Tuukka Niinimäki

HIGH TIBIAL OSTEOTOMY AND UNICOMPARTMENTAL KNEE ARTHROPLASTY

THE TREATMENT OF ISOLATED MEDIAL OSTEOARTHRITIS OF THE KNEE – A REGISTRY-BASED STUDY IN FINLAND
TUUKKA NIINIMÄKI

HIGH TIBIAL OSTEOTOMY AND UNICOMPARTMENTAL KNEE ARTHROPLASTY
The treatment of isolated medial osteoarthritis of the knee – A registry-based study in Finland

Academic Dissertation to be presented with the assent of the Doctoral Training Committee of Health and Biosciences of the University of Oulu for public defence in Auditorium 1 of Oulu University Hospital, on 10 January 2014, at 12 noon
Niinimäki, Tuukka, High tibial osteotomy and unicompartmental knee arthroplasty. The treatment of isolated medial osteoarthritis of the knee – a registry-based study in Finland
University of Oulu Graduate School; University of Oulu, Faculty of Medicine, Institute of Clinical Medicine, Department of Surgery; Oulu University Hospital
University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

High tibial osteotomy (HTO) and unicompartmental knee arthroplasty (UKA) are performed for the treatment of isolated medial osteoarthritis (OA) of the knee.

In the treatment of knee OA, the incidence of osteotomies has decreased with the popularisation of knee arthroplasties, but it is still indicated in young and active patients. Results of HTO tend to deteriorate over the time and patients may need to undergo subsequent total knee arthroplasty (TKA). TKA after HTO is a demanding procedure, and the influence of previous osteotomy on the results of TKA is not defined.

Results of UKAs are controversial. Single centre studies have shown good results, but arthroplasty registers report consistently inferior survivorships compared with TKAs. However, comparison of register survivals may be inadequate because differences in the demographics of the patients have not been taken into account.

The aims of the current nationwide register-based study were to assess incidence of osteotomies and survivorship of HTO in the treatment of knee OA, and to compare survivorship of TKAs performed after HTO with primary TKAs between 1987 and 2008 in Finland. In addition, this study reports survivorship of UKAs between 1985 and 2011 and compare it with the survival of cemented TKAs.

Based on this study, the overall incidence of osteotomies has decreased, especially in females, in the treatment of knee OA during the last two decades. In the patients less than 50 years of age, the incidence of osteotomies has been stable or slightly increased. Register-based survivorship of HTO was inferior compared with smaller cohort studies and females and patients more than 50 years of age had the poorest results. The survivorship of TKA after osteotomy was slightly inferior compared with primary operations in general, but any clinical significance was minor. In this study UKA had inferior survivorship compared with TKA, even after adjusting for the age and gender of the patients. The reported survivorship of UKA was similar to those from available unadjusted arthroplasty register data. Surgeons should be made aware of this, but the reasons for incoherence with single-centre studies are not yet established and need further study.

Keywords: arthroplasty, knee, osteoarthritis, osteotomy, unicompartmental
Niinimäki, Tuukka, Sääriuluunkääntöleikkaus ja osatekonivelileikkaus polven sisäsyrjän nivelrikon hoidossa. Suomalainen rekisteritutkimus

Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta, Kliinisen lääketieteen laitos, Kirurgia; Oulun yliopistollinen sairaala

Oulun yliopisto, PL 8000, 90014 Oulun yliopisto

Tiivistelmä


Asiasanat: luukirurgia, nivelrikko, polvet, sääriuluu, tekonivelet
To my family
Acknowledgements

This study was carried out at the Department of Surgery, University of Oulu, during the years 2007 to 2013.

I wish to express my sincere gratitude to my supervisor, the head of the Department of Orthopaedic Surgery, Docent Juhana Leppilahti, M.D., for his guidance during these years. His open-minded and supportive attitude has been essential for this work.

I thank Docent Kari Haukipuro, M.D., the head of the Division of Operative Care, and Timo Kaukonen, M.D., the chief of surgery, for the opportunity to work and do research in the Department of Surgery. I also thank professor Tatu Juvonen, M.D., for his support during this work.

I thank Docent Antti Eskelinen, M.D., my good friend and colleague, for his advice and valuable comments throughout the whole study. Your expertise in the field of arthroplasty research was essential.

Register-based studies cannot be conducted without good statistical knowledge. For statistical assistance and high commitment throughout the whole study, I want to thank Pasi Ohtonen, M.Sc.

I warmly thank Docent Petri Virolainen, M.D., and Docent Heikki Mäenpää, M.D., for their review of this manuscript. Their constructive and prompt criticism greatly improved it.

For significant collaboration and participation in this work, I want to acknowledge Docent Ville Remes, M.D., Keijo Mäkelä, M.D., Ph.D., and Bhupinder S Mann, MBBS. Without your help, completion of this study would have been extremely difficult. I warmly thank Mika Junnila, M.D., and Henri Miettinen, B.M., for helping me to collect data.

I express my special thanks to my fellow orthopaedic colleagues Juha Haataja, M.D., and Ari-Pekka Puhto, M.D., for your supportive attitude during these years. In addition, my warm thanks go to Maarit Valkealahti, M.D., Ph.D., Reeta Koivunen, M.D., and Outi Väyrynen, M.D., Ph.D., in our arthroplasty unit. I feel privileged to work with all of you.

For supportive attitudes toward this work, I want to thank Docent Jukka Ristiniemi, M.D., whose skills in deformity surgery are widely respected, and Harri Pakarinen, M.D., Ph.D., for showing me enthusiasm for doing research. Docent Taipro Flinkkilä, M.D., Pekka Hyvönen, M.D., Ph.D., Susanna Yli-Luukko, M.D., Samppa Harmainen, M.D., and Tomi Nousiainen, M.D., are acknowledged for their encouragement for this study.
Special thanks go to professor Ashley Blom, Ch.B., in Bristol, United Kingdom. I want to thank you for giving me the opportunity to work in the Avon Orthopaedic Centre, and for your supportive attitude and reviewing of manuscripts. You showed me how to combine clinical excellence and research, while being a great colleague and supervisor at the same time. This experience in Bristol made a difference in the whole life of our family.

I want to thank my parents, Aila and Timo, for their endless love and support throughout my life and during this study. You have both been exceptional role models for me, and I definitely would not have come this far without you. I thank my sister, Riitta, and brothers Jouko and Jaakko for their support during these years; with you I experienced much happiness in our childhood. Your academic achievements have definitely inspired this study. I extend my warmest gratitude to my parents-in-law, Hilka and Paavo Salonen, for their support in our everyday life, which was essential for this study.

My most loving thanks go to my wife Riitta, for being my greatest supporter and believing in this study. Without your inspiration, this study would never have commenced. I extend my dearest thanks to our lovely children, Niilo, Olli and Nelli, for their love and for bringing true happiness to my life.

This study was financially supported by the Finnish Arthroplasty Society, the Professor Pär Slätis Research Foundation, the Oulu Medical Research Foundation, the Research Foundation for Orthopaedics and Traumatology, Oulu University Hospital and University of Oulu.

Oulu, November 2013 Tuukka Niinimäki
Abbreviations

BMI  body mass index
CI   confidence interval
HR   hazard ratio
HTO  high tibial osteotomy
IRR  incidence rate ratio
NHDR National Hospital Discharge Register
NSAID non-steroidal anti-inflammatory drug
OA   osteoarthritis
PCA  Porous coated anatomic
RCT randomized controlled trial
SD   standard deviation
TKA  total knee arthroplasty
UKA  unicompartmental knee arthroplasty
List of original publications

This thesis is based on the following original articles, which are referred to in the text by their Roman numerals.


# Contents

Abstract

Tiivistelmä

Acknowledgements 9

Abbreviations 11

List of original publications 13

Contents 15

1 Introduction 17

2 Review of Literature 19

2.1 Knee osteoarthritis .......................................................... 19

2.1.1 Conservative treatment options ................................. 21

2.1.2 Operative treatment options ...................................... 22

2.2 High tibial osteotomy for the treatment of knee osteoarthritis ... 25

2.2.1 Indications ................................................................. 25

2.2.2 Planning the procedure .............................................. 26

2.2.3 Surgical technique ..................................................... 27

2.2.4 Incidence ................................................................. 28

2.2.5 Results ................................................................. 29

2.3 Total knee arthroplasty after high tibial osteotomy................ 31

2.3.1 Surgical procedure .................................................... 31

2.3.2 Reasons for total knee arthroplasty failure .................... 32

2.3.3 Results ................................................................. 32

2.4 Unicompartmental knee arthroplasty for the treatment of knee osteoarthritis......................................................... 33

2.4.1 Indications and contraindications ................................ 35

2.4.2 Unicompartmental or total knee arthroplasty .................. 36

2.4.3 Incidence ................................................................. 38

2.4.4 Results ................................................................. 39

3 Aims of the study 43

4 Materials and methods 45

4.1 Materials ................................................................. 45

4.1.1 Registers ................................................................. 45

4.1.2 Study groups .......................................................... 46

4.1.3 Control groups ......................................................... 51

4.2 Methods and statistical analyses ...................................... 52
5 Results

5.1 Incidence of osteotomies between 1987 and 2008 in Finland (I) .......... 55
5.2 Survivorship of high tibial osteotomies (II) ........................................ 59
5.3 Survivorship of total knee arthroplasty after high tibial osteotomy (III) .................................................................................. 61
5.4 Survivorship of unicompartmental knee arthroplasties compared with cemented total knee arthroplasties (IV) ............................... 63

6 Discussion

6.1 Validity of the data ............................................................................... 71
6.2 The incidence of osteotomies in the treatment of knee osteoarthritis (I) ......................................................................................... 73
6.3 Survivorship of high tibial osteotomy (II) ............................................. 73
6.4 Survivorship of total knee arthroplasty after high tibial osteotomy compared with primary total knee arthroplasty (III) ................. 74
6.5 Survivorship of unicompartmental knee arthroplasty (IV) ................. 75
6.6 Further studies...................................................................................... 76

7 Conclusions

References ................................. 81
Original publications .................. 99
1 Introduction

High tibial osteotomies (HTO) and unicompartamental knee arthroplasties (UKA) are performed for the treatment of isolated unicompartamental osteoarthritis (OA) of the knee. Before the development of knee arthroplasties, HTO was the most common operative treatment option for knee OA (Kurtz et al. 2005). Over the past two decades, the incidence of osteotomies has decreased, but symptomatic, radiologically mild or moderate knee OA is still commonly regarded as an indication of HTO in young and active patients (Amendola & Bonasia 2010).

The history of UKA began in the 1960s, with the introduction of the cobalt-chromium alloy McIntosh prosthesis, which was inserted into either the medial or lateral compartment (Jamali et al. 2009). The results of McIntosh prosthesis and other early designs were poor with high failure rates and low patient satisfaction (Insall & Aglietti 1980, Laskin 1978). After development and popularisation of total knee arthroplasty (TKA), the overall proportion of UKAs has decreased in the treatment of knee OA (SKAR 2012). However, UKA is provided as an option for TKA in cases of isolated unicompartamental knee OA, and significant numbers of UKAs are still performed worldwide.

Results of HTO are reported to be good, but they tend to deteriorate with time and patients may subsequently undergo TKA (Akizuki et al. 2008, Flecher et al. 2006, Gstottner et al. 2008, Papachristou et al. 2006, van Raaij et al. 2008). However, most of previous results for HTOs are reported from single centre or surgeon series, which limits their power of evidence. There is a paucity of larger, registry-based studies to report results of HTO in widespread use.

HTO alters the anatomy and biomechanics of the knee. The most common changes are ligamental imbalance, patellar tendon length alteration, scar formation and possible rotational deformities (Karabatsos et al. 2002). All these factors may make a subsequent TKA procedure more difficult, but most of the previous studies show no adverse effects on the results of subsequent TKA (Haslam et al. 2007, Kazakos et al. 2008, Ripanti et al. 2012, Treuter et al. 2012, van Raaij et al. 2007). However, these previously published studies have very limited cohort sizes. Only one is a register-based study, which reports that a TKA after an osteotomy has almost a three-fold higher early revision rate when compared to a primary TKA (Pearse et al. 2012).

Results of UKA operations are controversial. Most single centre studies report UKA results that are comparable with those of TKA (Lim et al. 2012, Macaulay & Yoon 2008, Newman et al. 2009, Pandit et al. 2006, Skowronski et
at. 2005). However, these studies are not supported by available arthroplasty register data from Australia, Finland, New Zealand, Norway, Sweden and the United Kingdom, which report repeatedly inferior survivorship of UKA compared with TKA patients (Australian National Joint Replacement Registry 2012, Koskinen et al. 2007, NAR 2010, National Joint Registry for England and Wales 2012, New Zealand Joint Registry 2011, SKAR 2012).

The first aim of the current registry-based study is to report the incidence of osteotomies and survivorship of HTO in the treatment of knee OA, and to assess survivorship of TKA after HTO between 1987 and 2008 in Finland. The second aim of is to assess survivorship of UKA and compare that to the results for TKAs between 1985 and 2011.

The findings of the current study provide extremely useful insight into the results and the current role of HTO and UKA in the treatment of isolated medial OA of the knee.
2 Review of Literature

2.1 Knee osteoarthritis

Knee OA is a chronic condition characterised by structural changes to the whole knee joint that include loss of articular cartilage, development of osteophytes, synovial inflammation, subchondral bone changes, meniscal damage, muscle weakness and ligamentous laxity (Fig.1). In addition to the damage to the articular cartilage, adverse effects of OA are seen in multiple components of the joint, including the peri-articular bone, synovia and adjacent supporting connective tissue elements.

![Fig. 1. Isolated medial osteoarthritis of the right knee.](image)

The etiology of knee OA is not defined. Multiple factors have been shown to affect the progression of OA, including the presence of polyarticular disease, increasing age, obesity, joint instability or malalignment. In addition, there is evidence that genetic factors contribute to the risk of OA (Goldring & Goldring 2006).
Symptoms of OA depend on the degree of arthritis and the stage of the inflammation process, and it causes pain, limits activity, and significantly impairs the physical quality of life (Muraki et al. 2010). Knee OA affects almost a tenth of the population aged over 55 years (Felson 1988).

A few population-based studies have reported the incidence and prevalence of knee OA. In the Finnish health survey study, symptomatic knee OA was rare in the population less than 45 years of age, but incidence increased after middle age. Among men 55–64 years old, the incidence was 9.1%, while it was 18.2% in women aged 65–74 (Arokoski et al. 2007). Leyland et al. (2012) reported an annual cumulative radiographic incidence of 2.3% in middle-aged women over a 15 year period. A systematic review reported prevalence rates of radiographic disease ranging from 4.3% to 78.6%, whereas rates were lower for symptomatic disease (from 3.2% to 13.5%) (Bennell et al. 2012).

Knee OA is more common in women and older people (Suri et al. 2012). Apart from ageing, much evidence mostly from North American and European cohorts, indicates that obesity or heavy occupational physical activities are clear risk factors for symptomatic knee OA (Jensen 2008). A systematic review indicated that the main factors consistently associated with knee OA were obesity, previous knee trauma, hand osteoarthritis, female gender and older age (Blagojevic et al. 2010). In young adults, knee OA is most commonly the result of a previous injury to the knee (Roos 2005).

Radiological classification of knee osteoarthritis

Establishment of a uniform definition of knee OA is difficult, as discordance exists between the pathological evidence of OA and the presence and severity of clinical symptoms (Hannan et al. 2000). Partly because of this lack of agreement, and due to the lack of a gold standard definition, many different radiological and clinical classification criteria for knee OA exist.

The most common radiological classification is probably the Kellgren-Lawrence classification (Kellgren & Lawrence 1957) (Table 1). Another commonly used radiological staging is the Ahlbäck classification (Ahlback 1968). A common weakness of radiological classifications is that they can only be used to grade the radiological severity of OA; they do not provide information about symptoms or functional outcome, and their role in choosing between treatment strategies is very limited. Radiological classifications are observer-dependent and
reproducibility is relatively poor; therefore, visual-based classifications are prone to bias (Weidow et al. 2006).

Table 1. Kellgren-Lawrence classification of knee OA.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Radiological findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Doubtful narrowing of the joint space, possible osteophytes.</td>
</tr>
<tr>
<td>II</td>
<td>Small osteophytes, possible narrowing of the joint.</td>
</tr>
<tr>
<td>III</td>
<td>Multiple, moderately sized osteophytes, definite joint space narrowing, some sclerotic areas, possible deformation of bone ends.</td>
</tr>
<tr>
<td>IV</td>
<td>Multiple large osteophytes, severe joint space narrowing, marked sclerosis and definite deformity of bone ends.</td>
</tr>
</tbody>
</table>

2.1.1 Conservative treatment options

Symptomatic knee OA is primarily treated by conservative means. The stage of OA and patient related factors will determine the most suitable treatment options. Most often, conservative treatment is multimodal and combines different non-surgical treatment options.

Physical activity and exercise are essential for all patients, irrespective of disease severity, age, co-morbidities, pain severity, or disability. Meta-analysis shows small to moderately sized effects of exercise on pain and function (Fransen & McConnell 2009). In addition, local muscle strengthening and general aerobic exercise are recommended (Hochberg et al. 2012, Zhang et al. 2008). Physiotherapy, including both manual treatments and physical modalities, may be beneficial (Current Care guideline 2012).

Obesity is consistently related as a cause of knee OA (Blagojevic et al. 2010). A randomised trial that confirmed that reducing body weight is beneficial in overweight and obese patients (Christensen et al. 2007). A systematic review of the benefits of bariatric surgery in obese patients with hip and knee OA demonstrated that this surgery might benefit obese patients. However, the review identified the need for randomised controlled trials (RCTs) to clarify the role and indications for bariatric surgery (Gill et al. 2011).

Analgesics can be useful in pain relief. Paracetamol is currently recommended for the initial treatment of mild to moderate pain of OA of the knee (Zhang et al. 2010). A systematic review of RCTs, which provided a head-to-head comparison between paracetamol and non-steroidal anti-inflammatory drugs (NSAID), showed better efficacy and patient preference for NSAIDs, although
the side effects were greater (Zhang et al. 2010). Opioids, excluding tramadol, are not recommended to be routinely used because the small to moderate beneficial effect is associated with large increases in the risk of adverse events (Nuesch et al. 2009).

Glucosamine is a precursor of glycosaminoglycans, a major component of joint cartilage. Glucosamine is quite widely used among knee OA patients. However, RCTs have indicated that glucosamine has a similar effect to placebo on pain, with industry independent trials showing smaller effects than commercially funded ones (Zhang et al. 2010).

The role of intra-articular injections is controversial. A Cochrane review found that the pain reduction lasted for only one to two weeks after a corticosteroid injection (Bellamy et al. 2006). Meta-analysis showed that trials of use of intra-articular injections of hyaluronic acid are generally low quality and that viscosupplementation is associated with a small and clinically irrelevant reduction in pain (Rutjes et al. 2012).

RCTs have shown that unloading knee braces can improve malalignment and improve symptoms, but their use in clinical practice has been limited by important patient factors including adherence, comfort and fitting (Brouwer et al. 2006b).

2.1.2 Operative treatment options

The optimal surgical treatment of knee OA, especially in the young and active patient, is still insufficiently defined. Operative measures include arthroscopic debridement with or without microfractures, HTO, UKA and TKA. The type of procedure generally depends on the surgeon’s preference and skills, as well as patient factors such as radiographic findings, age, weight, specific knee mechanics, etiology of malalignment, course and progression of symptoms, and lifestyle.

Arthroscopy

In the treatment of knee OA, arthroscopy has no demonstrable effect on pain, with the latest RCT showing similar benefits to optimised physical and medical treatment (Kirkley et al. 2008). The American Academy of Orthopaedic Surgeons cannot recommend performing arthroscopy with lavage and/or debridement in patients with a primary diagnosis of symptomatic OA of the knee (AAOS 2013).
The Cochrane review of arthroscopic debridement for knee OA reports that arthroscopic debridement has no benefit for undiscriminated knee OA, including both mechanical and inflammatory causes (Laupattarakasem et al. 2008).

High tibial osteotomy and unicompartmental knee arthroplasty

HTO and UKA are performed for the treatment of knee OA isolated to a single compartment. These procedures are explained in more detail in chapters 2.2 and 2.4.

Total knee arthroplasty

The history of knee arthroplasties began in the late 1800s when the first ivory hinge TKA was performed (Zipple & Meyer-Ralfs 1975). Several hinge designs were developed in the 1950s, with unsatisfactory results (Walldius 1953). John Insall (1976) developed the total condylar prosthesis, which was implanted for the first time in 1974. This design formed the basis of today’s TKA designs.

TKA is reserved for knee OA patients with severe disease in one or more compartments. The operation may be performed with or without patellar resurfacing. Generally accepted indications for TKA are defined as persistent moderate to severe pain, functional limitation, and reduced quality of life despite optimal conservative treatment, together with radiological disease (Bennell et al. 2012). Although no RCTs have been performed, higher quality prospective studies of consecutive unselected patients report that TKA is generally successful, with 80% of patients reporting reduction of pain (Beswick et al. 2012) and survivorship ranging from 90% to 95% at 10 to 15 years (Laskin 2001, Robertsson et al. 2001). Cemented TKA has evolved to become the gold standard for the treatment of knee OA, to which other surgical means should be compared (Fig. 2).
Fig. 2. Cemented total knee arthroplasty.

The world population is ageing due to rising life expectancy; consequently, the number of TKAs has been increasing every year in developed countries (Singh et al. 2010).

Despite encouraging results, patients aged less than 55 years have more variable outcomes than do those older than 55 years (Diduch et al. 1997, Lonner et al. 2000, Price et al. 2010). Registries have shown that the risk of revision is 2.5 times higher in OA patients younger than 65 years than in those aged 65 years or older (Australian National Joint Replacement Registry 2012, SKAR 2012). No definite reason is known for the higher revision rate among young patients. Functional demands are higher in younger patients than in older ones and TKA may fail to meet their expectations of kneeling, squatting and stair climbing, which are especially important among younger patients (Scott et al. 2012). It is possible that higher activity increases polyethylene wear, which may be related to higher revision rates (Harrysson et al. 2004). Despite the reported register results, a rapid increase is noted in the incidence of TKA among patients with primary knee OA, especially in those ages 50–59 years (Leskinen et al. 2012).
2.2 High tibial osteotomy for the treatment of knee osteoarthritis

HTO is viewed as a feasible alternative in cases of isolated medial compartmental knee OA as a way to maintain function, relieve pain and gain time when the articular cartilage is not completely worn and relatively young patients do not want to modify their activity levels (Fig. 3). In addition, HTO can be effective in delaying the need for TKA (Brouwer et al. 2007). Because the popularisation of TKA, the overall role of HTO in the treatment of knee OA has decreased since Jackson (1958) introduced this procedure. However, in the 1990s, in sports medicine, the role of correction of varus alignment in the treatment of ligamentous injuries and imbalance of the knee led to a reappraisal of osteotomy (Noyes et al. 1993).

![Fig. 3. Bilateral open wedge high tibial osteotomies.](image)

2.2.1 Indications

The main indication for HTO is the correction of varus alignment in medial unicompartmental OA of the knee. The aim of the procedure is to reduce load on
the medial compartment by correcting or slightly overcorrecting alignment of the knee into the valgus.

Selecting the ideal patient is crucial in achieving good results with HTO for medial knee OA. The list of characteristics for the ideal HTO patient, according to the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine, is: Isolated medial joint line pain, age 40 to 60 years, body mass index (BMI) < 30, high-demand activity but no running or jumping, varus malalignment < 15 degrees, metaphyseal varus of tibia > 5 degrees, full range of movement, normal lateral and patellofemoral compartments, no defect of the posteromedial tibia, normal ligament balance, non-smoker and some level of pain tolerance (Rand & Neyret 2005). The possibility to return to a sporting activity can also be an important consideration in the decision-making process for treatment of knee OA (Bonnin et al. 2013).

2.2.2 Planning the procedure

Careful preoperative planning is mandatory in HTO. The initial assessment includes weight-bearing anteroposterior and lateral radiographs and axial views of the patellofemoral joint, as well as whole-leg standing radiographs in order to assess alignment. Abnormal ligamentous laxity is noted on clinical examination and on optional stress radiographs.

Generally, the principles of the correction of deformity as formulated by Paley (2002) should be respected. At the beginning of planning the HTO, a line is drawn from the centre of the femoral head to the midpoint of the ankle joint on the whole-leg standing radiographs. A second line is drawn from the centre of the femoral head to a point in the lateral tibial plateau where transfer of load is desired. The angle between these two lines determines the degree of correction required of the mechanical axis.

The amount of correction and optimal postoperative alignment is not fully determined. The normal anatomical load-bearing axis of the knee is viewed as ranging from 5 to 7 degrees of valgus and approximately 60% of the weight-bearing force is thought to transmit through the medial compartment and 40% through the lateral compartment (Haddad & Bentley 2000). However, these numbers do not represent the case for all patients, as a wide variety of normal mechanical and anatomical axes of the lower limb has been described (Eckhoff et al. 2005). For a HTO, post-operative correction from 8 to 10 degrees valgus relative to the anatomical axis, and 3 to 5 degrees valgus relative to mechanical
axis, has been proposed (Coventry 1985, Hernigou et al. 1987, Koshino et al. 1989, Myrnerts 1980). More recent authors have used the position of the mechanical leg axis relative to the width of the tibial plateau, pre- and post-operatively, as a guideline for the amount of correction needed (Pape 2006). Their recommendations are based on the work of Fujisawa et al. (1979), who concluded that, for optimal results, the corrected axis should run through the lateral 30% to 40% of the tibial plateau. Based on this clinical work, many other authors recommend that the post-operative mechanical axis should run laterally through the tibial plateau, at 62% of its centre width, measured from the medial side (Agneskirchner et al. 2007, Dugdale et al. 1992, Miniaci et al. 1989). Usually this point, the “Fujisawa point”, is located at the junction of the medial two-thirds and lateral one-third of the articular surface of the proximal tibia (Fujisawa et al. 1979).

2.2.3 Surgical technique

Various models of corrective osteotomy of the proximal tibia have been described since the concept was introduced in 1958 (Jackson). Generally, HTO may be performed by a subtractive technique (closed wedge), by an additive technique (open wedge) or by a barrel vault (dome) osteotomy.

Coventry (1965) first popularised the HTO by using a lateral closing wedge osteotomy proximal to the tibial tuberosity. The closed wedge osteotomy is mechanically stable and may be fixed with staples or plates without bone grafting. However, this technique implies fibular osteotomy or proximal tibiofibular joint disruption, lateral muscle detachment, peroneal nerve dissection, bone stock loss and possible more demanding subsequent TKA (Brouwer et al. 2006a). For all these reasons, the medial opening wedge osteotomy, which was originally described by Hernigou et al. (1987), has gained popularity and became a widely used alternative option. The potential advantages of this technique include easier correction of coronal and sagittal plane deformities, preservation of bone stock and normal proximal tibial anatomy without disruption of the proximal tibiofibular joint, and avoidance of the peroneal nerve and muscles of the anterior compartment (Hooper et al. 2005).

However, the medial opening-wedge technique is mechanically more demanding in terms of fixation because of the axial and torsional forces in the proximal tibia. The disadvantages of this technique include the risk of delayed or non-union, loss of correction, hardware failure, intra-operative fracture of the

Several techniques have been used for fixation of opening wedge osteotomies. Possible alternatives are external fixators (both axial and circular) and plates (conventional and locking with or without a spacer). Most of the early failures of the open-wedge technique have been related to poor mechanical stability of the fixation devices used (Nelissen et al. 2010). A few biomechanical studies comparing the different fixation devices have been published, but the most reliable fixation system is still controversial (Amendola & Bonasia 2010).

In addition, the open-wedge technique involves the creation of an osseous gap in the tibia. Filling the gap with autologous iliac bone graft was recommended in the classic open-wedge description, to prevent complications such as correction loss or delayed bone union (Hernigou et al. 1987). Since then, many different methods have been used to fill the gap of opening wedge osteotomy, including bone grafts and synthetic bone substitutes (hydroxyapatite, tricalcium phosphate and bone cement) with or without platelet-rich plasma, growth factors and bone marrow stromal cells (Amendola & Bonasia 2010). The requirement to fill the gap is controversial and opening wedge osteotomy can also be performed successfully without any grafting (Brinkman et al. 2008, Zorzi et al. 2011).

In addition to medial and lateral wedge osteotomies various other osteotomy techniques have been described. Probably the best-known variation is the dome-shaped osteotomy first introduced by Blaimont et al. (1975) and popularised by Maquet (1980). The results of dome osteotomy have been shown to be similar to opening and closing wedge osteotomies and do not have the same problems with patella infera (Chiang et al. 2006, Takahashi et al. 2000). However, this procedure is technically more difficult to perform and if an external fixator is used, its associated problems are encountered (Parker & Viskontas 2007).

The original principles of the osteotomy largely remain unchanged; however, pre-operative preparations, operative techniques including types of fixation, and post-operative management have undergone several modifications over the past decades.

2.2.4 Incidence

Over the last three decades HTOs have been used for the treatment of OA isolated to a medial compartment of the knee. However, over the past decade, the
incidence of osteotomies has decreased because of the clinical success of TKA (Kurtz et al. 2005) and enthusiasm for the use of HTO has declined. Furthermore, at the same time, the number of UKAs has grown (Koskinen et al. 2007), which may also have contributed to the decreased number of osteotomies performed.

In contrast to the case for knee arthroplasties, no national registers exist for osteotomies, and therefore the number of studies is limited with respect to the incidence of tibial osteotomies in the treatment of knee OA. Wright et al. (1995), in their epidemiological analysis of tibial osteotomies in United States and Canada between 1985 and 1990, reported that rates of tibial osteotomies are decreasing, particularly among elderly patients. Osteotomy rates decreased in both countries; by approximately 1% to 14% per year in patients 65 years and older and by 3% to 4% per year in patients younger than 65 years. Twice as many osteotomies were performed in men than in women in both countries. A study by W-Dahl et al. (2012) reported that the number of HTOs in Sweden has decreased by one third from 1998 to 2007. In 1998, HTOs constituted 6.8% of the primary knee reconstruction surgery in Sweden, as compared with 2.5% in 2007.

### 2.2.5 Results

Results of HTO performed for the treatment of knee OA can be divided to outcome and survivorship results of the operation. The majority of the published HTO studies focus on the survivorship of the operation.

After an osteotomy, a more normal appearing weight-bearing pattern is achieved and the knee adduction moment is decreased, indicating a decrease in contact pressure in the medial degenerative compartment of the knee (DeMeo et al. 2010). In addition, young motivated patients may be able to resume strenuous activities (Bonnin et al. 2013, Salzmann et al. 2009) and many sporting activities (for example, running and jumping) may be possible at least for the first decade after the surgery (Nagel et al. 1996). In most patients, HTO may delay the need for TKA for 10–15 years, and some patients never need subsequent knee surgery (Papachristou et al. 2006).

Most single-surgeon or single-hospital studies have reported good early or mid-term survivorship for HTO, but the results of osteotomy tend to deteriorate over the time (Table 2). However, drawing clear conclusions based on published studies is difficult owing to the heterogeneous patient groups and surgical techniques. Only one previous population-based study of HTO, conducted in
Sweden, is available. It reports 70% survivorship for HTO at ten years (W-Dahl et al. 2012).

Table 2. Survivorship of high tibial osteotomy for the treatment of knee osteoarthritis.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>N</th>
<th>Survivorship, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>At 5 years</td>
</tr>
<tr>
<td>Naudie et al.</td>
<td>1999</td>
<td>106</td>
<td>73</td>
</tr>
<tr>
<td>Billings et al.</td>
<td>2000</td>
<td>64</td>
<td>85</td>
</tr>
<tr>
<td>Sprenger &amp; Doerzbacher</td>
<td>2003</td>
<td>76</td>
<td>86</td>
</tr>
<tr>
<td>Koshino et al.</td>
<td>2004</td>
<td>75</td>
<td>98</td>
</tr>
<tr>
<td>Tang &amp; Henderson</td>
<td>2005</td>
<td>67</td>
<td>90</td>
</tr>
<tr>
<td>Flecher et al.</td>
<td>2006</td>
<td>301</td>
<td>95</td>
</tr>
<tr>
<td>Papachristou et al.</td>
<td>2006</td>
<td>44</td>
<td>91</td>
</tr>
<tr>
<td>Galötter et al.</td>
<td>2008</td>
<td>134</td>
<td>94</td>
</tr>
<tr>
<td>Van Raaij et al.</td>
<td>2008</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Akizuki et al.</td>
<td>2008</td>
<td>118</td>
<td>-</td>
</tr>
<tr>
<td>Efe et al.</td>
<td>2011</td>
<td>199</td>
<td>93</td>
</tr>
<tr>
<td>Hui et al.</td>
<td>2011</td>
<td>394</td>
<td>95</td>
</tr>
<tr>
<td>Schallberger et al.</td>
<td>2011</td>
<td>54</td>
<td>98</td>
</tr>
<tr>
<td>Combined previous studies</td>
<td>1999–2011</td>
<td>1,732</td>
<td>92</td>
</tr>
</tbody>
</table>

The influence of a defined surgical technique on the results of an operation has not been determined. Closed and opening wedge osteotomies are the most commonly used techniques. In the current literature, only one RCT has been reported to compare the closed and open wedge techniques. At the one-year follow-up, both groups showed improvement in knee function and pain, without significant differences between the groups (Brouwer et al. 2006a). In addition, two other non-randomised studies showed no difference between these two techniques (Hoell et al. 2005, Schallberger et al. 2011). However, no conclusion can be drawn regarding which technique is preferable and the choice remains a matter of preference of the surgeon, until further studies become available. Instead, a review of the literature discloses several conditions that are related to poorer results (Table 3).
Table 3. Conditions related to inferior results of high tibial osteotomy.

<table>
<thead>
<tr>
<th>Clinical condition</th>
<th>Studies</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender</td>
<td>3 Aglietti et al. 2003, Kinnunen 1990, van Raaij et al. 2008</td>
<td></td>
</tr>
<tr>
<td>Lateral tibial thrust</td>
<td>2 Madan et al. 2002a, Naudie et al. 1999</td>
<td></td>
</tr>
<tr>
<td>Patellofemoral arthritis</td>
<td>2 Majima et al. 2008, Rudan &amp; Simurda 1990</td>
<td></td>
</tr>
<tr>
<td>Joint instability</td>
<td>1 Rudan &amp; Simurda 1990</td>
<td></td>
</tr>
<tr>
<td>Previous arthroscopic</td>
<td>1 Naudie et al. 1999</td>
<td></td>
</tr>
<tr>
<td>debridement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Markedly decreased preoperative range of motion</td>
<td>1 Naudie et al. 1999</td>
<td></td>
</tr>
</tbody>
</table>

2.3 **Total knee arthroplasty after high tibial osteotomy**

The results of HTO tend to deteriorate over the time, and the patient may need to undergo subsequent TKA. Because of previous surgery, TKA after HTO may not be similar to the primary TKA in terms of surgical procedure and the outcome of the operation.

2.3.1 **Surgical procedure**

Current evidence indicates that TKA after a previous HTO is technically more difficult, which implies a greater risk of complications than with primary TKA (Parvizi et al. 2004). The potential problems during TKA following HTO include: Difficulty in eversion of the patella due to soft tissue problems, patella infera (baja), proximal tibial malformation (posterior shift, rotational deformity and decreased lateral bone stock), problems with ligament balancing and removal of internal fixation devices, peroneal nerve entrapment and abnormal patellar tracking (Haddad & Bentley 2000, Meding et al. 2000, Mont et al. 1994, Nizard
et al. 1998, Whitehead et al. 2009). Most of studies have reported these concerns following lateral closing or dome osteotomy.

### 2.3.2 Reasons for total knee arthroplasty failure

The mode of failure in TKA includes osteolysis, malalignment, wearing, infection and malpositioning of implants. Parvizi et al. (2004) found that the prevalence of radiolucent lines around the tibial and femoral components was significantly higher for knees that had undergone a previous osteotomy than for those that had not. Kazakos et al. (2008) published similar results, and even though they recorded significant differences particularly in the radiographic evaluation after HTO — this did not compromise the clinical results.

Primary TKA and TKA after HTO, as observed by several authors, showed no significant differences in migration, alignment or positioning of the TKA components (Amendola et al. 2010, Bae et al. 2010, Efe et al. 2010, Toksvig-Larsen et al. 1998). However, a significantly greater blood loss and other postoperative complications occurred among the previously osteotomised knees, indicating a more complicated procedure for the knee arthroplasty (Bergenudd et al. 1997).

### 2.3.3 Results

Because of small cohort sizes and short follow-up, there is a paucity of published survival results for TKA after HTO. Parvizi et al. (2004) reported the survival rate of their 118 patients series, with revision as the end point, of 97% (95% CI 94.7–100.0%) at five years, 92.3% (95% CI 87.3–97.6%) at ten years, and 89.0% (95% CI 81.3–97.5%) at fifteen years.

Studies comparing results of TKA after HTO to primary TKA have reported conflicting results. A registry-based study of TKA after previous osteotomy reports from the unmatched patient data indicated that TKA after an osteotomy has almost a three-fold higher early revision rate compared with primary TKA (Pearse et al. 2012). Several other authors have reported inferior results of TKA after HTO compared to results of primary TKAs. In contrast, the majority of previously published studies show minimal or no significant differences in the results between TKA with or without previous HTO (Table 4).
Table 4. Results of total knee arthroplasty after high tibial osteotomy compared with primary total knee arthroplasty.

<table>
<thead>
<tr>
<th>Result</th>
<th>Studies</th>
</tr>
</thead>
</table>

This wide range of differences in outcome may be caused by the wide heterogeneity among the published studies, and pooling of the results is a challenge, as described by van Raaij et al. (2009). In their systematic review of non-randomised studies analysing the effect of HTO on TKA, these authors concluded that osteotomy does not compromise subsequent TKA. However, the low quality of the evidence precludes solid clinical conclusions. Even though the majority of previous studies showed no significant difference between TKA after HTO and primary TKA, the trend seems to favour primary TKAs.

The effect of the previous osteotomy technique is unclear. Most studies of TKA after HTO report results after closed wedge osteotomies; only one involved an open wedge HTO and reported inferior clinical results for TKA after open-wedge osteotomy compared with a group who underwent TKA without previous tibial osteotomy (Erak et al. 2011).

### 2.4 Unicompartmental knee arthroplasty for the treatment of knee osteoarthritis

Gunston (1971) designed the Polycentric knee prosthesis in the 1968 as a replacement for both medial and lateral compartments of the knee. Gunston’s prosthesis fostered some of the early ideas concerning UKA. Marmor (1973) introduced the first UKA in 1973 and it subsequently became an attractive concept and an alternative procedure to HTO. Marmor prosthesis had a narrow femoral runner with a single peg and an inlay tibial component. In Europe, Engelbrecht and Zippel (1973) designed the St Georg sled prosthesis in 1969,
which featured a wider tibial component. Many of the later fixed bearing UKA designs were modifications of both the Marmor and the St Georg sled prostheses. UKAs with a flat-on-flat design that increased the surface contact were subject to failure (Bert & Smith 1997). The Oxford mobile meniscal bearing system (Oxford UKA), designed by Goodfellow and O’Connor (1986), addressed these problems by allowing more conformity between the femoral component and the tibial insert in order to reduce the surface forces. This then allowed the polyethylene to move on the underlying tibial tray, thereby avoiding the problems of increased constraint (Fig.4).

A mean annual wear rate as low as 0.022 millimetres per year was reported for the Oxford UKA phase II mobile bearing (Kendrick et al. 2011). However, the advantage of low wear is compromised by the possibility that the mobile bearing may dislocate. Therefore, the use of a fixed or a mobile meniscal bearing UKA is still controversial (Confalonieri et al. 2004, Li et al. 2006). A comparative study showed no difference in survivorship between fixed and mobile-bearing designs after a mean 17 years of follow-up (Parratte et al. 2012).

![Fig. 4. Uncemented medial unicompartmental knee arthroplasty.](image)

Contemporary UKAs have two anchor lugs for the femoral component or a single lug with a keel. Tibial components have multiple lugs, a keel, or a rough surface.
to enhance implant fixation. Femoral components are designed to have the same thickness as the resected or lost bone of the distal and posterior aspect of the femoral condyle. The tibial trays are sized with respect to the dimensions of the cut surface of the tibia. The polyethylene thickness is varied according to the residual space in flexion and full extension. The tibial components are either modular or a single, monoblock polyethylene implant.

Most UKAs are cemented on both the femoral and tibial sides. Cementless designs have been fraught with loosening and sinkage (Bernasek et al. 1988, Bert & Smith 1997). Despite the fact that aseptic loosening is uncommon in designers’ and independent series, especially in mobile bearing designs, joint registry data have persistently demonstrated a higher revision rate for UKA compared with TKA, with aseptic loosening and pain being the most common indication for revision (Table 5).

Table 5. Reasons for UKA and TKA revisions in the national arthroplasty registries in Norway, Australia, New Zealand, Sweden and United Kingdom.

<table>
<thead>
<tr>
<th>Reasons for revision, %</th>
<th>Norway UKA</th>
<th>Norway TKA</th>
<th>Australia UKA</th>
<th>Australia TKA</th>
<th>New Zealand UKA</th>
<th>New Zealand TKA</th>
<th>Sweden UKA</th>
<th>Sweden TKA</th>
<th>United Kingdom UKA</th>
<th>United Kingdom TKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aseptic loosening</td>
<td>30</td>
<td>23</td>
<td>47</td>
<td>30</td>
<td>34</td>
<td>27</td>
<td>35</td>
<td>25</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Progression of OA</td>
<td>-</td>
<td>-</td>
<td>23</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>29</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pain</td>
<td>36</td>
<td>27</td>
<td>11</td>
<td>9</td>
<td>36</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>Infection</td>
<td>2</td>
<td>13</td>
<td>4</td>
<td>22</td>
<td>3</td>
<td>17</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>Other reasons</td>
<td>32</td>
<td>37</td>
<td>15</td>
<td>49</td>
<td>20</td>
<td>34</td>
<td>33</td>
<td>47</td>
<td>44</td>
<td>40</td>
</tr>
</tbody>
</table>

All numbers express percentages of all revised implants. Higher percentage between UKA and TKA is indicated in bold.

This discrepancy may be a result of errors in cementation; therefore, interest is increasing in the use of uncemented designs, which have yielded promising short-term results (Epinette & Manley 2008, Hall et al. 2012, Liddle et al. 2013, New Zealand Joint Registry 2011, Pandit et al. 2013).

### 2.4.1 Indications and contraindications

UKAs are performed for isolated medial or lateral knee OA, as it appears quite reasonable to replace only the involved unilateral compartment of the knee. In the majority knee OA patients, the disease is known to originate in the medial compartment (White et al. 1991); therefore, medial UKA is much more commonplace than is lateral UKA. The data from the National Joint Registry for
England and Wales indicate that only 2,052 of 35,625 UKAs (6%) were inserted on the lateral side of the knee (Baker et al. 2012a).

Strict adherence to the indication criteria is required to achieve optimal survival for UKA. Some indications are generally accepted as isolated medial OA, with intact anterior cruciate ligament, full thickness of cartilage in the contralateral compartment, no previous HTO, correctable varus or valgus deformity, and fixed flexion deformity less than 15 degrees (Goodfellow et al. 2006). Some indications and contraindications remain controversial and the list has changed over the years.

Patellofemoral joint degeneration has been considered as a relative contraindication to medial UKA (Kozinn & Scott 1989, Stern et al. 1993). However, Beard et al. (2007) showed that full thickness cartilage loss of the patellofemoral joint does not compromise Oxford UKA outcome (Biomet, Warsaw, IN, USA) outcome, unless accompanied by severe degeneration in the lateral part of the patellofemoral joint (with bone loss or grooving). However, this result cannot be extrapolated to all UKA designs (Fuchs et al. 2005). In addition, evidence is increasing that cartilage damage of the affected side should be severe (bone-on-bone) and unpredictable results have been reported in the cases of partial thickness cartilage loss (Niinimaki et al. 2011, Pandit et al. 2011a). Most of the contraindications, for example, weight more than 82 kilograms, younger than 60 years, physically active and chondrocalcinosis, originally suggested by Kozinn and Scott (1989) have been found unnecessary (Pandit et al. 2011c).

In addition to knee OA, spontaneous osteonecrosis has been accepted as an indication for UKA (Lotke et al. 2001, Radke et al. 2005). Nevertheless, the literature reports limited data on clinical and radiographic outcomes of UKAs performed for this condition, which probably reflects its low incidence in the general population. Survivorship of UKA for spontaneous osteonecrosis of the knee ranges from 93% to 96.7% at 10 to 12 years, but these results are from the series reporting 23 to 33 patients (Myers et al. 2006). In a series of 84 patients, 89% ten-year survivorship has been reported (Bruni et al. 2012).

### 2.4.2 Unicompartmental or total knee arthroplasty

Even if UKA is contraindicated in most patients who might undergo TKA, indications for UKA overlap with TKA. It has been said that 20% of all knee OA patients are eligible for UKA (Arno et al. 2011). The decision-making process between UKA and TKA is heavily influenced by radiographic findings, but
individual surgeons are consistent in their own treatment choices (Beard et al. 2012).

There is a paucity of scientific evidence on which to base appropriate decision between UKA and TKA. Improvements in surgical techniques and instruments have given the UKA procedure potential advantages over TKA in properly selected patients. These include less bone resection, preservation of the cruciate ligaments, quicker recovery, decreased perioperative complications and a subjective preference as feeling “more normal”, returning to sports, improved walking ability, and lower cost (Amin et al. 2006, Brown et al. 2012, Hopper & Leach 2008, Isaac et al. 2007, Laurencin et al. 1991, Lombardi et al. 2009, Robertsson et al. 1999, Rougraff et al. 1991). These advantages are only potential and are not yet established.

Only two prospective RCTs have compared UKA and TKA procedures. In the first, 15-year follow-up study, UKA produced similar or slightly better results compared with TKA. The survivorship of the implant in both groups, with revision or a Bristol Knee Score < 60 as the endpoint, was 89.8% in the UKA group and 78.7% in the TKA group. The Bristol Knee Scores of the UKA group was better throughout the study period and at 15 years 15 of the surviving UKAs (71.4%) and 10 of the surviving TKAs (52.6%) achieved an excellent outcome. In the second RCT study, including 56 knees (mean follow-up 52 months, range 70–100), mobile bearing UKA achieved similar clinical effects to those of TKA, but had a higher first year revision rate because of the learning curve. According to the scale of the Knee Society, at the latest follow-up, the mean Knee Society score was 80.6 (range 70–100) and 78.9 (range 70–87) for UKA and TKA, respectively. Seven UKAs were converted to TKA due to component loosening – all of them within the first two years of starting the procedure and all of them in relatively young patients. None of the TKAs was revised (Sun & Jia 2012).

Three other non-randomised studies have compared UKA and TKA. In the first, with matched patients, the clinical outcome was similar, but the complication rate was possibly higher for UKA (Amin et al. 2006). In the second bilateral comparative study, patient preference was higher for UKA than for TKA, but the study patient cohort was only 23 (Laurencin et al. 1991). The third study consisted of patient-reported questionnaire data from Norway involving 972 TKAs and 372 UKAs and reported only small or no differences in pain and functional outcome scores between the groups (Lygre et al. 2010)

Assuming UKA patients are younger and probably more active compared with TKA patients, a change in functional scoring (preoperative and
postoperative) may be good way to measure the effect of the intervention. Lyons et al. (2012) showed that while patients with UKA had higher pre- and postoperative scores when compared to patients with TKA, the changes in scores were similar in both groups. Noticevala et al. (2012) have reported similar results.

2.4.3 Incidence

TKA was popularised in the 1980s and since then, the proportion of UKAs has decreased compared with TKAs for the treatment of knee OA (Koskinen et al. 2007, SKAR 2012). However, interest in UKA has been renewed and the absolute number of UKA operations has increased over the last two decades (Koskinen et al. 2007). In the United States, the use of UKA has increased in a linear fashion at an average rate of approximately 30% per year from 1998 to 2005. Despite the more rapid rate of growth of UKA than TKA, UKA still represented only 7.7% of all knee arthroplasty procedures done in 2004 (Riddle et al. 2008). According to the Swedish Knee Arthroplasty Registry, between 2002 and 2005 UKA accounted for between 9.4% and 11.7% of all knee arthroplasty procedures (SKAR 2012).

However, very recent registry data suggest that the proportion of UKAs has been decreasing among all knee arthroplasties. For example, the Canadian Joint Replacement Registry (2013) shows a decrease in the proportions of UKAs from 9.4% to 4.4% from 2005 to 2011 among all knee arthroplasties. The Australian National Joint Replacement Registry (2012) shows a steep decrease in the proportion of UKAs. The number of procedures reported in 2011 was 9.0% less than in 2010, and 42.4% less than in 2003. As a percentage of all knee replacement, UKA decreased from 14.5% in 2003 to 5.1% in 2011.

The New Zealand Joint Registry (2011) showed a gentle decline, as the proportion of UKAs among all arthroplasties has decreased from 10.1% to 8.1% between 2000 and 2011. Similar results have been published from the United Kingdom and Wales, where the proportion of UKAs among all knee arthroplasties increased from 7% to 8% between 2005 and 2011 (National Joint Registry for England and Wales 2012). In Norway, the incidence has remained the same from 1994 to 2009, with the UKA proportion being 10.8% and 10.4%, respectively (NAR 2010).
2.4.4 Results

Older studies have shown less favourable long-term survival or early failures of UKA that require revision to TKA or re-operation (Insall & Aglietti 1980, Laskin 1978, Marmor 1988, Padgett et al. 1991, Thornhill 1986). However, more recent results of UKA are controversial. Several single-centre or single-surgeon series, from both originator and non-originator data, have yielded good short-term or intermediate-term survivorship and functional outcomes for UKAs (Murray et al. 1998, Newman et al. 2009, Svard & Price 2001, Willis-Owen et al. 2009). However, clinical studies may be substantially affected by the influence of the developing hospital, and therefore subject to bias (Labek et al. 2011, Pabinger et al. 2013). In contrast to these good UKA results, less favourable results have recently been published in terms of outcome and survivorship (Chou et al. 2012, Edmondson et al. 2011, Epinette et al. 2012, O'Donnell & Neil 2010, Schroer et al. 2013). Over 30 follow-up studies reporting a minimum of 10-year survivorship have been published since 1988 (Table 6).

Table 6. Minimum of 10-year follow-up non-registry-based studies of unicompartmental knee arthroplasty.

<table>
<thead>
<tr>
<th>References</th>
<th>Year</th>
<th>N</th>
<th>UKA</th>
<th>10-year survivorship, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marmor</td>
<td>1988</td>
<td>228</td>
<td>Marmor</td>
<td>70</td>
</tr>
<tr>
<td>Scott et al.</td>
<td>1991</td>
<td>100</td>
<td>Unicomp</td>
<td>85</td>
</tr>
<tr>
<td>Cartier et al.</td>
<td>1996</td>
<td>60</td>
<td>Marmor</td>
<td>93</td>
</tr>
<tr>
<td>Ansari et al.</td>
<td>1997</td>
<td>461</td>
<td>St. Georg sled</td>
<td>87</td>
</tr>
<tr>
<td>Bert</td>
<td>1998</td>
<td>100</td>
<td>Performance</td>
<td>87</td>
</tr>
<tr>
<td>Tabor &amp; Tabor</td>
<td>1998</td>
<td>67</td>
<td>Marmor</td>
<td>84</td>
</tr>
<tr>
<td>Murray et al.</td>
<td>1998</td>
<td>143</td>
<td>Oxford</td>
<td>97</td>
</tr>
<tr>
<td>Berger et al.</td>
<td>1999</td>
<td>62</td>
<td>Miller-Galante</td>
<td>98</td>
</tr>
<tr>
<td>Squire et al.</td>
<td>1999</td>
<td>140</td>
<td>Marmor</td>
<td>90</td>
</tr>
<tr>
<td>Svard &amp; Price</td>
<td>2001</td>
<td>124</td>
<td>Oxford</td>
<td>95</td>
</tr>
<tr>
<td>Argenson et al.</td>
<td>2002</td>
<td>160</td>
<td>Miller-Galante</td>
<td>94</td>
</tr>
<tr>
<td>Skyrme et al.</td>
<td>2002</td>
<td>26</td>
<td>PCA</td>
<td>58</td>
</tr>
<tr>
<td>Perkins &amp; Gunckle</td>
<td>2002</td>
<td>40</td>
<td>Zimmer MG II</td>
<td>74</td>
</tr>
<tr>
<td>Rajasekhar et al.</td>
<td>2004</td>
<td>135</td>
<td>Oxford</td>
<td>94</td>
</tr>
<tr>
<td>Goe et al.</td>
<td>2003</td>
<td>516</td>
<td>several designs</td>
<td>89</td>
</tr>
<tr>
<td>Pennington et al.</td>
<td>2003</td>
<td>66</td>
<td>Miller-Galante</td>
<td>92</td>
</tr>
<tr>
<td>Naudie et al.</td>
<td>2004</td>
<td>113</td>
<td>Miller-Galante</td>
<td>90</td>
</tr>
<tr>
<td>Epinette et al.</td>
<td>2004</td>
<td>45</td>
<td>Unix uncemented HA</td>
<td>96</td>
</tr>
<tr>
<td>Keblish &amp; Briard</td>
<td>2004</td>
<td>177</td>
<td>Low Contact Stress (LCS)</td>
<td>82</td>
</tr>
<tr>
<td>Price et al.</td>
<td>2005b</td>
<td>114</td>
<td>Oxford</td>
<td>93</td>
</tr>
</tbody>
</table>
The arthroplasty registries show that UKA has been associated with consistently worse implant survival rates when compared to TKA (Table 7) (Australian National Joint Replacement Registry 2012, Knutson et al. 1994, Koskinen et al. 2007, NAR 2010, National Joint Registry for England and Wales 2012, New Zealand Joint Registry 2011).

**Table 7. Survivorships of unicompartmental and total knee arthroplasties in arthroplasty registries.**

<table>
<thead>
<tr>
<th>Registry</th>
<th>Implant</th>
<th>At 5 years</th>
<th>At 8 years</th>
<th>At 10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>UKA</td>
<td>91.5 (91.1–91.8)</td>
<td>-</td>
<td>84.8 (84.1–85.4)</td>
</tr>
<tr>
<td></td>
<td>TKA</td>
<td>96.2 (96.1–96.3)</td>
<td>-</td>
<td>94.4 (94.3–94.6)</td>
</tr>
<tr>
<td>New Zealand</td>
<td>UKA</td>
<td>93.3</td>
<td>-</td>
<td>88.0</td>
</tr>
<tr>
<td></td>
<td>TKA</td>
<td>97.3</td>
<td>-</td>
<td>95.7</td>
</tr>
<tr>
<td>Sweden</td>
<td>UKA</td>
<td>92.8</td>
<td>-</td>
<td>86.7</td>
</tr>
<tr>
<td></td>
<td>TKA</td>
<td>97.1</td>
<td>-</td>
<td>95.9</td>
</tr>
<tr>
<td>UK and Wales</td>
<td>UKA</td>
<td>92.8 (92.4–93.1)</td>
<td>89.2 (88.4–89.9)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TKA</td>
<td>98.0 (97.9–98.0)</td>
<td>97.2 (97.1–97.3)</td>
<td>-</td>
</tr>
</tbody>
</table>
**Reasons for failure**

The arthroplasty registries indicated that the commonest reasons for UKA revision are aseptic loosening, pain and progression of disease (Table 5). Mobile bearing UKAs also have potential risk for bearing dislocation, which is a very rare complication in TKAs (Choy et al. 2011).

Scientific data on the influence of the patients’ age or BMI on the UKA procedure is controversial and limited. Heyse et al. (2012) reported 93.5% survivorship at ten-years in 223 UKA patients aged less than 60 years. These results were supported by Pennington et al. (2003) with 92% survivorship at 11-years, and Price et al. (2005a) with 91% survivorship at ten-years in the similar age group. Kuipers et al. (2010) published opposite results, reporting a 2.2-fold increase in the adjusted risk of revision in patients less than 60 years old. In addition, in the Australian and Swedish Knee Registries patients aged less than 65 years had higher rates of revision when compared to patients 65 or older (W-Dahl et al. 2010). On the other hand, good results have been published for patients over 80 years of age when compared with younger ones (Ingale & Hadden 2013).

Matharu et al. (2012) reported good midterm survival and functional outcome in 459 UKA patients, and concluded that age and gender should not be considered as contraindications for performing UKA. Several other previously published series reported no influence of gender on results of UKA (Koskinen et al. 2007, Kuipers et al. 2010, Lustig et al. 2012). Obesity is not shown to be associated with a decreased implant survival (Kuipers et al. 2010).
3 Aims of the study

This study used nationwide register-based data to investigate the results of HTO, TKA and UKA procedures performed between 1985 and 2011 in Finland. The specific aims were:

1. To assess the incidence of tibial and femoral osteotomies performed for treatment of knee OA.
2. To investigate the survivorship of HTO using the TKA operation as an end-point.
3. To evaluate the survivorship of TKAs after HTO comparing that to the results of primary TKAs.
4. To report the survivorship of UKA and to compare that to survivorship of cemented TKAs.
4 Materials and methods

4.1 Materials

4.1.1 Registers

In the current study, we used four different registers to collect data for statistical analysis. The permission to use registers was authorised by the Ministry of Social Affairs and Health. In this study, only registers were used and no contact was made with patients; therefore, no permission was required from an ethical committee.

*Statistics Finland (I)*

Statistics Finland provides a variety of statistical information relating to the population. This information includes data (for example, annual structure and age of the population) that were needed in this study.

*The Finnish National Hospital Discharge Register (I–III)*

The Finnish National Hospital Discharge register (NHDR) was established in 1969. Since its founding, the basic structure of the register has remained unchanged and includes data of patients discharged from the hospitals. A crucial change, in terms of the current study, took place in 1987 as the register since then has also included surgical codes of surgical procedures performed on the patients during their hospitalisation.

*The Finnish Arthroplasty Register (II–IV)*

The Finnish Arthroplasty Register has recorded arthroplasties performed in Finland since 1980. In 1987, management of the register changed from The Finnish Orthopaedic Association to medical authorities. At present, the National Institute for Health and Welfare is responsible for maintaining the register.
The Population Register Centre (I–IV)

The Population Register Centre is the controller for the Finnish Population Information System. This system includes, for example, information on deaths and emigration of the population.

4.1.2 Study groups

Osteotomies and total knee arthroplasties (I)

The NHDR data were used to identify all patients aged 18 years or more who had undergone either tibial or femoral osteotomy for the treatment of knee OA between 1987 and 2008. Data were extracted using the diagnostic codes for primary, secondary, post-traumatic and undefined knee OA, as well as surgical codes for femoral and tibial osteotomies (Table 8). Indications for osteotomy other than OA were excluded from the study. A total of 6,004 osteotomies performed for knee OA were identified in 5,734 patients (Table 9). From these patients, diagnostic codes, the side upon osteotomy was performed, operation date, date of birth and personal identification number (social security number) were recorded.

The number of TKA and UKA procedures over the study period was obtained from the Finnish Arthroplasty Register.

Table 8. Diagnosis and procedure codes used in data extraction (I–III).

<table>
<thead>
<tr>
<th>Years</th>
<th>Diagnosis codes¹</th>
<th>Procedure codes²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987–1996</td>
<td>7151F primary knee OA</td>
<td>9112 correction osteotomy</td>
</tr>
<tr>
<td></td>
<td>7152F secondary knee OA</td>
<td>9292 femoral osteotomy</td>
</tr>
<tr>
<td></td>
<td>9112 correction osteotomy</td>
<td>9312 tibial or femoral osteotomy</td>
</tr>
<tr>
<td>1997–2008</td>
<td>M17.0 primary knee OA, bilateral</td>
<td>NGK30 tibial osteotomy</td>
</tr>
<tr>
<td></td>
<td>M17.1 primary knee OA</td>
<td>NFK30 femoral osteotomy</td>
</tr>
<tr>
<td></td>
<td>M17.2 post-traumatic knee OA, bilateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M17.3 post-traumatic knee OA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M17.4 secondary knee OA, bilateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M17.5 secondary knee OA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M17.9 knee OA, undefined</td>
<td></td>
</tr>
</tbody>
</table>

Codings used in data extraction: ¹ICD-10 and Tautiluokitus 1987; ²Toimenpideluokitus 1996 and Toimenpidenimikkeistö 1983
Table 9. Demographics of tibial and femoral osteotomies performed for knee osteoarthritis (I).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Operation period 1987–2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteotomies, N</td>
<td>6,004</td>
</tr>
<tr>
<td>Patients, N</td>
<td>5,734</td>
</tr>
<tr>
<td>Females, N (%)</td>
<td>3,032 (50.5)</td>
</tr>
<tr>
<td>Age, years</td>
<td></td>
</tr>
<tr>
<td>Mean (range)</td>
<td>54 (18–86)</td>
</tr>
<tr>
<td>Indication, N (%)</td>
<td></td>
</tr>
<tr>
<td>Primary osteoarthritis</td>
<td>5,414 (90.2)</td>
</tr>
<tr>
<td>Secondary osteoarthritis</td>
<td>341 (5.7)</td>
</tr>
<tr>
<td>Post-traumatic osteoarthritis</td>
<td>212 (3.5)</td>
</tr>
<tr>
<td>Undefined osteoarthritis</td>
<td>34 (0.6)</td>
</tr>
<tr>
<td>Operation site coded, N (%)</td>
<td></td>
</tr>
<tr>
<td>Tibial</td>
<td>2,207 (36.8)</td>
</tr>
<tr>
<td>Femoral</td>
<td>121 (2.0)</td>
</tr>
<tr>
<td>Tibial or femoral</td>
<td>3,676 (61.2)</td>
</tr>
</tbody>
</table>

High tibial osteotomies, and total knee arthroplasties after high tibial osteotomy (II–III)

A total of 6,004 osteotomies performed for knee OA were identified from the NHDR. Data regarding the operated side (right/left) were incomplete in the register; therefore, the operated side was identified for only 1,218 knees. Missing information was retrieved from the patient records at 13 randomly selected hospitals, of varying sizes and geographical position, which were felt to be representative of patients throughout Finland. Ultimately, we were able to obtain information on the operated side for a total of 3,270 osteotomies (54%), which were performed in 36 different hospitals (Fig. 5).
Table 10. Demographics of high tibial osteotomy patients (II).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Operation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original cohort, N</td>
<td>6,004</td>
</tr>
<tr>
<td>Included HTO patients, N (%)</td>
<td>3,195 (53.2)</td>
</tr>
<tr>
<td>Females, N (%)</td>
<td>1,604 (50.2)</td>
</tr>
<tr>
<td>Age (years) Mean (range)</td>
<td>54 (18–84)</td>
</tr>
<tr>
<td>≤ 50 years, N (%)</td>
<td>1,093 (34.2)</td>
</tr>
<tr>
<td>&gt; 50 years, N (%)</td>
<td>2,102 (65.8)</td>
</tr>
<tr>
<td>Mean follow-up, years (range)</td>
<td>10.4 (0–22.8)</td>
</tr>
<tr>
<td>Indications, N (%)</td>
<td></td>
</tr>
<tr>
<td>Primary osteoarthritis</td>
<td>2,888 (90.4)</td>
</tr>
<tr>
<td>Secondary osteoarthritis</td>
<td>178 (5.6)</td>
</tr>
<tr>
<td>Post-traumatic osteoarthritis</td>
<td>117 (3.6)</td>
</tr>
<tr>
<td>Undefined osteoarthritis</td>
<td>12 (0.4)</td>
</tr>
</tbody>
</table>

Of the 3,270 osteotomies, femoral osteotomies (n = 75) were excluded. From the remaining 3,195 osteotomies, 1,280 (39%) were coded as tibial (HTO). The remaining 1,915 (59%) osteotomies were operated on prior to year 1997 and were coded as single code, including both tibial and femoral osteotomies. These 1,915
operations were assumed to be tibial (HTO) because, prior to 1997 a separate code was used for femoral osteotomy, but all HTOs had to be coded as ‘tibial or femoral’ (Table 10).

The personal identification numbers of HTO patients were used to identify patients from the Finnish Arthroplasty Register, who had subsequently undergone TKA on the same side, which was defined as the end-point for HTO survival analysis. From the Arthroplasty Register patient data were extracted, including information on implants and revisions (Table 11).

The extraction of corresponding control group for TKAs after HTO (primary TKAs) is explained in chapter 4.1.3.

Table 11. Demographic data on TKA after HTO (study group) and primary TKA (control group) (III).

<table>
<thead>
<tr>
<th>Variables</th>
<th>TKA after HTO (study)</th>
<th>Primary TKA (control)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total knee arthroplasties, N (%)</td>
<td>1,036 (100)</td>
<td>4,143 (100)</td>
<td>0.9</td>
</tr>
<tr>
<td>Women</td>
<td>635 (59.0)</td>
<td>2,553 (59.1)</td>
<td></td>
</tr>
<tr>
<td>Revised</td>
<td>93 (9.0)</td>
<td>258 (6.2)</td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>64.3 (34–91)</td>
<td>64.7 (34–86)</td>
<td>0.17</td>
</tr>
<tr>
<td>Follow-up, years (range)</td>
<td>6.7 (0–22)</td>
<td>6.2 (0–22)</td>
<td>0.001</td>
</tr>
<tr>
<td>Implant type, N (%)</td>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Cruciate retaining</td>
<td>816 (78.8)</td>
<td>3,515 (84.9)</td>
<td></td>
</tr>
<tr>
<td>Posterior stabilised</td>
<td>183 (17.7)</td>
<td>539 (13.0)</td>
<td></td>
</tr>
<tr>
<td>Semi-constrained</td>
<td>31 (3.0)</td>
<td>70 (1.7)</td>
<td></td>
</tr>
<tr>
<td>Hinged</td>
<td>6 (0.6)</td>
<td>16 (0.4)</td>
<td></td>
</tr>
<tr>
<td>Patellar resurfacing, N (%)</td>
<td>386 (37.3)</td>
<td>1,272 (30.7)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Unicompartmental knee arthroplasties (IV)

Patients who had undergone UKA from 1985 to 2011 for the treatment of primary knee OA were extracted from the data of the Finnish Arthroplasty Register. We obtained information regarding 5,211 UKAs, including 11 different implant designs. After identifying all the UKAs, we excluded those designs that had been implanted in fewer than 100 knees over the study period (n = 208) or that had fewer than 20 knees at risk after 10 years (n = 112). We used the same exclusion criteria that had been used in previous register-based arthroplasty studies (Eskelinen et al. 2006). In addition, we excluded UKAs, which had been implanted for reasons other than primary knee OA (n = 178). This resulted in
retention of data for 4,713 UKAs, which represented 90% of all implanted UKAs (Fig. 6) (Table 12).

The extraction of corresponding control group (cemented TKAs) is explained in chapter 4.1.3.

Fig. 6. The number of UKAs performed for primary knee osteoarthritis between 1985 and 2011 in Finland is shown graphically.

Table 12. Demographic data of UKA (study group) and TKA (control group) patients (IV).

<table>
<thead>
<tr>
<th>Variables</th>
<th>UKA (Study group)</th>
<th>TKA (Control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knees, N</td>
<td>4,713</td>
<td>83,511</td>
</tr>
<tr>
<td>Women (%)</td>
<td>2,956 (62.7)</td>
<td>58,582 (70.1)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (range)</td>
<td>63.5 (33–95)(^a)</td>
<td>69.5 (23–106)(^a)</td>
</tr>
<tr>
<td>Follow-up, years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (range)</td>
<td>6.0 (0–24.1)</td>
<td>6.4 (0–27.8)</td>
</tr>
<tr>
<td>Implant design, N (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxford</td>
<td>4,084 (86.7)</td>
<td>83,520 TKAs</td>
</tr>
<tr>
<td>Miller-Galante</td>
<td>318 (6.7)</td>
<td>37 different designs(^1)</td>
</tr>
<tr>
<td>PCA</td>
<td>171 (3.6)</td>
<td></td>
</tr>
<tr>
<td>Duracon</td>
<td>140 (3.0)</td>
<td></td>
</tr>
</tbody>
</table>

PCA = Porous coated anatomic; \(^aP < 0.001, \(^1)cemented, cruciate retaining, or posterior stabilised
4.1.3 Control groups

Total knee arthroplasties without previous osteotomy (III)

We matched every patient who had undergone TKA after HTO (study group) with four other patients (control group) who had been randomly extracted from the Finnish Arthroplasty Register over the same time period as the study group (1987–2008). Control patients had undergone primary TKA without previous osteotomy, and these patients were matched by age and gender to the study group patients. One control was excluded because of missing implant data in the register. The final control group included 4,143 TKAs (Table 11).

Total knee arthroplasties (IV)

From the Arthroplasty Register, we obtained data for all TKAs implanted in Finland. From this group, we extracted a control group, which consisted of all patients who had undergone cemented TKA for primary knee OA from 1985 to 2011. Constrained models other than cruciate retaining or posterior stabilised were excluded. In total, we included 83,511 TKAs (Table 12) (Fig 7).

We obtained control TKA designs corresponding to four UKA designs included in the study by extracting four TKAs between 1985 and 2011 that fulfilled the following inclusion criteria: more than 100 operations performed, 20 or more knees at risk after 15 years and performed for primary knee OA. The search started from the most popular TKA designs and proceeded to less frequently used designs (Table 16).
4.2 Methods and statistical analyses

In Study I, the incidence of osteotomies and arthroplasties was calculated as the number of hospitalisations per 100,000 patients. Incidence was separately calculated for each study year, and was also analysed for both genders and for six different age groups (18–29, 30–39, 40–49, 50–59, 60–69, and ≥ 70 years). The incidence rate ratio (IRR) was calculated for the annual increase/decrease, and this was used to compare the effect of the group (gender, and age < 50 or ≥ 50 years) on incidence. The increase in IRR is presented as a percentage (for example, IRR = 0.938 is shown as a 6.2% decrease) with a 95% confidence interval (CI).

In Study II, using TKA operation after HTO as the endpoint in survivorship, analyses were performed according to the patients’ age, gender and time of operation. The summary measurements are presented as means with standard deviations (SD) unless otherwise stated. Kaplan-Meier survival curves were prepared and univariate group comparisons were done using a log-rank test. The Cox proportional hazard model was used to obtain hazard ratios (HR) with 95% CI. The variables analysed with the multivariate Cox model were age, gender and operation period (1987–1997 vs. 1998–2008). The proportionality assumption of each Cox model was assessed graphically for the categorical variables. In
statistical analyses, the osteotomy was censored after a patient’s death or emigration.

In Study III, the end-point for survivorship analysis was defined as revision of TKA when either the whole implant or any component was removed, exchanged, or implanted for any reason. Kaplan-Meier survival curves were drawn, and univariate between-group comparisons were performed using the log-rank test. The Cox proportional hazard model was used to obtain HR and 95% CI. The variables entered into the multivariate Cox model included study group, age, sex and the operation year. The proportionality assumption of each Cox model was assessed graphically for the categorical variables. In statistical analyses the TKA was censored after a patient’s death or emigration.

In Study IV, in the Kaplan-Meier survivorship analysis, the survival endpoint of UKA or TKA was defined as revision of the knee for any reason. Revisions included changing, removing, or adding any component to the prosthesis. In the Kaplan-Meier analysis, patients were censored at the date of death or emigration, but they were not excluded from the study. Kaplan-Meier survival of UKA and TKA groups was assessed. Univariate analysis for comparison of the two groups was performed using the log-rank test. The Cox proportional hazard model was used to obtain HR and the 95% CI. Three different Cox proportional hazard models were created to perform comparison between: 1. UKA and TKA; 2. Different UKA designs; and 3. Different TKA designs. Age and gender were used as adjusting factors. Age was categorised (≤ 65 years and > 65 years), because the linearity assumption did not hold.

In all studies (I–IV), the differences between groups were considered statistically significant if the P-value was less than 0.05 in a two-tailed test. SPSS (version 19.0, IBM, Armonk, NY, USA) and STATA (version 11.0, StataCorp LP, College Station, TX, USA) were used for analysis.
5 Results

5.1 Incidence of osteotomies between 1987 and 2008 in Finland (I)

A total of 6,004 osteotomies, including both tibial and femoral, were performed for 5,734 patients between 1987 and 2008. The incidence of osteotomies decreased steadily over the study period, on average by 6.2% annually. While the annual incidence of these procedures has markedly declined in both sexes, the decline has been significantly steeper in female patients (9.0% vs. 3.6%, IRR = 5.9%, 95% CI 5.0–6.8, P < 0.001) (Fig. 8)

Fig. 8. The incidence of osteotomies around the knee performed for treatment of knee osteoarthritis.

At the same time, the incidence of TKA has increased annually by 9.8%, on average. The incidence of TKA has increased significantly more in male than in female patients, by 12.4% and 8.9%, respectively (IRR = 3.3%, 95% CI 3.0–3.5, P < 0.001) (Fig. 9). The most prominent decrease in the incidence of osteotomies has taken place among older patients (patients more than 50 years of age) (Fig. 10). In these patients, the incidence of osteotomies has declined annually by 10.3% on average, while the average annual incidence of TKAs has increased by 8.8%. However, in patients aged less than 50 years, the incidence of both
osteotomy and TKA has increased by 1.4% and 8.8%, respectively (Figs. 10 and 11).

Fig. 9. The incidence of total knee arthroplasty for the treatment of knee osteoarthritis.

Fig. 10. High tibial osteotomies performed per year for the treatment of knee osteoarthritis in Finland in different age groups.
Fig. 11. The incidence of total knee arthroplasty by age groups for the treatment of knee osteoarthritis.

The annual decrease in the incidence of osteotomies was significantly higher in the older age groups (IRR = 11.5%, 95% CI 10.7–12.2, P < 0.001), but no difference was noted in the incidence of TKA (IRR = 0.0%, P ≥ 0.9). The number of UKAs performed increased sharply after introduction of the Oxford UKA, phase 3, in 1998. The number of operations was highest in 2006 (n = 514), and during recent years the number of operations has shown a slight decrease (Fig. 12 and 13). In 2002, the incidences of UKAs and osteotomies were equal, but since then UKAs have been performed more than osteotomies.
Fig. 12. Incidence of UKA in different age groups.

Fig. 13. Incidence of UKA performed by gender.
5.2 Survivorship of high tibial osteotomies (II)

Of the knees treated with HTO, 1,054 (33.0%) required subsequent TKA. Kaplan-Meier analysis revealed that the overall survivorship of HTO was 89% (95% CI 88–99) at five years, and 73% (95% CI 72–75) at ten years, and 73% (95% CI 72–75) at ten years (Fig. 14). The survival curves crossed for male and female patients (Fig. 15), but adjusting for age and operation period resulted in non-crossing curves with poorer survivorship for female patients ...(HR = 1.26, 95% CI 1.11–1.14, P < 0.001).

Patients aged > 50 years had a significantly higher risk of conversion to TKA than did patients aged ≤ 50 years (HR = 1.4, 95% CI 1.2–1.6, P < 0.001) (Fig. 16). Univariate Cox regression analysis revealed that HTOs performed between 1987 and 1997 had significantly better overall survivorship than did HTOs performed between 1998 and 2008 (HR = 1.5, 95% CI 1.3–1.8, P < 0.001) (Fig. 17). Similar results were obtained from Cox regression analysis when adjusted for age and gender (HR = 1.7, 95% CI 1.4–2.0, P < 0.001).

Fig. 14. Kaplan-Meier survivorship analysis for HTOs performed for the treatment of knee OA.
Fig. 15. Kaplan-Meier HTO survivorship analysis (with 95% confidence intervals) for male and female patients.

Fig. 16. Kaplan-Meier HTO survivorship analysis (with 95% confidence intervals) for patients aged ≤ 50 years and > 50 years.
5.3 Survivorship of total knee arthroplasty after high tibial osteotomy (III)

Over the study period, 93 of 1,036 TKAs (9.0%) TKAs in the study group and 258 of 4,143 TKAs (6.2%) TKAs in the control group were revised (Table 13). Kaplan-Meier survivorships were calculated separately at five-, ten- and 15-years, and were found to be higher in the control group at all time points (Table 14). Operation year-adjusted survivorship was significantly poorer for the study group than for the control group (HR = 1.4, 95% CI 1.1–1.8, P = 0.01) (Fig. 18).
<table>
<thead>
<tr>
<th>Variables</th>
<th>Study Group</th>
<th>Control Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total knee arthroplasties, N (%)</td>
<td>1,036 (100.0)</td>
<td>4,143 (100.0)</td>
<td>0.003</td>
</tr>
<tr>
<td>Revised</td>
<td>93 (9.0)</td>
<td>258 (6.2)</td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>635 (61.3)</td>
<td>2,553 (61.6)</td>
<td>0.9</td>
</tr>
<tr>
<td>Reasons for revision, N (%)</td>
<td></td>
<td></td>
<td>0.56</td>
</tr>
<tr>
<td>Malalignment</td>
<td>16 (19.3)</td>
<td>23 (10.5)</td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>14 (16.9)</td>
<td>31 (14.1)</td>
<td></td>
</tr>
<tr>
<td>Aseptic loosening</td>
<td>9 (10.8)</td>
<td>28 (12.7)</td>
<td></td>
</tr>
<tr>
<td>Patellar complication</td>
<td>8 (9.6)</td>
<td>22 (10.0)</td>
<td></td>
</tr>
<tr>
<td>Implant failure</td>
<td>3 (3.6)</td>
<td>14 (6.4)</td>
<td></td>
</tr>
<tr>
<td>Dislocation</td>
<td>1 (1.2)</td>
<td>5 (2.3)</td>
<td></td>
</tr>
<tr>
<td>Periprosthetic fracture</td>
<td>1 (1.2)</td>
<td>2 (0.9)</td>
<td></td>
</tr>
<tr>
<td>Other reason</td>
<td>31 (37.3)</td>
<td>95 (43.2)</td>
<td></td>
</tr>
</tbody>
</table>

Table 14. Survivorship of TKA after HTO (study group) and primary TKA (control).

<table>
<thead>
<tr>
<th>Follow-up</th>
<th>At Risk, N</th>
<th>Survivorship¹, % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>1,036</td>
<td>95.3 (93.7–96.4)</td>
</tr>
<tr>
<td>Control</td>
<td>4,143</td>
<td>97.2 (96.7–97.7)</td>
</tr>
<tr>
<td>10 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>599</td>
<td>91.8 (89.9–93.3)</td>
</tr>
<tr>
<td>Control</td>
<td>2,117</td>
<td>94.5 (93.8–95.2)</td>
</tr>
<tr>
<td>15 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>244</td>
<td>88.4 (86.2–90.2)</td>
</tr>
<tr>
<td>Control</td>
<td>823</td>
<td>90.6 (89.7–91.5)</td>
</tr>
</tbody>
</table>

¹adjusted for operation year.
When the same was calculated separately for two different time periods, the study group effect was found to be stronger for 1998 to 2009 (HR = 1.61, 95% CI 1.12–2.32, P = 0.01) than for 1986 to 1997 (HR = 1.36, P = 0.09). Female gender was not a risk factor for revision (HR = 0.95, P = 0.66). The risk for revision decreased with age (HR = 0.99, 95% CI 0.97–1.00, P = 0.04). In the study group, more constrained implant designs were used and patellar resurfacing was more common (Table 11). No significant between-group differences were noted in the indications for revision (Table 13).

5.4 Survivorship of unicompartmental knee arthroplasties compared with cemented total knee arthroplasties (IV)

UKA had inferior survivorship compared with TKA, even after adjusting for age and gender of the patients (HR = 2.2, 95% CI 2.0–2.4, P < 0.001). Overall, Kaplan-Meier survivorship of UKA was 89.4% (95% CI 88.4–90.2) at five years, 80.6% (95% CI 79.4–81.7) at ten years, and 69.6% (95% CI 68.2–70.9) at 15 years. Survivorship of TKA was 96.3% at five years (95% CI 96.2–96.4), 93.3%
at ten years (95% CI 93.1–93.4) and 88.7% at 15 years (95% CI 88.5–88.9) (Fig. 19). Survivorship varied by UKA design (Fig. 20), although Porous coated anatomic (PCA) had the significantly shortest survivorship when compared with other designs (Table 15). For comparison, we obtained survival data for four different TKA designs that corresponded to the UKA designs (Table 16).

Fig. 19. Overall Kaplan-Meier survivorship for UKA and TKA is shown over the study period. The end point was defined as any revision, including when either the whole implant or any one component was removed, exchanged, or implanted for any reason. Adjustments were made for age and gender.
Fig. 20. Kaplan-Meier survivorship for different UKA designs is shown over the study period. The end-point was defined as revision when either the whole implant or one component was removed, exchanged, or implanted for any reason. Data were adjusted for age and gender.
Table 15. Survivorship for different UKA designs.

<table>
<thead>
<tr>
<th>Implant</th>
<th>Period</th>
<th>N¹</th>
<th>Mean follow-up years/(range)</th>
<th>Survivorship, % (95% CI)</th>
<th>HR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>At 5 years</td>
<td>At 10 years</td>
<td>At 15 years</td>
<td></td>
</tr>
<tr>
<td>Oxford</td>
<td>1990–2011</td>
<td>439/4,084</td>
<td>5.2 (0–21)</td>
<td>90.4 (89.4–91.3)</td>
<td>83.7 (82.5–84.8)</td>
<td>76.9 (75.6–78.2)</td>
</tr>
<tr>
<td>Miller-Galante</td>
<td>1990–2005</td>
<td>90/318</td>
<td>11.3 (1–21)</td>
<td>89.1 (85.0–92.2)</td>
<td>77.4 (72.4–81.8)</td>
<td>66.7 (63.7–74.1)</td>
</tr>
<tr>
<td>Duracon</td>
<td>1993–2000</td>
<td>39/140</td>
<td>10.5 (0–19)</td>
<td>84.8 (77.6–90.1)</td>
<td>76.7 (68.7–83.3)</td>
<td>70.7 (62.3–77.9)</td>
</tr>
<tr>
<td>PCA</td>
<td>1985–1995</td>
<td>95/171</td>
<td>9.5 (1–24)</td>
<td>75.7 (68.4–81.7)</td>
<td>53.1 (45.3–60.7)</td>
<td>38.7 (31.4–46.4)</td>
</tr>
</tbody>
</table>

¹Number of revisions/number of total operations; PCA = Porous-coated anatomic; HR=hazard ratio
Table 16. Survivorship for four different TKA designs.

<table>
<thead>
<tr>
<th>Implant</th>
<th>Period</th>
<th>N(^1)</th>
<th>Mean follow-up years/(range)</th>
<th>Survivorship, % (95% CI)</th>
<th>HR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>At 5 years</td>
<td>At 10 years</td>
<td>At 15 years</td>
</tr>
<tr>
<td>Duracon</td>
<td>1992–2011</td>
<td>990/18,199</td>
<td>8.5 (0–19)</td>
<td>96.4 (96.1–96.7)</td>
<td>94.4 (94.0–94.7)</td>
<td>91.9 (91.5–92.3)</td>
</tr>
<tr>
<td>P.F.C. Sigma</td>
<td>1989–2011</td>
<td>590/13,292</td>
<td>6.2 (0–22)</td>
<td>96.8 (96.4–97.1)</td>
<td>94.8 (94.4–95.2)</td>
<td>88.9 (88.3–89.4)</td>
</tr>
<tr>
<td>Miller-Galante II</td>
<td>1989–1998</td>
<td>111/1,008</td>
<td>11.5 (0–20)</td>
<td>95.5 (94.0–96.7)</td>
<td>90.8 (88.8–92.4)</td>
<td>86.9 (84.7–88.9)</td>
</tr>
<tr>
<td>PCA modular</td>
<td>1985–1996</td>
<td>143/935</td>
<td>12.4 (0–23)</td>
<td>94.3 (92.5–95.6)</td>
<td>89.2 (87.0–91.1)</td>
<td>83.2 (80.7–85.6)</td>
</tr>
</tbody>
</table>

\(^1\)Number of revisions/number of total operations; P.F.C. = Press Fit Condylar; PCA = Porous-coated anatomic; HR=hazard ratio
Aseptic loosening was the most common reason for the revision in patients undergoing either the UKA or TKA procedure, but was more common among patients undergoing UKA (HR = 4.4, 95% CI 3.7–4.8, P < 0.001; adjusted by age and gender) (Table 17). In UKA patients, neither age (≤ 65 years or > 65 years; HR = 0.89, P = 0.13) nor gender (HR = 1.02, P = 0.77) affected the revision rate. In TKA patients, patients aged ≤ 65 years had increased revision rate compared with patients > 65 years (HR = 2.1, 95% CI 1.9–2.2, P < 0.001).

**Table 17. Reasons for UKA and TKA revisions between 1985 and 2011 in Finland.**

<table>
<thead>
<tr>
<th>Reasons for revision</th>
<th>UKA, N (%)</th>
<th>TKA, N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aseptic loosening</td>
<td>310 (46.8)</td>
<td>1,178 (26.7)</td>
</tr>
<tr>
<td>Malalignment</td>
<td>40 (6.0)</td>
<td>395 (9.0)</td>
</tr>
<tr>
<td>Prosthesis fracture</td>
<td>29 (4.4)</td>
<td>144 (3.3)</td>
</tr>
<tr>
<td>Luxation</td>
<td>19 (2.9)</td>
<td>101 (2.3)</td>
</tr>
<tr>
<td>Infection</td>
<td>18 (2.7)</td>
<td>528 (12.0)</td>
</tr>
<tr>
<td>Fracture</td>
<td>14 (2.1)</td>
<td>92 (2.1)</td>
</tr>
<tr>
<td>Patella complication</td>
<td>1 (0.2)</td>
<td>478 (10.8)</td>
</tr>
<tr>
<td>Other reason</td>
<td>232 (35.0)</td>
<td>1,496 (33.9)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>663 (100.0)</td>
<td>4,412 (100.0)</td>
</tr>
</tbody>
</table>

UKA patients were significantly younger than TKA patients were, with mean ages of 63 (range 33–91) and 69 (range 23–96) years, respectively (P < 0.001). The mean age of the UKA patients decreased over the study period, being 69.1 years between 1985 and 1993, 66.4 years between 1994 and 2002, and 62.1 years between 2003 and 2011. The corresponding mean ages of TKA patients were 69.5, 70.4, and 69.1 years, respectively (Fig. 21). The decline in the mean age was significantly steeper in UKA patients than in TKA patients (P < 0.001).
Fig. 21. The mean age of patients undergoing UKA and those undergoing TKA operated on in Finland is shown graphically.
6 Discussion

6.1 Validity of the data

Finland provides good potential for population-based register studies. Every resident has an individual identification code (social security number), which allows tracking down patients from different registers and hospital data. In addition, the low rate of emigration from Finland increases the reliability of this study. Only eight (0.3%) patients lived abroad at the end of the study period (II). Also, information on possible patient mortality can be retrieved from the Population Register Centre and this was taken into account by censoring patients after death in statistical analysis (II–IV).

The strengths of the current study are its long-term follow-up, large nationwide cohort and combination of data from national registries with demonstrated good accuracy and coverage. For example, the Finnish Arthroplasty Register covered 90% of hip implants for the year 1995, and after that, the coverage increased to 98% (Makela et al. 2008). The accuracy of the NHDR has been reported to be even better. In the late 1980s, at least 95% of operations were recorded in it (Keskimäki & Aro 1991).

Most of the weaknesses of the current study are common in all register-based studies (I–IV). First, in register-based study, the researcher has to rely on the accuracy of the registers, and accept the fact that register data have errors, including false and missing codes. However, nationwide registers provide large cohort sizes, thereby decreasing the effect of deficiencies. Second, register data do not include any information of the patient’s medical history, including medication, symptoms, radiographs or body mass index, which are crucial information when judging the processes leading to primary or revision surgery. Third, arthroplasty survival studies are prone to the following selection bias: 1. Revision indication for certain conditions varies. For example, elderly patients are less likely to be revised compared with younger ones, because of shorter life expectancy or poor medical condition, even if the implant fails and functional result is poor; 2. Implants with easier or less invasive revision are probably more likely to be revised; 3. Different patient groups have different implants (for example, young patient more likely undergo uncemented total hip arthroplasty with ceramic bearings, and elderly patients undergo cemented or hybrid metal-on-polyethylene arthroplasty); and 4. In survival studies, revision of a prosthesis is
used as an objective outcome measure to determine whether surgery has been a success or a failure. Thus, it is possible that if patient does not want to undergo revision, even if indications are obvious in the failed implant, arthroplasty is recorded as successful. The lack of functional outcome information in arthroplasty registers is a particular major weakness, as using the revision of the implant as end-point is criticised (Wylde & Blom 2011).

Despite these limitations, register-based study is a good method to research rare conditions, such as failure of HTO or revision of arthroplasty. Register-based study allows large sample sizes and usually long-term follow-up. It gives a better picture of the success of a certain surgery in widespread use, compared with single-centre or single hospital series. It also overcomes the fact that good results of surgery are more often reported than are poor ones. Registers are good tools for researchers, but users should be aware of their limitations.

The current study also has other limitations. We could include only 54% (n = 3,270) (II–III) of all the osteotomies identified because the side of the HTO was not recorded. However, patients who were excluded were distributed evenly over the whole study period. Other potential weaknesses are that we could not obtain information regarding whether the osteotomy was tibial or femoral in over half the cases (II–III). All the HTO operations performed before 1997 were coded as “tibial or femoral osteotomy”, as there was no separate code for tibial in contrast to femoral osteotomy at that time. After 1997, the number of femoral osteotomies (n = 75) was < 6% of the number of tibial osteotomies (n = 1,280). Using same ratio, we can be presume that over 94% of operations in which the site was not specified were HTOs rather than femoral osteotomies. Although we were not able to ascertain the precise operation technique used, we can also assume that over the first ten-year period, more closed wedge osteotomies were performed than opening wedge osteotomies. However, in previous studies, no differences were identified in the results of closed and open wedge osteotomy (Hoell et al. 2005, Magyar et al. 1999); therefore, this lack of detail has not likely compromised this study.

Finally, comparing UKA results with TKA results is a complicated exercise (IV). Even if one could match patients by age and sex, which we could not do in this large registry setting, the characteristics of patients undergoing UKA and those undergoing TKA may be quite different. In general, it can be assumed that patients undergoing UKA are more active and their expectations after surgery are higher. To limit this bias, we adjusted Cox models for age and gender.
6.2 The incidence of osteotomies in the treatment of knee osteoarthritis (I)

The overall incidence of osteotomies around the knee performed for the treatment of symptomatic knee OA has steadily decreased over the last two decades. This decline has occurred in both female and male patients; however, the incidence has slightly increased for patients less than 50 years of age. The reason behind the declining osteotomy figures may very well be the improved outcome of TKA in all patient groups during the last two decades. Additionally, UKAs have been performed in patients with less severe arthritis (Niinimaki et al. 2011), which may have decreased the number of osteotomies performed.

In female patients, the decline in incidence has been steeper than that seen for male patients. Furthermore, during the last decade, osteotomies were more commonly performed in male patients than in female patients. This must be considered controversial, as knee OA is more common among the female population, with female patients generally suffering worse symptoms and greater disability than male patients (Hawker et al. 2000). This is supported by the fact that TKAs and UKAs are commonly performed in female patients (Culliford et al. 2010).

Despite the fact that the overall incidence of osteotomies has decreased, it has, however, slightly increased in patients aged less than 50 years. This suggests that TKA has not totally replaced osteotomy in young and active patients, especially in males. Based on our findings, the current overall role of osteotomies is clearly minor in treatment of patients with knee OA aged more than 60 years.

6.3 Survivorship of high tibial osteotomy (II)

Most previous studies reporting survivorship for HTO were either single-hospital or single-surgeon series and were presumably carried out where there was particular expertise in HTO. Previous single-centre or single-surgeon series have reported a five-year survivorship ranging from 73% to 98% and a ten-year survivorship ranging from 51% to 98% for HTO (Table 2). In the current study, the survivorship at five years was similar to that of previous studies; however, the ten-year survivorship was poorer than in most of the previous studies. Only one previous population-based study documents HTO survivorship (W-Dahl et al. 2012): It reports 70% survivorship at ten years in Sweden, which is similar to the current series. In the current study, females had poorer HTO survivorship than
males. Similar results have been published previously (Gstottner et al. 2008, Sprenger & Doerzbacher 2003, W-Dahl et al. 2012), but the reason for this poorer survivorship is unknown. It is interesting to note that survivorship was better for HTOs carried out between 1987 and 1997 than for those carried out subsequently. This may because during the last decade, patients with a previous HTO are more likely to have a subsequent TKA due to the increasing clinical success and popularity of TKA. However, the incidence of osteotomies was higher between 1987 and 1997, and it is also possible that surgeons at that time were more familiar with the procedure and this is reflected in the higher rates of survival.

6.4 Survivorship of total knee arthroplasty after high tibial osteotomy compared with primary total knee arthroplasty (III)

A review of the medical literature reveals that this is the first published register-based case-control study of survivorship of TKA after HTO. For the study group with TKA after HTO, we report overall Kaplan-Meier survivorships of 95.3% at five years, 91.8% at 10 years, and 88.4% at 15 years. These survivorship values are slightly poorer compared with those obtained for TKAs without previous osteotomy. The differences in survivorship between the study and control groups were found to increase for the first five years, after which the difference was quite steady. In the study group, more constrained implant designs were used and patellar resurfacing was more common compared with control group.

Previously published studies have reported conflicting results of TKAs after HTO. Only one recent registry-based study has looked at TKA after previous osteotomy (Pearse et al. 2012): It reports that TKAs after an osteotomy have almost a three-fold higher early revision rate than do primary TKAs alone. However, in their study, the indications for osteotomy and osteotomy site were unknown and the patient data were unmatched.

Previous studies have described technical difficulties during the TKA operation, but have found that previous HTO has no adverse effect on the outcome and functional result of the subsequent TKA (Table 4). However, these studies have included a relatively small number of patients, restricting the strength of the survivorship results. Parvizi et al. (2004) reported Kaplan-Meier survivorship of 97.5% at 5 years, 92.3% at ten years, and 89.0% at fifteen years in 166 TKAs after HTO. The five- and ten-year survivorships reported in the present study were slightly poorer.
6.5 Survivorship of unicompartmental knee arthroplasty (IV)

In the arthroplasty register reports, overall survivorship of UKA is poorer compared to TKA (Australian National Joint Replacement Registry 2012, NAR 2010, National Joint Registry for England and Wales 2012, SKAR 2012). However, direct comparison of UKA and TKA survival may be inadequate, because of different implant designs, indications for operation, variety of operation years and differences in patient demographics. This study compared age and gender adjusted survival of UKA and cemented TKA performed for primary knee OA over the 25 years period of time.

In this study, the overall survivorship of UKA performed for primary knee OA, even for the best performing UKA designs, was inferior to that of cemented TKA. In addition, the age of both TKA and UKA patients had decreased over the study period, but in UKA patients this decline has been significantly steeper.

The reasons for the higher revision rate and decreasing number of UKAs are most likely to be multifactorial. First, UKA has unique reasons for revisions; in particular, the progression of arthritis to a contralateral compartment, which does not exist for TKAs and may partly explain the higher revision rates. Second, aseptic loosening is more frequent with patients undergoing UKA compared with patients undergoing TKA (Australian National Joint Replacement Registry 2012, NAR 2010, National Joint Registry for England and Wales 2012, SKAR 2012). The higher rate of loosening in UKAs may be explained by the smaller contact area between the implant and bone when compared with TKA. Additionally, the UKA cementing technique is technically demanding, in particular if limited incisions are used and bone is sclerotic (Hamilton et al. 2006, Miskovsky et al. 1992). The solution may be uncemented UKA designs, which have shown promising results for the rate of aseptic loosening in short-term follow-up (Lecuire et al. 2013, Liddle et al. 2013, New Zealand Joint Registry 2011, Pandit et al. 2013). We believe that aseptic loosening is a substantial reason for revision, but, especially for the Oxford UKA, radiolucent lines under the fixed tibial tray may be misleading (Gulati et al. 2009), but only in a relatively small number of patients. Even so, it appears that reliable fixation for UKAs remains an unsolved problem. Third, patients undergoing UKA are younger and probably more active than are TKA patients. Therefore, their expectations are high, and the results of UKAs in these patients may be disappointing. Thus, cases of unexplained pain in this patient group might lead to higher risk of revision, even without clear indications (Baker et al. 2012b, Goodfellow et al. 2010). Fourth, there is
increasing evidence that patients with mild or moderate OA who undergo knee arthroplasty, even those with severe symptoms, have a higher revision rate than do patients with severe OA (Niinimaki et al. 2011, Pandit et al. 2011a, Polkowsi et al. 2013, Schnurr et al. 2013). These patients may be over-presented in the UKA group, as the less invasive operation may be performed for cases of less severe arthritis. Finally, a number of arthroplasty patients have long-term pain after operation. The proportion of people with an unfavourable long-term pain outcome in studies range from 10% to 34% after knee replacement (Beswick et al. 2012). In the available register data, UKAs are revised more often because of unexplained pain than are TKAs, even if the knee score is similar (Goodfellow et al. 2010). Again, this may partly explain higher revision rates, but when the revisions for unexplained pain are discounted, UKA still has a significantly greater risk of revision from other reasons than TKA has (Baker et al. 2012b).

6.6 Further studies

Overall, the role of HTO has decreased in the treatment of knee OA. However, further studies are needed to clarify indications for HTO for improving long-term results among younger patients. In addition, research is needed to assess why females have inferior survivorship after HTO when compared with males.

TKA after HTO seems to have a statistically, but not clinically, significantly higher risk for revision compared with primary TKA. Therefore, more studies with large cohorts of patients are needed to define the differences in outcome results.

Survivorship of UKA is poorer compared with TKA in arthroplasty registers. However, this patient group may suffer in register-based survivorship studies (Wylde & Blom 2011). To clarify the outcome of UKA, we need long-term studies conducted in independent hospitals with large cohort sizes. Furthermore, we need information on the outcome of the UKA operations and the reasons for revisions.

Finally, the preoperative radiological degree of OA has an effect on the arthroplasty results (Polkowski et al. 2013, Schnurr et al. 2013). UKAs performed on patients with mild OA have poorer outcomes and increased risk of revision compared to patients with severe bone-on-bone OA (Niinimaki et al. 2011, Pandit et al. 2011a). It may be that UKAs are frequently performed on patients with OA not severe enough to justify any arthroplasty procedure, which would partly explain higher revision rates compared with the TKAs in the
arthroplasty registers. This hypothesis and ideal indications for UKA procedures need further study.
7 Conclusions

The following conclusion can be made based on the results of this study.

1. The overall incidence of osteotomies in the treatment of knee OA has decreased steadily over the last two decades, but in the age group less than 50 years, the incidence has slightly increased. The decline in incidence has been steeper in female patients.

2. The short-term survivorship of HTO at a nationwide level is comparable with that regularly reported in single-hospital or surgeon series, but the mid-term survivorship is worse. Females and patients aged more than 50 years have poorer results.

3. The survivorship of TKAs after previous HTO is satisfactory when compared with that following routine primary TKAs.

4. The survivorship of UKA cases is poorer compared that of TKA. Critical patient screening for indications and adequate surgical techniques are crucial to provide satisfactory UKA results for selected patients with isolated knee osteoarthritis. In addition, UKA patients have a high revision rate, especially because of aseptic loosening.
References


Original publications

This thesis is based on the following original articles, which are referred to in the text by their Roman numerals.


Reprinted with kind permission from Springer Science and Business Media (I, III, IV) and with permission and copyright © of the British Editorial Society of Bone and Joint Surgery (II).

Original publications are not included in the electronic version of the dissertation.

1214. Kaakinen, Pirjo (2013) Pitkääikaissairaiden aikuisten ohjauksen laatu sairaalassa

1215. Pasanen, Anna Kaisa (2013) A translational study on the roles of redox molecules, cell cycle regulators and chemokine receptors as prognostic factors in diffuse large B-cell lymphoma

1216. Malo, Elina (2013) The role of low birth weight and resistin in metabolic syndrome


1219. Koskela, Sanna (2013) Granulosa cell anti-Müllerian hormone secretion in ovarian development and disease

1220. Soini, Heidi (2013) Mitochondrial DNA sequence variation in Finnish patients with maternally inherited type 2 diabetes, epilepsy and mitochondrial disease: risk and novel mutations


1222. Vuorela, Mikko (2013) Role of the RNF8, UBC13, MMS2 and RAD51C DNA damage response genes and rare copy number variants in hereditary predisposition to breast cancer

1223. Aujula, Meju (2013) Studies about contribution of leptin receptor in cardiovascular risk

1224. Turunen, Pauliina (2013) Natural antibodies to malondialdehyde adducts in atherosclerosis


1226. Turk, Eva (2013) Patient reported outcomes in elderly patients with Diabetes Mellitus Type 2 in Slovenia

Book orders:
Granum: Virtual book store
http://granum.uta.fi/granum/
Tuukka Niinimäki

HIGH TIBIAL OSTEOTOMY AND UNICOMPARTMENTAL KNEE ARTHROPLASTY

THE TREATMENT OF ISOLATED MEDIAL OSTEOARTHRITIS OF THE KNEE – A REGISTRY-BASED STUDY IN FINLAND

University of Oulu Graduate School, University of Oulu, Faculty of Medicine, Institute of Clinical Medicine, Department of Surgery, Oulu University Hospital