and 12 months after patellofemoral arthroplasty. The contra-lateral knee was used as a control, with BMD measurements performed in identical ROIs.

Results: The mean change from baseline BMD in the operated knees after 1 year was –0.169 g/cm^2 (95% CI: –0.293 to –0.046 g/cm^2) behind the anterior flange (–15%), and –0.076 g/cm^2 (95% CI: –0.177 to 0.024 g/cm^2) in the supracondylar area 1 cm above the prosthesis (–8%) (p=0.01 and p=0.13, respectively). The mean change from baseline BMD in the non-operated knees after 1 year was 0.016 g/cm^2 (95% CI: –0.152 to 0.185 g/cm^2) in the anterior ROI (2%), and 0.023 g/cm^2 (95% CI: –0.135 to 0.180 g/cm^2) in the supracondylar area (2%) (p=0.83, and p=0.76, respectively).

Conclusions: Our findings suggest that patellofemoral arthroplasty results in a statistically significant decrease in BMD behind the anterior flange.

Introduction

After total knee arthroplasty (TKA), the bone mineral density (BMD) of the distal femur decreases by 16–36% within one year because of the femoral component's stress-shielding effect (Liu et al. 1995, Petersen et al. 1995, Karbowski et al. 1999, Spittlehouse et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004, Abu-Rajab et al. 2006). Although the femoral component in patellofemoral arthroplasty is smaller than in TKA, the mechanical loading, and consequently the stress distribution of the distal femoral bone, is altered compared with the physiological situation. This can lead to bone remodelling, resulting in decreased BMD behind the anterior flange of the femoral component. In TKA, bone loss in the distal anterior femur can lead to supracondylar fractures or loosening of the implant, and may induce difficulties during revision arthroplasty (van Loon et al. 1999, Hernigou et al. 2006). Since patellofemoral arthroplasty is typically used in younger patients, conversion to TKA after painful femorotibial osteoarthritis develops will eventually be performed in a relatively large proportion of patients (van Jonbergen et al. 2010d). Although the clinical outcome of TKA done later does not appear to be influenced by prior patellofemoral arthroplasty (van Jonbergen et al. 2009), the results of such a revision may, however, be compromised by loss of bone stock.

To date, no clinical studies have addressed the possible decrease in distal femoral BMD as a parameter of bone remodelling following patellofemoral arthroplasty. We hypothesized that because of the relative small size there is no significant stress-shielding effect behind the femoral component of a patellofemoral prosthesis resulting in a decrease in BMD in the distal femur. The primary objective was, therefore, to determine the change from baseline in the BMD behind the anterior flange 1 year after patellofemoral arthroplasty using dual-energy X-ray absorptiometry (DXA).

Methods

In 2007, we initiated a prospective study to investigate the distal femoral BMD using DXA in patients undergoing patellofemoral arthroplasty. All patients who were planned for patellofemoral arthroplasty for isolated patellofemoral osteoarthritis at Deventer Hospital, Deventer, The Netherlands, were evaluated for

inclusion in the study. Patients with known rheumatic, renal, hepatic, or gastrointestinal disease, and patients using medication that interferes with mineral metabolism (i.e. treatment for osteoporosis or long-term steroid therapy) were excluded from the study. Additionally, patients with a previous TKA or patellofemoral arthroplasty of the contra-lateral knee were excluded. The study was approved by the Regional Ethics Committee (NL16145.075.07, December 2007) and Institutional Review Board.

Sample size was calculated using estimates of mean femoral BMD and standard deviation (SD) behind the anterior flange after TKA (Abu-Rajab et al. 2006). The reported mean BMD behind the anterior flange of a total knee prosthesis in the replaced knee was 0.94 g/cm^2 (0.31), and 1.25 g/cm^2 (0.30) in the contra-lateral, non-replaced knee (Abu-Rajab et al. 2006). A group sample size of 13 patients achieves 95% power to detect a difference of 0.31 g/cm2 between the null hypothesis that both group means are 1.25 g/cm^2, and the alternative hypothesis that the mean of group 2 (replaced knee) is 0.94 g/cm^2 with known group SDs of 0.31 g/cm^2 and 0.30 g/cm^2 and with a significance level (alpha) of 0.05 using a two-tailed paired t-test (PASS 2008, NCSS software, Kaysville, Utah).

Between December 2007 and December 2008, 2 orthopedic surgeons who performed patellofemoral arthroplasty at Deventer Hospital recruited 14 patients. All patients provided written informed consent. All eligible patients were preoperatively assessed by 1 of the 2 participating orthopedic surgeons, who completed the Knee Society Knee Score (KSKS) and the Knee Society Functional Score (KSFS). The Dutch version of the Western Ontario and McMaster Universities Osteoarthritis Index 3.1 (WOMAC) was completed by all patients. Measurement of the BMD in the distal femur was performed using DXA in the lateral view (GE Lunar Prodigy system, General Electrics, Oldelft Benelux B.V., Delft/Veenendaal, The Netherlands) 2 weeks before patellofemoral arthroplasty and 12 months after arthroplasty. Measurements of a calibration phantom were performed each day before scanning the patients. All measurements were made by an independent radiographic technician. Both the scanning procedure and positioning of the patients and knees were standardized, with the patient in the lateral decubitus position and the knee flexed 15–30 degrees to obtain a true lateral scan. Two regions of interest (ROI) were selected; one in the distal anterior area just behind the anterior flange of the prosthesis (centered between the tip of the fixation peg and the proximal end of the prosthesis) (ROI 1), and the other more proximally, in

the supracondylar area 1 cm superior to the anterior flange of the femoral component (ROI 2) (**Figure 1**). ROI 2 was selected as a reference ROI above the prosthesis, where stress-shielding was assumed to be negligible. The measured area of each ROI was 1 x 1cm. The contra-lateral, non-operated knee was used as a control, with BMD measurements in identical ROIs. We employed knee-specific software in all cases.

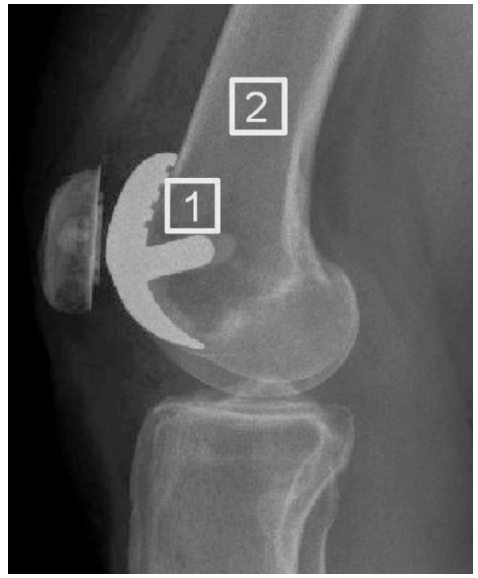

Figure 1 Location of regions of interest (ROI) on a lateral radiograph of a right knee.

Two similarly experienced surgeons at our institution performed patellofemoral arthroplasty with the currently commercially available Richards type II prosthesis (Smith & Nephew Inc., Memphis, Tennessee). Surgery was performed under pneumatic tourniquet control and antibiotic prophylaxis using intravenous Cefazoline 1 g, 3 times daily, for the first 24 hours with the first dose administered 30 minutes before application of the tourniquet. All operations were performed in an identical manner according to the manufacturers' instruction, as described elsewhere (van Jonbergen et al. 2010d). No intramedullary guiding rod was used during surgery. All 14 patients received the same postoperative treatment. We

allowed patients protected weight bearing with crutches immediate after surgery, and full unrestricted weight bearing was allowed 6 weeks after surgery. All patients routinely received antithrombotic prophylaxis with a low-molecular-weight heparin (Fragmin) for 6 weeks.

All patients had regular clinical follow-ups at 2 and 8 weeks to evaluate wound healing and rehabilitation, DXA was not performed at these follow-up visits. At the 1-year follow-up, patients were clinically assessed using the KSKS and KSFS, and were asked to complete the WOMAC questionnaire. During follow-up, the radiological examinations consisted of 2 radiographs (anteroposterior standing and lateral non-weight bearing) performed 6 weeks and one year post surgery (**Figure 2**). Radiological findings were reported using the Knee Society total knee arthroplasty roentgenographic evaluation and scoring system (Ewald 1989).

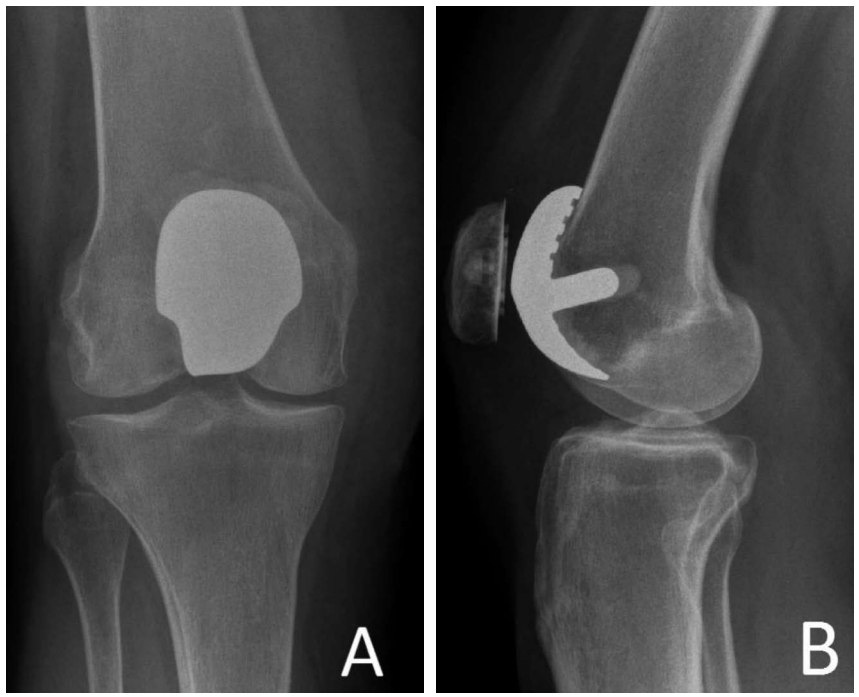

Figure 2 Anteroposterior (A) and lateral (B) radiographs of a right knee one year after patellofemoral arthroplasty.

All pertinent data were entered in a spreadsheet program and analyzed using PASW Statistics 18 software (SPSS Inc, Chicago, Illinois). We performed descriptive analysis using the mean and standard deviation for continuous variables, and frequencies for categorical variables. The 95% confidence intervals (CI) were calculated for the absolute changes in BMD from baseline. The two-tailed paired t test was used to analyze for differences in preoperative and postoperative BMD. A linear regression model was used to evaluate for influence of BMI, age, and sex on change in BMD from baseline. A p-value of less than 0.05 was considered significant in all the tests.

Results

Between December 2007 and December 2008, 14 patients had unilateral patello-femoral arthroplasty, receiving the Richards type II patellofemoral prosthesis. All 14 patients were available for the one year follow-up. The patient's demographic data are presented in **Table 1**.

Table 1 Patient characteristics.

Characteristic	
Number of knees	14
Side (right: left)	7 : 7
Mean (SD) age at surgery	53 (10) years
Sex (female: male)	9 : 5
Mean (SD) Height	175 (5) cm
Mean (SD) Weight	87 (13) kg
Mean (SD) body mass index	28 (4) kg/m^2

Continuous values are given as the mean with standard deviation in parentheses.

Mean KSKS improved from 61 (range, 50 to 78) preoperatively to 88 (range, 60 to 100) one year after surgery ($p<0.001$). Mean KSFS improved from 65 (range, 50 to 80) preoperatively to 86 (range, 50 to 100) one year after surgery ($p=0.004$). The mean preoperative WOMAC scores improved from 50 (range, 22 to 69) to 23 (range, 4 to 39) one year after surgery ($p<0.001$). No complications were noted

from the surgical procedure within the study period. The 1-year radiographic follow-up showed that all prostheses were in good alignment without radiolucent lines or osteolysis.

Results of the BMD measurements are summarized in **Table 2**. In the operated knees, there was a 15% decrease in mean BMD at 12 months in ROI 1 (p=0.01), and an 8% decrease in ROI 2 (p=0.13). In the non-operated knees, there was a 2% increase in the mean BMD at 12 months in both ROI 1 and ROI 2 (p=0.83 and p=0.76, respectively).

Table 2 Bone mineral density (BMD, g/cm^2) measured in the distal femur before (t=0) and 12 months after (t=12) patellofemoral arthroplasty.

	BMD (t = 0)	BMD (t = 12)	Change from baseline	95% CI for the difference	p-value
Operated knee					
ROI 1	1.106 (0.229)	0.937 (0.362)	−0.169 (0.204)	−0.293 to −0.046	0.01
ROI 2	0.981 (0.272)	0.905 (0.261)	−0.076 (0.167)	−0.177 to 0.024	0.13
Non-operated knee					
ROI 1	1.099 (0.266)	1.115 (0.315)	0.016 (0.251)	−0.152 to 0.185	0.83
ROI 2	0.930 (0.175)	0.952 (0.266)	0.023 (0.234)	−0.135 to 0.180	0.76

Continuous values are given as the mean with standard deviation in parentheses.
CI, confidence interval; ROI, region of interest.

Regression analysis of the change from baseline BMD for both regions of interest against BMI (regression coefficient = 0.017, p=0.3), age (regression coefficient = 0.002, p=0.8), and sex (regression coefficient = −0.063, p=0.6) demonstrated no significant relationships.

Discussion

The results of our prospective, 1-year DXA study demonstrate a statistically significant 15% decrease in BMD behind the anterior flange of the femoral component during the first year after patellofemoral arthroplasty. To our knowledge, there has been no previous study that attempted to use DXA measurements to evaluate changes in the distal femoral BMD after patellofemoral arthroplasty. Several investigators reported the results of BMD measurements after TKA and demonstrated periprosthetic bone loss of up to 36% adjacent to the implants (Petersen et al. 1995, Liu et al. 1995, Karbowski et al. 1999, Spittlehouse et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004, Abu-Rajab et al. 2006). The general BMD as measured in hip and spine, or the BMD in the contra-lateral knee, did not change after arthroplasty (Karbowski et al. 1999, van Loon et al. 2001, Abu-Rajab et al. 2006).

Finite-element models were used to determine whether patterns of bone resorption behind the femoral component in TKA could be explained by strain-adaptive bone remodelling (Tissakht et al. 1996, van Lenthe et al. 1997). With a bonded femoral component, the predicted long-term bone loss would occur at the most distal part of the femur and behind the anterior part of the prosthesis (van Lenthe et al. 1997). These findings are in agreement with the results of clinical DXA studies, which observed loss of BMD behind the anterior flange of the femoral component in TKA (Liu et al. 1995, Petersen et al. 1995, Karbowski et al. 1999, Spittlehouse et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004, Abu-Rajab et al. 2006). Our results show that comparable distal femoral bone loss occurs following patellofemoral arthroplasty. This suggests that the stress-shielding effect is similar to that which occurs after TKA, even with the smaller femoral component of the patellofemoral prosthesis (**Figure 2**). However, the clinical results do not seem to be compromised by the observed loss of bone. In a recent study, the long-term outcomes of the Richards type II patellofemoral arthroplasty were reported (van Jonbergen et al. 2010d). The most common reasons for conversion in this series were progression of femorotibial osteoarthritis and revision for malpositioning that resulted in catching and instability. Loosening of the femoral component was not observed, which is in accordance with the literature. Furthermore, the clinical outcome of later TKA does not appear to be influenced by prior patellofemoral arthroplasty (Lonner et al. 2006, van Jonbergen et al. 2009). No technical difficulties were experienced during conversion, and the condylar support in each knee was uncompromised.

The observed decrease in the BMD in the supracondylar reference ROI 2 was not statistically significant. Other investigators demonstrated an 8% decrease in the BMD in this diaphyseal ROI at 1 year after total knee arthroplasty (van Loon et al. 2001, Soininvaara et al. 2004). Soininvaara et al. suggested that this less pronounced bone loss represented both operation-related and postoperative immobilization-induced bone loss, because age-related bone loss is minor (Soininvaara et al. 2004). However, physical activity had improved in our patients, as demonstrated by the improvement in KSFS and WOMAC scores.

The current study has some limitations that should be noted. Follow-up examinations were performed at 1 year after surgery. With TKA, several investigators report that no additional remodelling occurs after 6–12 months (Spittlehouse et al. 1999, Karbowski et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004), while others stated that loss of BMD stabilizes within 2 years (Cameron and Cameron 1987, Abu-Rajab et al. 2006). Finite element models predict that bone resorption may continue after 2 years (van Lenthe et al. 1997). Thus, it is possible that a further decrease in BMD occurs in our patients. Another limitation is that we performed no precision measurements in our relatively small series. Therefore, we assumed a precision similar to those reported by others using the same Lunar Prodigy system, albeit with possible software differences. The reported precision for BMD measurements on the lateral view of the anterior femur ranges from 1.3% to 3.6% (Liu et al. 1995, Petersen et al. 1995, Trevisan et al. 1998, Soininvaara et al. 2000, van Loon et al. 2001). Because of the relatively small size of the patellofemoral prosthesis, the ROI behind the anterior flange was also necessarily small, which may have resulted in weakened precision (Soininvaara et al. 2000).

Although our study protocol excluded medical conditions that could have affected the BMD, it is possible that other conditions may have existed that influenced the results. None of the patients had a severe medical disability that limited the ability to walk, or had a disabling disease involving other joints of the lower extremities. We did not assess the amount of physical activity at one-year follow-up and were therefore not able to evaluate for a relationship with change from baseline BMD.

Conclusions

Our findings suggest that Richards type II patellofemoral arthroplasty results in a statistically significant decrease in BMD behind the anterior flange. Newer designs, such as the Journey patellofemoral prosthesis (Smith&Nephew) and the Zimmer Gender Solutions PFJ system, employ a broader trochlear component. In theory, the geometry, size, and material properties may result in different patterns of stress shielding. Future studies should be aimed at evaluating BMD changes in these newer patellofemoral prostheses.

6

Stress shielding in distal femur: Dynamic finite element analysis in patellofemoral arthroplasty and total knee arthroplasty

van Jonbergen H P W, Innocenti B, Gervasi G L, Labey L, Verdonschot N.

Paper in preparation.

Abstract

Background: Patellofemoral joint replacement is a successful treatment option for isolated patellofemoral osteoarthritis. However, the results of later conversion to total knee replacement may be compromised by periprosthetic bone loss. Clinical studies demonstrated a decrease in distal femoral bone mineral density after patellofemoral joint replacement. The main objective of this study was to evaluate the stress shielding effect of prosthetic replacement with 2 different patellofemoral prosthesis designs and with a total knee prosthesis.

Methods: The following finite element models were developed: an intact patellofemoral joint, a replaced patellofemoral joint with a Journey PFJ and a Richards II prosthesis, and total knee replacement with a Genesis II prosthesis. For each of these 4 finite element models, the average Von Mises stress in 2 regions of interest was evaluated during a squatting movement until 120° of flexion.

Findings: During deep knee flexion, in the anterior region of interest, the average Von Mises stress with the Journey PFJ design was comparable to the physiological knee, while the Richards II design showed lower stress. The Genesis II design induced the lowest stress of all models. The average Von Mises stress in the supracondylar region of interest was similar for both patellofemoral prosthesis designs and the physiological model, with slightly lower stress for the Genesis II design.

Interpretation: These findings are in agreement with previous clinical studies that have indicated that patellofemoral joint replacement leads to a smaller decrease in distal femoral bone mineral density than total knee replacement. However, specific design properties may result in differences in femoral stress shielding.

Introduction

Patellofemoral joint replacement is a successful treatment option for isolated patellofemoral osteoarthritis (van Jonbergen et al. 2010c). The long-term outcomes are related to progression of femorotibial osteoarthritis and the need for conversion to total knee replacement (van Jonbergen et al. 2010d). Because the results of conversion to total knee replacement may be compromised by loss of bone behind the femoral component, this phenomenon needs to be prevented as much as possible. After total knee replacement, loss of bone occurs due to the stress shielding effect of the femoral component (Tissakht et al. 1996, van Lenthe et al. 1997). Although the femoral component of a patellofemoral prosthesis is smaller than in total knee replacement, it is unknown whether mechanically induced periprosthetic bone remodelling occurs following patellofemoral joint replacement.

Measurements of the periprosthetic bone mineral density (BMD) using dual-energy x-ray absorptiometry (DXA) demonstrated a 15% decrease in BMD behind the anterior flange of the femoral component during the first year after Richards II patellofemoral joint replacement (van Jonbergen et al. 2010b), but it is not known whether this is due to stress shielding. Finite element analyses have been used extensively in the evaluation of prosthetic load and bone remodelling after total hip and knee replacement (Qian et al. 2009, Zelle et al. 2009). Some investigators have also used numerical models to calculate the stress distribution within the patellar components after patellofemoral replacement (Najarian et al. 2005, Morra and Greenwald 2006). However, none of these models used a dynamically loaded distal femur to investigate the stress shielding effect of the femoral component on the periprosthetic bone.

The objective of this study was to investigate the effect of patellofemoral replacement on the expected stress-shielding of the distal femur leading to bone remodelling. For this purpose, the patellofemoral joint was modelled in a dynamic finite element knee model with and without a patellofemoral joint replacement. Furthermore, to investigate the effects of different patellofemoral replacement designs, we compared the stress shielding effect between the Journey PFJ patellofemoral prosthesis, the Richards II patellofemoral prosthesis, and the Genesis II total knee prosthesis.

Methods

Knee joint geometry

A three-dimensional dynamic finite element knee model was designed consisting of a distal femur, patella, and patellar tendon. MR imaging data (slice thickness 1.5mm, pixel dimension 0.43mm, field of view 220mm) from the right knee of a healthy 47 year old volunteer without any known musculoskeletal disease were manually segmented using MIMICS 13 and 3-matic 4.2 software (Materialise, Belgium) to obtain a three-dimensional model of the osseous and cartilaginous geometries of distal femur and patella with patellar tendon and insertion of the quadriceps tendon (**Figure 1**).

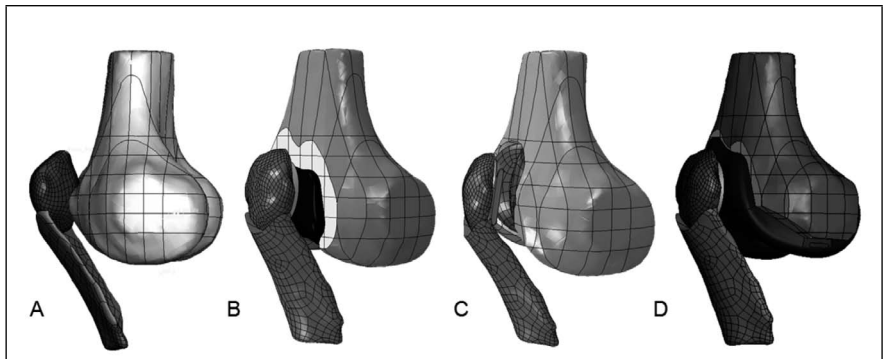

Figure 1 Model geometries used in this study.

Physiological model (A). Journey PFJ model (B). Richards II PFA model (C). Genesis II TKA model (D).

Knee joint material properties

The trabecular bone of the distal femur was modelled as a homogenous isotropic linear elastic material (E=300 MPa, Poisson ratio v=0.30, density=1g/cm^3) (Linde 1994, Heegaard et al. 2001, Beillas et al. 2004). The cortical bone was modelled as an orthotropic 2mm thick layer with material properties reported in **Table 1** (Heegaard et al. 2001, Taylor et al. 2002, Beillas et al. 2004). The patella was modelled as a homogenous isotropic linear elastic material (E=15000 MPa, Poisson ratio v=0.30, density=2g/cm^3), with a 2.5mm thick layer of homogenous isotropic linear elastic cartilage in contact with the femoral trochlea (Hart et al. 1999, Beillas et al. 2004, Iranpour et al. 2008). Articular cartilage was assumed to behave as a single-phase linear elastic and isotropic material (E=5 MPa, Poisson ratio v=0.46, density=1g/cm^3) (Li et al. 2001, Beillas et al. 2004, Pena et al. 2005, Pena et al. 2006). The friction coefficient between patella and trochlear groove was set at 0.001 based on experimental data (Besier et al. 2005). We assumed no differences in material properties between tendon and insertion. The patellar tendon was modelled as an isotropic and hyperelastic material (Pena et al. 2005), characterized by an incompressible Neo-Hookean behaviour with the strain energy density (W) function: $W = C1(I1 - 3)$, were C1 is the initial shear modulus (with value 2.75) (Pena et al. 2006) and I1 is the first modified invariant of the right Cauchy-Green strain tensor.

Table 1 Cortical bone material properties (Taylor et al. 2002).

E1 (MPa)	E2 (MPa)	E3 (MPa)	G23 (MPa)	G31 (MPa)	G12 (MPa)
17900	18800	22800	7110	6580	5710
v12	**v13**	**v23**	**v32**	**v21**	**v31**
0.26	0.30	0.31	0.37	0.28	0.38

Knee joint load and constraints

The simulated motion consisted of a 10s loaded full squat (one cycle), starting from 0° until a maximum flexion angle of 120°. These settings match the experimental kinematics simulations performed in a previous *in vitro* analysis on physiological cadaver legs (Innocenti et al. 2009, Victor et al. 2009, Victor et al. 2010). The patella model was constrained by fixing the distal part of the patellar ligament and applying a quadriceps force distributed on the quadriceps insertion on the proximal surface of the patella. Thus, the patella was allowed to move along the trochlear surface of the femur (Sharma et al. 2008). The magnitude and direction of the quadriceps force as well as the 3D kinematics of the femur were derived from the above mentioned tests on healthy, full leg cadaver specimens (Victor et al. 2010) and were applied using the Grood-Suntay coordinate system (**Figure 2**) (Grood and Suntay 1983), using as origin the midpoint between the condylar center (Innocenti et al. 2009, Victor et al. 2009, Victor et al. 2010).

Since bone remodelling is thought to be provoked by the maximal stresses and strains experienced by the bone (Robling et al. 2006), rather than average daily stresses and strains, squatting rather than gait was preferred as the simulated motor task. Squatting is indeed a motor task which produces higher joint contact forces and therefore higher stresses and strains in the bone compared to gait (Zheng et al. 1998, Taylor et al. 2004). Moreover, as squatting gives rise to higher stresses, it should also induce a larger change in stress between the physiological and replaced knee. Finally, the analysis of a squat, up to 120°, was preferred since it reaches a larger range of motion compared to gait which is usually limited to 60° of flexion (ISO/CD 14243-1 1999).

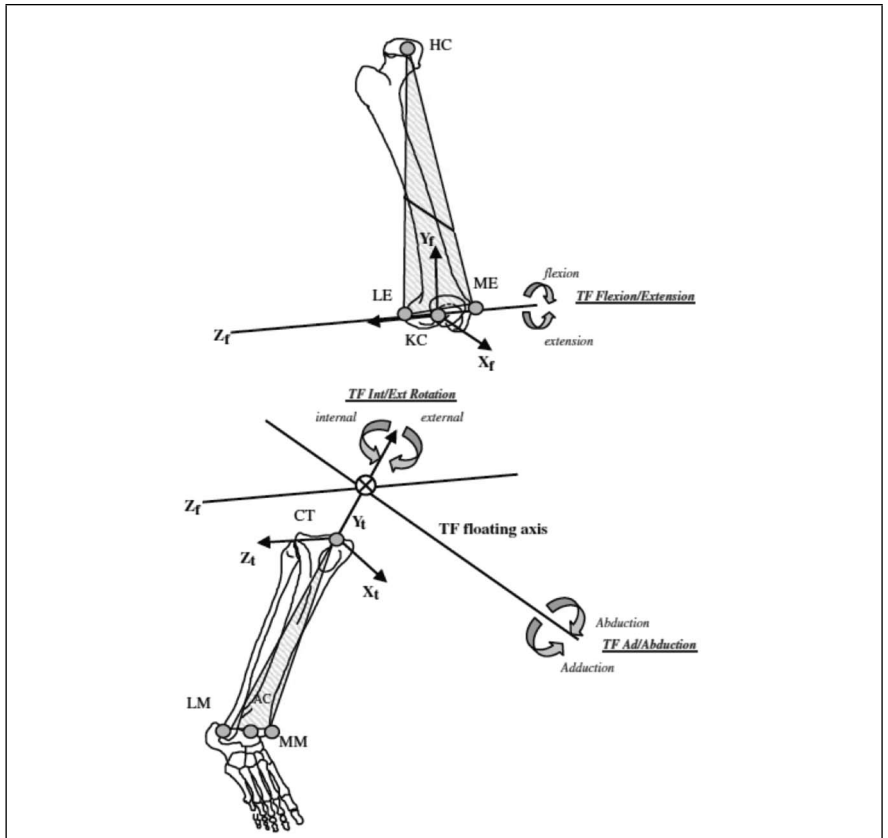

Figure 2 The Grood-Suntay system (Grood and Suntay 1983).

Physiological knee joint numerical model

The three-dimensional models of femur, patella and patellar tendon were imported in commercially available finite element analysis software (Abaqus 6.8EF-1, Dassault Systemes Simulia, Providence, RI, USA). The models were meshed with 2mm 6-noded triangle elements for the cortical and cartilage layers, and 2mm 10-noded tetrahedral elements for the trabecular bone, patellar bone and patellar ligament. The number of elements for each component of the physiological knee model is given in **Table 2**. A convergence analysis was used to validate mesh adequacy.

Two regions of interest (ROI) were defined in the femoral bone: an anterior and a proximal ROI (**Figure 3**). The location of the ROIs was defined to fit the same regions as used in a previous BMD analysis following patellofemoral arthroplasty (van Jonbergen et al. 2010b). The ROIs were 1cm high in femoral proximo-distal direction and 1cm long in the anteroposterior direction. They spanned the entire medio-lateral width. During the dynamic simulation the average Von Mises stress in each ROI was calculated.

Table 2 Number of elements for each component for the different finite element models.

Finite element model	Femur	Patella	Patellar ligament	Femoral component	Patellar component
Physiological model	326737	93830	6914	/	/
Journey PFJ model	496078	26791	6914	18396	13346
Richards II model	318408	9375	6914	19522	4636
Genesis II TKA model	160486	26791	6914	65503	13346

Journey PFJ numerical model

The geometries of the prosthetic components were taken from CAD files provided by the manufacturer (Smith&Nephew, Memphis, TN). The Journey PFJ femoral component (size medium) and ∅32 mm patellar component were incorporated in the knee model following the manufacturers' instructions (**Figure 1**). The femoral component (oxidized zirconium or Oxinium™, Smith&Nephew, Memphis, TN, USA) was modelled as an isotropic linear elastic material (E=97905 MPa, Poisson

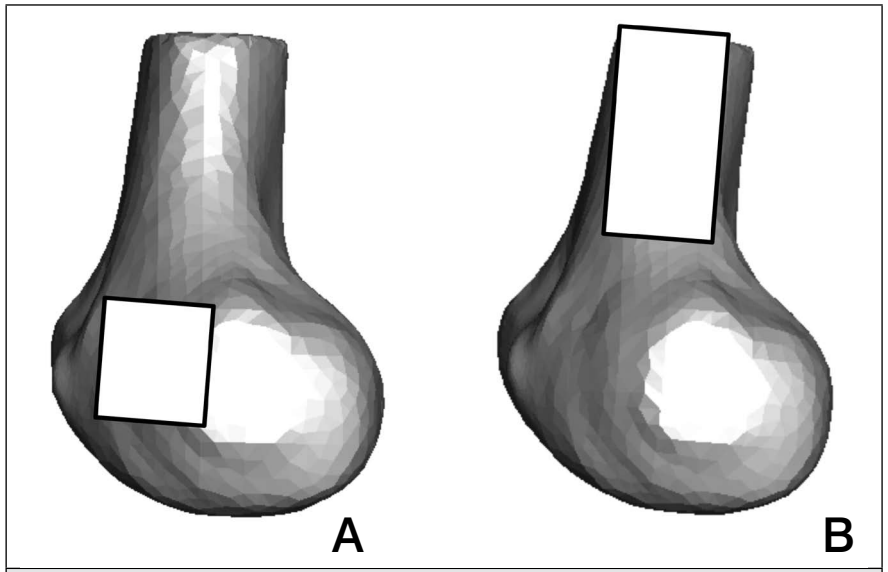

Figure 3 Model of distal femur with anterior (A) and proximal (B) regions of interest (ROI).

ratio v=0.3, density=6.62 g/cm^3) (Zirconium Products: Technical Data Sheet 2003). The UHMWPE patellar component was modelled as a non-linear elasto-plastic material (E=684.65 MPa, Poisson ratio v=0.45) (Godest et al. 2002, Halloran et al. 2005, Innocenti et al. 2009). A 2mm cement layer with linear elastic material properties (E=3000 MPa, Poisson ratio v=0.3) was modelled between the prosthetic components and the cut bone surfaces (Janssen et al. 2008, Vaninbroukx et al. 2009). Contact between cement and bone was modelled using a node-to-surface contact algorithm. The frictional coefficient between the UHMWPE patellar component and the Oxinium femoral component was set at 0.04 based on experimental data (Poggie et al. 1992). The models were meshed with 2mm 6-noded triangle elements for the cortical bone and cement layers, and 2mm 10-noded tetrahedral elements for the cancellous bone, patellar bone, femoral component, patellar component and patellar ligament. The number of elements for each component of the Journey PFJ model is given in **Table 2**. A convergence analysis was used to validate mesh adequacy.

We defined an anterior and a posterior ROI in the same positions and with the same dimensions as in the physiological model. During the dynamic simulation the average Von Mises stress in each ROI was recorded.

Richards type II numerical model

A CAD file of a Richards II patellofemoral prosthesis (Smith&Nephew, Memphis, TN, USA) was obtained by a 3D scan of a real component (size Small). The geometries of the femoral and patellar components were incorporated in the model using the previously described surgical technique (van Jonbergen et al. 2010d) (**Figure 1**). The femoral component (CoCr) was modelled as an isotropic linear elastic material (E=240000 MPa, Poisson ratio v=0.3) (Davis 2003). The material properties of both the patellar component (UHMWPE) and cement were the same as in the Journey PFJ model. Also, the contact and mesh properties were the same as in the Journey PFJ model. We used a friction coefficient of 0.08 in the contact zone between the polyethylene patellar component and the CoCr femoral trochlear component (Poggie et al. 1992). The number of elements for each component of the Richards II model is reported in **Table 2**. A convergence analysis was used to validate mesh adequacy.

We defined an anterior and a posterior ROI in the same positions and with the same dimensions as in the physiological model. During the dynamic simulation the average Von Mises stress in each ROI was recorded.

Genesis II total knee prosthesis numerical model

The geometries of the prosthetic components were taken from CAD files provided by the manufacturer (Smith&Nephew, Memphis, TN, USA). The Genesis II posterior stabilized total knee femoral component (size 5) and ∅32mm patellar component were incorporated in the knee model following the manufacturers' instructions (**Figure 1**). The Genesis II total knee prosthesis was chosen for the total knee model because the geometry of the articular surface of the femoral component of this prosthesis is exactly the same as the geometry of the articular surface of the Journey PFJ femoral component. The material properties of the femoral component (Oxinium™), patellar component and cement were the same as in the Journey PFJ model. Also, the contact, friction and mesh properties were the same as in the Journey PFJ model. The number of elements for each component of the Genesis II model is given in **Table 2**. A convergence analysis was used to validate mesh adequacy.

We defined an anterior and a posterior ROI in the same positions, and with the same dimensions as in the physiological model. During the dynamic simulation the average Von Mises stress in each ROI were recorded.

Results

Figures 4 and 5 show the average Von Mises stress in the anterior and proximal ROIs in the 4 models estimated by the dynamic finite element simulation as a function of time. **Figures 6 and 7** show the average Von Mises stress in the anterior and proximal ROI in the 4 models estimated by the dynamic finite element simulation for 4 different flexion angles.

Overall, the average Von Mises stress in both ROIs increased with the flexion angle. Maximum values of 2.8–3.8 MPa were reached at 90° flexion angle for the anterior ROI, and 1.4–1.6 MPa for the proximal ROI.

During deep knee flexion, the average Von Mises stresses in the anterior ROI with the Journey PFJ design were comparable to the physiological knee. The Richards II design demonstrated lower average Von Mises stress in the anterior ROI compared with the physiological knee, and the Genesis II total knee design demonstrated the lowest average Von Mises stress. The lower average Von Mises stress in the Richards II design was most pronounced at 90 degrees of flexion.

The average Von Mises stress in the proximal ROI was similar for both patellofemoral designs and the physiological model, with slightly lower average Von Mises stress for the Genesis II total knee prosthesis.

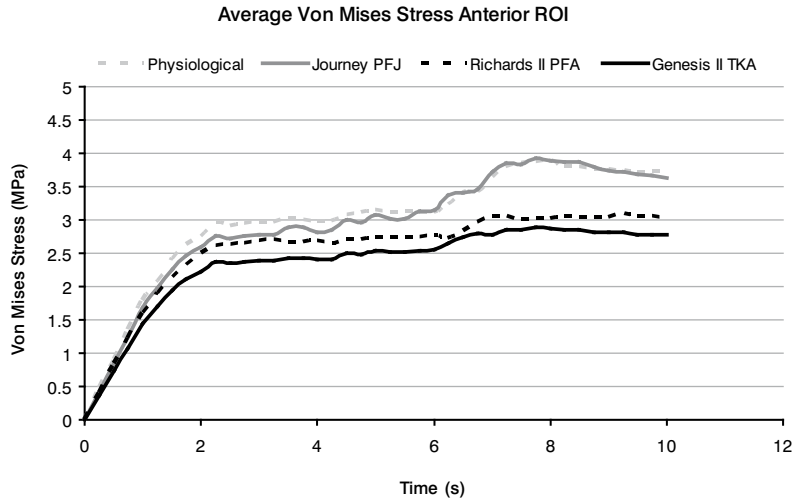

Figure 4 Average Von Mises stress in the anterior ROI in the 4 models as a function of time.

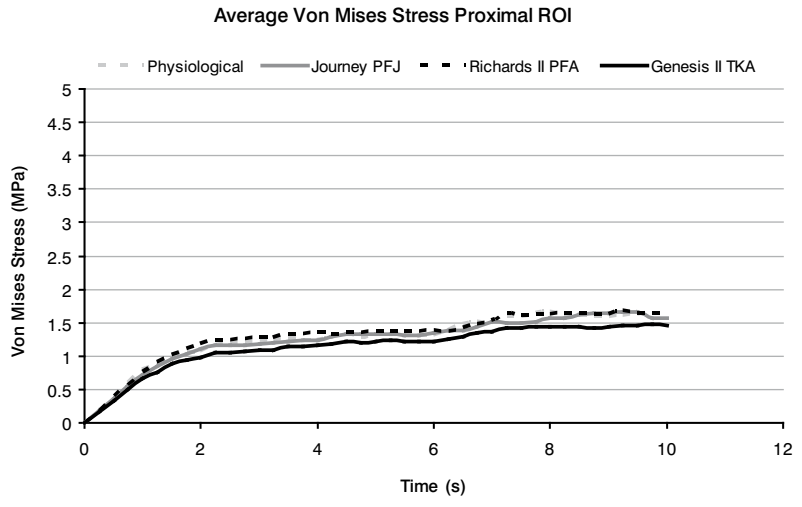

Figure 5 Average Von Mises stress in the proximal ROI in the 4 models as a function of time.

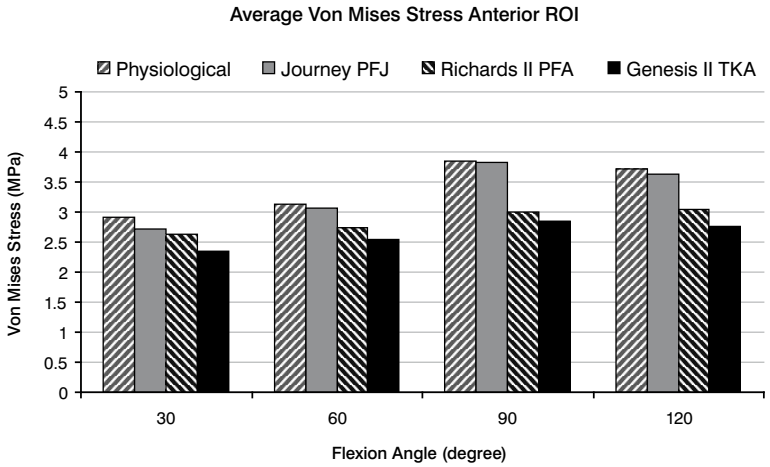

Figure 6 Average Von Mises stress in the anterior ROI in the 4 models for 4 different flexion angles.

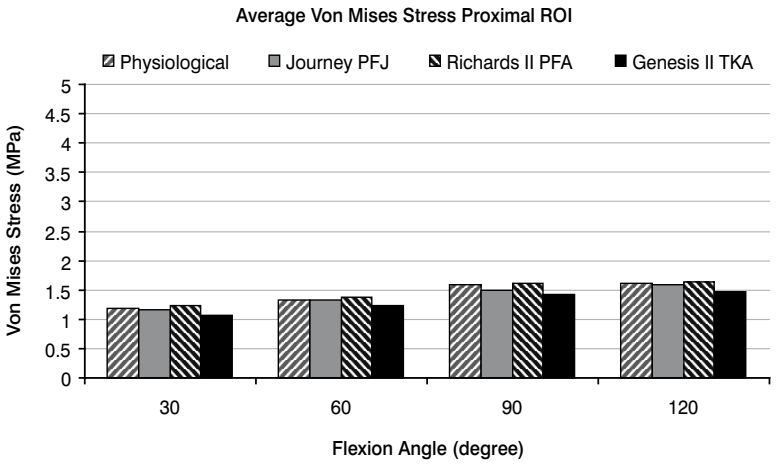

Figure 7 Average Von Mises stress in the proximal ROI in the 4 models for 4 different flexion angles.

Discussion

The aim of the current study was to evaluate the effect of patellofemoral joint replacement on the expected stress-shielding of the distal femur leading to bone remodelling. We modelled a patellofemoral joint in a finite element knee model with and without a patellofemoral joint replacement. In order to investigate the effects of different patellofemoral replacement designs, we also compared the stress shielding effect between the Journey PFJ patellofemoral prosthesis, the Richards II patellofemoral prosthesis, and the Genesis II total knee prosthesis.

In summary, our dynamic finite element modelling demonstrated comparable Von Mises stress in the anterior region of interest for the Journey PFJ design and the physiological knee. The Richards II design demonstrated lower average Von Mises stress in the anterior region of interest compared with the physiological knee, and the Genesis II total knee design demonstrated the lowest average Von Mises stress. The average Von Mises stress in the proximal region of interest was similar for both patellofemoral designs and the physiological model, with a slightly lower average Von Mises stress for the Genesis II total knee prosthesis.

Stress shielding behind the anterior flange of a patellofemoral prosthesis may result in mechanically induced bone remodelling with resulting decrease in BMD. Our Journey PFJ model predicted no significant stress shielding, implying that the physiological strains are maintained. However, the Richards II model predicted a reduction in average Von Mises stress compared to the physiological model. This is in agreement with the recently reported results of clinical dual-energy X-ray absorptiometry (DXA) measurements obtained in 14 patients (van Jonbergen et al. 2010b). In this prospective 1-year DXA study a 15% decrease in BMD was found behind the anterior flange of the Richards type II patellofemoral prosthesis.

The observed differences in the stress shielding effect between the Richards II and Journey PFJ prosthesis may result from differences in both material and geometrical properties. The Richards II prosthesis is a first-generation CoCr prosthesis. The non-anatomic trochlear component is highly constrained with a deep central groove, and the polyethylene patellar component has a longitudinal ridge. In addition, the femoral component has an approximately 2cm long central fixation peg for added stability. In contrast, the Journey PFJ prosthesis is considered a third generation patellofemoral prostheses. The implant is characterized by a

broad anatomical trochlear component made of oxidized zirconium (Oxinium™) which has a coefficient of friction that is half that of CoCr. There are 4 small fixation pegs on the posterior aspect of the femoral component. The stress shielding effect of the Richards II prosthesis was most pronounced at 90° of flexion. At this flexion angle, the patella contacts the femur below the position of the central fixation peg and thus the stress shielding effect of the peg is most pronounced in this configuration.

The curve of the average Von Mises stress in the anterior ROI for the Journey PFJ prosthesis features a gradual transition from the Richards II prosthesis curve (from extension to early flexion) to the physiological curve (between early flexion and deep flexion) (**Figure 4**). This transition can be explained most probably by the fact that the Journey PFJ femoral component is shorter in the sagital plane than the Richards II component. As a result, in deep flexion the patellar button contacts the native femoral surface beyond 90 degrees of flexion while in the Richards II design there is still contact between the femoral component and the patellar button. Moreover the Richards II patellar and femoral components are highly congruent, forcing the patellar component to remain within the femoral component medio-laterally within the entire flexion range.

After total knee replacement, the BMD of the distal femur decreases by 16–36% within one year because of the femoral component's stress-shielding effect (Liu et al. 1995, Petersen et al. 1995, Karbowski et al. 1999, Spittlehouse et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004, Abu-Rajab et al. 2006). Finite element analyses have shown that with a bonded femoral component, the predicted long-term bone loss would occur at the most distal part of the femur and behind the anterior part of the prosthesis (Tissakht et al. 1996, van Lenthe et al. 1997). Only one previous study reported results from a finite element knee model in patellofemoral joint replacement (Morra and Greenwald 2006). Using the geometries of the Low Contact Stress (LCS), Vanguard, and Scout patellofemoral prostheses, a three-dimensional finite element model of each particular design was created. Stress distributions within the patellar components were calculated for three common daily activities: walking, ascending stairs, and rising from a chair. Only static loading was applied with 420N patellofemoral joint reaction force in 15° of flexion (walking gait), 1760N in 45° of flexion (stair ascent), and 1950N in 90° of flexion (chair rise). Based on these models, the authors concluded that different patellofemoral implant design geometries influence the

polymer stress within the patellar component. To minimize contact and delamination stresses, they further stated that contemporary designs should employ a broad trochlear groove to maximize congruent patellar component contact. No attempt was however made to evaluate for altered stress distributions in the periprosthetic distal femur. In an experimental setup using tri-axial strain gauges in synthetic femurs before and after Journey PFJ patellofemoral joint replacement, Meireles et al. determined the strain shielding effect in the distal femur (Meireles et al. 2010). Although a strain shielding effect was found, the results are difficult to interpret as only static loading of the patellofemoral joint was evaluated in 12, 50, and 90 degrees of flexion. The results showed a reduction in strain in the medial and distal regions of the femur when deep bending occurred, with higher values of strain in the anterior region proximal to the prosthesis. This distal diaphyseal increase in strain has also been noted in finite element models with total knee replacement (van Lenthe et al. 1997).

Strengths of the current study include the fact that it is the first to specifically evaluate for the stress-shielding effect of a patellofemoral prosthesis, and that we compared the stress-shielding effect of 3 different patellofemoral replacement designs. However, correct interpretation of results obtained from numerical models requires careful consideration of several important issues (Viceconti et al. 2005). Finite element modeling is subject to limitations due to inherent uncertainties concerning geometry, load situation, and material properties. Although the results of our modelling are in agreement with the observed decrease of distal femoral bone mineral density after patellofemoral replacement, validation of our model requires more clinical data on the decrease of distal femoral bone mineral density with other patellofemoral prosthesis designs.

Conclusions

Dynamic finite element analyses of knee models with a patellofemoral joint replacement predict a decrease in strain energy density behind the anterior flange of the femoral component. This reduction was more pronounced in the Richards II design than in the Journey PFJ design, and may be related to specific design properties.

7

A Dutch survey on circumpatellar electrocautery in total knee arthroplasty

van Jonbergen H P W, Barnaart A F W, Verheyen C C P M.
Open Orthop J 2010; 4: 201-203.

Abstract

Introduction: Anterior knee pain following total knee arthroplasty (TKA) is estimated to occur in 4 to 49% of patients. Some orthopedic surgeons use circumpatellar electrocautery (diathermy) to reduce the prevalence of postsurgical anterior knee pain; however, the extent of its use is unknown.

Materials and Methodology: In April 2009, a postal questionnaire was sent to all 98 departments of orthopedic surgery in The Netherlands. The questions focused on the frequency of total knee arthroplasties, patellar resurfacing, and the use of circumpatellar electrocautery.

Results: The response rate was 92%. A total of 18,876 TKAs, 2,096 unicompartmental knee arthroplasties, and 215 patellofemoral arthroplasties are performed yearly in The Netherlands by the responding orthopedic surgeons. Of the orthopedic surgeons performing TKA, 13% always use patellar resurfacing in TKA for osteoarthritis, 49% use selective patellar resurfacing, and 38% never use it. Fifty-six percent of orthopedic surgeons use circumpatellar electrocautery when not resurfacing the patella, and 32% use electrocautery when resurfacing the patella.

Conclusion: There is no consensus among Dutch orthopedic surgeons on the use of patellar resurfacing or circumpatellar electrocautery in total knee replacement performed for osteoarthritis. A prospective clinical trial is currently underway to fully evaluate the effect of circumpatellar electrocautery on the prevalence of anterior knee pain following TKA.

Introduction

An estimated 4 to 49% of patients report anterior knee pain following total knee arthroplasty (TKA) (Wood et al. 2002, Waters and Bentley 2003, Popovic and Lemaire 2003, Burnett et al. 2004, Burnett et al. 2007, Smith et al. 2008). The cause is unknown, but is hypothesized to be related to patient characteristics (Barrack and Burak 2001, Wood et al. 2002, Smith et al. 2004), prosthetic design (Popovic and Lemaire 2003, Skwara et al. 2008, Breugem et al. 2008), operative technique (Fern et al. 1992), and/or the use of patellar resurfacing (Cameron 1991, Wood et al. 2002, Waters and Bentley 2003). Both the peripatellar soft tissues and the infrapatellar fat pad have been implicated as the source of anterior knee pain (Maculé et al. 2005, Lehner et al. 2008). Immunohistochemical studies on innervation of the anterior knee demonstrated substance-P nociceptive afferent fibers in the peripatellar soft tissues (Wojtys et al. 1990). Production of a lesion in these pain receptors using electrocautery (diathermy) could theoretically achieve desensitization or denervation of the anterior knee (Moati and Zucman 1987, Maralcan et al. 2005, Vega et al. 2006).

Some orthopedic surgeons perform circumpatellar electrocautery to reduce the prevalence of anterior knee pain after TKA. The extent of its use in clinical practice both in The Netherlands and elsewhere is at present unknown. We aimed to determine the prevalence of circumpatellar electrocautery performed during TKA for osteoarthritis in The Netherlands.

Materials and methodology

In April 2009, a postal questionnaire with cover letter and postage free, addressed return envelope was sent to all 98 departments of orthopedic surgery in The Netherlands. The questions related to TKA for osteoarthritis (but not rheumatoid arthritis), patellar resurfacing, and the use of circumpatellar electrocautery. Furthermore, the questionnaire evaluated the number of orthopedic surgeons in each practice, the number performing knee replacement surgery, and the number and type of knee arthroplasties performed (TKA, unicompartmental arthroplasty, and patellofemoral arthroplasty).

If after 3 weeks no completed questionnaire was received, a reminder with a copy of the questionnaire was sent. Remaining nonresponders were contacted by telephone after 6 weeks.

Results

The response rate was 62% after the first questionnaire, 82% after repeat mailing, and 92% after telephone contact.

A total of 18,876 TKAs, 2,096 unicompartmental knee arthroplasties, and 215 patellofemoral arthroplasties are performed yearly in The Netherlands by 383 of the 477 responding orthopedic surgeons; 80% of responding surgeons perform knee arthroplasty. Among respondents, the average number of TKAs by surgeons who perform knee replacements was 50 per year (range, 18 to 101).

Of the orthopedic surgeons performing TKA, 13% always use patellar resurfacing in TKA for osteoarthritis, 49% use selective patellar resurfacing, and 38% never use it.

Fifty-six percent of orthopedic surgeons performing knee replacements use circumpatellar electrocautery when not resurfacing the patella, and 32% use electrocautery when resurfacing the patella.

Surgeons were questioned regarding the clinical conditions that were treated with selective resurfacing. A total of 78% of orthopedic surgeons who use selective resurfacing mentioned articular cartilage or severity of patellofemoral osteoarthritis, 34% preoperative anterior knee pain, 20% patellofemoral instability, 11% poor congruency of the native patella with the prosthetic trochlear groove, 1% the type of knee prosthesis used, and 4% reported other indications.

Discussion

The source of anterior knee pain after TKA is poorly understood; both the peripatellar soft tissues and the infrapatellar fat pad have been implicated (Maculé et al. 2005, Lehner et al. 2008). Immunohistochemical studies on innervation of the anterior knee demonstrate hyperinnervation of the peripatellar soft tissues (Wojtys et al. 1990). Production of a surgical lesion in these pain receptors could theoretically achieve desensitization or denervation of the anterior knee (Moati and Zucman 1987, Maralcan et al. 2005, Vega et al. 2006). The use of circumpatellar electrocautery in order to reduce the prevalence of anterior knee pain after TKA is reported by several authors (Keblish et al. 1994, Barrack and Burak 2001, Pellengahr et al. 2002, Kim et al. 2008, van Hemert et al. 2009, Seo et al. 2009). However, only one clinical study has addressed the efficacy of circumpatellar electrocautery in TKA to date (Saoud 2004). Results showed improved pain relief after patellar denervation, but the inferior study design of this trial prevents confident application of this procedure to clinical practice. Prior to the current study, the extent to which surgeons use circumpatellar electrocautery in clinical practice was unknown.

The use of patellar resurfacing varies between countries. According to the 2009 Annual Report of the Swedish Knee Arthroplasty Register (The Swedish Knee Arthroplasty Register 2009), patellar resurfacing is used in less than 10% of TKA cases in Sweden, 70% of cases in Denmark, 5% in Norway, and 45% of cases in Australia. The reasons for these regional differences are unclear. In 1996, a survey of TKA techniques in the United Kingdom showed 32% of orthopedic surgeons always performing patellar resurfacing, 49% sometimes using resurfacing, and 19% never using it (Phillips et al. 1996). This great disparity as to whether the patella should be resurfaced was apparent in the present study as well, with surgeons reporting always, selectively, or never performing resurfacing in 13, 49 and 38 percent, respectively. Clearly, the ongoing debate on the need for patellar resurfacing has not resolved this important issue.

Strengths of the current study include the high response rate and the fact that our study is the first to determine the prevalence of circumpatellar electrocautery among orthopedic surgeons. The present survey has some limitations that should be considered. Firstly, we cannot rule out the possibility that a nonresponse bias was introduced using the survey. To reduce the chance of a nonresponse bias,

we maximized the response rate by designing a mixed-mode (mail and telephone) survey following the recommendations by others (Sprague et al. 2009). No non-response analysis was performed to determine if characteristics of respondents and non-respondents differ. Additionally, we assumed the group of responders to be a representative sample of all Dutch orthopedic surgeons. Secondly, we did not inquire about the technique used to perform circumpatellar electrocautery. Currently, there is no adequate description of the technique in the literature. One could argue that the different procedures collectively described as patelloplasty may also result in partial denervation. These patelloplasties consist of various combinations of debriding or shaving of the patella, removal of osteophytes, peripatellar synovectomy, and reduction of size of the patella (Wood et al. 2002, Popovic and Lemaire 2003, Burnett et al. 2004, Oh et al. 2006, Burnett et al. 2007, Smith et al. 2008). As patellar resurfacing requires removal of osteophytes and synovial tissue to enable accurate resection and restore patellar thickness, this may, at least in part, also be considered denervation. Thirdly, the survey was limited to orthopedic surgeons in The Netherlands, and the results may therefore not be representative for the practice pattern in other countries.

A prospective, randomized controlled trial comparing TKA with and without the use of circumpatellar electrocautery is currently underway to determine the effect of this intervention on post-TKA anterior knee pain (Netherlands Trial Register, NTR1326).

Conclusion

Of the Dutch orthopedic surgeons performing TKA, 56% use circumpatellar electrocautery when not resurfacing the patella, and 32% use diathermy when resurfacing the patella. A prospective clinical trial is currently underway to fully evaluate the effect of circumpatellar electrocautery on the prevalence of anterior knee pain following TKA.

8

Circumpatellar electrocautery in total knee arthroplasty without patellar resurfacing: A randomized controlled trial

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on behalf of the Anterior Knee Pain Study Group.
Submitted for publication.

Abstract

Background: Patellofemoral complications may compromise the outcome of total knee arthroplasty. The efficacy of circumpatellar electrocautery in reducing the risk of postsurgical anterior knee pain is unknown.

Methods: We conducted a single-centre, outcome-assessor and patient-blinded, parallel group, randomized controlled trial to determine the clinical efficacy of circumpatellar electrocautery versus no electrocautery in total knee arthroplasty without patellar resurfacing. Patients requiring knee replacement for primary knee osteoarthritis were randomly assigned to circumpatellar electrocautery or to no electrocautery. The primary outcome measure was the prevalence of anterior knee pain. Secondary outcomes included standardized clinical and patient-reported outcomes (KSKS, KSFS, and WOMAC scores).

Results: A total of 131 knees received circumpatellar electrocautery, and 131 knees received no electrocautery. The overall prevalence of anterior knee pain at 1-year follow-up was 26% (20% to 31%), with 19% (12% to 26%) in the intervention group, and 32% (24% to 40%) in the control group ($p=0.02$). Relative risk reduction (RRR) was 40% (9% to 61%) and number needed to treat (NNT) 7.7 (4.3 to 41.4). The intervention group demonstrated better total WOMAC scores at 1-year follow-up compared with the control group ($p=0.04$). Postoperative KSKS ($p=0.14$), KSFS ($p=0.49$), and adverse events were similar in both groups.

Conclusions: In patients with primary knee osteoarthritis having total knee arthroplasty without patellar resurfacing, the use of circumpatellar electrocautery results in a lower prevalence of anterior knee pain and better WOMAC scores at the 1-year follow-up compared with no circumpatellar electrocautery, but not in better standardized clinical outcomes (Netherlands Trial Register NTR1326).

Introduction

Patellofemoral complications may compromise the outcome of total knee arthroplasty and are the primary non-infectious indication for revision surgery (Eisenhuth et al. 2006). Anterior knee pain is reported to occur in 4–49% of patients following primary total knee arthroplasty (Wood et al. 2002, Popovic and Lemaire 2003, Waters and Bentley 2003, Smith et al. 2004, Burnett et al. 2004, Arbuthnot et al. 2004, Oh et al. 2006, Campbell et al. 2006, Oztuna et al. 2007, Burnett et al. 2007, Breugem et al. 2008, Kim et al. 2008, Smith et al. 2008, Erak et al. 2009, Burnett et al. 2009). The cause is unknown, but may be related to patient characteristics (Wood et al. 2002, Smith et al. 2004), degree of patellar cartilage wear (Rodriguez-Merchan and Gomez-Cardero 2010), prosthetic design (Popovic and Lemaire 2003, Skwara et al. 2008, Breugem et al. 2008), operative technique (Fern et al. 1992, Barrack et al. 2001b, Maculé et al. 2005), and the use of patellar resurfacing (Wood et al. 2002, Waters and Bentley 2003, Calvisi et al. 2009). Both the peripatellar soft tissues and the infrapatellar fat pad have been implicated as a source of anterior knee pain (Maculé et al. 2005, Lehner et al. 2008). Immunohistochemical studies on innervation of the anterior knee demonstrated substance-P nociceptive afferent fibers in the peripatellar soft tissues (Wojtys et al. 1990). Therefore, production of a lesion in these pain receptors using electrocautery could theoretically achieve desensitization or denervation of the anterior knee with less postsurgical anterior knee pain (Moati and Zucman 1987, Maralcan et al. 2005, Vega et al. 2006, McPherson 2006).

Several research papers have described the use of circumpatellar electrocautery in total knee arthroplasty with (Barrack and Burak 2001, Larson et al. 2001, van Hemert et al. 2009) and without patellar resurfacing (Pellengahr et al. 2002, Kim et al. 2008, van Hemert et al. 2009). To date, only one clinical study specifically addressed the results of circumpatellar electrocautery in primary total knee arthroplasty (Saoud 2004). Results showed improved pain relief after patellar denervation, but the inferior study design prevents confident application of this procedure to clinical practice. A recent postal survey with a 92% response rate revealed that 56% of orthopedic surgeons in The Netherlands use circumpatellar electrocautery when not resurfacing the patella, and 32% use electrocautery when resurfacing the patella (van Jonbergen et al. 2010a).

We hypothesized that primary total knee arthroplasty with circumpatellar electrocautery leads to partial denervation of the anterior knee with resulting better pain relief and patient reported clinical outcomes than primary total knee arthroplasty without circumpatellar electrocautery. The primary objective of the present blinded, prospective, parallel randomized study was therefore to determine the clinical effect of circumpatellar electrocautery in total knee arthroplasty without patellar resurfacing with regard to the prevalence of anterior knee pain. Secondary objectives were to evaluate for differences in standardized clinical and patient-reported outcomes.

Materials and methods

Study design

In 2008, a prospective, outcome-assessor and patient-blinded, parallel group, randomized clinical trial adhering to the CONSORT statement 2001 was initiated (Moher et al. 2001, Boutron et al. 2008a). The study was approved by the Regional Ethics Committee (NL21569.075.08, February 2008) and Institutional Review Board. Before start of the study, the protocol was registered with the Netherlands Trial Register (NTR1326).

Study population

All patients who were to have total knee arthroplasty for primary knee osteoarthritis were evaluated for inclusion in the study. They were not admitted to the study if any of the following criteria were present: isolated patellofemoral osteoarthritis, contralateral patellar resurfacing (primary or as revision), insufficient Dutch language skills, total hip replacement or contralateral total knee replacement within the study period or less than one year before entering the study, inflammatory arthritis, a history of patellar fracture, prior patellectomy, patellofemoral instability, prior unicondylar knee replacement, previous high tibial or distal femoral osteotomy, any prior operation involving the extensor mechanism, a severe medical disability that limits the ability to walk, and disabling disease involving other joints of the lower extremities.

With allowance for patients whose data could not be evaluated, 352 consecutive patients were recruited by all 5 orthopedic surgeons performing total knee arthroplasty, and 300 provided written informed consent (**Figure 1**).

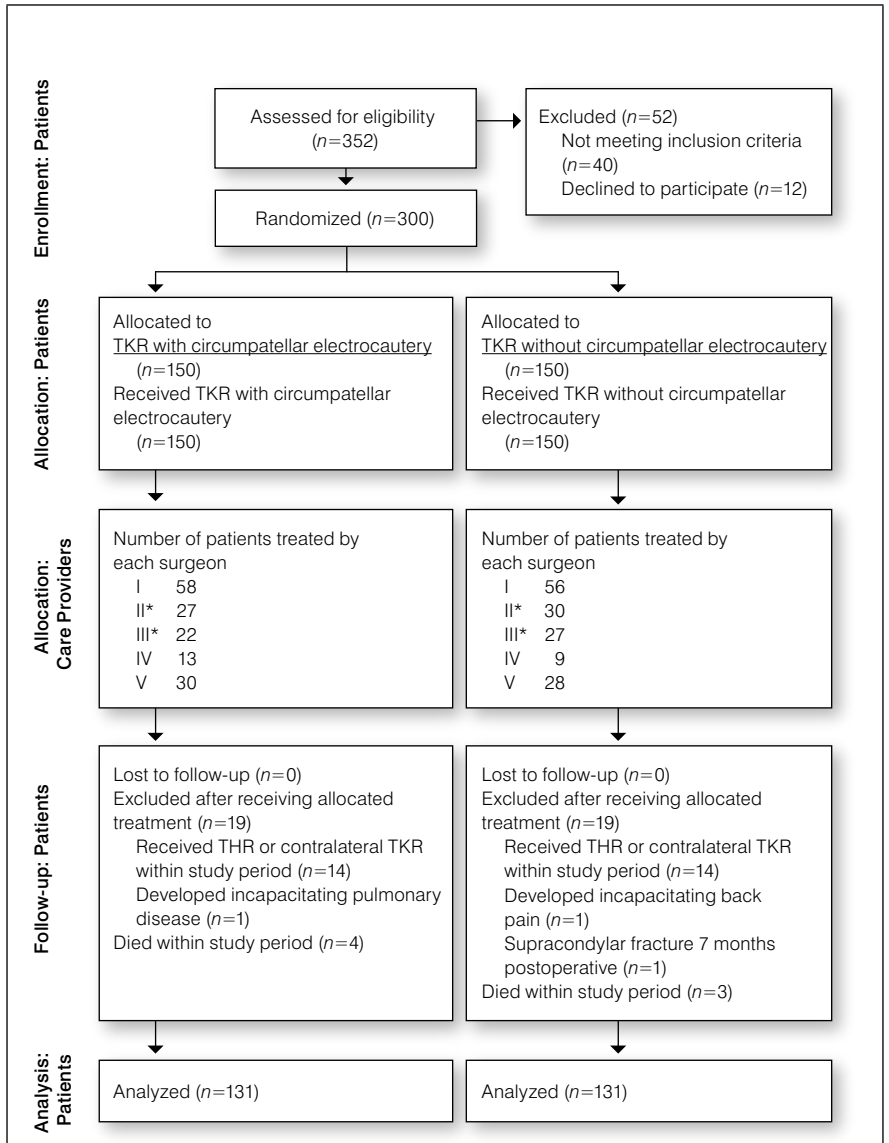

Figure 1 CONSORT flow diagram. Enrollment of patients, treatment allocation and completion of the study.

* Denotes surgeon's preference for electrocautery.

Baseline studies

All eligible patients were preoperatively assessed by one of the five participating orthopedic surgeons who obtained the Knee Society Knee Score (KSKS) and Knee Society Functional Score (KSFS). The Dutch version of the 24-item Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Likert version 3.0 was completed by all patients.

Study treatment

All 300 patients participated in a standardized preoperative workup program which has been in use at our institution since 2004. This program consists of patient education, physical therapy instructions for walking with crutches, and preoperative screening by an anesthesiologist. Patients were admitted to the hospital on the morning of surgery.

Total knee arthroplasty was performed by all five participating general orthopedic surgeons in a standardized manner according to the manufacturers' instruction. Patients were operated under spinal anesthesia combined with a femoral nerve block and with pneumatic tourniquet control. Blinding of the patient was achieved by shielding the subject's view by a vertical drape. In all cases the NexGen LPS (NexGen, Zimmer, Warsaw, IN) posterior stabilized, non-rotating, total knee prosthesis was used without patellar resurfacing. After a midline skin incision and medial arthrotomy, the patella was everted to the lateral side, and remained in this position until stability was assessed using the trial femoral and tibial components. In all cases, the patellar fat pad was resected to adequately visualize the proximal tibia. We employed five degrees of distal femoral valgus, and three degrees of external rotation relative to the posterior condyles. After cementing both femoral and tibial components, the degree of damage to the patellar articular cartilage was assessed according to the Outerbridge grading system, and the patella was debrided by removal of osteophytes only if considered necessary for patellar tracking. Also, a lateral release at least 2cm lateral to the lateral border of the patella was only performed as clinically indicated after a 'no thumbs' assessment of patellofemoral instability on passive testing of the range of motion.

Randomization

Patients were randomly assigned to receive total knee arthroplasty with circumpatellar electrocautery (intervention group) or to receive total knee arthroplasty without circumpatellar electrocautery (control group). The randomization was

performed during surgery using sequentially numbered, opaque sealed envelopes, each bearing on the outside only a number. All 300 envelopes containing a total of 150 instructions for circumpatellar electrocautery, and 150 instructions for no additional treatment were prepared before start of the study by an assistant who did not participate in the study, using computer generated random-number tables.

To maintain allocation concealment, the next available numbered envelope was opened by a nurse in the operating room after cementing both femoral and tibial components, assessment of patellar cartilage, and proper management of patello-femoral instability. The contained instructions described the required further treatment of the patella: subsequent circumpatellar electrocautery, or no circumpatellar electrocautery. The treatment assignment was not revealed to the patient. In case electrocautery was required as per instruction, diathermy was performed using the Valleylab electrocautery unit (Valleylab Inc., Boulder, CO) with monopolar diathermy with powersetting 50W and use of coagulation. The technique employed only superficial electrocautery to a depth of no more than 1 mm in a circular (360 degrees) fashion within 5 mm of the edge of the patella (**Figure 2**). After lavage, the medial arthrotomy, subcutaneous tissue, and skin were closed in layers over a suction drain. In case no electrocautery was required as per instruction, the knee was lavaged and closed in layers over a suction drain.

Postoperative management

All 300 patients received the same postoperative treatment according to an integrated pathway protocol with analgesia monitored by an anesthesiologist. Physical therapy followed an identical program in both groups with immediate postoperative protected weight bearing with crutches. Patients were discharged from hospital after four days if they were able to actively flex the operated knee to 90 degrees. All patients routinely received antithrombotic prophylaxis with a low-molecular-weight heparin (Dalteparin) for six weeks. After six weeks full unrestricted weight bearing was allowed without walking aids. All patients had a scheduled clinical follow-up at 2 weeks, 8 weeks, and one year post-surgery. During follow-up, the radiological examination consisted of two radiographs (antero-posterior standing and lateral non-weight bearing) at eight weeks and one year post surgery. All health care professionals following the participants after the surgical procedure were blinded to group assignment.

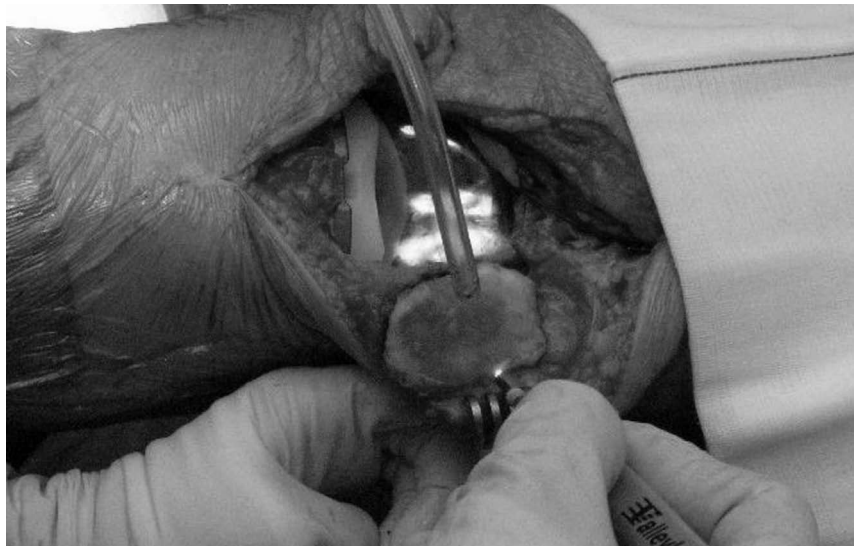

Figure 2 Intra-operative photograph depicting circumpatellar electrocautery performed after cementing femoral and tibial components.

Surgeons' expertise

The five participating general orthopedic surgeons perform a total of 300 total knee replacements yearly averaging more than fifty arthroplasties each, and each had five or more years of experience with the procedure and the type of knee prosthesis used. **Figure 1** shows the number of patients treated by each surgeon in our study. We also assessed surgeon's preference for either electrocautery or standard care (**Figure 1**).

Outcome measures

A trained nurse practitioner, who was blinded to the treatment arm, assessed the clinical outcome one year after total knee arthroplasty.

The primary outcome was the prevalence of anterior knee pain at one year after the intervention. To determine the prevalence of anterior knee pain, the Clinical Anterior Knee Pain Rating system as described by Waters and Bentley was used (**Table 1**) (Waters and Bentley 2003). Together with the question: 'do you experience pain at the anterior side of the knee', patients who responded affirmative were

further questioned whether it interfered with activity, and whether its severity warranted further surgery.

The secondary outcomes at one year were assessed with the KSKS and KSFS scores obtained by the nurse practitioner, and with the WOMAC questionnaire completed by all patients.

Table 1 Clinical Anterior Knee Pain Rating system described by Waters and Bentley (Waters and Bentley 2003).

Rating	Description
0	No pain
I	Mild pain that does not intrude on daily activities
II	Moderate pain that is a nuisance; patient not considering further surgery
III	Severe pain; patient considering further surgery

Statistical analysis

Baseline characteristics were analyzed by descriptive statistics using the mean and standard deviation for continuous variables and frequencies for categorical variables.

For the primary outcome measure, the Clinical Anterior Knee Pain Rating system was dichotomized. A Rating of I, II or III was coded as "presence of anterior knee pain", while a rating of 0 was coded as "absence of anterior knee pain" (Waters and Bentley 2003). The prevalence of anterior knee pain in both groups including 95%-confidence intervals were calculated, and the chi-squared test was used to compare the categorical data between the two study groups. A two-sided p-value of 0.05 was considered to indicate statistical significance. The relative risk reduction (RRR) and number needed to treat (NNT) with 95% confidence intervals were calculated.

For the three secondary outcome measures (KSKS, KSFS, and WOMAC), data were first assessed for normality using the Kolmogorov-Smirnov test with $p<0.05$, after which repeated measures ANOVA was used to analyze for differences over time between both groups. All analyses were performed according to the intention-to-treat principle.

Before start of the study, sample size calculation was performed using estimates of the prevalence of anterior knee pain of 25% after total knee arthroplasty without patellar resurfacing (Waters and Bentley 2003). We considered a difference of 15 percentage-points clinically relevant although no pilot study was performed, and no previous study assessed the prevalence of anterior knee pain after total knee arthroplasty with and without the use of circumpatellar electrocautery. With use of a 15% effect size, significance level (alpha) of 0.05 using a two-sided test, and power of 80%, a sample size of 113 knees in each group would be required to detect a significant difference.

Results

Baseline characteristics of study population

Baseline demographic and clinical characteristics of both groups are summarized in **Table 2**. No statistically significant differences between groups were found with respect to these baseline characteristics. **Figure 1** shows the disposition of the study participants outlined in a Consolidated Standards of Reporting Trials (CONSORT) diagram (Boutron et al. 2008a, Boutron et al. 2008b). Patients were included between May 2008 and May 2009 with surgery performed between May 2008 and June 2009. The 19 patients who were excluded after receiving the study intervention did not differ with respect to baseline characteristics from the 19 patients who were excluded after receiving the control treatment.

Surgical procedure

All patients received the allocated treatment. The number of knees requiring a lateral release was 8 in the intervention group, and 9 in the control group.

Adverse events

Three knees, two knees in the intervention group, and one knee in the control group, showed signs of a deep infection within 6 weeks after arthroplasty and received adequate operative and antibiotic treatment. At the 1-year follow-up, these knees had no clinical signs of infection of the total knee prosthesis. In three knees in the intervention group and in one knee in the control group, manipulation under anesthesia was performed to improve flexion after the fourth postoperative week. These patients obtained more than 90° of flexion at final review.

Table 2 Baseline demographic and clinical characteristics of each group.

Characteristic	Intervention group (n=131)	Control group (n=131)	p-value
Side (right : left)	77 : 54	81 : 50	0.71
Age at operation (years)	71 (8.0)	72 (7.9)	0.87
Sex (female : male)	95 : 36	84 : 47	0.14
Height (cm)	167 (9.1)	169 (9.2)	0.21
Weight (kg)	84 (14.7)	84 (15.4)	0.88
Body mass index (kg/m^2)	30.1 (4.7)	29.4 (4.3)	0.22
ASA PS Classification			0.46
ASA PS 1	13	10	
ASA PS 2	105	102	
ASA PS 3	13	19	
Predominant location of pre-operative knee pain			0.97
Anterior	16	14	
Medial	67	69	
Posterior	3	2	
Lateral	10	12	
Generalized	35	34	
Intra-operative cartilage patella (Outerbridge grading)			0.96
Grade 0	10	13	
Grade 1	11	12	
Grade 2	40	36	
Grade 3	39	39	
Grade 4	31	31	
Mean duration of follow-up (years)	1.1 (0.1)	1.0 (0.1)	0.45

ASA PS, American Society of Anesthesiologists Physical Status.
* Continuous values are given as the mean with standard deviation in parentheses.

No radiologic signs of patellar osteonecrosis were seen at 1-year follow-up (Melloni et al. 2008).

Primary outcome measure

The overall prevalence of anterior knee pain at 1-year follow-up was 26% (95% confidence interval 20% to 31%). A statistically significant lower prevalence of

anterior knee pain was found in the intervention group (19%; 95% confidence interval 12% to 26%) as compared to the control group (32%; 95% confidence interval 24% to 40%) (chi-squared test, p=0.02). The number of knees in each group with grading according to the Clinical Anterior Knee Pain Rating system is presented in **Table 3**. The difference in proportions was statistically significant (chi-squared test, p=0.03). Use of circumpatellar electrocautery results in a 40% (95% confidence interval 9% to 61%) Relative risk reduction (RRR) for postsurgical anterior knee pain, with number needed to treat (NNT) 7.7 (95% confidence interval 4.3 to 41.4).

Table 3 Patient categories and prevalence of anterior knee pain at 1 year follow-up.

	Intervention group (n=131)	Control group (n=131)
Anterior Knee Pain Rating		
Grade 0	106	89
Grade I	18	24
Grade II	6	9
Grade III	1	9

Secondary outcome measures

The intervention group demonstrated better total WOMAC scores at 1-year follow-up compared with the control group (p=0.04). Additional analysis of the component items within the WOMAC questionnaire demonstrated a statistically significant better WOMAC function subscale (p=0.02) for the intervention group. However, no statistically significant differences for the WOMAC pain (p=0.14) and stiffness subscales (p=0.18) were noted between groups. No statistically significant differences were observed between the treatment groups for the change from baseline KSKS (p=0.14) and KSFS scores (p=0.49) (**Table 4**). Also, for those patients reporting anterior knee pain, no statistically significant differences were found between the treatment groups for VAS scores for pain (p=0.65).

Table 4 Clinical outcome after total knee arthroplasty with preoperative and postoperative clinical scores.

	Intervention group (n=131)	Control group (n=131)	p-value
Knee Society Knee Score			
Preoperative	51.7 (11.9)	52.7 (12.2)	
Postoperative	92.4 (10.8)	90.4 (13.0)	0.14
Knee Society Function Score			
Preoperative	54.4 (15.7)	54.4 (15.7)	
Postoperative	86.5 (15.0)	84.4 (16.2)	0.49
WOMAC total score			
Preoperative	56.6 (16.5)	57.0 (14.9)	
Postoperative	16.3 (15.4)	21.6 (18.5)	0.04
WOMAC pain score			
Preoperative	54.2 (17.9)	55.3 (17.7)	
Postoperative	10.7 (15.1)	15.8 (17.8)	0.14
WOMAC stiffness score			
Preoperative	58.8 (20.7)	59.1 (21.1)	
Postoperative	23.2 (19.3)	28.2 (22.5)	0.18
WOMAC function score			
Preoperative	57.0 (18.7)	56.3 (17.0)	
Postoperative	15.3 (17.1)	20.4 (20.2)	0.02

WOMAC scores are normalized and expressed on 0–100 scales.

Discussion

In patients with primary knee osteoarthritis having total knee arthroplasty without patellar resurfacing, the use of circumpatellar electrocautery results in a lower prevalence of anterior knee pain at 1-year follow-up compared with no circumpatellar electrocautery, with a relative risk reduction of 40% for postsurgical anterior knee pain. Moreover, we found better WOMAC scores in the intervention group, mostly because of better scores in the function component of the WOMAC, suggesting that anterior knee pain may be associated with the functional results.

Both the presence and severity of anterior knee pain, together with standardized clinical and patient-reported outcomes were used to assess patient functioning at different levels (Poolman et al. 2009). We believe measuring outcomes at several

levels in a conceptual framework of outcome measurement does not need correction for multiple endpoints since each endpoint measures different aspects of the patient's wellbeing (Poolman et al. 2009). Correcting for multiple endpoints utilizing Bonferroni's method, adjusting the significance level to p=0.017 (0.05/3) would yield less striking results for our secondary endpoints.

To our knowledge, the present study is the first to use a prospective randomized, assessor and patient blinded trial to investigate the effect of circumpatellar electrocautery on the prevalence of anterior knee pain in patients undergoing total knee arthroplasty without patellar resurfacing. Numerous studies have assessed the various factors thought to be related to anterior knee pain, including patient characteristics (Wood et al. 2002, Smith et al. 2004), degree of patellar cartilage wear (Rodriguez-Merchan and Gomez-Cardero 2010), prosthetic design (Popovic and Lemaire 2003, Skwara et al. 2008, Breugem et al. 2008), operative technique (Fern et al. 1992, Barrack et al. 2001b, Maculé et al. 2005), and the use of patellar resurfacing (Wood et al. 2002, Waters and Bentley 2003, Calvisi et al. 2009). Although some of these factors could be related to denervation, others are probably not. It is thus probable that the occurrence of anterior knee pain after total knee arthroplasty is multifactorial. Some of these variables may have influenced our results. In a randomized controlled trial comparing patellar resurfacing with retention, weight but not body mass index was associated with the development of anterior knee pain in the patients without patellar resurfacing (Wood et al. 2002). In our study, baseline characteristics including weight, length and body mass index did not differ between groups. We have however not stratified our analysis for weight or body mass index. The degree of patellar cartilage wear is another factor potentially influencing the prevalence of anterior knee pain (Rodriguez-Merchan and Gomez-Cardero 2010). Selective resurfacing has been recommended in Outerbridge grade IV patellae as patients with Outerbridge Class IV patellofemoral findings were 21 times more likely to require revision for patellar resurfacing than patients in whom Outerbridge Class I, II, and III findings were documented (Rodriguez-Merchan and Gomez-Cardero 2010). We did not find a correlation between the prevalence of anterior knee pain and the extent of cartilage damage, and this lack of correlation has been reported by others as well (Barrack et al. 2001a, Wood et al. 2002, Burnett et al. 2004, Oh et al. 2006). We used the posterior stabilized, fixed-bearing NexGen prosthesis in all patients, use of which may result in a higher prevalence of anterior knee pain than observed with a mobile-bearing prosthesis (Breugem et al. 2008). We also employed

total knee arthroplasty without patellar resurfacing, as definite evidence for use of primary patellar resurfacing is currently lacking (Calvisi et al. 2009).

To enhance the generalizability of our research findings, we used broad inclusion criteria and maximized the sample size. The study was undertaken at a single general teaching hospital by five general orthopedic surgeons using a commonly used prosthesis. Validity was maximized by parallel randomization and allocation concealment, adequate blinding of patient and outcome assessor, careful follow-up with no patients lost to follow-up, well defined intervention and control procedures, and use of both standardized clinical and patient-reported outcomes. Most importantly, we used outcome measures important to patients rather than surrogate endpoints (Poolman 2009).

The mechanism by which circumpatellar electrocautery results in a lower prevalence of anterior knee pain could be that production of a lesion in the pain receptors resulted in desensitization or denervation of the anterior knee (Vega et al. 2006, McPherson 2006). By this mechanism, the different procedures collectively described as patelloplasty may also result in partial denervation. As patellar resurfacing requires removal of osteophytes and synovial tissue to enable accurate resection and restore patellar thickness, this may, at least in part, also result in denervation. After our study was completed, Gupta et al. reported a lack of improvement after patellar rim electrocautery in total knee arthroplasty without patellar resurfacing (Gupta et al. 2010b). The procedures used in this retrospective, comparative cohort study leave much to be desired because matching was only done for age and sex while introducing substantial bias by comparing results from two different surgeons; one performing electrocautery and the other not.

The number of procedure-related adverse events in our study compares favorably with data from the literature (Blom et al. 2004, Yercan et al. 2006). In theory, electrocautery could result in disruption of the patellar vascularization leading to osteonecrosis. No radiological signs of patellar osteonecrosis were noted at 1-year follow-up. We followed our patients for 1 year. Some authors (Wood et al. 2002, Arbuthnot et al. 2004) reported a gradual decrease in anterior knee pain after total knee replacement, whereas others (Campbell et al. 2006) describe an increase in the incidence over time. To assess the long-term outcomes, we will re-evaluate the patients in the future because the clinical effect of circumpatellar electrocautery may diminish over time.

In summary, the results of this randomized controlled trial provides evidence that the use of circumpatellar electrocautery in total knee arthroplasty without patellar resurfacing results in a lower prevalence of anterior knee pain and better WOMAC scores at 1-year follow-up compared with no circumpatellar electrocautery. Considering the significant clinical benefit of this simple procedure and the lack of harms we suggest routine use of circumpatellar electrocautery in total knee arthroplasty without patellar resurfacing.

Acknowledgements

Members of the Anterior Knee Pain Study Group are: A.F.W. Barnaart, R.H.G.P. van Erve, H.P.W. van Jonbergen, A. van Kampen, R. Koorevaar, D.D. Langeloo, R.W. Poolman, and D.M. Werkman.
We thank Mrs I. Wippert for her invaluable assistance in evaluating the patients and coordinating the hip and knee replacement integrated care pathway.

9

Summary and general discussion

Background

Isolated patellofemoral joint osteoarthritis is a degenerative disorder of the knee estimated to occur in approximately 4% to 24% of patients with osteoarthritis of the knee (Barrett, Jr. et al. 1990, McAlindon et al. 1992, Davies et al. 2002). Mild isolated patellofemoral osteoarthritis is significantly associated with pain, stiffness, and functional limitations (Hunter et al. 2003, Duncan et al. 2009). Most patients can be successfully treated with nonoperative measures. In patients with disabling complaints who are unresponsive to non-surgical treatment, a multitude of operative treatment modalities have been used, and patellofemoral joint replacement can be considered for selected patients (Grelsamer and Stein 2006, Leadbetter et al. 2006).

In patellofemoral joint replacement, the femorotibial compartments, with cruciate ligaments and menisci, are spared, which may preserve the physiological kinematics of the femorotibial joint. The reported clinical results are related to patient selection, prosthetic design properties, and surgical technique (Leadbetter et al. 2005, Leadbetter et al. 2006, Gupta et al. 2010a). Development of painful femorotibial osteoarthritis is an important reason for converting a patellofemoral joint replacement to a total knee replacement, and predictive factors for developing femorotibial osteoarthritis remain unidentified. The results of conversion may be compromised by prior patellofemoral joint replacement.

Patellofemoral complications are the primary non-infectious indication for revision surgery after primary total knee replacement (Eisenhuth et al. 2006). Some orthopaedic surgeons use electrocautery of the patellar rim to reduce the prevalence of anterior knee pain after total knee arthroplasty.

Aims of the thesis

The aims of this thesis were formulated as follows:

- To clarify the role of nonoperative and operative treatment modalities in isolated patellofemoral osteoarthritis;
- To evaluate the long-term outcomes of a patellofemoral prosthesis, and to identify the different failure mechanisms;
- To investigate whether prior patellofemoral joint replacement has an effect on

the clinical outcome of later conversion to total knee replacement for femorotibial osteoarthritis;
- To evaluate the possible loss of distal femoral bone after patellofemoral joint replacement;
- To investigate the efficacy of circumpatellar electrocautery in total knee replacement.

Key findings of the thesis

In **Chapter 2**, we present a systematic review of the literature on the nonoperative and operative treatment options for isolated patellofemoral osteoarthritis. Our results show that presently there are no publications describing the long-term outcomes (more than 1 year) of nonoperative treatment. A multitude of studies with a generally low methodological quality reported the short- and long-term results of surgical management. Despite these limitations, we present treatment recommendations based on the best available evidence. Using the GRADE approach (Grading of Recommendations Assessment, Development and Evaluation) for each intervention, both a recommendation for the use in clinical practice and the quality of the evidence supporting that recommendation was assessed. Nonoperative treatment using physical therapy (GRADE: high quality, weak recommendation for use), taping (GRADE: moderate quality, weak recommendation for use), or injection therapy (GRADE: very low quality, weak recommendation for use) may result in short-term relief. Joint-preserving surgical treatment may result in insufficient, unpredictable, or only short-term improvement (GRADE: low quality, weak recommendation against use). Total knee replacement with patellar resurfacing results in predictable and durable good results (GRADE: low quality, weak recommendation for use). Outcome after patellofemoral joint replacement in selected patients is good to excellent (GRADE: low quality, weak recommendation for use).

Chapter 3 describes the long-term outcomes of the Richards II patellofemoral prosthesis. After a median of 13.3 years follow-up in 181 patellofemoral arthroplasties, we found no differences in implant survival between patients with primary isolated patellofemoral osteoarthritis, posttraumatic patellofemoral osteoarthritis, and patellofemoral osteoarthritis with a previous realignment procedure for patellar subluxation or trochlear dysplasia. Furthermore, the results

from our study demonstrate that patients who were younger than 50 years of age at the time of the primary procedure did not have a higher risk of revision for any reason than did patients who were older than 50 years. No differences in revision rate between female and male patients were found. The rate of revision in obese patients (body mass index >30 kg/m^2) was higher than that in non-obese patients. The main mode of failure of the Richards II patellofemoral joint replacement was development of painful femorotibial osteoarthritis, which necessitated conversion to total knee replacement in 13% of knees a mean of 12 years after the primary operation.

In **Chapter 4**, we assess the clinical results of converting patellofemoral joint replacement to total knee replacement for the development of painful femorotibial osteoarthritis. Using a matched case-control study, we found that patellofemoral joint replacement does not have a negative effect on the clinical outcome of later total knee replacement as assessed with standardised clinical and patient-relevant outcome measures. In the patellofemoral conversion group, however, a high number of manipulations under anaesthesia for failure to achieve 90 degrees of flexion by 6 weeks postoperatively were noted. The reason for this elevated manipulation rate remains unresolved.

The results presented in **Chapter 5** show that Richards II patellofemoral joint replacement leads to a statistically significant decrease in bone mineral density behind the anterior flange of the femoral component. The bone mineral density was assessed using dual-energy X-ray absorptiometry (DXA) before and 1 year after arthroplasty.

Chapter 6 describes a finite element analysis of distal femoral stress distributions after patellofemoral joint replacement. We modelled a patellofemoral joint in a dynamic finite element knee model without patellofemoral replacement and with replacement using the Journey PFJ patellofemoral prosthesis, the Richards II patellofemoral prosthesis, and the Genesis II total knee prosthesis with patellar resurfacing. For each of the 4 finite element models, the bone stress distributions in the same 2 regions of interest described in the previous chapter were evaluated during a squatting movement of 120° of flexion. Our modelling predicted a higher degree of stress-shielding in the anterior region of interest with the Richards II patellofemoral prosthesis compared with the Journey PFJ prosthesis, and the Genesis II total knee prosthesis demonstrated the highest degree of stress-

shielding. The differences between the observed degrees of stress-shielding with the 2 patellofemoral designs may be related to specific design properties.

Chapter 7 describes the results of a postal questionnaire sent to all 98 orthopaedic departments in The Netherlands. The questions focused on the frequency of total knee replacements, patellar resurfacing, and the use of circumpatellar electrocautery in total knee replacement. In summary, of the orthopaedic surgeons performing knee replacements, 13% always use patellar resurfacing in total knee replacement for osteoarthritis, 49% use selective patellar resurfacing, and 38% never use it. Fifty-six percent of orthopaedic surgeons use circumpatellar electrocautery when not resurfacing the patella, and 32% use electrocautery when resurfacing the patella. These results show there is no consensus among Dutch orthopaedic surgeons on the use of patellar resurfacing or electrocautery of the patellar rim in total knee replacement performed for osteoarthritis.

In **Chapter 8**, we studied the efficacy of circumpatellar electrocautery in total knee replacement without patellar resurfacing in a prospective, outcome-assessor and patient-blinded, parallel group, randomised clinical trial. Our study shows that in patients with primary knee osteoarthritis having total knee arthroplasty without patellar resurfacing, the use of circumpatellar electrocautery results in a lower prevalence of anterior knee pain at the 1-year follow-up compared with no circumpatellar electrocautery, with a relative risk reduction of 40% for postsurgical anterior knee pain. Moreover, we found better WOMAC scores in the intervention group, mostly because of better scores in the function component of the WOMAC, suggesting that anterior knee pain may be associated with the functional results.

Comparison with other studies

Presently, there are no other published peer-reviewed systematic reviews describing the results of nonoperative and operative treatment modalities in isolated patellofemoral osteoarthritis. Therefore, we were unable to compare our findings and recommendations with other high quality sources. The value of narrative reviews is obviously hampered by selection bias and reporting bias.

The long-term outcomes of patellofemoral joint replacement have been reported by other authors (Kooijman et al. 2003, Cartier et al. 2005, Argenson et al. 2005).

Our results show cumulative survivals of 84% (95% confidence interval, 78–90%) at 10 years and 69% (95% confidence interval, 59–79%) at 20 years with the Richards II patellofemoral prosthesis. This conversion rate is superior to the long-term follow-up revision rates described in the literature, although no confidence intervals for the survival data were previously reported (Cartier et al. 2005, Argenson et al. 2005). We also investigated the influence of diagnostic group on the long-term outcomes because some authors reported better outcomes in patients with patellofemoral instability (Arciero and Toomey 1988, Argenson et al. 1995, Argenson et al. 2005) or posttraumatic patellofemoral osteoarthritis (Argenson et al. 1995). Because these authors performed no statistics, the value of their observations is obviously limited. Similarly, some researchers reported better outcomes in female patients (Arciero and Toomey 1988, Krajca-Radcliffe and Coker 1996). We found that diagnosis, sex, or age at time of patellofemoral joint replacement does not influence the outcome.

The Australian Orthopaedic Association National Joint Replacement Registry stated the revision rates for several patellofemoral prosthetic designs in its 2009 Annual Report (Australian Orthopaedic Association National Joint Replacement Registry 2009). These revision rates should be interpreted with care because only more detailed data on the reasons for revision will enable us to directly compare the different patellofemoral designs in use. Most conversions to total knee replacement are performed because painful femorotibial osteoarthritis develops and are not prosthesis related (e.g., malpositioning, loosening, and/or wear of the prosthesis) (Leadbetter et al. 2005). Moreover, some investigators consider patellofemoral joint replacement a ‘bridging procedure’ since it is not as major a procedure as primary total knee replacement (Leadbetter et al. 2005, Argenson et al. 2005, Lonner 2007, Farr and Barrett 2008). The higher risk of later conversion to total knee replacement is accepted largely because it was thought that conversion would be relatively straightforward and have a similar outcome to that of primary total knee replacement. Indeed, several case series reported improvement in post-revision outcome scores compared with pre-operative scores in patients undergoing revision surgery (Sisto and Cook 1997, Lonner et al. 2006, Porteous et al. 2007). However, less favourable results were observed after revision for technical error or unexplained pain (Mulford et al. 2009). Because the main reason for revision is painful femorotibial osteoarthritis, we specifically investigated whether the clinical results after conversion for femorotibial osteoarthritis were comparable to those after primary total knee replacement and

found comparable results. The revision procedure was straightforward with no technical difficulties, which was noted by others as well (Lonner et al. 2006, Mulford et al. 2009). To overcome the need to revise the patellar resurfacing, the patellar button in patellofemoral joint replacement should be compatible with current total knee designs (Argenson et al. 2005). We did not evaluate the revision rate among secondary total knee replacements. In the future, the results of nationwide joint registries may demonstrate an increased rate of revision among the secondary total knee replacements, as this is a concern with medial uni-compartmental knee replacements (Australian Orthopaedic Association National Joint Replacement Registry 2009).

After total knee replacement, the bone mineral density of the distal femur, as assessed by DXA, decreases by 16% to 36% within 1 year because of the femoral component's stress-shielding effect (Petersen et al. 1995, Spittlehouse et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004). Likewise, our DXA study shows that Richards II patellofemoral joint replacement results in periprosthetic femoral bone loss (15%). This was an unexpected finding because the femoral component is markedly smaller in size.

Finite element analyses are used extensively in the evaluation of prosthetic load and bone remodelling after total hip and knee replacement (Qian et al. 2009, Zelle et al. 2009). However, no previous peer-reviewed publications report the use of finite element analysis to evaluate distal femoral stress distributions after patellofemoral joint replacement. Therefore, no direct comparison with other studies is possible. The results of finite element analysis in total knee replacement, however, show that with a bonded femoral component, the predicted long-term bone loss occurs at the most distal part of the femur and behind the anterior part of the prosthesis (Tissakht et al. 1996, van Lenthe et al. 1997). This is in accordance with our findings.

Circumpatellar electrocautery denervation is used by a number of orthopaedic surgeons to reduce the prevalence of anterior knee pain after total knee arthroplasty. Only one previous clinical study reported results on patellar rim electrocautery (Saoud 2004). Unfortunately, the design of this study precludes drawing conclusions about the efficacy of the procedure. After our study was completed, Gupta et al. reported a lack of improvement after patellar rim electrocautery in total knee arthroplasty without patellar resurfacing (Gupta et al. 2010b). The procedures used in this retrospective, comparative cohort study leave much to be desired because matching was only done for age and sex while introducing substantial bias by comparing results from two different surgeons; one performing electrocautery and the other not.

A multitude of studies assess the various factors thought to be related to anterior knee pain, including patient characteristics (Wood et al. 2002, Smith et al. 2004), degree of patellar cartilage wear (Rodriguez-Merchan and Gomez-Cardero 2010), prosthetic design (Popovic and Lemaire 2003, Skwara et al. 2008, Breugem et al. 2008), operative technique (Fern et al. 1992, Barrack et al. 2001b, Maculé et al. 2005), and the use of patellar resurfacing (Wood et al. 2002, Waters and Bentley 2003, Calvisi et al. 2009). Although some of these factors could be related to denervation, others are not. It is thus probable that the occurrence of anterior knee pain after total knee replacement is multifactorial. Patellar resurfacing requires removal of synovial and fibrous tissue around the patellar rim to enable accurate resection and restore patellar thickness. Therefore, the lower prevalence of postsurgical anterior knee pain after total knee replacement with patellar resurfacing may be the result of denervation. In these cases, additional electrocautery of the patellar rim may not result in a further reduction in the prevalence of anterior knee pain.

Strengths and limitations

The systematic review presented in **Chapter 2** was performed using both well-articulated patient-oriented clinical questions (PICO) and an evaluation with the GRADE approach to obtain an evidence-based discussion of nonoperative and operative treatment options in isolated patellofemoral osteoarthritis (Atkins et al. 2004, Petrisor et al. 2006, Guyatt et al. 2008). There is, however, always a possibility that we have failed to identify some studies, although a comprehensive search strategy was used including visually searching the reference lists of all eligible articles. Furthermore, because there are currently no standardised diagnostic criteria for patellofemoral osteoarthritis, it is possible that we included studies with important heterogeneity regarding the degree of osteoarthritis and clinical complaints. Our systematic review shows that the current best available evidence for treating isolated patellofemoral osteoarthritis is sparse and generally of low methodological quality. The lack of randomised controlled studies may

have resulted in substantial selection bias. Also, comparing the results of different treatments was hampered by the extensive heterogeneity among the outcome instruments used.

The strengths of our follow-up study (**Chapter 3**) on the outcomes of the Richards II patellofemoral joint replacement include the median 13.3 (range, 2 to 30.6) years of follow-up and findings that correlate the long-term survival of patellofemoral joint replacement with primary diagnosis, age, sex, and body mass index. Furthermore, our study describes the results of all consecutive Richards II patellofemoral joint replacements performed at Deventer hospital from 1976 onwards with only 4 of 185 patients lost to follow-up. With a maximum follow-up of more than 30 years, however, the use of the same clinical scoring system for all cases was not feasible, which eliminated our ability to compare preoperative and follow-up clinical scores for the group as a whole.

Our retrospective case-control study (**Chapter 4**) is the first to compare the outcome of patients with a patellofemoral joint replacement converted to a total knee replacement for femorotibial osteoarthritis with that of a matched group of patients with a primary total knee replacement for femorotibial osteoarthritis. Thus, the study is strengthened by having included only patients needing conversion for femorotibial osteoarthritis and not including failures owing to patellar maltracking or incorrect diagnosis. An important limitation, however, is that potential differences in improvement between the two groups were not evaluated because preoperative Knee Society knee scores (KSKS), Knee Society function scores (KSFS), and WOMAC scores for the entire group were not available.

The study described in **Chapter 5** is strengthened by being the first prospective clinical study specifically designed to address the issue of potential loss of femoral bone after patellofemoral joint replacement. We assessed the bone mineral density using DXA both preoperatively and at the 1 year follow-up; however, it is possible that further decreases in bone mineral density occur in our patients. Furthermore, the preoperative DXA measurements were used as baseline; we cannot rule out the possibility that the prosthesis influenced the DXA measurements, even though knee-specific software was used. Although our study protocol excluded medical conditions that could have affected the bone mineral density, it is possible that other conditions may have existed that influenced

the results. None of the patients had a severe medical disability that limited their ability to walk or had a disabling disease involving other joints of the lower extremities. Regression analysis of the change from baseline bone mineral density for both regions of interest against body mass index, age, and sex demonstrated no significant relationships. However, we did not assess the amount of physical activity at the 1-year follow-up and therefore were not able to evaluate possible relationships with change from baseline bone mineral density.

The strengths of our finite element analysis (**Chapter 6**) to evaluate distal femoral stress distributions after patellofemoral joint replacement include comparing the stress-shielding effect of 3 different patellofemoral replacement designs, and verification of the results against those in the previous chapter. However, finite element modelling is associated with limitations owing to inherent uncertainties concerning material properties, geometry, and load situation.

Strengths of the postal survey study (**Chapter 7**) include the high response rate (92%) and that our study is the first to determine the prevalence of circumpatellar electrocautery and patellar resurfacing performance among orthopaedic surgeons. To reduce the chance of a non-response bias, we improved the response rate by designing a mixed-mode (mail and telephone) survey and using the appropriate strategies suggested by others (Sprague et al. 2009).

The study described in **Chapter 8** is the first prospective, outcome-assessor and patient-blinded, parallel group, randomised clinical trial to study the effect of circumpatellar electrocautery in total knee replacement without patellar resurfacing. We followed the CONSORT guidelines for reporting clinical trials of non-pharmacologic treatments (Boutron et al. 2008a, Boutron et al. 2008b). The CONSORT statement is intended to improve the reporting of a randomised controlled trial, enabling readers to understand a trial's design, conduct, analysis and interpretation, and to assess the validity of its results. Generalisability describes the extent to which research findings can be applied to settings other than that in which they were originally tested. To enhance the generalisability of our research findings, we used broad inclusion criteria and maximised the sample size. The study was undertaken at a general teaching hospital by 5 different general orthopaedic surgeons using a commonly used prosthesis. Furthermore, validity was maximised by randomisation and allocation concealment, adequate blinding, careful follow-up with no patients lost to follow-up, and use of both

standardised clinical and patient-reported outcomes. Most importantly, we used outcome measures important to patients rather than surrogate endpoints (Poolman 2009). We followed our patients for 1 year. Some authors (Wood et al. 2002, Arbuthnot et al. 2004) reported a gradual decrease in anterior knee pain after total knee replacement, whereas others (Campbell et al. 2006) describe an increase in the incidence over time. To assess the long-term outcomes, we will re-evaluate the patients in the future because the clinical effect of circumpatellar electrocautery may diminish over time.

Implications of this thesis

Methodologically good quality comparative studies, preferably using a patient-relevant outcome instrument, are needed to establish the optimal treatment strategy for patients with isolated patellofemoral osteoarthritis. Presently, there is no convincing evidence that one specific treatment modality is superior to another in terms of better outcomes. Initially, patients with isolated patellofemoral osteoarthritis can be treated with a nonoperative approach, such as physical therapy, taping, or injection therapy. If nonoperative treatment fails to alleviate the symptoms, operative treatment using patellofemoral joint replacement may be considered for selected patients. Diagnosis, sex, or age at time of patellofemoral joint replacement do not influence outcome; however, obese patients may consider losing weight because higher revision rates are noted in obese patients. Although development of painful femorotibial osteoarthritis is a major reason for conversion to total knee replacement, our results show that the clinical outcome of total knee replacement is not influenced by prior patellofemoral joint replacement. However, during conversion to total knee replacement, decreased bone quality may be encountered behind the femoral component as a result of stress shielding. It is possible that this will lead to a higher revision rate among secondary knee replacements. With regard to anterior knee pain after total knee replacement, we suggest routine use of circumpatellar electrocautery to reduce the prevalence of anterior knee pain and to achieve better functional results.

Future research

This thesis raises the following future research questions: (a) Which nonoperative and operative treatment modalities result in superior clinical outcomes in patients with isolated patellofemoral osteoarthritis? (b) How do the long-term outcomes of newer patellofemoral prostheses compare with those achieved with the Richards II prosthesis? (c) How does the revision rate of secondary total knee replacements after conversion from patellofemoral joint replacement compare with the revision rate of primary total knee replacements? (d) What is the source of anterior knee pain after total knee replacement? (e) Is the lower prevalence of anterior knee pain in patients with total knee replacement with patellar resurfacing a result of denervation because of the requirement to remove synovial tissue to enable resurfacing? (f) What would the clinical outcome of patellofemoral joint replacement be without patellar resurfacing?

Conclusions

With regard to the aims of this thesis:

- The role of nonoperative and operative treatment modalities in isolated patello-femoral osteoarthritis needs further study;
- The long-term outcomes of the Richards II patellofemoral joint replacement are not influenced by diagnosis, sex, or age at time of patellofemoral joint replacement, and development of painful femorotibial osteoarthritis is the main mode of failure;
- Prior patellofemoral joint replacement has no effect on the clinical outcome of later conversion to total knee replacement for femorotibial osteoarthritis;
- The stress-shielding effect of the femoral component in the Richards II patellofemoral joint replacement results in a decrease in the bone mineral density in the periprosthetic femur;
- Circumpatellar electrocautery in total knee replacement is used by approximately 50% of orthopaedic surgeons in The Netherlands. The use of electrocautery results in a lower prevalence of anterior knee pain and better functional results.

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Samenvatting en discussie

Achtergrond

Geïsoleerde patellofemorale artrose is een degeneratieve aandoening van de knie die bij ongeveer 4 tot 24% van de patiënten met artrose van de knie voorkomt (Barrett, Jr. et al. 1990, McAlindon et al. 1992, Davies et al. 2002). Matige geïsoleerde patellofemorale artrose is geassocieerd met pijn, stijfheid en functieverlies (Hunter et al. 2003, Duncan et al. 2009). De meeste patiënten kunnen succesvol worden behandeld met een niet-operatieve benadering. Voor patiënten met invaliderende pijnklachten na falen van conservatieve therapie zijn verschillende operatieve behandelmethodes beschreven, en patellofemorale gewrichtsvervanging is voor geselecteerde patiënten een behandeloptie (Grelsamer and Stein 2006, Leadbetter et al. 2006).

Bij patellofemorale gewrichtsvervanging worden de femorotibiale gewrichtscompartimenten evenals de menisci en kruisbanden ongemoeid gelaten, zodat mogelijk de fysiologische kinematica van de knie behouden blijft. De beschreven klinische resultaten van patellofemorale gewrichtsvervanging zijn afhankelijk van patiëntenselectie, geometrische eigenschappen van de prothese en de operatietechniek (Leadbetter et al. 2005, Leadbetter et al. 2006, Gupta et al. 2010a). Het ontwikkelen van pijnlijke femorotibiale artrose na patellofemorale gewrichtsvervanging is een belangrijke reden voor conversie naar een totale knievervanging, en voorspellende factoren zijn vooralsnog niet bekend. De resultaten van conversie worden mogelijk negatief beïnvloed door de eerdere patellofemorale gewrichtsvervanging.

Problemen voortkomend uit het patellofemorale gewricht vormen de belangrijkste niet-infectieuze reden voor revisieoperaties na primaire totale knievervanging (Eisenhuth et al. 2006). Sommige orthopedisch chirurgen maken tijdens totale knievervanging gebruik van electrocauterisatie (diathermie) rond de patella om de prevalentie van anterieure kniepijn te verminderen.

Doel van dit proefschrift

De doelstellingen van dit proefschrift werden als volgt geformuleerd:

- Het verhelderen van de rol van niet-operatieve en operatieve behandelmethodes bij geïsoleerde patellofemorale artrose;

- Het evalueren van de langetermijnresultaten van een patellofemorale prothese en het identificeren van de verschillende faalmechanismen;
- Het onderzoeken van het effect van eerdere patellofemorale gewrichtsvervanging op de klinische resultaten van latere conversie naar totale knievervanging wegens femorotibiale artrose;
- Het evalueren van mogelijk verlies van femoraal bot na patellofemorale gewrichtsvervanging;
- Het onderzoeken van de werkzaamheid van electrocauterisatie rond de patella bij totale knievervanging.

De belangrijkste bevindingen van dit proefschrift

Hoofdstuk 2 beschrijft de resultaten van een systematisch literatuuroverzicht van de niet-operatieve en operatieve behandelmethodes bij geïsoleerde patellofemorale artrose. Onze resultaten laten zien dat er momenteel geen publicaties zijn die de langetermijnresultaten (meer dan 1 jaar) van niet-operatieve behandeling beschrijven. Een groot aantal methodologisch zwakke studies beschrijft de korte- en langetermijnresultaten van operatieve behandeling. Ondanks deze beperkingen presenteren wij aanbevelingen voor de behandeling van geïsoleerde patellofemorale artrose gebaseerd op het hoogst beschikbare niveau van bewijs. Gebruik makend van de GRADE-methodiek (Grading of Recommendations Assessment, Development and Evaluation) hebben wij voor iedere interventie zowel een aanbeveling voor het gebruik in de klinische praktijk, als de kwaliteit van het beschikbare bewijs voor deze aanbeveling beoordeeld. Niet-operatieve behandeling met fysiotherapie (GRADE: hoge kwaliteit, zwakke aanbeveling voor gebruik), tapebehandeling (GRADE: matige kwaliteit, zwakke aanbeveling voor gebruik), en intra-articulaire injecties (GRADE: heel lage kwaliteit, zwakke aanbeveling voor gebruik) kunnen resulteren in tijdelijke vermindering van klachten. Een niet-gewrichtsvervangende operatieve behandeling kan resulteren in onvoldoende, onvoorspelbare of alleen kortdurende vermindering van klachten (GRADE: lage kwaliteit, zwakke aanbeveling tegen gebruik). Totale knievervanging met patellaresurfacing resulteert in voorspelbare en duurzaam goede resultaten (GRADE: lage kwaliteit, zwakke aanbeveling voor gebruik). De resultaten van een patellofemorale gewrichtsvervanging zijn bij geselecteerde patiënten goed tot uitstekend (GRADE: lage kwaliteit, zwakke aanbeveling voor gebruik).

De langetermijnresultaten van de Richards II patellofemorale prothese worden beschreven in **hoofdstuk 3**. Na een mediane follow-up van 13,3 jaar bij 181 patellofemorale gewrichtsvervangingen vonden wij geen verschil in overleving van de prothese tussen patiënten met primaire geïsoleerde patellofemorale artrose, posttraumatische patellofemorale artrose en patellofemorale artrose met een patella-stabiliserende ingreep in het verleden. Daarnaast laten de resultaten van ons onderzoek zien dat patiënten jonger dan 50 jaar op het moment van de patellofemorale gewrichtsvervanging geen grotere kans op revisie hebben dan patiënten ouder dan 50. De overleving van de prothese is bij mannen en vrouwen gelijk. De kans op revisie is bij obese patiënten (BMI $>$ 30 kg/m^2) hoger dan bij niet-obese patiënten. Het belangrijkste faalmechanisme van de Richards II patellofemorale gewrichtsvervanging is het ontwikkelen van pijnlijke femorotibiale artrose, welke bij 13% van de knieën na gemiddeld 12 jaar conversie naar totale knievervanging noodzakelijk maakte.

In **hoofdstuk 4** worden de klinische resultaten van conversie van een patellofemorale gewrichtsvervanging naar een totale knievervanging wegens femorotibiale artrose geëvalueerd in een patiënt-controleonderzoek. Wij vonden dat patellofemorale gewrichtsvervanging geen negatief effect heeft op de klinische resultaten van latere totale knievervanging zoals gemeten met gestandaardiseerde klinische en patiënt relevante uitkomstinstrumenten. In de conversie groep werd wel een relatief groot aantal manipulaties verricht wegens niet bereiken van 90 graden flexie na 6 weken. De oorzaken hiervoor zijn niet duidelijk.

De resultaten gepresenteerd in **hoofdstuk 5** laten zien dat Richards II patellofemorale gewrichtsvervanging resulteert in een statistisch significante vermindering van de botdichtheid achter de femorale component. De botdichtheid werd vastgesteld met ‘dual-energy X-ray absorptiometry’ (DXA) metingen verricht voor en 1 jaar na plaatsing van de prothese.

Hoofdstuk 6 beschrijft een eindige elementen analyse van de mechanische botspanningen in het femorale bot na patellofemorale gewrichtsvervanging. Vier verschillende eindige elementen modellen van het patellofemorale gewricht werden ontwikkeld: zonder patellofemorale gewrichtsvervanging, na patellofemorale gewrichtsvervanging met de Journey PFJ patellofemorale prothese, na patellofemorale gewrichtsvervanging met de Richards II patellofemorale prothese en na totale knievervanging met de Genesis II prothese met patellaresurfacing.

Voor elk van de 4 modellen werden de gemiddelde botspanningen in dezelfde 2 regio's als beschreven in het vorige hoofdstuk bepaald tijdens een beweging van stand naar hurkzit met 120 graden flexie. Onze modellen voorspellen een hogere mate van afscherming van mechanische botspanningen in de anterieure regio met de Richards II prothese in vergelijking met de Journey PFJ prothese, en de Genesis II totale knieprothese toonde de hoogste mate van afscherming van mechanische botspanningen. De verschillen in de mate van afscherming van mechanische botspanningen met de 2 patellofemorale protheses zijn mogelijk gerelateerd aan specifieke ontwerpkarakteristieken.

Hoofdstuk 7 beschrijft de resultaten van een schriftelijke enquête verzonden naar alle 98 afdelingen orthopedie in Nederland. De vragenlijst richtte zich op het aantal totale knievervangingen, het gebruik van resurfacing van de patella, en het gebruik van electrocauterisatie rond de knieschijf bij totale knievervangingen. Van de orthopedisch chirurgen die knieprotheses plaatsen gebruikt 13% altijd patellaresurfacing bij totale knievervanging wegens artrose, 49% plaatst selectief een patellacomponent en 38% gebruikt nooit patellaresurfacing. Zesenvijftig procent van de orthopedisch chirurgen gebruikt electrocauterisatie rond de patella indien de patella niet geresurfaced wordt, en 32% gebruikt electrocauterisatie bij patellaresurfacing. Deze resultaten laten zien dat onder Nederlandse orthopedisch chirurgen consensus ontbreekt als het gaat om resurfacing en het gebruik van circumpatellaire electrocauterisatie bij totale knievervanging wegens artrose.

In **hoofdstuk 8** hebben wij in een prospectief, patiënt en uitkomstbeoordelaar geblindeerd, parallel gerandomiseerd onderzoek het effect van electrocauterisatie rond de knieschijf bij totale knievervanging zonder patellaresurfacing bestudeerd. Onze resultaten laten zien dat bij patiënten met totale knievervanging zonder patellaresurfacing, het gebruik van electrocauterisatie rondom de patella resulteert in een lagere prevalentie van anterieure kniepijn na 1 jaar follow-up in vergelijking met geen electrocauterisatie, met een relatieve risicoreductie van 40%. Daarnaast vonden wij betere WOMAC scores in de interventiegroep, vooral door de betere scores in de functiecomponent van de WOMAC. Dit suggereert dat anterieure kniepijn mogelijk gerelateerd is aan de functionele resultaten.

Vergelijking met andere studies

Op dit moment zijn er geen gepubliceerde systematische literatuuroverzichten die de resultaten van niet-operatieve en operatieve behandelmethodes bij geïsoleerde patellofemorale artrose beschrijven. Wij kunnen daarom onze resultaten niet vergelijken met de bevindingen en aanbevelingen van andere hoge kwaliteit studies. De waarde van de beschikbare verhalende ('narratieve') literatuuroverzichten is uiteraard beperkt door selectie- en publicatiebias.

De langetermijnresultaten van patellofemorale gewrichtsvervanging werden door verschillende auteurs beschreven (Kooijman et al. 2003, Cartier et al. 2005, Argenson et al. 2005). Onze resultaten laten een cumulatieve overleving van de Richards II patellofemorale prothese zien van 84% (95% betrouwbaarheidsinterval, 78%–90%) na 10 jaar, en 69% (95% betrouwbaarheidsinterval, 59%–79%) na 20 jaar. Deze cumulatieve overleving is beter dan de door andere auteurs beschreven langetermijn overleving, hoewel door hen geen betrouwbaarheidsintervallen werden gemeld (Cartier et al. 2005, Argenson et al. 2005). Wij onderzochten ook de invloed van de diagnostische groep op de langetermijnresultaten omdat sommige onderzoekers betere uitkomsten beschreven bij patiënten met patellofemorale instabiliteit (Arciero and Toomey 1988, Argenson et al. 1995, Argenson et al. 2005) en posttraumatische patellofemorale artrose (Argenson et al. 1995). Aangezien geen van deze onderzoekers gebruik hebben gemaakt van statistiek is de waarde van hun observaties beperkt. Een aantal auteurs beschreven betere resultaten bij vrouwelijke patiënten (Arciero and Toomey 1988, Krajca-Radcliffe and Coker 1996). Wij vonden dat de diagnostische groep, het geslacht, of de leeftijd bij operatie geen invloed heeft op de klinische uitkomst.

In het Jaarverslag 2009 van de 'Australian Orthopaedic Association National Joint Replacement Registry' worden de revisierisico's van verschillende typen patellofemorale protheses beschreven (Australian Orthopaedic Association National Joint Replacement Registry 2009). Deze revisierisico s moeten voorzichtig worden geïnterpreteerd omdat vergelijken van de verschillende protheses alleen mogelijk is als de specifieke redenen voor revisie bekend zijn. De meeste conversies naar totale knievervanging worden verricht wegens de ontwikkeling van pijnlijke femorotibiale artrose en niet vanwege prothese gerelateerde factoren, zoals malpositie, loslating en/of slijtage van de prothese (Leadbetter et al. 2005). Bovendien stellen sommige onderzoekers dat patellofemorale gewrichtsvervanging

beschouwd kan worden als een 'overbruggings'-operatie omdat het een relatief beperkte ingreep is, en later alsnog kan worden geconverteerd naar totale knievervanging (Leadbetter et al. 2005, Argenson et al. 2005, Lonner 2007, Farr and Barrett 2008). De grotere kans op latere conversie naar totale knievervanging wordt daarbij geaccepteerd omdat zij stellen dat conversie relatief eenvoudig is en de klinische uitkomsten vergelijkbaar zijn met de uitkomsten na primaire totale knievervanging. Inderdaad laten enkele observationele studies een verbetering van de uitkomstscores na conversie zien (Sisto and Cook 1997, Lonner et al. 2006, Porteous et al. 2007). Minder gunstige resultaten werden echter geobserveerd na revisie wegens onbegrepen pijn of suboptimaal plaatsen van de patellofemorale prothese (Mulford et al. 2009). Omdat de ontwikkeling van pijnlijke femorotibiale artrose de belangrijkste reden voor revisie is, hebben wij specifiek onderzocht of de klinische resultaten na conversie wegens femorotibiale artrose vergelijkbaar zijn met de resultaten na primaire totale knievervanging, en wij vonden vergelijkbare resultaten. Overigens was de revisieoperatie relatief eenvoudig zonder technische problemen, hetgeen ook door andere auteurs werd gemeld (Lonner et al. 2006, Mulford et al. 2009). Om te voorkomen dat ook de patellacomponent gereviseerd moet worden, is het noodzakelijk dat de patella-component bij patellofemorale gewrichtsvervanging compatibel is met de momenteel gebruikte totale kniesystemen (Argenson et al. 2005). Wij hebben de kans op revisie bij de secundaire knievervangingen niet bestudeerd. Het is mogelijk dat de resultaten van nationale implantatenregistraties in de toekomst een verhoogde kans op revisie laten zien bij deze secundair verrichte totale knie-vervangingen, aangezien dit momenteel een punt van zorg is bij de mediale hemiknievervangingen (Australian Orthopaedic Association National Joint Replacement Registry 2009).

Na totale knievervanging vermindert de met DXA vastgestelde botdichtheid van het distale femur met 16 tot 36% binnen het eerste jaar doordat de femorale component een deel van de mechanische botspanningen opvangt (Petersen et al. 1995, Spittlehouse et al. 1999, van Loon et al. 2001, Soininvaara et al. 2004). Onze DXA studie laat zien dat Richards II patellofemorale gewrichtsvervanging evenzo resulteert in periprothetisch botverlies (15%). Dit hadden wij niet verwacht aangezien de femorale component van een patellofemorale prothese aanmerkelijk kleiner is dan die van een totale knieprothese.

Eindige elementen analyses worden op uitgebreide schaal gebruikt bij de evaluatie van krachtinwerking op protheses en botremodellering na totale knie- en heupvervanging (Qian et al. 2009, Zelle et al. 2009). Er zijn echter geen eerdere publicaties die de resultaten van eindige elementen analyse bij de beoordeling van mechanische botspanningen in het distale femur na patellofemorale gewrichtsvervanging beschrijven. Directe vergelijking met andere studies is daardoor niet mogelijk. De resultaten van eindige elementen analyse bij totale knievervanging laten echter zien dat het voorspelde botverlies bij een goed gefixeerde femorale component optreedt in het meest distale deel van het femur en direct achter het voorste deel van de prothese (Tissakht et al. 1996, van Lenthe et al. 1997). Dit is in overeenstemming met onze bevindingen.

Sommige orthopedisch chirurgen gebruiken circumpatellaire electrocauterisatie om de prevalentie van postoperatieve pijnklachten aan de voorzijde van de knie na totale knievervanging te verminderen. Slechts één klinische studie beschreef de resultaten van circumpatellaire diathermie (Saoud 2004). Helaas laat de gebruikte studieopzet geen conclusies toe betreffende de effectiviteit van de procedure. Nadat onze studie was beëindigd, beschreven Gupta et al. het ontbreken van verbetering na electrocauterisatie rondom de patella bij totale knievervanging zonder resurfacing (Gupta et al. 2010b). De onderzoeksmethoden van deze retrospectief vergelijkende studie laten echter veel te wensen over, daar 'matching' alleen gedaan werd voor leeftijd en geslacht, en belangrijke bias werd geïntroduceerd door de resultaten van twee verschillende chirurgen te vergelijken; de een gebruikte wel electrocauterisatie, en de ander niet.

Een veelheid van studies heeft de verschillende factoren bestudeerd die mogelijk gerelateerd zijn aan anterieure kniepijn: patiënt karakteristieken (Wood et al. 2002, Smith et al. 2004), de mate van degeneratieve veranderingen van de patella (Rodriguez-Merchan and Gomez-Cardero 2010), ontwerpkarakteristieken van de prothese (Popovic and Lemaire 2003, Skwara et al. 2008, Breugem et al. 2008), operatietechniek (Fern et al. 1992, Barrack et al. 2001b, Maculé et al. 2005) en het gebruik van patellaresurfacing (Wood et al. 2002, Waters and Bentley 2003, Calvisi et al. 2009). Het is mogelijk dat een aantal van deze factoren gerelateerd is aan denervatie, voor andere variabelen geldt dit niet. Het lijkt dus aannemelijk dat het optreden van anterieure kniepijn na totale knievervanging multifactorieel bepaald is. Overigens vereist patellaresurfacing dat synovium en fibreus weefsel rondom de patella verwijderd wordt zodat accuraat kan worden gereseceerd en

de patelladikte kan worden hersteld. De lagere prevalentie van anterieure kniepijn na totale knievervanging mèt patellaresurfacing kan dus het gevolg zijn van denervatie. Additionele electrocauterisatie rondom de patellaresurfacing resulteert dan mogelijk niet in een verdere afname van de prevalentie van anterieure kniepijn.

Enkele sterke en zwakke punten van het onderzoek

Het systematisch literatuuroverzicht beschreven in **hoofdstuk 2** is het eerste literatuuroverzicht dat gebruik maakt van zowel helder geformuleerde patiënt georiënteerde klinische vragen (PICO) als van een evaluatie met de GRADE benadering om te komen tot een op bewijs gebaseerde bespreking van de niet-operatieve en operatieve behandelmethodes bij geïsoleerde patellofemorale artrose (Atkins et al. 2004, Petrisor et al. 2006, Guyatt et al. 2008). Het is uiteraard mogelijk dat wij enkele studies niet hebben geïdentificeerd, hoewel wij gebruik maakten van een zorgvuldige zoekstrategie inclusief het visueel controleren van de literatuurverwijzingen van de geïncludeerde artikelen. Omdat er geen gestandaardiseerde diagnostische criteria voor patellofemorale artrose zijn, is het mogelijk dat wij onderzoeken hebben geïncludeerd met belangrijke verschillen in de mate van degeneratieve veranderingen en ernst van de klachten. Ons systematisch literatuuroverzicht laat zien dat het best beschikbare bewijs voor de behandeling van geïsoleerde patellofemorale artrose schaars is en over het algemeen van zwakke methodologische kwaliteit. Het ontbreken van gerandomiseerde onderzoeken (RCTs) kan hebben geresulteerd in een belangrijke selectiebias. Daarnaast werd het vergelijken van de resultaten van de verschillende behandelmethodes bemoeilijkt door belangrijke verschillen in de gebruikte uitkomstmaten.

De sterke punten van ons onderzoek naar de langetermijnresultaten (**hoofdstuk 3**) van de Richards II patellofemorale prothese zijn de mediane follow-up van 13,3 (2 tot 30,6) jaar en het onderzoek naar overleving van de prothese gerelateerd aan factoren als primaire diagnose, leeftijd, geslacht en BMI. Daarnaast worden in onze studie de resultaten beschreven van alle opeenvolgende Richards II patellofemorale gewrichtsvervangingen die vanaf 1976 in Deventer zijn verricht, met een uitval uit de nacontroles van slechts 4 van de 185 patiënten. Met een maximale follow-up van meer dan 30 jaar is gebruik van dezelfde klinische score echter niet mogelijk, waardoor vergelijking tussen preoperatieve en postoperatieve scores niet voor de gehele groep patiënten mogelijk was.

Ons retrospectief patiënt-controleonderzoek (**hoofdstuk 4**) is de eerste studie die de resultaten vergelijkt tussen patiënten met een patellofemorale prothese geconverteerd naar een totale knievervanging wegens femorotibiale artrose en een 'gematchte' patiëntengroep met een primaire totale knievervanging wegens femorotibiale artrose. Het sterke punt van onze studie was het beperken van de onderzoekspopulatie met uitsluitend femorotibiale artrose als reden voor de revisie, en niet falen door problemen met de patellasporing of onjuiste diagnose. Een belangrijke beperking is echter dat de mogelijke verschillen in klinische verbetering tussen de 2 groepen niet werden beoordeeld aangezien de preoperatieve Knee Society knee scores (KSKS), Knee Society function scores (KSFS) en WOMAC scores niet voor alle patiënten beschikbaar waren.

Hoofdstuk 5 beschrijft de resultaten van de eerste prospectieve klinische studie die specifiek werd opgezet om het mogelijke verlies van femoraal bot na patellofemorale gewrichtsvervanging te evalueren. Wij beoordeelden de botdichtheid met DXA zowel voor de operatie als 1 jaar na de operatie, en het is mogelijk dat een verdere afname van botdichtheid optreedt bij onze patiënten. De preoperatief bepaalde botdichtheid werd als uitgangswaarde gebruikt. Wij kunnen daarom niet uitsluiten dat de 1-jaars metingen beïnvloed zijn door de aanwezigheid van de prothese, zelfs met het gebruik van knie-specifieke software. Hoewel ons onderzoeksprotocol patiënten met een medische aandoening die de botdichtheid kan beïnvloeden excludeerde, is het mogelijk dat andere factoren de resultaten hebben beïnvloed. Geen van de patiënten had een ernstige medische beperking die het lopen beperkte, of een aandoening van de andere gewrichten aan de onderste extremiteit. Regressie analyse van de verandering van de botdichtheid versus de BMI, leeftijd en geslacht lieten geen significante relaties zien. Wij hebben echter niet specifiek naar de mate van lichaamsbeweging gekeken en zijn daarom niet in staat een relatie met de verandering van de botdichtheid te beoordelen.

De sterke punten van onze eindige elementen analyse (**hoofdstuk 6**) welke werd opgezet om de botspanningen in het femorale bot na patellofemorale gewrichtsvervanging te evalueren zijn de vergelijking van 3 verschillende patellofemorale gewrichtsvervangingen en de verificatie van het model met de resultaten uit het vorige hoofdstuk. Het is echter mogelijk dat het door ons ontwikkelde model intrinsieke tekortkomingen bevat met betrekking tot geometrie, duur van de krachtinwerking en materiaaleigenschappen.

Sterke punten van onze schriftelijke enquête (**hoofdstuk 7**) zijn de hoge respons van 92% en het feit dat onze studie de eerste is die de mate van het gebruik van electrocauterisatie rond de patella onder een grote groep orthopedisch chirurgen heeft vastgesteld. Om het risico op een non-respons bias te verminderen hebben wij een 'mixed-mode' (schriftelijke en telefonische) enquête gebruikt volgens de aanbevelingen van anderen (Sprague et al. 2009).

Het onderzoek beschreven in **hoofdstuk 8** is het eerste prospectief, patiënt en uitkomstbeoordelaar geblindeerd, parallel gerandomiseerd onderzoek naar het effect van electrocauterisatie rond de knieschijf bij totale knievervanging zonder patellaresurfacing. Wij volgden de CONSORT richtlijnen voor het rapporteren van klinische studies van niet-farmacologische behandelingen (Boutron et al. 2008a, Boutron et al. 2008b). De CONSORT verklaring is bedoeld om de kwaliteit van rapporteren van een gerandomiseerde studie te verbeteren, zodat lezers de studieopzet, uitvoering, analyse en interpretatie van de trial kunnen begrijpen, en de validiteit van de verkregen resultaten kunnen beoordelen. De generaliseerbaarheid van een studie beschrijft de mate waarin de onderzoeksresultaten kunnen worden toegepast in een andere omgeving dan die waarin ze oorspronkelijk werden getest. Om de generaliseerbaarheid van onze onderzoeksresultaten te verbeteren, gebruikten wij ruime inclusiecriteria en een grote onderzoeksgroep. Het onderzoek werd uitgevoerd in een algemeen opleidingsziekenhuis waar 5 orthopedisch chirurgen gebruik maakten van een veelgebruikte prothese. Validiteit van de resultaten werd zo groot mogelijk gemaakt door randomisatie en blindering van de behandelaar voor de toegewezen interventie, adequate blindering van patiënt en uitkomstbeoordelaar, nauwkeurige follow-up zonder verlies van patiënten voor nacontrole, en het gebruik van zowel gestandaardiseerde klinische scores als door patiënten beoordeelde uitkomsten. Nog belangrijker, wij gebruikten uitkomstmaten die belangrijk zijn voor patiënten, en geen surrogaat eindpunten (Poolman 2009). Wij volgden onze patiënten gedurende één jaar. Sommige auteurs (Wood et al. 2002, Arbuthnot et al. 2004) beschreven een geleidelijke afname van anterieure kniepijn na totale knievervanging, terwijl anderen (Campbell et al. 2006) een toename van de incidentie over de tijd rapporteerden. Om de langetermijnresultaten te beoordelen zullen wij onze patiënten in de toekomst herevalueren; het klinische effect van denerveren zou geleidelijk kunnen verminderen.

Implicaties van dit proefschrift

Methodologisch goed opgezette vergelijkende onderzoeken, bij voorkeur gebruik makend van patiëntrelevante uitkomstinstrumenten, zijn nodig voor het bepalen van de optimale behandelstrategie voor patiënten met geïsoleerde patellofemorale artrose. Op dit moment is geen overtuigend bewijs voorhanden dat de ene behandelmethode voor wat betreft uitkomstinstrumenten beter is dan de andere. Initieel kunnen patiënten met een niet-operatieve benadering bestaande uit fysiotherapie, tapen en gewrichtsinjecties behandeld worden. Als de niet-operatieve behandeling faalt bij het verminderen van klachten kan bij geselecteerde patiënten operatieve behandeling met een patellofemorale gewrichtsvervanging worden overwogen. Diagnose, geslacht en leeftijd bij operatie beïnvloeden de overleving van de prothese niet. Wel moeten obese patiënten overwegen af te vallen omdat de overleving van de prothese korter is bij overgewicht. Hoewel het ontstaan van pijnlijke femorotibiale artrose een belangrijke reden voor conversie naar totale knievervanging is, laten onze onderzoeksresultaten zien dat de klinische resultaten van latere totale knievervanging niet negatief beïnvloed worden door de eerdere patellofemorale gewrichtsvervanging. Wel mag verminderde botdichtheid achter de femorale component van een patellofemorale prothese verwacht worden doordat de prothese een deel van de mechanische botspanningen opvangt. Dit zou aanleiding kunnen geven tot een verhoogde kans op revisie bij secundaire totale knievervangingen. Met betrekking tot anterieure kniepijn na totale knievervanging adviseren wij standaard gebruik van electrocauterisatie rondom de patella om de kans op anterieure kniepijn te verminderen en betere functionele resultaten te verkrijgen.

Toekomstig onderzoek

Dit proefschrift stelt de volgende onderzoeksvragen voor toekomstig onderzoek: (a) Welke niet-operatieve en operatieve behandelmethodes resulteren in de beste klinische resultaten bij patiënten met geïsoleerde patellofemorale artrose? (b) Zijn de langetermijnresultaten van nieuwe patellofemorale protheses vergelijkbaar met die van de Richards II prothese? (c) Is het risico op revisie bij secundaire totale knievervangingen na eerdere conversie van patellofemorale gewrichtsvervanging vergelijkbaar met het risico op revisie na primaire totale knievervangin-

gen? (d) Wat is de oorzaak van anterieure kniepijn na totale knievervanging? (e) Is de lagere prevalentie van anterieure kniepijn na totale knievervanging mèt patellaresurfacing het gevolg van denervatie vanwege de vereiste excisie van synovium om te kunnen resurfacen? en (f) Hoe zijn de klinische resultaten na patellofemorale gewrichtsvervanging zònder patellaresurfacing?

Conclusies

Met betrekking tot de doelstellingen van dit proefschrift kunnen wij concluderen dat:

- De rol van niet-operatieve en operatieve behandelingsmodaliteiten bij patiënten met geïsoleerde patellofemorale artrose verder onderzoek vereist;
- De langetermijnresultaten van de Richards II patellofemorale gewrichts-vervanging niet afhankelijk zijn van primaire diagnose, geslacht of leeftijd bij operatie, en het ontwikkelen van pijnlijke femorotibiale artrose de belangrijkste reden is voor conversie naar een totale knievervanging;
- Voorgaande patellofemorale gewrichtsvervanging geen invloed heeft op de klinische resultaten van latere conversie naar een totale knievervanging wegens femorotibiale artrose;
- Patellofemorale gewrichtsvervanging in een afname van de botdichtheid achter de femorale component resulteert doordat de prothese een deel van de mechanische botspanningen opvangt;
- Electrocauterisatie rond de patella bij totale knievervanging door ongeveer de helft van de orthopedisch chirurgen in Nederland wordt gebruikt en dat electro-cauterisatie in een lagere prevalentie van anterieure kniepijn resulteert met betere functionele resultaten.

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References

References

Abu-Rajab R B, Watson W S, Walker B, Roberts J, Gallacher S J, Meek R M. Peri-prosthetic bone mineral density after total knee arthroplasty. Cemented versus cementless fixation. J Bone Joint Surg Br 2006; 88: 606-13.

Ackroyd C E, Chir B. Development and early results of a new patellofemoral arthroplasty. Clin Orthop 2005; 436: 7-13.

Ackroyd C E, Newman J H, Evans R, Eldridge J D, Joslin C C. The Avon patellofemoral arthroplasty: Five-year survivorship and functional results. J Bone Joint Surg Br 2007; 89: 310-5.

Aderinto J, Cobb A G. Lateral release for patellofemoral arthritis. Arthroscopy 2002; 18: 399-403.

Ahlbäck S. Osteoarthrosis of the knee. A radiographic investigation. Acta Radiol Diagn (Stockh) 1968; Suppl 277: 7-72.

Alemdaroglu K B, Cimen O, Aydogan N H, Atlihan D, Iltar S. Early results of arthroscopic lateral retinacular release in patellofemoral osteoarthritis. Knee 2008; 15: 451-5.

Amin A K, Clayton R A, Patton J T, Gaston M, Cook R E, Brenkel I J. Total knee replacement in morbidly obese patients. Results of a prospective, matched study. J Bone Joint Surg Br 2006; 88: 1321-6.

Arbuthnot J E, McNicholas M J, McGurty D W, Rowley D I. Total knee replacement and patellofemoral pain. Surgeon 2004; 2: 230-3.

Arciero R A, Toomey H E. Patellofemoral arthroplasty. A three- to nine-year follow-up study. Clin Orthop 1988; 236: 60-71.

Argenson J N, Flecher X, Parratte S, Aubaniac J M. Patellofemoral arthroplasty: An update. Clin Orthop 2005; 440: 50-3.

Argenson J N, Guillaume J M, Aubaniac J M. Is there a place for patellofemoral arthroplasty? Clin Orthop 1995; 321: 162-7.

Arnbjornsson A H, Ryd L. The use of isolated patellar prostheses in Sweden 1977-1986. Int Orthop 1998; 22: 141-4.

Atkins D, Best D, Briss P A, Eccles M, Falck-Ytter Y, Flottorp S, Guyatt G H, Harbour R T, Haugh M C, Henry D, Hill S, Jaeschke R, Leng G, Liberati A, Magrini N, Mason J, Middleton P, Mrukowicz J, O'Connell D, Oxman A D, Phillips B, Schunemann H J, Edejer T T, Varonen H, Vist G E, Williams J W, Jr., Zaza S. Grading quality of evidence and strength of recommendations. BMJ 2004; 328: 1490.

Australian Orthopaedic Association National Joint Replacement Registry. Hip and Knee arthroplasty. Annual Report 2009. http://www.dmac.adelaide.edu.au/aoanjrr/documents/aoanjrrreport_ 2009.pdf (Accessed 16-10-2010).

Barrack R L, Bertot A J, Wolfe M W, Waldman D A, Milicic M, Myers L. Patellar resurfacing in total knee arthroplasty. A prospective, randomized, double-blind study with five to seven years of follow-up. J Bone Joint Surg Am 2001a; 83: 1376-81.

Barrack R L, Burak C. Patella in total knee arthroplasty. Clin Orthop 2001; 389: 62-73.

Barrack R L, Schrader T, Bertot A J, Wolfe M W, Myers L. Component rotation and anterior knee pain after total knee arthroplasty. Clin Orthop 2001b; 392: 46-55.

Barrett J P, Jr., Rashkoff E, Sirna E C, Wilson A. Correlation of roentgenographic patterns and clinical manifestations of symptomatic idiopathic osteoarthritis of the knee. Clin Orthop 1990; 253: 179-83.

Becher C, Renke A, Heyse T J, Schofer M, Tibesku C O, Fuchs-Winkelmann S. Patellofemorale Endoprothetik in Deutschland - eine Standortbestimmung und Überblick über die Literatur. Z Orthop Unfall 2008; 146: 773-81.

Becker R, Ropke M, Krull A, Musahl V, Nebelung W. Surgical treatment of isolated patellofemoral osteoarthritis. Clin Orthop 2008; 466: 443-9.

Beillas P, Papaioannou G, Tashman S, Yang K H. A new method to investigate in vivo knee behavior using a finite element model of the lower limb. J Biomech 2004; 37: 1019-30.

Beltran J E. Resection arthroplasty of the patella. J Bone Joint Surg Br 1987; 69: 604-7.

Besier T F, Gold G E, Beaupre G S, Delp S L. A modeling framework to estimate patellofemoral joint cartilage stress in vivo. Med Sci Sports Exerc 2005; 37: 1924-30.

Blazina M E, Fox J M, Del P W, Broukhim B, Ivey F M. Patellofemoral replacement. Clin Orthop 1979; 144: 98-102.

Blom A W, Brown J, Taylor A H, Pattison G, Whitehouse S, Bannister G C. Infection after total knee arthroplasty. J Bone Joint Surg Br 2004; 86: 688-91.

Board T N, Mahmood A, Ryan W G, Banks A J. The Lubinus patellofemoral arthroplasty: a series of 17 cases. Arch Orthop Trauma Surg 2004; 124: 285-7.

Boegard T, Rudling O, Petersson I F, Jonsson K. Correlation between radiographically diagnosed osteophytes and magnetic resonance detected cartilage defects in the patellofemoral joint. Ann Rheum Dis 1998; 57: 395-400.

Boutron I, Moher D, Altman D G, Schulz K F, Ravaud P. Extending the CONSORT statement to randomized trials of nonpharmacologic treatment: explanation and elaboration. Ann Intern Med 2008a; 148: 295-309.

Boutron I, Moher D, Altman D G, Schulz K F, Ravaud P. Methods and processes of the CONSORT Group: example of an extension for trials assessing nonpharmacologic treatments. Ann Intern Med 2008b; 148: W60-W66.

Breugem S J, Sierevelt I N, Schafroth M U, Blankevoort L, Schaap G R, van Dijk C N. Less anterior knee pain with a mobile-bearing prosthesis compared with a fixed-bearing prosthesis. Clin Orthop 2008; 466: 1959-65.

Burnett R S, Boone J L, McCarthy K P, Rosenzweig S, Barrack R L. A prospective randomized clinical trial of patellar resurfacing and nonresurfacing in bilateral TKA. Clin Orthop 2007; 464: 65-72.

Burnett R S, Boone J L, Rosenzweig S D, Steger-May K, Barrack R L. Patellar resurfacing compared with nonresurfacing in total knee arthroplasty. A concise follow-up of a randomized trial. J Bone Joint Surg Am 2009; 91: 2562-7.

Burnett R S, Haydon C M, Rorabeck C H, Bourne R B. Patella resurfacing versus nonresurfacing in total knee arthroplasty: results of a randomized controlled clinical trial at a minimum of 10 years' followup. Clin Orthop 2004; 428: 12-25.

Calvisi V, Camillieri G, Lupparelli S. Resurfacing versus nonresurfacing the patella in total knee arthroplasty: a critical appraisal of the available evidence. Arch Orthop Trauma Surg 2009; 129: 1261-70.

Cameron H U. Comparison between patellar resurfacing with an inset plastic button and patelloplasty. Can J Surg 1991; 34: 49-52.

Cameron H U, Cameron G. Stress-relief osteoporosis of the anterior femoral condyles in total knee replacement. A study of 185 patients. Orthop Rev 1987; 16: 449-56.

Campbell D G, Duncan W W, Ashworth M, Mintz A, Stirling J, Wakefield L, Stevenson T M. Patellar resurfacing in total knee replacement: a ten-year randomised prospective trial. J Bone Joint Surg Br 2006; 88: 734-9.

Carofino B C, Fulkerson J P. Anteromedialization of the tibial tubercle for patellofemoral arthritis in patients > 50 years. J Knee Surg 2008; 21: 101-5.

Cartier P, Sanouiller J L, Grelsamer R. Patellofemoral arthroplasty. 2-12-year follow-up study. J Arthroplasty 1990; 5: 49-55.

Cartier P, Sanouiller J L, Khefacha A. Long-term results with the first patellofemoral prosthesis. Clin Orthop 2005; 436: 47-54.

Clarke S, Lock V, Duddy J, Sharif M, Newman J H, Kirwan J R. Intra-articular hylan G-F 20 (Synvisc) in the management of patellofemoral osteoarthritis of the knee (POAK). Knee 2005; 12: 57-62.

Cushnaghan J, McCarthy C, Dieppe P. Taping the patella medially: a new treatment for osteoarthritis of the knee joint? BMJ 1994; 308: 753-5.

Dalury D F. Total knee replacement for patellofemoral disease. J Knee Surg 2005; 18: 274-7.

Davies A P, Vince A S, Shepstone L, Donell S T, Glasgow M M. The radiologic prevalence of patellofemoral osteoarthritis. Clin Orthop 2002; 402: 206-12.

Davis, J. R. Handbook of Materials for Medical Devices. ASM International, Materials Park, Ohio 2003.

de Cloedt P, Legaye J, Lokietek W. Les prothèses fémoro-patellaires: Étude rétrospective de 45 cas successifs avec un recul de 3 à 12 ans. Acta Orthop Belg 1999; 65: 170-5.

de Winter W E, Feith R, van Loon C J. The Richards type II patellofemoral arthroplasty: 26 cases followed for 1-20 years. Acta Orthop Scand 2001; 72: 487-90.

Dejour D, Barbosa J, Jacquot N, Neyret P. Résultats des prothèses totales du genou dans l´arthrose fémoro-patellaire isolée. Rev Chir Orthop 2004; 90: 1S111-3.

Donell S T, Glasgow M M. Isolated patellofemoral osteoarthritis. Knee 2007; 14: 169-76.

Duncan R, Peat G, Thomas E, Wood L, Hay E, Croft P. Does isolated patellofemoral osteoarthritis matter? Osteoarthritis Cartilage 2009; 17: 1151-5.

Eisenhuth S A, Saleh K J, Cui Q, Clark C R, Brown T E. Patellofemoral instability after total knee arthroplasty. Clin Orthop 2006; 446: 149-60.

Erak S, Rajgopal V, Macdonald S J, McCalden R W, Bourne R B. Ten-year results of an inset biconvex patella prosthesis in primary knee arthroplasty. Clin Orthop 2009; 467: 1781-92.

Ewald F C. The Knee Society total knee arthroplasty roentgenographic evaluation and scoring system. Clin Orthop 1989; 248: 9-12.

Farr J, Barrett D. Optimizing patellofemoral arthroplasty. Knee 2008; 15: 339-47.

Fern E D, Winson I G, Getty C J. Anterior knee pain in rheumatoid patients after total knee replacement. Possible selection criteria for patellar resurfacing. J Bone Joint Surg Br 1992; 74: 745-8.

Fink B, Schneider T, Tillmann K, Ruther W. Die Femoropatellarendoprothese - in der heutigen Zeit sinnvoll? Z Orthop 1999; 137: 247-52.

Gadeyne S, Besse J L, Galand-Desme S, Lerat J L, Moyen B. Résultats de la prothèse fémoro-patellaire autocentrique: à propos d'une série continue de 57 prothèses. Rev Chir Orthop 2008; 94: 228-40.

Gioe T J, Novak C, Sinner P, Ma W, Mehle S. Knee arthroplasty in the young patient: survival in a community registry. Clin Orthop 2007; 464: 83-7.

Godest A C, Beaugonin M, Haug E, Taylor M, Gregson P J. Simulation of a knee joint replacement during a gait cycle using explicit finite element analysis. J Biomech 2002; 35: 267-75.

Grelsamer R P, Stein D A. Patellofemoral arthritis. J Bone Joint Surg Am 2006; 88: 1849-60.

Grood E S, Suntay W J. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng 1983; 105: 136-44.

Gupta R R, Zywiel M G, Leadbetter W B, Bonutti P, Mont M A. Scientific evidence for the use of modern patellofemoral arthroplasty. Expert Rev Med Devices 2010a; 7: 51-66.

Gupta S, Augustine A, Horey L, Meek R M, Hullin M G, Mohammed A. Electrocautery of the patellar rim in primary total knee replacement: beneficial or unnecessary? J Bone Joint Surg Br 2010b; 92: 1259-61.

Guyatt G H, Oxman A D, Kunz R, Vist G E, Falck-Ytter Y, Schunemann H J. What is "quality of evidence" and why is it important to clinicians? BMJ 2008; 336: 995-8.

Halloran J P, Petrella A J, Rullkoetter P J. Explicit finite element modeling of total knee replacement mechanics. J Biomech 2005; 38: 323-31.

Harrysson O L, Robertsson O, Nayfeh J F. Higher cumulative revision rate of knee arthroplasties in younger patients with osteoarthritis. Clin Orthop 2004; 421: 162-8.

Hart A N, Minns R J, Nabhani F N, Muckle D S. An examination of the internal stresses in articular cartilage of the human patella. The Knee 1999; 6: 171-4.

Heegaard J H, Leyvraz P F, Hovey C B. A computer model to simulate patellar biomechanics following total knee replacement: the effects of femoral component alignment. Clin Biomech (Bristol, Avon) 2001; 16: 415-23.

Hernigou P, Mathieu G, Filippini P, Demoura A. Facteurs du risque de fracture du fémur distal dans les prothèses totales du genou : Étude de 32 fractures per et postopératoires. Rev Chir Orthop 2006; 92: 140-7.

Huff T W, Sculco T P. Management of bone loss in revision total knee arthroplasty. J Arthroplasty 2007; 22: 32-6.

Hunter D J, March L, Sambrook P N. The association of cartilage volume with knee pain. Osteoarthritis Cartilage 2003; 11: 725-9.

Innocenti B, Truyens E, Labey L, Wong P, Victor J, Bellemans J. Can medio-lateral baseplate position and load sharing induce asymptomatic local bone resorption of the proximal tibia? A finite element study. J Orthop Surg Res 2009; 4: 26.

Insall J N, Dorr L D, Scott R D, Scott W N. Rationale of the Knee Society clinical rating system. Clin Orthop 1989; 248: 13-4.

Iranpour F, Merican A M, Amis A A, Cobb J P. The width:thickness ratio of the patella: an aid in knee arthroplasty. Clin Orthop 2008; 466: 1198-203.

ISO/CD 14243-1. Implants for surgery: Wear of total knee joint prostheses. Part 1: Loading and displacement parameters for wear testing machines with load control and corresponding environmental conditions for testing. International Organization for Standardization, London, 1999.

Iwano T, Kurosawa H, Tokuyama H, Hoshikawa Y. Roentgenographic and clinical findings of patellofemoral osteoarthrosis. With special reference to its relationship to femorotibial osteoarthrosis and etiologic factors. Clin Orthop 1990; 252: 190-7.

Jacquot N, Barbosa J, Dejour D, Neyret P. Résultats du traitement conservateur chirurgical dans l'arthrose fémoro-patellaire isolée. Rev Chir Orthop 2004; 90: 1S97-9.

Janssen D, Mann K A, Verdonschot N. Micro-mechanical modeling of the cement-bone interface: the effect of friction, morphology and material properties on the micromechanical response. J Biomech 2008; 41: 3158-63.

Kadambande S S, Auyeung J, Ghandour A, Mintowt-Czyz W. A review of wound healing following Maquet osteotomy. Knee 2004; 11: 463-7.

Karbowski A, Schwitalle M, Eckardt A, Heine J. Periprosthetic bone remodelling after total knee arthroplasty: early assessment by dual energy X-ray absorptiometry. Arch Orthop Trauma Surg 1999; 119: 324-6.

Keating E M, Ritter M A, Harty L D, Haas G, Meding J B, Faris P M, Berend M E. Manipulation after total knee arthroplasty. J Bone Joint Surg Am 2007; 89: 282-6.

Keblish P A, Varma A K, Greenwald A S. Patellar resurfacing or retention in total knee arthroplasty. A prospective study of patients with bilateral replacements. J Bone Joint Surg Br 1994; 76: 930-7.

Kellgren J H, Lawrence J S. Radiological assessment of osteo-arthrosis. Ann Rheum Dis 1957; 16: 494-502.

Kim J, Nelson C L, Lotke P A. Stiffness after total knee arthroplasty. Prevalence of the complication and outcomes of revision. J Bone Joint Surg Am 2004; 86: 1479-84.

Kim T H, Lee D H, Bin S I. The NexGen LPS-flex to the knee prosthesis at a minimum of three years. J Bone Joint Surg Br 2008; 90: 1304-10.

Kirkley A, Birmingham T B, Litchfield R B, Giffin J R, Willits K R, Wong C J, Feagan B G, Donner A, Griffin S H, D'Ascanio L M, Pope J E, Fowler P J. A randomized trial of arthroscopic surgery for osteoarthritis of the knee. N Engl J Med 2008; 359: 1097-107.

Kohn D, Steimer O, Seil R. Der Anteromedialisierung der Tuberositas tibiae. Orthopäde 2004; 33: 218-23.

Kooijman H J, Driessen A P, van Horn J R. Long-term results of patellofemoral arthroplasty. A report of 56 arthroplasties with 17 years of follow-up. J Bone Joint Surg Br 2003; 85: 836-40.

Krajca-Radcliffe J B, Coker T P. Patellofemoral arthroplasty. A 2- to 18-year followup study. Clin Orthop 1996; 330: 143-51.

Larson C M, McDowell C M, Lachiewicz P F. One-peg versus three-peg patella component fixation in total knee arthroplasty. Clin Orthop 2001; 392: 94-100.

Laskin R S, Van Steijn M. Total knee replacement for patients with patellofemoral arthritis. Clin Orthop 1999; 367: 89-95.

Leadbetter W B, Ragland P S, Mont M A. The appropriate use of patellofemoral arthroplasty: An analysis of reported indications, contraindications, and failures. Clin Orthop 2005; 436: 91-9.

Leadbetter W B, Seyler T M, Ragland P S, Mont M A. Indications, contraindications, and pitfalls of patellofemoral arthroplasty. J Bone Joint Surg Am 2006; 88: 122-37.

Lehner B, Koeck F X, Capellino S, Schubert T E, Hofbauer R, Straub R H. Preponderance of sensory versus sympathetic nerve fibers and increased cellularity in the infrapatellar fat pad in anterior knee pain patients after primary arthroplasty. J Orthop Res 2008; 26: 342-50.

Lewallen D G, Riegger C L, Myers E R, Hayes W C. Effects of retinacular release and tibial tubercle elevation in patellofemoral degenerative joint disease. J Orthop Res 1990; 8: 856-62.

Li G, Lopez O, Rubash H. Variability of a three-dimensional finite element model constructed using magnetic resonance images of a knee for joint contact stress analysis. J Biomech Eng 2001; 123: 341-6.

Linde F. Elastic and viscoelastic properties of trabecular bone by a compression testing approach. Dan Med Bull 1994; 41: 119-38.

Liu T K, Yang R S, Chieng P U, Shee B W. Periprosthetic bone mineral density of the distal femur after total knee arthroplasty. Int Orthop 1995; 19: 346-51.

Lonner J H. Patellofemoral arthroplasty: pros, cons, and design considerations. Clin Orthop 2004; 428: 158-65.

Lonner J H. Patellofemoral arthroplasty. J Am Acad Orthop Surg 2007; 15: 495-506.

Lonner J H. Patellofemoral Arthroplasty: The Impact of Design on Outcomes. Orthop Clin North Am 2008; 39: 347-54.

Lonner J H, Jasko J G, Booth R E, Jr. Revision of a failed patellofemoral arthroplasty to a total knee arthroplasty. J Bone Joint Surg Am 2006; 88: 2337-42.

Maculé F, Sastre S, Lasurt S, Sala P, Segur J M, Mallofré C. Hoffa's fat pad resection in total knee arthroplasty. Acta Orthop Belg 2005; 71: 714-7.

Maralcan G, Kuru I, Issi S, Esmer A F, Tekdemir I, Evcik D. The innervation of patella: anatomical and clinical study. Surg Radiol Anat 2005; 27: 331-5.

McAlindon T E, Snow S, Cooper C, Dieppe P A. Radiographic patterns of osteoarthritis of the knee joint in the community: The importance of the patellofemoral joint. Ann Rheum Dis 1992; 51: 844-9.

McDonnell S M, Bottomley N J, Hollinghurst D, Rout R, Thomas G, Pandit H, Ostlere S, Murray D W, Beard D J, Price A J. Skyline patellofemoral radiographs can only exclude late stage degenerative changes. Knee 2009; in press.

McKeever D C. Patellar prosthesis. J Bone Joint Surg Am 1955; 37: 1074-84.

McPherson E J. Patellar tracking in primary total knee arthroplasty. Instr Course Lect 2006; 55: 439-48.

Meding J B, Wing J T, Keating E M, Ritter M A. Total knee arthroplasty for isolated patellofemoral arthritis in younger patients. Clin Orthop 2007; 464: 78-82.

Meireles S, Completo A, Antonio S J, Flores P. Strain shielding in distal femur after patellofemoral arthroplasty under different activity conditions. J Biomech 2010; 43: 477-84.

Melloni P, Valls R, Veintemillas M. Imaging patellar complications after knee arthroplasty. Eur J Radiol 2008; 65: 478-82.

Merchant A C. Early results with a total patellofemoral joint replacement arthroplasty prosthesis. J Arthroplasty 2004; 19: 829-36.

Merchant A C. A modular prosthesis for patellofemoral arthroplasty: design and initial results. Clin Orthop 2005; 436: 40-6.

Mertl P, Tran Van F, Bonhomme P, Vives P. Traitement de l'arthrose fémoro-patellaire par prothèse sphéro-centrique: Etude rétrospective de 50 implants. Rev Chir Orthop 1997; 83: 712-8.

Moati J C, Zucman J. Place de la dénervation rotulienne dans le traitement des chondropathies fémoro-patellaires. Rev Chir Orthop 1987; 73: 126-9.

Moher D, Cook D J, Eastwood S, Olkin I, Rennie D, Stroup D F. Improving the quality of reports of meta-analyses of randomised controlled trials: the QUOROM statement. Quality of Reporting of Meta-analyses. Lancet 1999; 354: 1896-900.

Moher D, Schulz K F, Altman D G. The CONSORT statement: revised recommendations for improving the quality of reports of parallel-group randomised trials. Lancet 2001; 357: 1191-4.

Mont M A, Haas S, Mullick T, Hungerford D S. Total knee arthroplasty for patellofemoral arthritis. J Bone Joint Surg Am 2002; 84: 1977-81.

Morra E A, Greenwald A S. Patellofemoral replacement polymer stress during daily activities: a finite element study. J Bone Joint Surg Am 2006; 88 (Suppl 4): 213-6.

Moseley J B, O'Malley K, Petersen N J, Menke T J, Brody B A, Kuykendall D H, Hollingsworth J C, Ashton C M, Wray N P. A controlled trial of arthroscopic surgery for osteoarthritis of the knee. N Engl J Med 2002; 347: 81-8.

Mulford J S, Eldridge J D, Porteous A J, Ackroyd C E, Newman J H. Revision of isolated patellofemoral arthroplasty to total knee

replacement. Current Orthopaedic Practice 2009; 20: 437-41.
Najarian, S, Rostami, M, Rezaei, T. Biomechanical analysis of patellofemoral joint prosthesis using finite element method. BioMech 2005, Benidorm, Spain: 7-9 September 2005. Proceedings of the Second IASTED International Conference 2005; 265-268.
Nicol S G, Loveridge J M, Weale A E, Ackroyd C E, Newman J H. Arthritis progression after patellofemoral joint replacement. Knee 2006; 13: 290-5.
Oh I S, Kim M K, You D S, Kang S B, Lee K H. Total knee arthroplasty without patellar resurfacing. Int Orthop 2006; 30: 415-9.
Oztuna V, Karatosun V, Unver B, Ayan I, Kuyurtar F. An alternative patellar resurfacing technique in knee replacement: patellofemoral fascial interposition arthroplasty. Knee Surg Sports Traumatol Arthrosc 2007; 15: 1210-4.
Parvizi J, Stuart M J, Pagnano M W, Hanssen A D. Total knee arthroplasty in patients with isolated patellofemoral arthritis. Clin Orthop 2001; 392: 147-52.
Paulos L E, O'Connor D L, Karistinos A. Partial lateral patellar facetectomy for treatment of arthritis due to lateral patellar compression syndrome. Arthroscopy 2008; 24: 547-53.
Paxton E W, Fithian D C. Outcome instruments for patellofemoral arthroplasty. Clin Orthop 2005; 436: 66-70.
Pellengahr C, Maier M, Müller P E, Dürr H R, Schulz C, Zysk S, Trouiller H, Lindhorst E, Jansson V, Reflor H J. Surgical and anatomic parameters influencing femoropatellar pain in total knee arthroplasty. Eur J Trauma 2002; 28: 242-6.
Pena E, Calvo B, Martinez M A, Doblare M. A three-dimensional finite element analysis of the combined behavior of ligaments and menisci in the healthy human knee joint. J Biomech 2006; 39: 1686-701.
Pena E, Calvo B, Martinez M A, Palanca D, Doblare M. Finite element analysis of the effect of meniscal tears and meniscectomies on human knee biomechanics. Clin Biomech (Bristol, Avon) 2005; 20: 498-507.
Petersen M M, Olsen C, Lauritzen J B, Lund B. Changes in bone mineral density of the distal femur following uncemented total knee arthroplasty. J Arthroplasty 1995; 10: 7-11.
Petrisor B A, Keating J, Schemitsch E. Grading the evidence: levels of evidence and grades of recommendation. Injury 2006; 37: 321-7.
Phillips A M, Goddard N J, Tomlinson J E. Current techniques in total knee replacement: results of a national survey. Ann R Coll Surg Engl 1996; 78: 515-20.
Poggie R A, Wert J J, Mishra A K, Davidson J A. Friction and wear characterization of UHMWPE in reciprocating sliding contact with Co-Cr, Ti-6Al-4V and zirconia implant bearing surfaces. In: Wear and Friction of Elastomers, ASTM STP 1145. (Eds. Denton R, Keshavan M K). Philadelphia, PA: American Society for Testing and Materials 1992: 65-81.
Poolman R W. Adjunctive non-invasive ways of healing bone fractures. BMJ 2009; 338: b11.
Poolman R W, Kerkhoffs G M, Struijs P A, Bhandari M, International Evidence-Based Orthopedic Surgery Working Group. Don't be misled by the orthopedic literature: tips for critical appraisal. Acta Orthop 2007a; 78: 162-71.
Poolman R W, Petrisor B A, Marti R K, Kerkhoffs G M, Zlowodzki M, Bhandari M. Misconceptions about practicing evidence-based orthopedic surgery. Acta Orthop 2007b; 78: 2-11.
Poolman R W, Swiontkowski M F, Fairbank J C, Schemitsch E H, Sprague S, de Vet H C. Outcome instruments: rationale for their use. J Bone Joint Surg Am 2009; 91: 41-9.
Popovic N, Lemaire R. Anterior knee pain with a posterior-stabilized mobile-bearing knee prosthesis: the effect of femoral component design. J Arthroplasty 2003; 18: 396-400.
Porteous, A J, Mulford, J S, Newman, J H, Ackroyd, C E. A review of revision patellofemoral arthroplasty patients. British Association for Surgery of the Knee, Belfast, Northern Ireland: 23, 24 March 2007. J Bone Joint Surg Br 2007; 575.
Qian J G, Song Y W, Tang X, Zhang S. Examination of femoral-neck structure using finite element model and bone mineral density using dual-energy X-ray absorptiometry. Clin Biomech (Bristol, Avon) 2009; 24: 47-52.
Quilty B, Tucker M, Campbell R, Dieppe P. Physiotherapy, including quadriceps exercises and patellar taping, for knee osteoarthritis with predominant patello-femoral joint involvement: randomized controlled trial. J Rheumatol 2003; 30: 1311-7.
Robling A G, Castillo A B, Turner C H. Biomechanical and molecular regulation of bone remodeling. Annu Rev Biomed Eng 2006; 8: 455-98.
Rodriguez-Merchan E C, Gomez-Cardero P. The outerbridge classification predicts the need for patellar resurfacing in TKA. Clin Orthop 2010; 468: 1254-7.
Saleh K J, Arendt E A, Eldridge J, Fulkerson J P, Minas T, Mulhall K J. Symposium. Operative treatment of patellofemoral arthritis. J Bone Joint Surg Am 2005; 87: 659-71.
Saoud A M F. Patellar denervation in non-patellar resurfacing total knee arthroplasty. Pan Arab J Orth Trauma 2004; 8: 25-30.
Seo S S, Ha D J, Kim C W, Choi J S. Effect of posterior condylar offset on cruciate-retaining mobile TKA. Orthopedics 2009; 32: 44-8.
Sharma A, Leszko F, Komistek R D, Scuderi G R, Cates H E, Jr., Liu F. In vivo patellofemoral forces in high flexion total knee arthroplasty. J Biomech 2008; 41: 642-8.
Sisto D J, Cook D L. Total knee replacement in patients with a failed patellofemoral replacement. Orthop Trans 1997; 21: 115.
Sisto D J, Sarin V K. Custom patellofemoral arthroplasty of the knee. J Bone Joint Surg Am 2006; 88: 1475-80.
Skwara A, Tibesku C O, Ostermeier S, Stukenborg-Colsman C, Fuchs-Winkelmann S. Differences in patellofemoral contact stresses between mobile-bearing and fixed-bearing total knee arthroplasties: a dynamic in vitro measurement. Arch Orthop Trauma Surg 2008; 129: 901-7.
Slingenberg E J R, Driessen A P. Patellofemoral prosthesis: preliminary report of 31 cases. Neth J Surg 1982; 34: 31-4.
Smith A J, Lloyd D G, Wood D J. Pre-surgery knee joint loading patterns during walking predict the presence and severity of anterior knee pain after total knee arthroplasty. J Orthop Res 2004; 22: 260-6.
Smith A J, Wood D J, Li M G. Total knee replacement with and without patellar resurfacing: a prospective, randomised trial using the profix total knee system. J Bone Joint Surg Br 2008; 90: 43-9.
Smith A M, Peckett W R, Butler-Manuel P A, Venu K M, d'Arcy J C. Treatment of patello-femoral arthritis using the Lubinus patello-femoral arthroplasty: a retrospective review. Knee 2002; 9: 27-30.
Soininvaara T, Kroger H, Jurvelin J S, Miettinen H, Suomalainen O, Alhava E. Measurement of bone density around total knee arthroplasty using fan-beam dual energy X-ray absorptiometry. Calcif Tissue Int 2000; 67: 267-72.
Soininvaara T A, Miettinen H J, Jurvelin J S, Suomalainen O T, Alhava E M, Kroger H P. Periprosthetic femoral bone loss after total knee arthroplasty: 1-year follow-up study of 69 patients. Knee 2004; 11: 297-302.
Spak R T, Teitge R A. Fresh osteochondral allografts for patellofemoral arthritis: Long-term followup. Clin Orthop 2006; 444: 193-200.
Spittlehouse A J, Getty C J, Eastell R. Measurement of bone mineral density by dual-energy X-ray absorptiometry around an uncemented knee prosthesis. J Arthroplasty 1999; 14: 957-63.
Sprague S, Quigley L, Bhandari M. Survey design in orthopaedic surgery: getting surgeons to respond. J Bone Joint Surg Am 2009; 91 (Suppl 3): 27-34.
Steimer O, Kohn D. Anteromedialization of the tibial tubercle. Oper Tech Orthop 2007; 17: 66-71.
Stroup D F, Berlin J A, Morton S C, Olkin I, Williamson G D, Rennie D, Moher D, Becker B J, Sipe T A, Thacker S B. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. JAMA 2000; 283: 2008-12.
Tauro B, Ackroyd C E, Newman J H, Shah N A. The Lubinus patellofemoral arthroplasty. A five- to ten-year prospective study. J Bone Joint Surg Br 2001; 83: 696-701.
Taylor W R, Heller M O, Bergmann G, Duda G N. Tibio-femoral loading during human gait and stair climbing. J Orthop Res 2004; 22: 625-32.
Taylor W R, Roland E, Ploeg H, Hertig D, Klabunde R, Warner M D, Hobatho M C,

Rakotomanana L, Clift S E. Determination of orthotropic bone elastic constants using FEA and modal analysis. J Biomech 2002; 35: 767-73.
The Swedish Knee Arthroplasty Register. Annual Report 2009. http://www.knee.nko.se/english/online/uploadedFiles/113_SVK2009ENGL1.0.pdf (Accessed 16-10-2010).
Thompson N W, Ruiz A L, Breslin E, Beverland D E. Total knee arthroplasty without patellar resurfacing in isolated patellofemoral osteoarthritis. J Arthroplasty 2001; 16: 607-12.
Tissakht M, Ahmed A M, Chan K C. Calculated stress-shielding in the distal femur after total knee replacement corresponds to the reported location of bone loss. J Orthop Res 1996; 14: 778-85.
Trevisan C, Bigoni M, Denti M, Marinoni E C, Ortolani S. Bone assessment after total knee arthroplasty by dual-energy X-ray absorptiometry: analysis protocol and reproducibility. Calcif Tissue Int 1998; 62: 359-61.
van Hemert W L, Senden R, Grimm B, Kester A D, van der Linde M J, Heyligers I C. Patella retention versus replacement in total knee arthroplasty; functional and clinimetric aspects. Arch Orthop Trauma Surg 2009; 129: 259-65.
van Jonbergen H P W, Barnaart A F W, Verheyen C C P M. A Dutch survey on circumpatellar electrocautery in total knee arthroplasty. Open Orthop J 2010a; 4: 201-3.
van Jonbergen H P W, Koster K, Labey L, Innocenti B, van Kampen A. Distal femoral bone mineral density decreases following patellofemoral arthroplasty: 1-year follow-up study of 14 patients. BMC Musculoskelet Disord 2010b; 11: 74.
van Jonbergen H P W, Poolman R W, van Kampen A. Isolated patellofemoral osteoarthritis: A systematic review of treatment options using the GRADE approach. Acta Orthop 2010c; 81: 199-205.
van Jonbergen H P W, Werkman D M, Barnaart L F, van Kampen A. Long-term outcomes of patellofemoral arthroplasty. J Arthroplasty 2010d; 25: 1066-71.
van Jonbergen H P W, Werkman D M, van Kampen A. Conversion of patellofemoral arthroplasty to total knee arthroplasty. A matched case-control study of 13 patients. Acta Orthop 2009; 80: 62-6.
van Lenthe G H, de Waal Malefijt M C, Huiskes R. Stress shielding after total knee replacement may cause bone resorption in the distal femur. J Bone Joint Surg Br 1997; 79: 117-22.
van Loon C J, de Waal Malefijt M C, Buma P, Verdonschot N, Veth R P. Femoral bone loss in total knee arthroplasty. A review. Acta Orthop Belg 1999; 65: 154-63.
van Loon C J, Oyen W J, de Waal Malefijt M C, Verdonschot N. Distal femoral bone mineral density after total knee arthroplasty: a comparison with general bone mineral density. Arch Orthop Trauma Surg 2001; 121: 282-5.
Vaninbroukx M, Labey L, Innocenti B, Bellemans J. Cementing the femoral component in total knee arthroplasty: which technique is the best? Knee 2009; 16: 265-8.
Vega J, Golano P, Perez-Carro L. Electrosurgical arthroscopic patellar denervation. Arthroscopy 2006; 22: 1028-3.
Vermeulen H, Donker E d, Watillon M. Les prothèses rotuliennes de Mac Keever dans l´arthrose fémoropatellaire. Acta Orthop Belg 1973; 39: 79-90.
Viceconti M, Olsen S, Nolte L P, Burton K. Extracting clinically relevant data from finite element simulations. Clin Biomech (Bristol, Avon) 2005; 20: 451-4.
Victor J, Labey L, Wong P, Innocenti B, Bellemans J. The influence of muscle load on tibiofemoral knee kinematics. J Orthop Res 2010; 28: 419-28.
Victor J, Van Glabbeek F, Vander Sloten J, Parizel P M, Somville J, Bellemans J. An experimental model for kinematic analysis of the knee. J Bone Joint Surg Am 2009; 91 (Suppl 6): 150-63.
Waters T S, Bentley G. Patellar resurfacing in total knee arthroplasty. A prospective, randomized study. J Bone Joint Surg Am 2003; 85: 212-7.
Weaver J K, Wieder D, Derkash R S. Patellofemoral arthritis resulting from malalignment. A long-term evaluation of treatment options. Orthop Rev 1991; 20: 1075-81.
Werkman D M. La prothèse fémoro-patellaire. Rev Chir Orthop 1991; 77: 136.
Wojtys E M, Beaman D N, Glover R A, Janda D. Innervation of the human knee joint by substance-P fibers. Arthroscopy 1990; 6: 254-63.
Wood D J, Smith A J, Collopy D, White B, Brankov B, Bulsara M K. Patellar resurfacing in total knee arthroplasty: a prospective, randomized trial. J Bone Joint Surg Am 2002; 84: 187-93.
Yercan H S, Ait Si Selmi T, Neyret P. The treatment of patellofemoral osteoarthritis with partial lateral facetectomy. Clin Orthop 2005; 436: 14-9.
Yercan H S, Sugun T S, Bussiere C, Ait Si Selmi T., Davies A, Neyret P. Stiffness after total knee arthroplasty: prevalence, management and outcomes. Knee 2006; 13: 111-7.
Zelle J, Van der Zanden A C, De Waal M M, Verdonschot N. Biomechanical analysis of posterior cruciate ligament retaining high-flexion total knee arthroplasty. Clin Biomech (Bristol, Avon) 2009; 24: 842-9.
Zheng N, Fleisig G S, Escamilla R F, Barrentine S W. An analytical model of the knee for estimation of internal forces during exercise. J Biomech 1998; 31: 963-7.
Zirconium Products: Technical Data Sheet. Wah Chang: An Allegheny Technologies Company. http://www.wahchang.com/pages/products/data/pdf/Zr_Products_Zr702_705.pdf (Accessed 16-10-2010).

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Publications

Publications

van Jonbergen H P W, Werkman D M, Barnaart L F, van Kampen A. Long-term outcomes of patellofemoral arthroplasty. J Arthroplasty 2010; 25: 1066-71.

van Jonbergen H P W, van Lingen C P. Patellofemoral joint replacement. Minerva Ortopedica e Traumatologica 2010; 61: 305-18.

van Jonbergen H P W, Barnaart A F W, Verheyen C C P M. A Dutch survey on circumpatellar electrocautery in total knee arthroplasty. Open Orthop J 2010; 4: 201-3.

van Jonbergen H P W, Koster K, Labey L, Innocenti B, van Kampen A. Distal femoral bone mineral density decreases following patellofemoral arthroplasty: 1-year follow-up study of 14 patients. BMC Musculoskelet Disord 2010; 11: 74.

van Jonbergen H P W, Poolman R W, van Kampen A. Isolated patellofemoral osteoarthritis: A systematic review of treatment options using the GRADE approach. Acta Orthop 2010; 81: 199-205.

Reuver J, Barnaart A F W, **van Jonbergen H P W**. Intertrochantere fracturen, altijd kopsparend? Ned Tijdschr Traumatologie 2010; 18: 43-6.

Bisschop R, **van Jonbergen H P W**. Traumatische atlanto-axiale rotatoire subluxatie; case report en behandelvoorstel. Ned Tijdschr Traumatologie 2009; 17: 100-4.

Huizinga M, Hentenaar B, **van Jonbergen H P W**. Geschiedenis van patellofemorale gewrichtsvervanging. Ned Tijdschr Orthopaedie 2009; 16: 152-5.

van Jonbergen H P W, van Egmond K. Patellofemoral arthroplasty for symptomatic nonunion after trochlear osteotomy for patellar instability: a case report. Cases J 2009; 2: 9086.

van Jonbergen H P W, Werkman D M, Barnaart A F W. Dissociation of mobile-bearing patellar component in low contact stress patellofemoral arthroplasty, its mechanism and management: two case reports. Cases J 2009; 2: 7502.

van Jonbergen H P W, Werkman D M, van Kampen A. Conversion of patellofemoral arthroplasty to total knee arthroplasty. A matched case-control study of 13 patients. Acta Orthop 2009; 80: 62-6.

van Jonbergen H P W, Spruit M, Anderson P G, Pavlov P W. Anterior cervical interbody fusion with a titanium box cage: early radiological assessment of fusion and subsidence. Spine J 2005; 5: 645-9.

Spruit M, **van Jonbergen H P W**, de K M. A concise follow-up of a previous report: posterior reduction and anterior lumbar interbody fusion in symptomatic low-grade adult isthmic spondylolisthesis. Eur Spine J 2005; 14: 828-32.

de Kleuver M, **van Jonbergen H P W**, Langeloo D D. Asymptomatic massive dural ectasia associated with neurofibromatosis type 1 threatening spinal column support: treatment by anterior vascularized fibula graft. J Spinal Disord Tech 2004; 17: 539-42.

van Jonbergen H P W, Anderson P G, Faber F W M. Total hip arthroplasty with Boneloc cement: unsatisfactory results in 163 hips after 9 to 11 years. Hip International 2004; 14: 229-32.

van Jonbergen H P W, Faber F W M, Treurniet F E E. Non-traumatic isolated rupture of the flexor hallucis longus tendon related to an os trigonum: a case report. Foot Ankle Surg 2001; 7: 109-11.

van Jonbergen H P W, Sauter A J M. Slechte resultaten van totale heupartroplastieken met Boneloc cement. Ned Tijdschr Orthopaedie 1999; 6: 19-22.

Holman E R, **van Jonbergen H P W**, van Dijkman P R, van der Laarse A, de R A, van der Wall E E. Comparison of magnetic resonance imaging studies with enzymatic indexes of myocardial necrosis for quantification of myocardial infarct size. Am J Cardiol 1993; 71: 1036-40.

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Curriculum Vitae

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The author of this thesis was born on July 1st, 1967 in Laren (NH), The Netherlands. In 1986, he graduated from secondary school at the St. Vitus College in Bussum, and started medical school in the same year at Leiden University. After his graduation in 1994, he served two years in the Royal Netherlands Navy.
In 1997, he started his general surgery training at the Medisch Spectrum Twente in Enschede (prof.dr. P.A.M. Vierhout). In 1999, he continued his orthopedic surgery training at Leyenburg Hospital in The Hague (dr. L.N.J.E.M. Coene), with further training at Erasmus Medical Center in Rotterdam (prof.dr. J.A.N. Verhaar) and Sophia Children's Hospital in Rotterdam (dr. A.F.M. Diepstraten). After finishing his residency program in 2003, he completed a one year fellowship training program in spine surgery at the Maartenskliniek in Nijmegen (dr. P.W. Pavlov). In 2004 he joined the orthopedic staff at Deventer Hospital.
He is happily living in Deventer together with his lovely wife Carolien and their two lovely daughters: Sophie and Fleur.