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KONSTA PAMILO

EFFECT OF HOSPITAL VOLUME AND PROCESS OPTIMIZATION ON OUTCOME AFTER HIP AND KNEE ARTHROPLASTY

Effect of hospital volume and process optimization on outcome after hip and knee arthroplasty

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ABSTRACT

The prevalence of hip and knee osteoarthritis (OA) is increasing. The main symptom of OA is pain and the primary treatment method is non-operative. Total hip replacement (THR) and total knee replacement (TKR) are the gold standard treatments for severe OA refractory to conservative treatment. The incidence and prevalence of these procedures are also expected to increase markedly in the future. Due to the potentially severe complications and high economic impact associated with these procedures, efforts to minimize the risks and to optimize perioperative efficiency are necessary.

In 2010, over 20 000 total joint replacements (TJR) (THRs or TKRs) were performed in over 50 hospitals in Finland. TJR procedure volumes and processes as well as outcomes after the operation vary between hospitals. Fast-tracking is an evidence-based way to standardize the TJR process. While short length of ward stay (LOS) per se is not the primary goal of fast-tracking, optimal care may eventually result in shorter LOS.

This study evaluated the effect of hospital procedure volume between 1998 and 2010 and fast-tracking during 2009-2010 and 2012-2013 on outcomes after primary TJR, in particular from the organizational point of view. The outcome measures for determining the effects of hospital TJR volume were length of stay (LOS), length of uninterrupted institutional care (LUIC), and number of readmissions and TJR revisions. A further purpose was to evaluate the association of hospital volume with discharge destination and manipulations under anesthesia (MUA) after TKR. The outcome measures for determining the effects of fast-tracking were LUIC, LOS, discharge destination, readmissions, early revisions, MUA and mortality rates.

This thesis is based on the PERFECT hip and knee replacement databases that collate data from the Finnish Hospital Discharge Register, cause of death statistics, the Prescription Register and the Special Refund Entitlement Register, and the Finnish Arthroplasty Register.

This research shows that both LOS and LUIC can be shortened by fast-tracking or by centralizing operations in higher volume hospitals. The patients operated on in the very-high-volume hospitals had a lower probability for readmission within 42 days of discharge after TKR and THR than those operated on in the low-volume hospitals. It seems that a change of protocol to fast-tracking gives rise to a learning curve causing more readmissions and revisions after THR in the early stage. Fast-tracking does not appear to increase complication or revision rates after TKR. Hospital volume or fast-tracking had no effect on MUA rates.

National Library of Medicine Classification: W 84.4, WE 860, WE 862, WE 870, WE 874, WO 500, WX 158

Medical Subject Headings: Osteoarthritis, Hip; Osteoarthritis, Knee; Arthroplasty, Replacement, Hip; Arthroplasty, Replacement, Knee; Hospitals, High-Volume; Hospitals, Low-Volume; Length of Stay; Patient Readmission; Reoperation; Treatment Outcome; Mortality; Registries; Humans; Finland

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TIIVISTELMÄ

Lonkan ja polven nivelrikot ovat huomattavasti yleistyneet viime vuosikymmenien aikana, ja tämän yleistymisen ennakoidaan jatkuvan. Lonkan ja polven nivelrikon tärkein oire on kipu, ja ensisijainen hoitomenetelmä on konservatiivinen (ei-leikkauksellinen). Tekonivelleikkaus on vakiintunut vaikean, konservatiiviseen hoitoon reagoimattoman lonkan ja polven nivelrikon hoitomuodoksi. Tekonivelkirurgian tarpeen on arvioitu enentyvän tuntuvasti tulevaisuudessa. Leikkaushoidon tarpeen lisääntyminen aiheuttaa merkittävän pulman terveydenhuoltojärjestelmälle. Tämä lisää erikoissairaanhoidon kustannuksia, ellei tekonivelleikkauksia voida tuottaa nykyistä halvemmalla, tehokkaammin ja pienemmällä uusintaleikkausriskillä.

Suomessa tehtiin yli 20 000 lonkan ja polven tekonivelleikkausta vuonna 2010. Tekonivelleikkausten jälkeiset tulokset vaihtelevat sairaaloittain, kuten myös sairaaloiden leikkausmäärät ja prosessit. Fast track on näyttöön perustuva tapa yhdenmukaistaa tekonivelpotilaan hoitoprosessi. Lyhyt sairaalassaoloaika ei ole sen päämäärä, mutta se voi olla hyvän näyttöön perustuvan hoidon tulos. Tämän tutkimuksen tarkoituksena oli selvittää sairaalassa tehtyjen tekonivelleikkausten määrien vaikutusta vuosina 1998-2010 sekä fast track -mallin käyttöönoton vaikutusta vuosina 2009-2010 ja 2012-2013 lonkan ja polven tekonivelleikkausten tuloksiin. Tutkimuksessa määritettiin sairaalan leikkausmäärän vaikutus hoitojaksojen pituuteen, leikkauksen jälkeisiin uusintakäynteihin ja -leikkauksiin sekä kuolleisuuteen. Lisäksi tutkittiin, miten sairaalassa toteutettujen polven tekonivelleikkausten määrä vaikuttaa leikkauksen jälkeen sairaalasta suoraan kotiin siirtyvien ja tekonivelleikkausten jälkeisten narkoosimanipulaatioiden (MUA) määrään. Rekisteristä määritettiin myös, miten fast track -ohjelman implementointi vaikuttaa leikkaus- ja kokonaishoitojakson kestoon, leikkausten jälkeen suoraan kotiin siirtyneiden osuuteen, suunnittelemattomiin uusintakäynteihin sairaalan osastolla, uusintaleikkauksiin, narkoosimanipulaatioiden määrään sekä kuolleisuuteen.

Tämä väitöskirja pohjautuu PERFECT-tekonivelkirurgiahankkeessa tuotettuun tietokantaan, johon on poimittu tiedot hoitoilmoitusrekisteristä, kuolinsyyrekisteristä, resepti- ja erityiskorvausoikeuksien tiedostoista sekä endoproteesirekisteristä.

Tutkimuksemme mukaan sekä keskittämällä tekonivelleikkauksia suuremman leikkausmäärän sairaaloihin että ottamalla käyttöön fast track -malli voidaan lyhentää leikkaushoitojaksojen ja kokonaishoitojaksojen pituutta. Potilaan riski joutua uudestaan sairaalaan 42 vuorokauden kuluessa tekonivelleikkauksesta on pienempi sairaaloissa, joissa tekonivelleikkauksia tehdään erittäin paljon, verrattuna sairaaloihin, joissa näitä leikkauksia tehdään vähän. Lonkan tekonivelleikkauksissa fast track -mallin käyttöönottoon vaikuttaa liittyvän oppimiskäyrä, minkä takia potilaiden riski suunnittelemattomiin uusintakäynteihin sairaalan osastolla ja uusintaleikkauksiin saattaa kasvaa muutoksen alkuvaiheessa. Sairaalan tekonivelleikkausmäärillä tai fast track -ohjelman käyttöönotolla ei ole vaikutusta MUA-riskiin. Fast track -mallin käyttöönotto polven tekonivelkirurgiassa ei lisää komplikaatioita eikä uusintaleikkauksia.

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Yleinen Suomalainen asiasanasto: nivelrikko; lonkka; polvet; tekonivelet; leikkaushoito; sairaalat; hoitoprosessit; sairaalahoito; hoitotulokset; kuolleisuus; tietokannat; rekisterit; Suomi

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Jyväskylä, August 2018

Konsta Pamilo

List of original publications

This dissertation is based on the following original publications, which are referred to in the text by roman numerals I-IV:

I Pamilo KJ, Peltola M, Mäkelä K, Häkkinen U, Paloneva J, Remes V. Is hospital volume associated with length of stay, re-admissions and reoperations for total hip replacement? A population-based register analysis of 78 hospitals and 54,505 replacements. *Arch Orthop Trauma Surg. 2013;133(12):1747-55.*

II Pamilo KJ, Peltola M, Paloneva J, Mäkelä K, Häkkinen U, Remes V. Hospital volume affects outcome after total knee arthroplasty: A nationwide registry analysis of 80 hospitals and 59,696 replacements. *Acta Orthop. 2015;86(1):41–7.*

III Pamilo KJ, Torkki P, Peltola M, Pesola M, Remes V, Paloneva J. Reduced length of uninterrupted institutional stay after implementing a fast-track protocol for primary total hip replacement. *Acta Orthop. 2018;89(1):10–6.*

IV Pamilo KJ, Torkki P, Peltola M, Pesola M, Remes V, Paloneva J. Fast-tracking for total knee replacement reduces use of institutional care without compromising quality. *Acta Orthop. 2018;89(2):184–9.*

Contents

Abbreviations

BMI	Body mass index
CI	Confidence interval
DDH	Developmental dysplasia of the hip
EICF	Extended institutional care facilities
FAR	Finnish Arthroplasty Register
FHDR	Finnish Hospital Discharge Register
ICD	International Statistical Classification of Diseases and Related Health Problems
LOS	Length of stay
LUIC	Length of uninterrupted institutional care
MUA	Manipulation under anesthesia
NOMESCO	the Nordic Medico-Statistical Committee
OA	Osteoarthritis
OR	Odds ratio
PERFECT	Performance, effectiveness and cost of treatment episodes
THR	Total hip replacement
TIVA	Total intravenous anesthesia
TJR	Total joint replacement
TKR	Total knee replacement

1 Introduction

Osteoarthritis is the most common articular disease in the developed world. In the Nordic countries, owing to population growth, aging and the obesity epidemic, the burden of OA on healthcare resources is high and rising (Kiadaliri et al. 2018). However, it has also been reported that the prevalence of hip and knee OA is not rising (Arokoski et al. 2007, Cross et al. 2014). In Finland, among people over age 30, the prevalence of diagnosed hip OA has been reported to be 6% in men and 5% in women, and the prevalence of knee OA to be 6% in men and 8% in women (Arokoski et al. 2007). The ultimate reason for OA is unknown. Several individual-level and joint-level risk factors have been found to be associated with OA. Age is the strongest risk factor. Thus, the incidence of symptomatic hip and knee OA increases with age, accelerating after age 50. Women have a higher incidence than men, especially after age 50 (Oliveria et al. 1995, Chung et al. 2010). Knee OA, in particular, is strongly associated with obesity: individuals with a body mass index (BMI) of ≥35 are at a 4.7-fold increased risk for knee OA (Toivanen et al. 2010, Lee and Kean 2012, Reyes et al. 2016). Interestingly, physical exercise does not increase the risk for OA at any level of BMI (Mork et al. 2012). There is also a genetic risk for knee and hip OA (Zengini et al. 2018). The heritable component of knee and hip OA has been estimated to be over 40% (Spector et al. 1996, MacGregor et al. 2000). Another commonly reported risk factor for knee OA is injury of the joint (Neogi and Zhang 2013, Silverwood et al. 2015). Typical symptoms of OA are pain, stiffness and loss of functional capacity.

Total hip replacement (THR) and Total knee replacement (TKR) are the gold standard treatments for severe osteoarthritis refractory to conservative treatment (Figures 1a and 1b). In Finland, the number of TJRs performed annually has increased over the past few decades. In 2016, over 23 000 TJRs (THRs or TKRs) were performed in over 40 hospitals in Finland (National Institute for Health and Wellfare 2017). Both procedures are also predicted to increase markedly in volume (Kurtz et al. 2007). Due to the potentially severe complications and high economic impact associated with these procedures, efforts to minimize the risks and optimize perioperative efficiency are mandatory.

In the 1970s, patients remained in hospital after TJR for several weeks (Ranawat et al. 1983, Roos and Lyttle 1985). In 1996, Gregor et al. (1996) reported that their next target would be to reduce length of stay (LOS) after TJR to one week. Since then, LOS has continued to decrease (Mäkelä et al. 2011a, Burn et al. 2018). Over the past two decades, special clinical pathway programs have been developed to reduce LOS, often for economic reasons (Kim et al. 2003). The more recent fast-tracking of TJR includes the continuous optimization of the whole treatment protocol by applying evidence-based knowledge, removing potentially harmful traditional practices and actively monitoring results. Such fast-track protocols are also less economically driven as cost reduction is not one of their main goals (Husted 2012). LOS is one of the measures that can be used to evaluate the effect of changes in the process. Short LOS is not the primary goal but the outcome of optimum care. The most important components of fast-tracking are standardized patient information that aims at fast recovery, standardized opioid-sparing anesthesia, avoidance of drains or urinary catheters, standardized opioid-sparing pain management, mobilization on the day of surgery and standardized discharge criteria.

It has been suggested that increased hospital volume and reduction in length of stay in the operating hospital after TJR are related. However, the findings reported on this issue are conflicting: some have found an association while others have observed no such association (Doro et al. 2006, Judge et al. 2006, Yasunaga et al. 2009, Bozic et al. 2010, Marlow et al. 2010, Paterson et al. 2010, Mäkelä et al. 2011a, Styron et al. 2011). Various studies have shown that a fast-track protocol reduces LOS after primary TJR (Husted and

Holm 2006, Husted et al. 2010b, 2012, den Hartog et al. 2013, Winther et al. 2015). However, the overall reduction in LOS, even without fast-tracking, has rarely been taken into account (Glassou et al. 2014).

The correlation between length of uninterrupted institutional care (LUIC) and hospital volume after THR has not been widely investigated (Mäkelä et al. 2011a, 2011b). Moreover, no previous effort has been made to study the association between LUIC after TKR and hospital volume. Apart from studies on LOS conducted only on hospitals directly discharging 100% of TJR patients to home (Husted et al. 2010b, 2011a, Jørgensen et al. 2013a), no reports have been published on LUIC after fast-track THR or TKR.

The data on the association between hospital volume and readmission rates after TJR are also conflicting (Judge et al. 2006, SooHoo et al. 2006b, Bozic et al. 2010, Paterson et al. 2010, Cram et al. 2011b, Mäkelä et al. 2011a). Moreover, findings on the association of hospital volume with revision risk after TJR remain inconclusive (Kreder et al. 1997, Battaglia et al. 2006, Judge et al. 2006, Shervin et al. 2007, Manley et al. 2008, 2009, Bozic et al. 2010, Paterson et al. 2010, Mäkelä et al. 2011a). One of the clinically relevant complications after TKR is stiff knee, and manipulation under anesthesia (MUA) is sometimes needed to treat it. The cause of stiff knee is multifactorial, including preoperative, intraoperative and postoperative patient and technical factors (Zachwieja et al. 2018). No previous effort has been made to study the association between incidence of MUA and hospital volume after TKR.

Since process standardization has an effect on outcome after TJR, it is also important to evaluate the effect of fast-tracking on complications (Bozic et al. 2010). Fast-tracking has not been found to be associated either with higher readmission, revision, mortality after TJR (Husted et al. 2010b, den Hartog et al. 2013, Glassou et al. 2014, Winther et al. 2015, Jørgensen et al. 2017) or with an increased rate of MUA after TKR or increased risk for dislocations after THR (Husted et al. 2010b, Gromov et al. 2015, Wied et al. 2015). However, the majority of these publications are from high-volume centers actively participating in the development of fast-track protocols.

This thesis aimed to evaluate the effect of hospital volume and fast-tracking on LOS, LUIC, readmissions, revisions after TJR, and MUA after TKR. Also evaluated were the effects of fast-tracking on discharge destination and mortality after TJR and the effect of hospital volume on discharge destination after TKR.

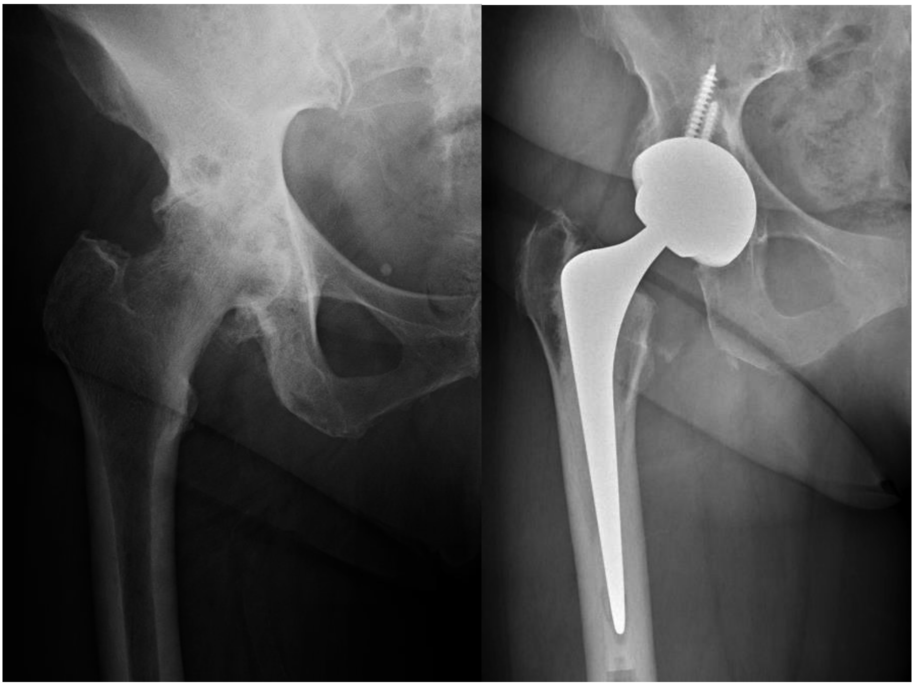

Figure 1a. An AP radiograph of the right hip demonstrating severe hip osteoarthritis (OA) with joint space narrowing, osteophytes, subchondral sclerosis, and a subchondral cyst in the femur and acetabulum (left). A radiograph of the same hip after a hybrid THR procedure (right).

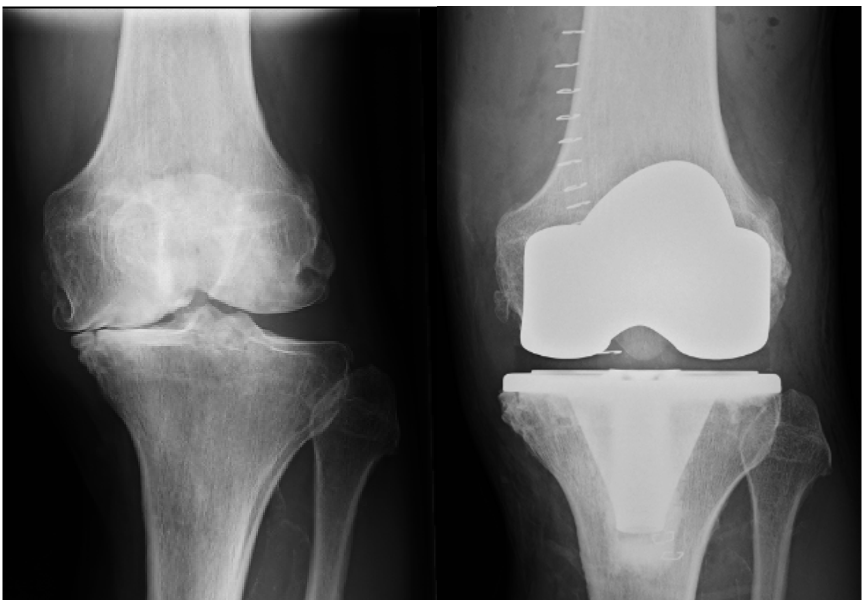

Figure 1b. An AP radiograph of the left knee demonstrating severe knee osteoarthritis (OA) with medial joint space narrowing, osteophytes and subchondral sclerosis (left). A radiograph of the same knee after cemented TKR (right).

2 Review of the literature

2.1 QUALITY AND COMMON OUTCOME MEASURES FOR TJR

The WHO´s definition of quality of health care comprises six domains: safe, effective, patient-centered, accessible, efficient and equitable (World Health Organization 2006). Different outcome measures after TJR have been used to evaluate different quality domains.

Outcome measures very commonly used in TJR studies are LOS, discharge destination, readmission, revision and mortality (Glassou et al. 2014, 2017, D'Apuzzo et al. 2017, Jeschke et al. 2017, McLawhorn et al. 2017, Meehan et al. 2017). From the quality perspective, LOS can affect patient accessibility. LOS is also a marker of efficiency, providing that shorter LOS does not cause an increase in adverse events. Revisions, readmissions, adverse events and mortality are related to effectiveness and safety, and thus to quality. Discharge destination, in turn, refers to patient accessibility and the effectiveness of treatment.

The Knee Society Score (KSS) and Harris Hip Score (HSS) are clinical-based outcomes (Harris 1969, Insall et al. 1989). They have previously been widely used as outcome measures after TJR, and continue to be actively used in arthroplasty studies (Ramkumar et al. 2018). These clinical-based outcome measures are administered by health care professionals. Patient-reported outcome measures (PROMs) have also been widely used (Ramkumar et al. 2018). These measures provide a more patient-centered evaluation of outcome after TJR, bridging the gap between clinical reality and the patient's world (Nelson et al. 2015). From the quality perspective, PROMs reflect the effectiveness of TJR. A systematic review reported the use of 28 different PROMs in rehabilitation studies after TJR (Alviar et al. 2011). These measures can be categorized as generic or specific. Two commonly used generic PROMS are the short form health surveys (SF-36 or SF-12) and EuroQol 5-dimension (EQ-5d) (Rolfson et al. 2016). Examples of good specific PROMS are the hip disability and osteoarthritis outcome score (HOOS), the Knee Injury and Osteoarthritis Outcome score (KOOS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Oxford Hip Score (OHS) and Oxford Knee Score (OKS) (Collins and Roos 2012). The KOOS, WOMAC and OKS have been translated into Finnish and found suitable for assessment of hip or knee status (Soininen et al. 2008, Reito et al. 2017, Multanen et al. 2018). The Finnish Arthroplasty Society recommends routine use of the Oxford questionnaires in follow-up after TJR. However, PROMs have not yet been included in the Finnish Arthroplasty Register (National Institute for Health and Wellfare 2017). If PROMS are to be included in the register, it is recommended that these are specific PROMs that have been appropriately developed for TJR patients and have good measurement properties (Rolfson et al. 2016). Only one study exists on the effect of hospital volume on PROM outcomes after TJR (Varagunam et al. 2015). The authors found no association between hospital volume and PROMs (OHS or EQ-5D) after TJR surgery. Only a few studies exist on PROMs after fast-tracking and no studies have compared PROM results between conventional and fast-track regimens (Petersen et al. 2008, Larsen et al. 2010, 2012, Winther et al. 2015).

Patient-reported experience measures (PREMS) focus on patients' experiences and satisfaction (Nilsson et al. 2016). These measures provide information on how acceptable, equitable and patient-centered treatment processes and TJR operations are. Better patient satisfaction after THR has been found in hospitals performing over 100 procedures annually (Katz et al. 2003). Risk of dissatisfaction has been coupled with lack of choice in selecting the operating hospital (Losina et al. 2005). Delanois et al. (2017) found that short

LOS did not affect patients´ hospital experience. In addition, patient satisfaction has been found to be good following fast-track TJR (Jones et al. 2014, Specht et al. 2015).
From the organizational point of view, THR and TKR processes are similar up to the point of surgery. THR is associated with greater blood loss and increased risk for blood transfusion compared to TKR (Bierbaum et al. 1999, Evans et al. 2011, Rai et al. 2018). Blood transfusions have been reported to be associated with longer LOS, increased costs, decreased discharge rate to home, surgical complication such as infections, and pulmonary complications (Saleh et al. 2014). Pain is one of the most common reasons for emergency visits after TJR (Kelly et al. 2018). Pain management after TKR tends to be more challenging than after THR, potentially causing more revisits (Wylde et al. 2011b). In addition, the incidence of persistent pain after the operation differs between these procedures, and pain has an effect on patient satisfaction (Wylde et al. 2011a, Howells et al. 2016). Reasons for readmission are somewhat different after THR and TKR (Kelly et al. 2018). Previous studies on the effect of hospital volume on revision risk after TJR speculated that the impact of volume on revision risk could be different between THR and TKR operations (Paterson et al. 2010, Prokopetz et al. 2012). For all the above-mentioned reasons, THR and TKR outcome analyses were performed separately in this thesis.
This thesis was based on register data. Thus, the outcome measures used were driven by the contents of the registers. The outcome measures selected for this thesis were LOS, LUIC, readmission, revision, mortality, MUA and discharge destination.

2.2 ECONOMIC ASPECT

TJR operations are costly procedures (Nichols and Vose 2016). Thus, from the organizational point of view, reducing costs is important. Resources released by reducing LOS can be utilized for other patients. Studies other than those focusing on fast-tracking have reported savings from LOS reduction (Mabrey et al. 1997, Nichols and Vose 2016, Martino et al. 2017, Regenbogen et al. 2017). These savings are not cancelled out by costs incurred by post discharge care or readmissions (Regenbogen et al. 2017, Haeberle et al. 2018). Since the primary focus of fast tracking is not economic, only a couple of studies exist on this specific issue. These studies have found fast-track TJR to be less costly than conventional pathways with longer LOS (Andreasen et al. 2016). In the study by Andreasen et al. (2016), costs were analyzed by using the time-driven activity-based costing method which calculates the time consumed by different staff members involved in patient care in the perioperative period. In addition, fast-track THR and TKR has been shown to reduce LOS with a high discharge rate to home and without an increase in the rate of readmissions or revisions (Glassou et al. 2014). Thus, potential savings from reduced LOS are not cancelled out by these events. However, for TKR, the operating day is the most expensive treatment day, accounting for 72% of total costs (Healy et al. 1997). Ward stay is associated with 12-23 % of total costs (Stern et al. 1995, Healy et al. 1997).
Several studies have reported that a higher hospital volume of THR or TKR is related to lower costs of both procedures (Martineau et al. 2005, Losina et al. 2009, Courtney et al. 2018, Haeberle et al. 2018).

2.3 PROCESS OPTIMIZATION IN THR AND TKR

In the past, the development of clinical pathways was primarily economically driven as, in line with Medicare´s diagnostic groups (DRGs), the system of payment adopted was prospective rather than retrospective (Coffey et al. 1992, Walter et al. 2007). The aim was to achieve economic goals by accelerating patient care and optimizing the use of resources. A later aim was to improve patient care and satisfaction (Walter et al. 2007). Today, the main clinical pathway objectives include process standardization and improvement,

interdisciplinary communication and collaboration, and patient/family engagement and education (Van Citters et al. 2014).
The overriding goal of fast-tracking surgery is to offer patients the best available treatment by applying evidence-based knowledge to standardize processes, and questioning and avoiding potentially harmful traditions (Husted 2012). Process optimization of this kind eventually results in reductions in LOS, morbidity and convalescence time, with no increase in readmission rates or safety risk (Kehlet 2013). The clinical elements for optimization and standardization are various. The primary elements are patient education, preoperative optimization of patients, analgesia and anesthesia, mobilization regimens and physiotherapy, selection of discharge criteria, postoperative urinary retention (POUR) management, blood transfusion management, use of drains, antithrombotic prophylaxis and continuous monitoring of outcome measures.

2.4 LOS AND LUIC

In the 1970s, post-operative TJR patients remained in hospital for several weeks (Ranawat et al. 1983, Roos and Lyttle 1985). In 1996, Gregor et al. (1996) reported their target of reducing length of stay (LOS) after TJR to one week. Since then, LOS has continued to decrease (Mäkelä et al. 2011a, Burn et al. 2018). Nowadays, even day-case TJR is feasible for selected patients and it has been reported that up to 15% of unselected patients can be discharged on the same day as their TJR surgery (Gromov et al. 2017).
Several factors have been reported to be associated with LOS after THR and TKR: surgeon volume, hospital volume, time between surgery and mobilization, and process standardization (such as fast-track programs), operation day and patient-related factors (Judge et al. 2006, Mitsuyasu et al. 2006, Bozic et al. 2010, Husted et al. 2010a, Paterson et al. 2010, Styron et al. 2011, Jans et al. 2016, Mathijssen et al. 2016). An annual decline in LOS after THR and TKR has also been reported (Mäkelä et al. 2011a, Cram et al. 2012, Wolf et al. 2012).

2.4.1 Association of hospital volume with LOS and LUIC

It has been suggested that increased hospital volume and reduction in LOS in the operating hospital after THR and THR are related. However, the findings reported on this issue are conflicting (Hervey et al. 2003, Judge et al. 2006, Yasunaga et al. 2009, Bozic et al. 2010, Marlow et al. 2010, Paterson et al. 2010, Mäkelä et al. 2011a, Styron et al. 2011, Kaneko et al. 2014, Ramkumar et al. 2018) (Table 1). In Finland, Mäkelä et al. (2011a) reported an association between hospital volume and LOS after THR and also found that very-high-volume hospitals (> 250 THRs annually) had shorter LUIC than low-volume hospitals (1-50 THRs annually). The association between hospital volume and LOS or LUIC after TKR has not, however, previously been evaluated in Finland. The correlation between the more important variable LUIC and hospital volume after THR or TKR has not been fully investigated. For example, one reason for short LOS may be that patients are more actively transferred to rehabilitation centers (Paterson et al. 2010).

2.4.2 LOS and LUIC after fast-track THR or TKR

The aim of fast-tracking is to optimize the whole treatment protocol, leading eventually to shorter LOS without compromising treatment quality (Husted 2012). Various studies have shown that a fast-track protocol reduces LOS after primary THR and TKR (Husted and Holm 2006, Husted et al. 2010b, 2012, den Hartog et al. 2013, Glassou et al. 2014, Winther et al. 2015, Maempel et al. 2016) (Table 2). Even same-day discharge after THR and TKR is feasible for some patients (Goyal et al. 2017, Gromov et al. 2017, Hoorntje et al. 2017). A median LOS of 2-3 days after THR and TKR has been reported in fast-track studies (den Hartog et al. 2013, Glassou et al. 2014, Husted et al. 2016, Pitter et al. 2016). Apart from studies on LOS conducted only on hospitals directly discharging 100% of patients to home (Husted et al. 2010b, 2011a, Jørgensen et al. 2013a), no reports have been published on the total length of uninterrupted institutional care (LUIC) after fast-track THR or TKR.

2.5 READMISSION

Unscheduled readmissions are widely used as a marker of quality of care. A recent systematic review and meta-analysis found the readmission rates for THR to be 5.6% within 30 days and 7.7% within 90 days, and the corresponding rates for TKR to be 3.3% and 9.7% (Ramkumar et al. 2015). In this systematic review, surgical site infection was the leading reason for readmission within 30 and 90 days after TKR. After THR, the most common reason for readmissions within 30 and 90 days was joint-specific (no more detailed reason was named) (Ramkumar et al. 2015). A recent study by Kelly et al. (2018) found that the most frequent reason for readmission within 90 days was gastrointestinal after TKR and infection after THR.

Several studies on THR or TKR that have evaluated the correlation between hospital volume and readmissions have reported conflicting results (Kreder et al. 1998, Judge et al. 2006, SooHoo et al. 2006a, 2006b, Bozic et al. 2010, Mäkelä et al. 2011a, Cram et al. 2012) (Table 3). However, in the more recent studies higher provider volume has been reported to be associated with lower readmission rates (Paxton et al. 2015, Chen et al. 2016, Kurtz et al. 2016, Laucis et al. 2016, Wilson et al. 2016, D'Apuzzo et al. 2017, Courtney et al. 2018). The correlation between LOS after THR or TKR and readmissions is also controversial: short LOS has been coupled with a higher rate of readmissions in some studies and no change in others (Husted et al. 2010b, Cram et al. 2011a, 2012, Vorhies et al. 2011, 2012, Keeney et al. 2012, Wolf et al. 2012). In Finland, Mäkelä et al. (2011a) found no association between hospital volume and readmission rates after THR.

The readmission rate within 90 days has been reported to be between 8.6% and 10.9 % after fast-track THR and between 8.3% and 15.6% after fast-track TKR in studies in which readmission has been clearly defined (Husted et al. 2010b, 2016, Jørgensen et al. 2013b, Glassou et al. 2014) (Table 4). However, no increase in total readmission rates after fast tracking has also been found after THR or TKR (Husted et al. 2010b, den Hartog et al. 2013, Glassou et al. 2014), although Glassou et al. (2014) found a possibility for increased risk of urinary tract infection after fast-track THR and TKR . They proposed two possible explanations for the lower rate of urinary tract infections in their conventional comparison cohort. First, early urinary tract infections that occur among patients in conventional settings where LOS is longer – and who are thus still in hospital – are not recorded as readmissions. Second, they did not have data on differences between cohorts in the use of prophylactic antibiotics.

2.6 REVISIONS AFTER THR AND TKR

The revision rate is commonly used as an outcome measure for failure after TJR and revision as an endpoint in arthroplasty registers. Kaplan-Meier survival analyses have traditionally been and commonly continue to be used to estimate the cumulative incidence of revisions after TJR. Revisions can be categorized as early and late. Early revisions have been defined as revisions performed within less than 10 years after the index operation (Dy et al. 2014a, 2014b). Factors related to the patient, surgeon, surgical technique used, and

choice of implant all contribute to both early and late revision risk. However, early revisions are often performed due to technical errors, early acceptance of alternative surgical techniques or innovations. By identifying and understanding the risk factors for both early and late revisions, we can improve outcomes in the future. (Karachalios et al. 2018)
Findings on the association between hospital volume and revision surgery after TKR are conflicting. Some studies have found that a higher hospital volume predicts a lower risk of revision after TKR (Kreder et al. 2003, Judge et al. 2006, Manley et al. 2009, Paterson et al. 2010, Badawy et al. 2013, Jeschke et al. 2017) and others have not (Judge et al. 2006, Shervin et al. 2007, Bozic et al. 2010) (Table 5). Baker et al. (2013), in turn, found hospital volume to be associated with lower risk of revision after unicondylar knee replacements. The effect of hospital volume on revision risk after THR has also been debated. A hospital volume of under 50 THRs has been found to be associated with increased long-term risk (>2 years) for revision after cemented THR (Glassou et al. 2016). A systematic review of the literature found an association between higher hospital volume and lower rates of hip dislocation after THR (Battaglia et al. 2006, Shervin et al. 2007). However, other studies have found no correlation between hospital volume and long-term risk for revision after THR (Kreder et al. 1997, Judge et al. 2006, Manley et al. 2008, Paterson et al. 2010, Mäkelä et al. 2011a, Katz et al. 2012, Prokopetz et al. 2012, Cossec et al. 2017).

The revision rate after fast-track THR has been reported to be between 1.4% and 2.9% within 90 days and 2.9% within one year, and the revision rate after fast-track TKR to be between 1.4 and 2% within 90 days and 3.3% within one year (Husted et al. 2008, 2011b, den Hartog et al. 2013, Glassou et al. 2014, Winther et al. 2015). No significant difference has been found in revision rates before and after fast-track TJR (den Hartog et al. 2013, Glassou et al. 2014). However, an earlier study raised the possibility of an association between the introduction of a fast-track protocol for THR and subsequent elevated infection-related revision risk (Amlie et al. 2016).

2.7 MANIPULATION UNDER ANESTHESIA (MUA)

Clear indications for MUA are unknown, but it is an effective treatment for stiff knee. Optimally, MUA should be performed within 3 months after TKR. (Kornuijt et al. 2018). In the absence of component malposition, the usual cause is unsatisfactory knee range of flexion after TKR. Several demographic (e.g. younger age), medical (e.g. diabetes) and knee-specific factors (e.g. lower preoperative range of motion) have been found to be associated with increased risk for MUA (Issa et al. 2015). Wied et al. (2015) reported a 5.8% incidence of MUA after fast-track TKR, mirroring previous reports on the incidence of MUA after non-fast-track TKR (Rubinstein and DeHaan 2010, Issa et al. 2015), while no increase in MUA incidence rates after fast-track TKR has been reported (Husted et al. 2015, Wied et al. 2015). No previous research effort has been made to study the association between MUA incidence and hospital volume.

2.8 DISCHARGE DESTINATION

Patient expectations is one of the most important factors predicting discharge destination after total joint replacement (TJR) (Halawi et al. 2015). The impact of hospital volume and shorter LOS on discharge destination has not been widely studied. It has been proposed that patients in higher volume hospitals are more likely to be directly discharged home after TJR (Bozic et al. 2010). However, shorter LOS has been coupled with a higher likelihood of discharge to an extended institutional care facility (EICF) (Paterson et al.

2010). It has also been proposed that discharging a healthy TJR patient to an EICF could lead to an increase in the number of unscheduled readmissions (Bini et al. 2010).

Two earlier fast-track studies reported no change in the proportion of patients discharged to their own homes after the introduction of a fast-track protocol, the rate remaining at about 80% after TJR (den Hartog et al. 2015, Winther et al. 2015).

2.9 MORTALITY

Death after fast-track THR or TKR is a relatively rare event, especially after TKR, and not always surgery-related (Jørgensen et al. 2017, Chan et al. 2018). Risk for death is elevated 30 to 90 days after TJR surgery, especially from causes related to the circulatory, respiratory and digestive systems (Lie et al. 2010, Hunt et al. 2014, 2017). The leading cause of death within 90 days after TJR is an ischemic heart disease (30%) (Hunt et al. 2017). Studies have reported 90-day mortality rates of 0.2%-0.5% after fast-track THR and TKR (Husted et al. 2010b, Malviya et al. 2011, Khan et al. 2014, Jørgensen et al. 2017). Savaridas et al. (2013) reported 1-year mortality of 1.3% and 2-year mortality of 2.7% with enhanced TJR recovery programs. Associations between higher hospital volume and lower mortality have been reported after both THR and TKR (SooHoo et al. 2010, Singh et al. 2011, Wilson et al. 2016). (Table 6)

Fast-tracking has been found to be associated both with and without a significant reduction in mortality after TJR (Malviya et al. 2011, Savaridas et al. 2013, Khan et al. 2014). However, for patients with a comorbidity burden at the time of surgery, mortality risk has not declined with fast-tracking (Glassou et al. 2017).

Table 1. The most relevant studies on the association between hospital volume and LOS after TJR.

Study	**Year**	**Country**	**Number of TJRs**	**TJR**	**Highest volume group**	**Hospital volume associated with longer LOS**
Hervey et al. 2003	1997	United States	50 874	TKR	250 or more	<85
Judge et al. 2006	1997-2002	United Kingdom	281 306 211 099	THR TKR	over 500 over 500	≤100 ≤100
Paterson et al. 2010	2000-2004	Canada	20 290 27 217	THR TKR	225 or more 270 or more	No association between hospital volume and LOS No association between hospital volume and LOS
Bozic et al. 2010	2003-2005	United States	182 146	THR/TKR	4th quartile	No association between hospital volume and LOS
Styron et al. 2011	2002	United States	40 333 67 13	THR TKR	225 or more 294 or more	<64 annually <100 annually
Mäkelä et al. 2011a	1998-2005	Finland	30 266	THR	over 300 THRs	<50 annually
Kaneko et al. 2014	2008	Japan	8 321	THR	55 /6 months	<55 within 6 months
Ramkumar et al, 2018	2009-2015	United States	136 501	THR	358 or more	≤120 annually

Table 2. The most relevant fast-track studies on LOS.

Study	**Year**	**Country**	**Number of TJRs**	**TJR**	**Effect of fast tracking on LOS**
Husted et al. 2010b	2004-2008	Denmark	1731	THR/TKR	LOS reduced
Husted et al. 2012	2000-2009	Denmark	104 899	THR/TKR	LOS reduced
den Hartog et al. 2013	2008-2012	Netherlands	1080	THR	LOS reduced
Glassou et al. 2014	2005-2011	Denmark	79 098	THR/TKR	LOS reduced
Winther et al. 2015	2010-2012	Norway	1069	THR/TKR	LOS reduced
Maempel eta la 2016	2005-2013	United Kingdom	1 161	THR	LOS reduced

Table 3. The most relevant studies on the association between hospital volume and readmission rate after TJR.

Study	**Year**	**Country**	**Number of TJRs or patients**	**TJR**	**Highest volume group**	**Hospital volume associated with higher readmission rate**
Judge et al. 2006	1997-2002	United Kingdom	281 306	THR/TKR	over 500	no association
SooHoo et al. 2006b	1991-2001	United States	222 684	TKR	highest 20th percentile	lowest 40th percentile vs highest 20th
Bozic et al. 2010	2003-2005	United States	182 146	THR/TKR	(4th quartile)	1st quartile vs 4th
Mäkelä et al. 2011a	1998-2005	Finland	30 266	THR	>300	no association
Cram et al. 2012	1991-2010	United States	3 271 851	TKR	4th quartile	lower quartiles
Paxton et al. 2015	2009-2011	United States	12 030	THR	≥200	<200
Kurtz et al. 2016	2010-2013	United States	442 333	THR	≥600	<450
Laucis et al. 2016	2000-2012	United States	several millions	THR/TKR	≥1000	<1000
Wilson et al. 2016	1997-2009	United States	289 976	TKR	≥645	<236
D'Apuzzo et al. 2017	1997-2014	United States	377 705	TKR	≥645	<236
Courtney et al. 2018	2014	United States	458 259	THR/TKR	≥100	<100

Table 4. The most relevant fast-track studies on readmission after TJR.

Study	Year	Country	Number of TJRs	TJR	30-day readmission	90-day readmission	Effect of fast tracking on readmissions
Husted et al. 2010b	2004-2008	Denmark	1731	THR TKR	Not studied Not studied	10.9 % 15,6%	No increase compared to literature
den Hartog et al. 2013	2008-2012	Netherlands	1080	THR	4.4%	Not studied	No change
Jørgensen et al. 2013b	2010-2011	Denmark	3222	THR/TKR	6.6%	9.3%	Not studied

Table 5. The most relevant studies on the effect of hospital volume on the revision rate after TJR.

Study	**Year**	**Country**	**Number of TJRs or patients**	**TJR**	**Highest volume group**	**Hospital volume associated with higher revision rate**
Kreder et al. 2003	1993-1996	Canada	14 352	TKR	>113 annually	<48 vs >113
Judge et al. 2006	1997-2002	United Kingdom	281 306 211 099	THR TKR	> 500 annually	≤500 no association
Manley et al. 2008	1997-2004	United States	26 036	THR	> 100 annually	no association
Manley et al. 2009	1997-2004	United States	53 971	TKR	> 200 annually	<25 vs >200
Paterson et al. 2010	2000-2004	Canada	20 290 27 217	THR TKR	≥ 225 annually ≥ 270 annually	no association 1st quartile vs 3rd and 4th
Bozic et al. 2010	2003-2005	United States	182 146	THR TKR	4th quartile	no association
Katz et al. 2012,	1995-1996	Canada	51 347	THR	> 50 annually	<25 vs >50
Badawy et al. 2013	1994-2010	Norway	26 698	TKR	≥ 150 annually	<25 vs ≥100
Glassou et al. (2016)	1995-2011	Nordic countries	417 687	THR	> 300 annually	≤50 (only cemented)
Jeschke et al. 2017	2012	Germany	45 165	TKR	5th quintile (>252)	<145

Table 6. The most relevant studies on mortality after TJR.

Study	**Year**	**Country**	**Number of TJRs or patients**	**TJR**	**Fast-track setting**	**Mortality**	**Hospital annual volume associated with higher mortality**
Husted et al. 2010b	2004-2008	Denmark	1731	THR/TKR	yes	0.8% within 90 days	not studied
SooHoo et al. 2010	1995-2005	United States	138 399	THR	no	0.7% within 90 days	< the highest 20th percentile
Singh et al. 2011	2002	United States	10 187	THR/TKR	no	2.5% within year	≤100
Malviya et al. 2011	2008-2009	United Kingdom	4500	THR/TKR	yes	0.2% within 90 days, reduced after fast-tracking	not studied
Savaridas et al. (2013)	2004-2008	United Kingdom	4500	THR/TKR	yes	1.3% within 1 year, reduced after fast-tracking	not studied
Khan et al. 2014	2004-2008	United Kingdom	6000	THR/TKR	yes	0.5% within 90 days	not studied
Wilson et al. 2016	1997-2009	United States	289 976	TKR	no	0.3% within 90 days	≤645
Glassou et al. 2017	1996-2013	Denmark	163 680	THR/TKR	no	mortality has declined over past 18 years	not studied
Jørgensen et al. 2017	2010-2013	Denmark	6553 7222	THR TKR	yes yes	0.4% within 90-days 0,2% within 90 days	not studied not studied

3 Aims of the study

The aim of the present study was to evaluate the effect of hospital procedure volume and implementation of fast-tracking on outcomes after THR and TKR from the organizational perspective. Specifically, the aims were:

1. To evaluate the association of hospital THR or TKR volume with LOS and LUIC, number of readmissions and revisions on the population level in Finland (I, II).

2. To evaluate the effect of fast-tracking on LUIC, LOS, readmissions, early revision, and mortality rates after TKR (III, IV).

3. To evaluate the effect of hospital volume and introduction of the fast-track protocol on discharge destination after THR or TKR (II, III, and IV).

4. To evaluate the effect of hospital volume and the introduction of a fast-track protocol on MUA after TKR (II, IV).

4 Materials and methods

4.1 PATIENTS

4.1.1 Effect of hospital volume on outcome after THR and TKR (Studies I and II)

The study population was formed by selecting operations from the Finnish Arthroplasty Register and the Hospital Discharge Register according to the WHO International Statistical Classification of Diseases and Related Health Problems (ICD-10 2010), applying the following criteria: M16.0/M16.1 for primary osteoarthritis (OA) of the hip or M16.2/M16.3 (Study I) for developmental dysplasia of the hip (DDH), associated with a code for primary THR over the period 1998–2010; and M17.0/M17.1 (Study II) for primary OA of the knee, associated with a code for primary TKR performed over the period 1998–2010. The codes for primary THR were NFB30, NFB40, NFB50, NFB60, NFB62, and NFB99 and the codes for primary TKR were NGB20, NGB30, NGB40 and NGB50. The accuracy of the diagnosis of primary OA was double-checked against the relevant data in the Finnish Arthroplasty Register. In Study II, unlike in Study I, the analyses only included patients′ first TKRs during the study period (Jan 1, 1998-Dec 31, 2010). This was done to minimize bias from bilateral observations. Total hip and knee replacements — not patients — were evaluated when considering the length of the surgical treatment period, length of institutional care, and unscheduled readmissions. The analysis included a total of 54 505 THRs and 59 696 TKRs. However, revisions in Studies I-II and MUA in Study II were only evaluated in patients with unilateral THR (n = 38 237) and unilateral TKR (n = 47 217) over the period 1987–2011 (Table 7), as the laterality of the MUA and revision surgery performed was not reliably coded in the hospital discharge register.

A patient was excluded from the study if a diagnosis of secondary OA had been recorded in the Hospital Discharge Register between the beginning of 1987 and the day of the operation (Table 8 and 9). Patients in the Social Insurance Institution database who were eligible for special reimbursement for drugs required to treat the sequelae of transplantation, uremia requiring dialysis, rheumatoid arthritis, or connective tissue disease were excluded from the study. In addition, we excluded patients with hip or other knee arthroplasty performed simultaneously, patients who were residents of Åland and patients who were not Finnish citizens.

Table 7. Number and percentage of hip (Nh-los) (I) and knee (Nk-los) (II) replacements in cohorts when analyzing length of stay and unscheduled readmissions, and number and percentage of hip (Nh-rev) and knee (Nk-rev) replacements in cohorts when analyzing revisions.

Cohort	**No. (Nh-los) of hips (%)**	**No. (Nh-rev) of hips (%)**	**No. (Nk-los) of knees (%)**	**No. (Nk-rev) of knees (%)**
1998	2858 (5.24)	1855 (4.85)	2959 (5.0)	1667 (3.5)
1999	3012 (5.53)	1916 (5.01)	2923 (4.9)	1787 (3.8)
2000	3262 (5.98)	2048 (5.36)	3138 (5.3)	2028 (4.3)
2001	3477 (6.38)	2279 (5.96)	3347 (5.6)	2281 (4.8)
2002	3852 (7.07)	2525 (6.60)	3850 (6.5)	2743 (5.8)
2003	4222 (7.75)	2862 (7.48)	4436 (7.4)	3209 (6.8)
2004	4018 (7.37)	2766 (7.23)	4055 (6.8)	3055 (6.5)
2005	4889 (8.97)	3413 (8.93)	5540 (9.3)	4443 (9.4)
2006	5249 (9.63)	3765 (9.85)	5995 (10.0)	4973 (10.5)
2007	4825 (8.85)	3546 (9.27)	5528 (9.3)	4719 (10.0)
2008	5305 (9.73)	3967 (10.37)	5998 (10.1)	5356 (11.3)
2009	4740 (8.70)	3654 (9.56)	5947 (10.0)	5425 (11.5)
2010	4796 (8.80)	3641 (9.52)	5980 (10.0)	5531 (11.7)
Total	54505 (100)	38237 (100)	59696 (100)	47217 (100)

Nh-rev is smaller than Nh-los, and Nk-rev is smaller than Nk-los, as only unilateral implants were included in the Nh-rev and Nk-rev cohorts.

Table 8. Exclusion criteria in Studies I and III (ICD-10 diagnosis).

S72.0	Fracture of neck of femur
S72.1	Pertrochanteric fracture of femur
S72.2	Subtrochanteric fracture of femur
M19.1	Juvenile osteochondrosis of head of femur (Legg-Calvê-Perthes)
M93.0	Slipped upper femoral epiphysis (nontraumatic)
S32.4	Fracture of acetabulum
M45.*	Ankylosing spondylitis
Q65.*	Congenital deformities of the hip
M16.4	Post-traumatic coxarthosis
M16.5	Other post-traumatic coxarthrosis
M16.6	Other secondary coxarthrosis, bilateral
M16.7	Other secondary coxarthrosis
M16.9	coxarthrosis, unspecified
M87.*	Osteonecrosis
M00.*	Pyogenic arthritis
M05.*	Seropositive rheumatoid arthritis
M06.*	Other rheumatoid arthritis
M07.*	Psoriatic and enteropathic arthropathies
M08.*	Juvenile arthritis
D66	Hereditary factor VIII deficiency
D67	Hereditary factor IX deficiency
D68	Other coagulation defects
M36.2	Hemophilic arthropathy
Q77	Osteochondrodysplasic with defects of growth of tubular bones and spine
Q78	Other osteochondrodysplasias
Q79	Congenital malformations of the musculoskeletal system, not elsewhere classified

*Includes all diagnoses in this diagnostic group

Table 9. Exclusion criteria in Studies II and IV (ICD-10 diagnosis).

S82.0	Fracture of patellae
S82.1	Fracture of proximal tibia
S82.7	Multiple fractures of knee
S82.8	Other fracture of knee or tibia
S82.9	Fracture of knee ort tibia, unspecified
M45.*	Ankylosing spondylitis
M17.2	Post-traumatic bilateral knee-arthrosis
M17.3	Other post-traumatic knee-arthrosis
M17.4	Other secondary knee-arthrosis, bilateral
M17.5	Other secondary knee-arthrosis
M17.9	Knee-arthrosis, unspecified
M87.*	Osteonecrosis
M00.*	Pyogenic arthritis
M05.*	Seropositive rheumatoid arthritis
M06.*	Other rheumatoid arthritis
M07.*	Psoriatic and enteropathic arthropathies
M08.*	Juvenile arthritis
D66	Hereditary factor VIII deficiency
D67	Hereditary factor IX deficiency
D68	Other coagulation defects
M36.2	Haemophilic arthropathy
Q77	Ostechondrodysplasia with defects of growth of tubular bones and spine
Q78	Other osteochondrodysplasia
Q79	Congenital malformations of the musculoskeletal system, not elsewhere classified

*Includes all diagnoses in this diagnostic group

4.1.2 Effect of fast-tracking on outcomes after THR and TKR (III and IV)

For the studies on the effect of fast-tracking on outcomes after primary TJR (III, IV), we selected four similar Finnish public central hospitals, all with some teaching responsibilities, from a benchmarking database maintained by the Nordic Healthcare Group (NHG). Implementation of a fast-track protocol started in September 2011 in Hospital A, which soon after that date fulfilled all the fast-track criteria. The other hospitals (Hospitals B, C, and D) did not meet the fast-track criteria to the same extent (Table 10). The characteristics of the hospitals, drawn from the benchmarking database, are given in Table 11.

The study population was formed by selecting patients from the FHDR according to the WHO International Statistical Classification of Diseases and Related Health Problems (ICD-10) and applying the following criteria: M16.0/M16.1 for primary osteoarthritis (OA) of the hip or M16.2/M16.3 for developmental dysplasia of the hip (DDH) and M17.0/M17.1 for primary osteoarthritis (OA) of the knee, linked respectively with a code for primary THR or TKR during the same treatment period for operations performed over the periods 2009-2010 and 2012-2013. Patients with diagnosed DDH were included in the study owing to variation in the coding of mild DDH and primary OA. For primary THR, the codes were NFB30, NFB40, NFB50, NFB60, NFB62, and NFB99, and for primary TKR they were NGB20, NGB30, NGB40 and NGB50, according to the NOMESCO classification of surgical procedures, Finnish version. The accuracy of the diagnosis of primary OA was double-checked against the relevant data in the FAR. It should be noted that the length of the surgical treatment period, the length of institutional care, and unscheduled readmissions were evaluated for total hip and knee replacements — not for patients. In contrast to Study II, both sides were included if the operations were not performed simultaneously. Otherwise, the same exclusion criteria were used in Studies I and III as in Studies II and IV. The populations of Studies III and IV meeting the inclusion criteria are presented in Table 12.

Table 10. Criteria for a hospital to be characterized as a fast-track hospital. Fast-track TJR was implemented in Hospital A in 2011 and the criteria were fully met in 2012 and 2013.

Criteria	**Hospital A**		**Hospital B**		**Hospital C**		**Hospital D**	
	2009-2010	**2012-2013**	**2009-2010**	**2012-2013**	**2009-2010**	**2012-2013**	**2009-2010**	**2012-2013**
Standardized preoperative patient education aiming at early discharge home		X	X	X	X	X		since 2013
-Information on discharge criteria								
-Information on early mobilization								
-Information on pain management								
No routine use of drains	X	X	X	X	X	X	X	X
No standard use of urine catheters	X	X	X	X	X	X		
Discharge criteria from PACU		X						
Standardized anesthesia: low-dose spinal or general (TIVA) anesthesia (Opioid sparing)		X						
Standardized analgesia (multimodal opioid sparing)		X						
Mobilization on the day of surgery		X		since 2013			X	X
Discharge criteria (checking the fulfillment of discharge criteria several times per day)		X						

Table 11. Characteristics of the four benchmark hospitals included in the study. Hospital A was defined as a fast-track hospital after 2011.

	2009-2010				2012-2013			
Hospital characteristics	**Hospital A**	**Hospital B**	**Hospital C**	**Hospital D**	**Hospital A**	**Hospital B**	**Hospital C**	**Hospital D**
Orthopedic surgeons	9	6	7	8	11	6	7	12
Nurses	51	35	52	44	44	28	35	45
Beds in ward	65	46	65	47	59	31	39	42
Only arthroplasty patients in the ward			X				X	
Only orthopedic patients in the ward	X				X			
Orthopedic and trauma patients in the ward				X				X
Orthopedic, trauma and other surgery patients in the ward		X				X		
Posterior approach, number of surgeons	7	4	2	7	7(2012) 6(2013)	4	2	7
Anterolateral approach, number of surgeons	1	1	1	2 (2009) 1(2010)	0	1(2013)	1	1
Physiotherapist available at weekends		X	X	X		X	X	X
Teaching hospital	X	X	X	X	X	X	X	X

Table 12. Study populations in Studies III and IV. No statistically significant age or sex differences were observed before or after fast tracking in Hospital A, or between hospital A and the other hospitals.

Hospital	THRs (III)		TKRs (IV)	
	2009-2010	2012-2013	2009-2010	2012-2013
A	464	437	437	624
B	265	302	367	442
C	402	424	501	514
D	375	524	641	730
Total	1506	1687	1946	2310

4.2 METHODS

All public and private hospitals in Finland are obliged to report all surgical procedures to the Finnish Hospital Discharge Register (FHDR). Studies I-IV are all based on the PERFECT hip and knee replacement databases (Mäkelä et al. 2011), which use data from the Hospital Discharge Register (maintained by the National Institute for Health and Welfare), cause of death statistics published by Statistics Finland, the Social Insurance Institution's Drug Prescription Register and the Special Refund Entitlement Register, and the Finnish Arthroplasty Register (maintained by the National Institute for Health and Welfare).

4.2.1 Effect of hospital volume on outcome after THR and TKR (Studies I and II)

The association of hospital volume with LOS, LUIC, discharge destination, unscheduled readmissions, revisions (I and II) and MUA (II) were evaluated.

4.2.1.1 Definition of LOS and LUIC (Studies I and II)

LOS was counted as the number of postoperative nights in hospital until discharge, as recorded in the FHDR. LOS terminated in either discharge to home, transfer to another facility, or death. LUIC was defined as the combined surgical treatment period and any immediately following period of uninterrupted institutional care. Any rehabilitation given in an outpatient setting or at home was not included. LUIC ended in either death or discharge of the patient to home. LUIC includes patient transfers to another facility such as an old people’s home or institution run by a social welfare organization. In the analyses, the maximum length of institutional care was limited to 60 days. It was deemed that if a patient remains in a health care facility for more than 60 consecutive days after TKR, the reason is not directly related to the operation. The study period was from 1998 to 2010. Patients were followed until the end of 2011.

4.2.1.2 Hospital grouping (Study I)

In Study I, hospitals (n = 78) were classified into 4 groups according to their annual number of primary and revision THRs and TKRs (Nordic Medico-Statistical Committee (NOMESCO) codes NFB30-NFB99, NFC00-NFC99, NGB10-NGB99, NGC00-NGC99) performed for any reason throughout study period: 1–199 (low-volume hospitals, group 1), 200–499 (medium-volume hospitals, group 2), 500–899 (high-volume hospitals, group 3), and >900 (very-high-volume hospitals, group 4) (Table 13). Grouping was based on the annual volume of a hospital, with the annual period defined as from Jan 1st to Dec 31. Group 4 was used as the reference in the statistical analyses.

4.2.1.3 Hospital grouping (Study II)

In Study II, hospitals (n = 80) were classified into 4 groups according to the annual number of primary and revision TKRs (Finnish version of Nordic Medico-Statistical Committee (NOMESCO) codes, NGB10 (unicondylar knee arthroplasty), NGB20-60 (TKRs), NGB99 (other knee arthroplasty), NGC00-NGC99 (revision knee arthroplasties)) performed for any reason throughout the study period: 1–99 (low-volume hospitals, group 1), 100–249 (medium-volume hospitals, group 2), 250–449 (high-volume hospitals, group 3), and ≥450 (very-high-volume hospitals, group 4) (Table 14). Grouping was based on the annual volume of a hospital, with the annual period defined as from Jan 1st to Dec 31. Group 4 was used as the reference in the statistical analyses.

Table 13. Number of THR patients and annual number of hospitals in the different hospital volume groups in Finland, with annual number of private hospitals in shown in parentheses (I).

Group	**No. of patients**	**Annual no. of hospitals**												
	1998 -2010	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	12104	40(9)	40(10)	44(11)	42(11)	39(11)	32(11)	32(11)	29(10)	26(10)	27(12)	23(10)	23(12)	22(11)
2	18075	14(0)	17(0)	14(0)	16(1)	18(2)	16(2)	16(1)	19(3)	18(3)	16(1)	18(2)	18(1)	17(2)
3	13029	3(1)	4(1)	5(1)	6(1)	6(1)	7(1)	5(1)	6(1)	9(1)	8(1)	9(1)	7(0)	8(0)
4	11297	0	0	0(0)	0(0)	1(0)	2(1)	3(1)	4(1)	4(1)	4(1)	3(1)	4(1)	5(1)
Total	54505	57(10)	61(11)	63(12)	64(13)	64(14)	57(15)	56(14)	58(15)	57(15)	55(15)	53(14)	52(14)	52(14)

Hospitals were classified into 4 groups according to their mean number of primary and revision THRs and TKRs: 1–199 (low-volume hospitals, group 1), 200–499 (medium-volume hospitals, group 2), 500–899 (high-volume hospitals, group 3), and > 900 (very-high-volume hospitals, group 4).

Table 14. Number of TKR patients and annual number of hospitals in different hospital volume groups in Finland, with annual number of private hospitals shown in parentheses (II).

Group	No. of TKRs	Annual number of the hospitals												
	1998 -2010	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	11673	43(10)	44(9)	45(12)	44(11)	37(11)	31(12)	32(12)	31(14)	24(11)	26(13)	22(11)	24(13)	21(12)
2	21681	15(1)	16(1)	16(1)	17(1)	21(2)	18(2)	18(2)	21(3)	23(4)	20(2)	20(2)	16(1)	17(2)
3	12960	1(0)	1(0)	2(0)	3(1)	5(1)	6(0)	5(0)	7(1)	7(1)	7(0)	9(1)	8(0)	9(0)
4	13385	0	0	0(0)	0(0)	1(0)	2(1)	2(1)	4(1)	5(1)	3(1)	4(1)	6(1)	6(1)
Total	59699	59(11)	61(10)	63(13)	64(13)	64(14)	57(15)	57(15)	63(19)	59(17)	56(16)	55(15)	54(15)	53(15)

Hospitals were classified into 4 groups according to their mean number of primary and revision TKRs: 1–99 (low-volume hospitals, group 1), 100–249 (medium-volume hospitals, group 2), 250–449 (high-volume hospitals, group 3), and > 450 (very high-volume hospitals, group 4)

4.2.1.4 Unscheduled readmissions (Studies I and II)

An unscheduled readmission was recorded if a patient was re-admitted to hospital or had required medical attention in an outpatient department or emergency unit of any hospital in Finland during the first 14 or 42 days after discharge. Readmission within 14 days (2 weeks) was chosen as a marker of early complications. Readmission within 42 (6 weeks) days was chosen to estimate the total unplanned readmission rate. In Finland, scheduled post-operative visits typically take place between 8 and 12 weeks.

4.2.1.5 Revision (Studies I and II)

Revision for any cause (including removal or exchange of a component) on the same hip or knee after primary THR or TKR was deemed a revision. Patients were followed until the end of 2011. We decided to evaluate revisions instead of all reoperations as bias arising from bilateral observations for reoperations was more difficult to control for, as the laterality of the operations was not reliably coded in the hospital discharge register.

4.2.1.6 Statistics (Studies I and II)

A Poisson regression model for LOS and LUIC and a logistic regression model for revisions and readmissions at the individual level were used, with hospital volume (classified) as the explanatory variable. Adjusted estimates are given for all the dependent variables. In addition, 95% confidence intervals (CIs) were determined. Patient age (under 40 years, over 40 years (divided into 9 5-year incremental groups up to age 85, and over 85 years), sex, any previous THR (I) or TKR (II), co-morbidities and femoral head size (I) were included in all the adjusted analyses. The LOS and LUIC models also included dummies for the operation year. Co-morbidities were determined using the diagnoses obtained from the Hospital Discharge Register from the beginning of 1987 to the date of operation. In addition, the Social Insurance Institution database for eligibility for special reimbursement or for purchase of prescription drug, was used to adjust for co-morbidity (Table 15). The illnesses controlled for were of the kind that might have had an effect on prosthesis survivorship after THR or TKR (Jämsen et al. 2013), on LOS in the hospital, or on the rate of complications. Length of follow-up was also identified as a confounding factor for adjustment of the rates of revisions. P-values for the differences between mean LOS and LUIC in the hospital volume groups were calculated by the Tukey-Kramer test.

In Study II, the bias from bilateral observations was minimized by only including patients first TKR in the analyses for LOS, LUIC and readmissions. In Studies I-II only unilateral cases were included in the revision and MUA analyses.

Table 15. Comorbid diseases used in adjusting the results.

Hypertension	(ICD-10: I10*-I15*, ICD-9: 40*, entitlement to reimbursement from Social Insurance Institution: 205, use and cost of drugs ATC: C03*, C07* (if no coronary disease or atrial fibrillation), C09A*, C09B*, C09C*, C09D*, C08*)
Coronary disease	(ICD-10: I20*-I25*, ICD-9: 410*-414*, entitlement to reimbursement from Social Insurance Institution: 206, 213,280)
Atrial fibrillation	(ICD-10: I48*, ICD-9: 4273*, entitlement to reimbursement from Social Insurance Institution: 207, use and cost of drugs ATC: B01AA03)
Heart insufficiency	(ICD-10: I50*, ICD-9: 428*, entitlement to reimbursement from Social Insurance Institution: 201)
Diabetes	(ICD-10: E10*-E14*, ICD-9: 250*, entitlement to reimbursement from Social Insurance Institution: 103 use and cost of drugs ATC-DDD: A10A*, A10B*)
Cancer	(ICD-10: C00*-C99*, D00*-D09*, ICD-9: 140*-208*, entitlement to reimbursement from Social Insurance Institution: 115,116, 117, 128, 130, 180, 184, 185, 189, 311, 312, 316, use and cost of drugs ATC L01* except L01BA01)
COPD and asthma	(ICD-10: J44*-J46*, ICD-9: 4912*, 496*, 493*, entitlement to reimbursement from Social Insurance Institution: 203, use and cost of drugs ATC: R03*)
Depression	(ICD-10: F32*-F34*, ICD-9: 2960*, 2961*, 2069*, use and cost of drugs ATC: N06A*)
Parkinson's disease	(ICD-10: G20*, ICD-9: 332*, entitlement to reimbursement from Social Insurance Institution: 110, use and cost of drugs ATC: N04B*)
Dementia	(ICD-10: F00*-F03*, G30*, ICD-9: 290*, 3310*, entitlement to reimbursement from Social Insurance Institution: 307, use and cost of drugs ATC: N06D*)
Renal insufficiency	(ICD-10: N18*, ICD-9: 585*, entitlement to reimbursement from Social Insurance Institution: 137)
Mental disorders	(ICD-10: F20*-F31*, ICD-9: 295*-298*, except 2960*, 2961*, entitlement to reimbursement from Social Insurance Institution: N05A* except N05AB04 and N05AB01 and if no dementia)

4.2.2 Effect of fast-tracking on outcome after THR and TKR (Studies III and IV)

A hospital was classified as a fast-track hospital if it met all the fast-track criteria (Table 10). Fulfillment of the fast-track criteria were evaluated from answers to a written questionnaire sent to each participating hospital.

In comparison with the FHDR, the coverage of the FAR for primary hip replacements in the four target hospitals during the study period was 88% in Hospital A, 93% in Hospital B, 79% in Hospital C and 97% in Hospital D, and for primary knee replacements coverage was 91% in Hospital A, 96% in Hospital B, 81% in Hospital C and 97% in Hospital D (National Institute for Health and Welfare 2017). We evaluated LOS, LUIC, discharge destination, presence at home one-week post-surgery, readmissions, revisions and mortality in Studies III-IV and MUA in Study IV across two two-year periods, one before (2009-2010) and one after (2012-2013) fast-track implementation in Hospital A. Patients were followed up until the end of 2015. The results for Hospital A were also compared to those for the other hospitals (Hospitals B, C and D). However, readmission and MUA rates were not compared to those of the other hospitals due to variation in the readmission and MUA criteria.

LOS and LUIC were defined in the same manner as in Studies I and II.

4.2.2.1 Readmission (Studies III and IV)

A readmission was recorded if the patient had been re-admitted after discharge to any ward in any hospital in Finland during the first 14 or 42 days from the index operation. Readmissions did not include a direct transfer to another hospital or visit to an outpatient department or emergency unit. Only first readmissions for any reason after the index operation (also readmissions not directly related to the index THR or TKR operation) were included in the study.

4.2.2.2 Revision and MUA (Studies III and IV)

A systematic search for revision surgery on the same hip after THR was conducted using codes NFC00, NFC20, NFC30, NFC40, NFC50, NFC99, and revision surgery of the same knee after TKR was conducted using codes NGC00-NGC99. A search for MUA was conducted using code NGT60. A search for removal of the total prosthesis from the hip or knee was made in the Finnish Arthroplasty Register. Patients were followed up until the end of 2015. Only first revisions of the same hip or knee within 1 year of the primary THR or TKR were included. Only the first MUA of the same knee within 6 months of the primary TKR was included (IV). Non-standardized indications for MUA (IV) were flexion <90 degrees or unsatisfactory flexion.

4.2.2.3 Discharge destination and the percentage of patients who were at home one week after THR or TKR (Studies III and IV)

Some patients are admitted to hospital from other social and welfare institutions and therefore are unlikely to be discharged home. Thus, only patients who came from home to hospital for their THR or TKR were included in the discharge destination analyses. The percentage of patients who were at home one week after THR or TKR was also analyzed irrespective of the hospital discharge destination.

4.2.2.4 Statistics (Studies III and IV)

To adjust the dependent variables for confounding factors, we used Poisson regression models for LOS and LUIC and logistic regression models for revisions, readmissions, mortality, home one week after THR or TKR and discharge destination at the individual level. In addition, 95% confidence intervals (CIs) were determined. Patient ages (under 40 years, over 40 years (divided into 9 5-year incremental groups up to age 85, and over 85 years)), sex, any previous THR (III) or TKR (IV), co-morbidities and femoral head size were included in all the adjusted analyses. Co-morbidities were determined using the diagnoses obtained from the Hospital Discharge Register from the beginning of 1987 to the date of surgery. In addition, the Social Insurance Institution database showing eligibility for reimbursement for medication costs and drug prescription was used to adjust for co-morbidity (Table 15). The illnesses chosen for adjustment were those that could potentially affect prosthesis survivorship after THR (III) or TKR (IV), length of hospital stay, or the complications rate (Jämsen et al. 2013).

Differences in median LOS and in median LUIC were tested with the Mann-Whitney U-test (Wilcoxon rank sum test). Median values for LOS and LUIC were used owing to skewed distributions. The results for LOS and LUIC are presented with CIs and p values. Differences in discharge destination, home one week after THR or TKR, readmission, gender and age of patients were tested with the $\chi 2$ test and the results are presented with CIs and with p-values where appropriate. P-values less than 0.05 were considered statistically significant.

4.3 ETHICAL ISSUES (STUDIES I-IV)

Permission for Studies I-IV were obtained from each register, and for studies III-IV also from each study hospital. No ethical review board approval was required to perform these registry studies.

5 Results

5.1 STUDIES I AND II

The incidence of primary THRs and TKRs (those meeting the inclusion criteria) in Finland increased steadily up to 2006, peaking at approximately 5 000 operations for THR and 6 000 operations for TKR per year (Table 7). During the study period, hospital procedure volume increased while the number of public hospitals, particularly low-volume hospitals, decreased (Table 13).

5.1.1 LOS and LUIC

Both LOS and LUIC after THR and TKR declined steadily during the study period (Figures 2a, 2b, 3a and 3b). Poisson regression adjusting for age, sex, any previous TKR and co-morbidities showed that the larger the volume, the shorter the risk-adjusted mean LOS and LUIC (Tables 16 and 17). In addition, LOS analyses taking discharge disposition into account were also performed in Study II, and no change was observed. Distributions of age, sex and any previous TKR in the volume groups in Study II are given in Table 18.

If all the THRs and TKRs between years 2002 and 2010 in Finland had been performed in the very-high-volume hospitals, total LOS would have decreased by 137 551 days: 71 156 days for THR and 66 355 days for TKR. This would have meant a saving of 1.7 inpatient care days per every operated THR patient and a saving of 1.4 inpatient care days per every operated TKR patient. The mean length of stays and number of arthroplasties included in the calculations are presented in Figures 2a, 2b, 3a, 3b, 4a and 4b.

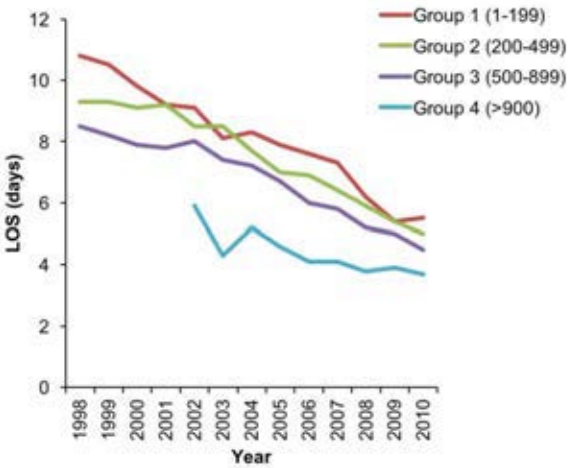

Figure 2a. LOS: annual mean length of stay (surgical treatment period) in days for primary total hip arthroplasty in the different hospital volume groups. Between 1998 and 2001 there were no hospitals in hospital volume group 4. Hospitals were classified into 4 groups according to the annual number of primary and revision THRs and TKRs: 1–199 (group 1), 200–499 (group 2), 500–899 (group 3), and >900 (group 4).

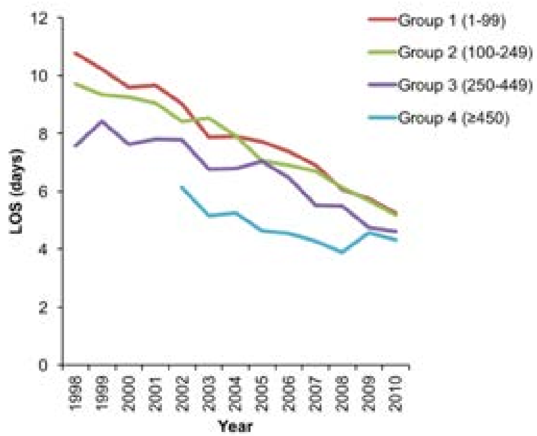

Figure 2b. LOS: annual mean length of stay (surgical treatment period) in days for primary total knee arthroplasty in the different hospital volume groups. Between 1998 and 2001 there were no hospitals in hospital volume group 4. Hospitals were classified into 4 groups according to the number of both primary and revision TKRs: 1–99 (group 1), 100–249 (group 2), 250–449 (group 3), and ≥450 (group 4).

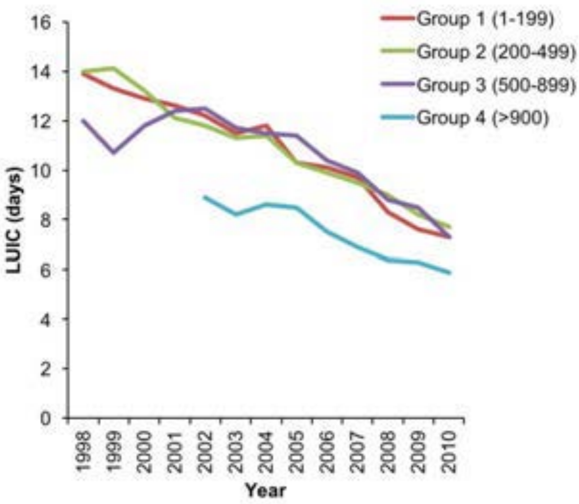

Figure 3a. LUIC: annual mean lengths of uninterrupted institutional care in days for primary total hip arthroplasty in the different hospital volume groups in Study I. Between 1998 and 2001 there were no hospitals in hospital volume group 4. Hospitals were classified into 4 groups according to the annual number of primary and revision THRs and TKRs: 1–199 (group 1), 200–499 (group 2), 500–899 (group 3), and >900 (group 4).

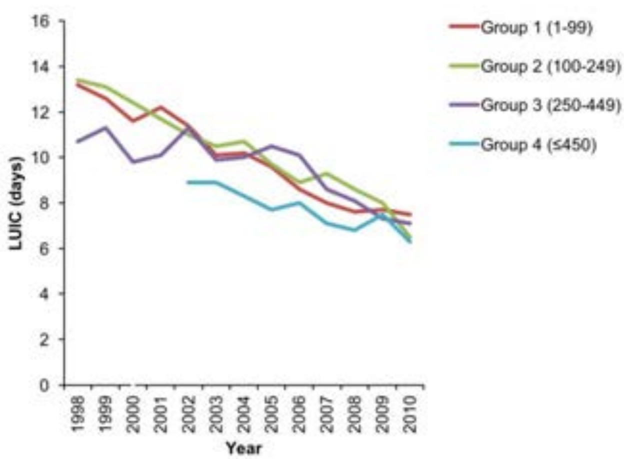

Figure 3b. LUIC: annual mean lengths of uninterrupted institutional care in days for primary total knee arthroplasty in the different hospital volume groups in Study II. Between 1998 and 2001 there were no hospitals in hospital volume group 4. Hospitals were classified into 4 groups according to the number of both primary and revision TKRs: 1–99 (group 1), 100–249 (group 2), 250–449 (group 3), and ≥450 (group 4).

Table 16. Mean LOS and LUIC after THR during the study period 1998-2010 and p-values for all pairwise comparisons of LOS and LUIC.

			All pairwise comparisons of means of LOS and LUIC			
	Mean LOS	**Mean LUIC**	**Group 1**	**Group 2**	**Group 3**	**Group 4**
Group 1	8,5	11,4		p<0,01	p<0,01	p<0,01
Group 2	7,7	11,0	p<0,01		p<0,01	p<0,01
Group 3	6,7	10,7	p<0,01	p<0,01		p<0,01
Group 4	4,4	7,5	p<0,01	p<0,01	p<0,01	

LOS: mean length of stay (surgical treatment period) in days. LUIC: mean length of uninterrupted institutional care in days.

Table 17. Group-specific estimated mean (95% confidence intervals) LOS and LUIC after TKR during the study period 1998-2010, and number of TKRs.

Group	LOS	95% CI	LUIC	95% CI	TKR
1	8.60	8.53-8.67	10.72	10.58-10.86	11661
2	7.59	7.54-7.63	10.18	10.07-10.28	21679
3	6.14	6.10-6.18	9.12	9.00-9.26	12966
4	4.51	4.47-4.55	7.39	7.26-7.51	13390

LOS: mean length of stay (surgical treatment period) in days. LUIC: mean length of uninterrupted institutional care in days. TKR: total knee replacement

Table 18. Percentage distributions of age, gender and any previous TKR in the volume groups.

	Age (%)												Any previous TKR in 1987-1997 (%)
Group	<40	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85	Gender female (%)	
1	0	0.2	0.9	3.1	7.2	11.8	18.5	24.8	21.8	9.7	2.1	69.6	8.5
2	0	0.2	1.1	3.9	8.3	12.7	18.2	23.0	21.0	9.6	2.1	70.3	8.9
3	0.1	0.2	1.2	4.2	9.7	13.2	17.8	22.2	19.9	9.3	2.2	68.2	6.5
4	0.0	0.3	1.7	4.7	11.3	14.1	17.1	19.8	19.2	9.2	2.6	68.9	5.2

Hospitals were classified into 4 groups according to the mean number of primary and revision TKRs and THRs: 1–99 (low-volume hospitals, group 1), 100–249 (medium-volume hospitals, group 2), 250–449 (high-volume hospitals, group 3), and > 450 (very-high-volume hospitals, group 4)

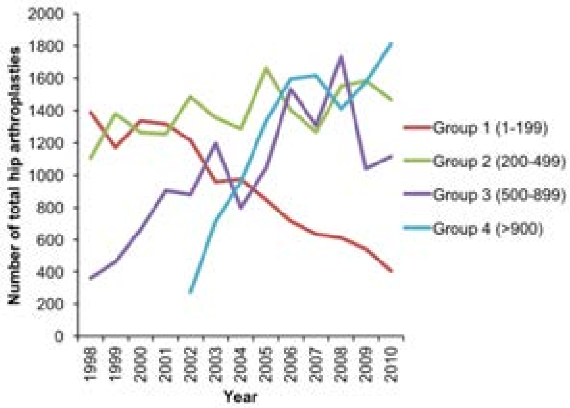

Figure 4a. Annual number of total hip replacements (THR) in different hospital volume groups in Study I. Between 1998 and 2001 there were no hospitals in hospital volume group 4. Hospitals were classified into 4 groups according to the annual number of primary and revision THRs and TKRs: 1–199 (group 1), 200–499 (group 2), 500–899 (group 3), and >900 (group 4).

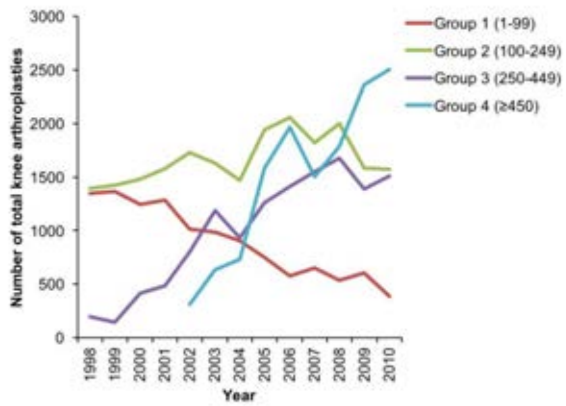

Figure 4b. Annual number of total knee replacements (TKR) in the different hospital volume groups in Study II. Between 1998 and 2001 there were no hospitals in hospital volume group 4. Hospitals were classified into 4 groups according to the number of both primary and revision TKRs: 1–99 (group 1), 100–249 (group 2), 250–449 (group 3), and ≥450 (group 4).

5.1.2 Revisions and readmissions

The adjusted data showed no statistically significant associations between the hospital volume groups and number of revisions after THR (Table 19) (I). In Study II, the adjusted data showed fewer revisions after TKR in the group 4 hospitals than in either the group 2 (OR = 1.27; 95% CI: 1.12-1.44) or group 3 (OR = 1.20; 95% CI: 1.05-1.37) hospitals. However, no statistically significant differences in risk for revisions after TKR were observed in hospital groups 4 and 1 (Table 20) (II).

After THR, no significant differences were observed in the 14-day readmission rate between group 1 and group 4. However, 42-day readmissions were more common in group 1 than in group 4 (I). In study II, readmissions within 14 days (OR = 1.10; 95% CI: 1.00-1.21) and within 42 days (OR = 1.11; 95% CI: 1.03-1.19) after TKR were more common in the group 1 than group 4 hospitals. Nevertheless, had all the THRs performed between the years 2002 and 2010 in Finland been carried out in the very-high-volume hospitals, this would have meant only 121 fewer readmissions within 42 days (I). Similarly, had all the group 1 TKRs performed between the years 2002 and 2010 in Finland been performed in the very-high-volume hospitals, this would have meant only 159 fewer readmissions within 42 days (II).

In study II, MUA was less frequent in group 4 than group 3 (OR = 1.44; 95% CI: 1.22-1.70) hospitals. However, no statistically significant difference in MUA was observed between group 4 and the other groups (Table 20). Short LOS did not increase the risk for MUA.

Table 19. Adjusted odds ratios for unscheduled readmissions within 14 and 42 days, and for revisions after THR.

	Readmissions 14 days		**Readmissions 42 days**		**Revisions**	
Groups	OR	95% CI	OR	95% CI	OR	95% CI
1 vs. 4	1.06	0.96-1.17	1.14	1.05-1.23	1.07	0.92-1.23
2 vs. 4	1.02	0.93-1.09	1.01	0.95-1.09	1.11	0.98-1.26
3 vs. 4	0.87	0.79-0.96	0.92	0.86-0.99	0.88	0.76-1.01

Table 20. Adjusted odds ratios for unscheduled readmissions within 14 and 42 days, for revisions and for manipulation under anesthesia (MUA) after TKR.

	Readmissions14 days		**Readmissions 42 days**		**Revisions**		**MUA**	
Groups	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
1 vs. 4	1.10	1.00-1.21	1.11	1.03-1.19	1.08	0.93-1.26	0.92	0.74-1.15
2 vs. 4	1.04	0.97-1.12	1.05	0.99-1.11	1.27	1.12-1.44	1.14	0.97-1.34
3 vs. 4	0.98	0.90-1.06	0.99	0.93-1.05	1.20	1.05-1.37	1.44	1.22-1.70

Logistic regression models were used to adjust for patient age, sex, any previous TKR and co-morbidities. In addition, length of follow-up was controlled for in the adjustment of the revision rates.

5.1.3 Discharge destination

After adjusting for age, sex, previous TKR and co-morbidities, the data showed that patients were less frequently discharged directly to home from the group 4 hospitals than group 3 (OR = 1.40; 95% CI: 1.32-1.48), group 2 (OR = 2.07; 95% CI: 1.96-2.19) or group 1 (OR = 3.08; 95% CI: 2.86-3.32) hospitals.

5.2 STUDIES III AND IV

5.2.1 Primary hospital stay

Before the implementation of fast tracking, median LOS in Hospital A was 5 (CI: 2-8) days after THR and 5 (CI 3-9) days after TKR. After fast-track implementation, median LOS fell to 2 (CI: 1-5) days after THR (p=<0.001) and to 3 (CI 1-5) days (p<0.001) after TKR (Figures 5 and 6). After fast-tracking, LOS following THR was statistically significantly shorter in Hospital A (2 days) than in Hospital C (4 days) (p=0.001) and LOS following TKR was statistically significantly shorter in Hospital A (3 days) than in Hospital B (4 days) (p<0.001) or C (4 days) (p<0.05). Unlike the other study hospitals, Hospital A, after fast-tracking, discharged 10% of THR and 5% of TKR patients to home on the first postoperative day. Despite the post-fast-tracking reduction in LOS, discharge destination rates to home in Hospital A increased significantly (from 66% to 75%, p=0.01) after TKR and non-significantly after THR (from 71% to 77%). No significant differences in discharge destination rates were observed between hospitals after THR. However, Hospitals B and C, with longer LOS, continued to discharge more TKR patients directly to home than Hospital A (p<0.001). After fast-tracking, Hospital D showed similar LOS (3 days; CI 3-5) and discharge rate to home (71%) after TKR as Hospital A.

5.2.2 Episode

Before implementation of fast-tracking, median LUIC in Hospital A was 6 (CI 3-30) days after THR and 7 (CI 3-24) days after TKR. After fast-tracking, median LUIC in Hospital A fell to 3 (CI 1-24) days (p=0.001) after THR and 3 (CI 2-20) days (p<0.001) after TKR (Figures 5 and 6). After fast-track implementation, median LUIC was shorter in Hospital A than in Hospital C after THR and TKR (p<0.01), but not significantly shorter than in Hospitals B or D. In Hospital A, the percentage of patients at home a week after TKR increased from 48% before fast-tracking to 75% thereafter (p<0.001). After THR, the corresponding percentage increased from 57% before fast-tracking to 75% (p<0.001) thereafter. After fast-tracking was implemented in Hospital A, the percentage of patients at home within a week after TKR was higher in Hospital B (84%, p<0.001) and after THR lower in Hospital C (66%, p=0.001).

5.2.3 Quality and complications

The revision rates in the study hospitals before and after implementation of fast-tracking in Hospital A are presented in Table 21 with 95% CIs. After fast-tracking in Hospital A, the THR revision rate increased. However, the numbers of revisions were too small and thus no statistical significant difference in revision rates was found. In the later study period, this increase in revisions in Hospital A was mainly due to revisions for hips operated in 2012: the rate of revision THR was 6.4% (95% CI: 4.2-8.6) in 2012, decreasing to 4.4% (95% CI: 2.3-6.4) one year later (III). For TKRs, no statistically significant differences in revision rates were observed between the 4 hospitals before or after the implementation of fast-tracking in Hospital A (IV). The rate of MUA after TKR (during the first 6 months after the primary operation) was 6.4% (CI 5.1-7.8) before and 5.9% (CI 4.8-7.0) after fast-track implementation in Hospital A (IV).

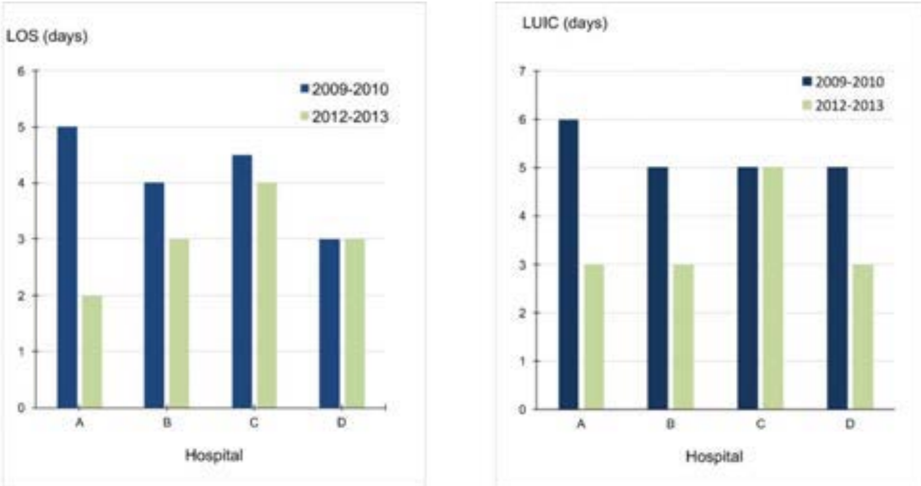

Figure 5. Median length of stay (LOS) and median lengths of uninterrupted institutional care (LUIC) during two two-year periods for primary total hip arthroplasty in four different hospitals. Hospital A was defined as a fast-track hospital after 2011.

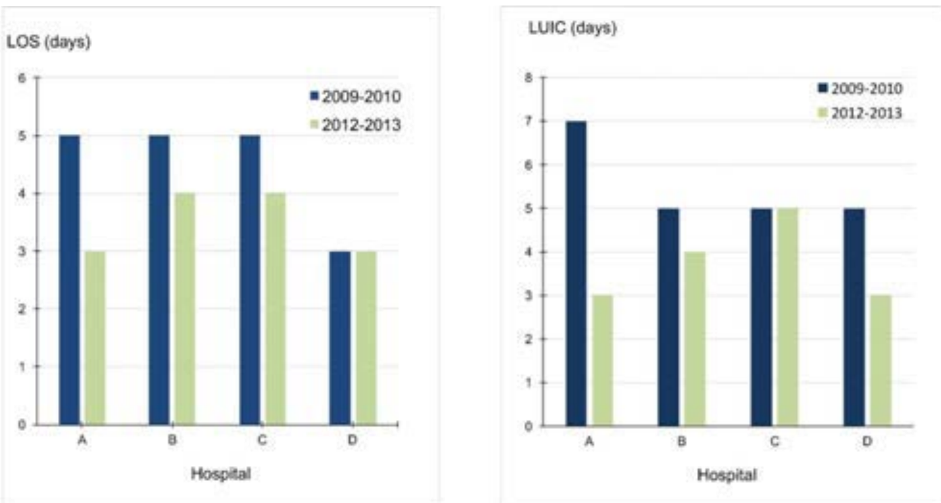

Figure 6. Median length of stay (LOS) and median lengths of uninterrupted institutional care (LUIC) during two two-year periods for primary total knee arthroplasty in four different hospitals. Hospital A was defined as a fast-track hospital after 2011.

Table 21. Adjusted annual revision rates after primary total hip and knee arthroplasty in two-year periods in four different hospitals. A fast-track protocol was implemented in Hospital A in 2011.

	2009-2010						**2012-2013**					
	Volume		**Revision THR**		**Revision TKR**		**Volume**		**Revision THR**		**Revision TKR**	
Hospital	THR	TKR	Percentage	95% CI	Percentage	95 % CI	THR	TKR	Percentage	95% CI	Percentage	95 % CI
A	464	437	1.8	0.5-3.1	1.1	0.0-2.2	437	624	5.5	4.0-7.1	2.4	1.4-3.4
B	265	367	2.4	0.6-4.3	1.8	0.5-3.1	302	442	3.5	1.7-5.4	1.8	0.6-3.1
C	402	501	1.2	0.0-2.7	1.4	0.3-2.5	424	514	2.7	1.1-4.3	1.4	0.3-2.5
D	375	641	3.1	1.7-4.6	1.7	0.8-2.7	524	730	3.0	1.5-4.4	2.7	1.7-3.6

5.2.4 Unscheduled readmissions

In Hospital A, the 14-day readmission rate for THR was 1.3% (95% CI: 0.2-2.3) before and 2.9% (95% CI: 1.7-4.1) after fast-track implementation. The corresponding percentages for TKR were 2.4% (CI 1.1-3.6) and 1.6% (CI 0.5-2.8). In Hospital A, the 42-day readmission rate for THR was 3.1% (95% CI 1.3-4.8) before and 8.3% (95% CI 6.3-10.2) after fast-track implementation. The corresponding percentages for TKR were 6.0% (CI 3.9-8.2) and 6.1% (CI 4.3-7.9). The increase in the 42-day readmission rate for THR in Hospital A was significant ($p<0.001$). Readmissions for THR due to a surgery-related infection (T84.5, T81.4) rose from 0.2% to 2.1% and for mechanical complications (M96.6, T84.0, T85.8) from 0.2% to 2.3% (III). The reasons for readmission recorded in the hospital discharge register are given in Tables 22 and 23.

5.2.5 Mortality

Mortality at one year after THR in Hospital A was 1.1% both before and after fast-track implementation. The corresponding percentages after TKR were 0.8% (CI 0.7-0.9) and 0.7% (CI 0.6-0.7) (Table 24). Mortality rates were similar between hospitals (III and IV).

Table 22. Reasons for readmissions within 42 days in Hospital A before and after fast-track implementation given as numbers of readmissions and percentage of THRs during the two study periods.

ICD-10		**2009-2010**		**2012-2013**	
		n	**%**	**n**	**%**
A415	Sepsis due to other Gram-negative organisms			2	0.5
E871	Hypo-osmolality and hyponatremia			1	0.2
F3210	Major depressive disorder, single episode	1	0.2		
I48	Atrial fibrillation and flutter	1	0.2		
I20.1	Angina pectoris with documented spasm			1	0.2
I50.0	Heart failure	1	0.2		
I50.9	Heart failure, unspecified	1	0.2	1	0.2
J18.9	Pneumonia, unspecified organism	2	0.4		
K55.0	Acute vascular disorders of intestine			1	0.2
K92.2	Gastrointestinal hemorrhage, unspecified			1	0.2
M16.0	Bilateral primary osteoarthritis of hip	1	0.2		
M16.1	Unilateral primary osteoarthritis of hip	1	0.2	2	0.5
M96.6	Fracture of bone following insertion of orthopedic implant, joint prosthesis, or bone plate	1	0.2		
N10	Acute pyelonephritis	1	0.2	1	0.2
N81.6	Rectocele			1	0.2
R06.0	Dyspnea			1	0.2
R07.4	Chest pain, unspecified			1	0.2
R10.4	Unspecified abdominal pain			1	0.2
R60.0	Localized edema	1	0.2		
S72.1	Pertrochanteric fracture	1	0.2		
S72.3	Fracture of shaft of femur	1	0.2		
S72.4	Fracture of lower end of femur			1	0.2
T81.0	Unspecified open wound, knee			2	0.5
T81.3	Disruption of wound, unspecified			1	0.2
T81.4	Infection following a procedure	1	0.2	6	1.4
T84.0	Mechanical complication of internal joint prosthesis			9	2.1
T84.5	Infection and inflammatory reaction due to unspecified internal joint prosthesis			3	0.7
T84.8	Other specified complications of internal orthopedic prosthetic devices, implants and grafts			1	0.2
Z01.8	Encounter for other specified special examinations	1	0.2		

Table 23. Reasons for readmissions within 42 days in Hospital A before and after fast-track implementation given as numbers of readmissions and percentage of TKRs during the two study periods (IV).

ICD-10		**2009-2010**		**2012-2013**	
		n	**%**	**n**	**%**
A46	Erysipelas			2	0.3
F05.9	Delirium			1	0.2
H25.1	Age-related nuclear cataract	1	0.2	1	0.2
H43.1	Vitreous hemorrhage			1	0.2
I48	Atrial fibrillation and flutter	2	0.5	2	0.3
I26.9	Pulmonary embolism without acute cor pulmonale	1	0.2		
I61.9	Non-traumatic intracerebral hemorrhage			1	0.2
K57.9	Diverticulosis of intestine	1	0.2		
K83.4	Spasm of sphincter of Oddi			1	0.2
M10.0	Gout	1	0.2		
M17.0	Bilateral primary osteoarthritis of knee	1	0.2	4	0.6
M17.1	Unilateral primary osteoarthritis of the knee	6	1.3	5	0.8
M17.3	Unilateral post traumatic osteoarthritis of the knee	1	0.2	2	0.3
M17.4	Other bilateral secondary osteoarthritis of the knee			1	0.2
M79.6	Pain in limb, unspecified	1	0.2	1	0.2
R06.0	Dyspnea			2	0.3
S83.0	Subluxation or dislocation of patella			1	0.2
T81.0	Unspecified open wound, knee			1	0.2
T81.3	Disruption of wound, unspecified			1	0.2
T81.4	Infection following a procedure	4	0.9	5	0.8
T84.4	Mechanical complication of other internal orthopedic devices			2	0.3
T84.5	Infection and inflammatory reaction due to unspecified internal joint prosthesis	2	0.5	3	0.5
	Total	21	5.5	37	5.9

Table 24. Adjusted annual mortality in two-year periods for primary total hip (THR) and knee (TKR) arthroplasty in four different hospitals. A fast-track protocol was implemented in Hospital A in September 2011.

	2009-2010						2012-2013					
Hospital	**Volume**		**Mortality (THR)**		**Mortality (TKR)**		**Volume**		**Mortality (THR)**		**Mortality (TKR)**	
	THR	**TKR**	**Rate (%)**	**95 % CI**	**Rate (%)**	**(95 % CI)**	**THR**	**TKR**	**Rate (%)**	**95 % CI**	**Rate (%)**	**(95 % CI)**
A	464	437	1.1	1.0-1.2	0.8	0.7-0.9	437	624	1.1	1.1-1.1	0.7	0.6-0.8
B	265	367	1.1	1.0-1.2	0.8	0.8-0.9	302	442	1.1	1.1-1.1	0.7	0.7-0.8
C	402	501	1.1	1.1-1.2	0.8	0.8-0.8	424	514	1.1	0.9-1.2	0.7	0.4-0.9
D	375	641	1	0.4-1.6	0.8	0.7-0.9	524	730	1.1	1.0-1.1	0.7	0.6-0.8

6 Discussion

6.1 VALIDITY OF DATA

6.1.1 Studies I and II

A systematic review of the literature found the level of completeness and accuracy in the Finnish Hospital Discharge Register to be satisfactory (Sund 2012). The coverage of knee and hip replacements in the Finnish Arthroplasty Register is good (National Institute for Health and Welfare 2017). A major strength of Studies I and II is the inclusion of operative data from both private and public hospitals. The analyses were also adjusted for patient age, sex and co-morbidities, for any previous THR and femoral head size (Study I) and for any previous TKR (Study II). In addition, in Study II, LOS analyses were performed taking discharge destination into account.

Studies I and II have some limitations. The side of the operation (left/right) is not reliably coded in the FHDR. Therefore, to minimize bias from bilateral observations, only patients with unilateral THR in Study I and TKR in Study II were included in the revision and MUA analyses. In study I, the association between hospital volume and hip dislocations was not evaluated, as it was not possible to adjust for all the factors (such as surgical approach) associated with the dislocation rate. Moreover, in some hospitals, reduction of a dislocated hip is performed in emergency departments under light sedation anesthesia. These patients are often discharged from emergency units after closed reduction without an overnight stay in hospital. In emergency departments, operation codes are not routinely reported. Also, owing to inaccuracies in the register data, it was not possible to evaluate the association between infections and hospital volume (I, II) (Jämsen et al. 2009). These studies were based on administrative data, which limits knowledge of possible confounding factors. The most important confounding factors that are missing are surgery in more complicated cases, BMI, alcohol abuse and smoking, number of other institutional care facilities in the hospital district, the distance between other care facilities and the hospital, surgeons' annual arthroplasty volume, and patient socio-economic status. In Finland, surgery in more complicated cases may be more likely to be performed in high- and very-high-volume hospitals. This potentially worsens the complication and discharge destination rates in the higher-volume units. However, we believe that this applies mainly to patients with secondary osteoarthritis, whereas the patient population with primary osteoarthritis is more homogeneous. Surgeons' annual arthroplasty volume clearly influences outcomes and therefore may also affect our results. However, the higher volume hospitals are often teaching hospitals with residents whose annual arthroplasty volume is relatively low, while the lower volume hospitals have fewer surgeons doing the annual case volume. In addition, some high-volume surgeons in high-volume hospitals also operate in low-volume (private) hospitals. We believe that the number of other institutional care facilities in the hospital district, the distance between other care facilities and the hospital, and patient socio-economic status may also affect LOS and LUIC. We were not able to include these variables in the adjusted analyses. We have no reason to assume that other unobserved confounders such as BMI, smoking or alcohol abuse would be unequally distributed across the different hospital volume groups, and hence, although their effect on outcomes was not taken directly into account, they are unlikely to bias the results on volume. Regarding possible over-adjustment, our sample size is rather large, which means that if the estimates suffer from bias related to over-adjustment, any such bias would be negligible.

In addition, we have no data on either mortality, short- or long-term patient-reported outcomes or patient satisfaction, which in addition to LOS, readmissions and revisions are important quality measures.

6.1.2 Studies III and IV

A major strength of Studies III and IV is the inclusion of data from all the private and public hospitals in Finland. Thus, all revisions, MUAs and readmissions were included in the analyses. Only one hospital (A) had fully implemented the fast-track protocol (Studies III and IV). In addition to fast-tracking, the changes in the studied parameters may also in part be explained by other factors, such as other processual changes and differences between surgeons in their annual arthroplasty volume.

6.2 HOSPITAL VOLUME CATEGORIZATION (STUDIES I AND II)

No uniform categorization of hospital volume exists in the literature. Calculations of volume vary across studies both in volume cut-off points and in the types of operations included: some studies include only THR or TKR and others both types (Katz et al. 2004, Singh et al. 2011, Glassou et al. 2016, Kurtz et al. 2016, Laucis et al. 2016, Wilson et al. 2016, D'Apuzzo et al. 2017). Some studies have only included selected age groups and some have omitted very small hospitals or private hospitals (Judge et al. 2006, Manley et al. 2008, Paterson et al. 2010). Hence, in Studies I and II the cut-off points for the different hospital volume groups were chosen arbitrarily. We consider, however, that the categorizations used in Studies I and II enabled properly-sized groups to be formed for the analyses. We included all the hospitals in Finland in our volume analyses, including private hospitals, which in Finland tend to be small volume hospitals (I, II).

6.3 LOS AND LUIC (STUDIES I, II, III AND IV)

Several factors have been reported to affect LOS: surgeon volume, hospital volume, time between surgery and mobilization, process standardization (such as fast-track programs), operation day and patient-related factors (Judge et al. 2006, Mitsuyasu et al. 2006, Bozic et al. 2010, Husted et al. 2010a, Paterson et al. 2010, Styron et al. 2011, Jans et al. 2016, Mathijssen et al. 2016). An annual decline in LOS after THR and TKR, including in the absence of a fast-track protocol, has been reported (Mäkelä et al. 2011a, Cram et al. 2012, Wolf et al. 2012, Cnudde et al. 2018, Burn et al. 2018). The same observation was also made in Studies I-IV. It is important to understand that LOS is not the most important indicator of hospital quality. However, if the aim is to optimize the whole treatment protocol, it will, if realized, eventually lead to shorter LOS without compromising quality. Shortening LOS means that a considerable proportion of resources can be freed in a situation characterized by an increasing need of care and a decreasing number of hospital staff (physicians and nurses). Thus, reduction in LOS can translate into substantial savings (Burn et al. 2018) .

In many previous studies, longer LOS after THR or TKR has been associated with lower provider volumes (Lavernia and Guzman 1995, Kreder et al. 2003, Doro et al. 2006, Judge et al. 2006, Yasunaga et al. 2009, Mäkelä et al. 2011a, Styron et al. 2011, Kaneko et al. 2014). However, it has also been claimed that short LOS is due to patient transfers to rehabilitation centers (Paterson et al. 2010). In contrast, several authors have reported no significant association between hospital volume and LOS (Lavernia and Guzman 1995, Kreder et al. 1997, Hervey et al. 2003, Bozic et al. 2010, Marlow et al. 2010, Paterson et al. 2010). The correlation between LUIC, which is the more important variable, and hospital volume has not been fully investigated. Mäkelä et al. (2011a) found that very high hospital volume was associated both with shorter LOS and shorter LUIC after THR. The association between hospital volume and LUIC after TKR has not previously been evaluated. The conflicting findings of earlier studies on the effect of hospital volume on LOS and the lack of a uniform categorization of hospital volume across studies make it difficult to draw firm conclusions on this issue. Moreover, since short LOS can be due to discharging patients to rehabilitation centers, studies comparing length of stay after any operation should compare LUIC not LOS.

We found that the use of hospitalization after THR and TKR diminished annually (between 1998 and 2010) and that both LOS and LUIC were shorter the greater the volume of the hospital (I, II). The effect of patient transfers to rehabilitation centers on length of stay was controlled for in our study, since this kind of inpatient care after THR or TKR is included in LUIC (I-II). In addition, testing for this (II) by adding discharge destination after TKR into the LOS modelling did not change the result. We found that very high hospital volume was coupled with both the shortest LOS and shortest LUIC after THR and TKR (I, II). The short LOS and LUIC in the very-high-volume centers may have been due to pressure to standardize patient care in order to optimize efficiency and manage patient flow. The rate of decrease in average LOS after THR and TKR was faster in the lower volume hospitals, indicating that these hospitals have enhanced their efficiency more rapidly than the higher volume hospitals (I, II). LUIC also decreased after THR and TKR, but this was almost wholly due to the reduction in LOS (I, II). Although LOS after THR and TKR has decreased in Finnish hospitals, comparison with fast-track results elsewhere indicates that the potential remains for further LOS reduction in Finland (den Hartog et al. 2013, Glassou et al. 2014, Winther et al. 2015).

Fast-track methods aim at optimizing the whole treatment protocol. If successful, this eventually leads to shorter LOS without compromising quality (Husted 2012). However, an annual decline in LOS after THR and TKR, even without a fast-track protocol, has been reported (Mäkelä et al. 2011a, Cram et al. 2012, Wolf et al. 2012). The same observation was also made in the present research (I, II, III and IV). The effect of this non-fast-track-related annual decline in LOS has not usually been taken into account in earlier fast-track studies (Husted et al. 2010b, den Hartog et al. 2013, Winther et al. 2015). Thus, it can be argued either that the effect of fast-tracking on LOS has been overestimated in those studies or that non-fast-track hospitals have adopted some of the features of fast-tracking, resulting in shorter LOS. The latter possibility was also noted by Glassou et al. (2014).

We found (III, IV) that fast-track implementation in Hospital A resulted in a statistically significant decrease in LOS and LUIC. Our finding of a median LOS of 2 days after THR and 3 days after TKR accords with previous reports on LOS after fast-track TJR (Husted et al. 2010b, 2016, den Hartog et al. 2013, Glassou et al. 2014, Winther et al. 2015, Pitter et al. 2016). After fast-tracking, median LUIC in our study was 3 days after THR and TKR, which accords with the results of studies on hospitals that discharge all their TJR patients directly home (Husted et al. 2010b, 2011a, Jørgensen et al. 2013a). The other hospitals in our study had implemented some elements of the fast-track protocol. However, median LOS and LUIC decreased statistically significantly only in Hospital A, which had systematically and comprehensively implemented fast-tracking to its full extent. LOS was significantly shorter after fast-tracking in Hospital A than in hospital C after THR and shorter than in hospitals B and C after TKR. LUIC was statistically significantly shorter in Hospital A only when compared to Hospital C after both THR and TKR (III, IV). Since hospital´s A primary THR and TKR volume only slightly increased during the study periods, we believe that bias from the effect of volume on LOS is negligible in Studies III and IV.

Centralizing THR and TKR operations in higher volume units or/and by fast-tracking could reduce national mean LOS and LUIC. This reduction could translate into substantial savings. Volumes of >250 THRs and >255 TKRs are the largest to affect LOS that have been published. The cut-off value above which volume no longer has this positive effect remains unknown. According to the literature, surgeons' procedure volume has an even greater effect on LOS than hospital volume (Bozic et al. 2010, Paterson et al. 2010, Styron et al. 2011). Thus, centralizing THR and TKR operations to higher volume surgeons inside hospitals is also an important consideration.

6.4 DISCHARGE DESTINATION

Patient expectations, one of the most important factors predicting discharge destination (Halawi et al. 2015), presents a challenge for preoperative patient education. Discharging TKR patients to a skilled care facility has been associated with higher readmission rates (Keswani et al. 2016, McLawhorn et al. 2017, Ricciardi et al. 2017). The economic wisdom of discharging patients to an extended institutional care facility instead of allowing longer LOS has also been disputed (Sibia et al. 2017). It would, therefore, be important to undertake a thorough re-evaluation of which patient groups truly need and will benefit from discharge to an EICF.

The impact of hospital volume and shorter LOS on discharge destination has not been widely studied. It has been proposed that patients in higher volume hospitals are more likely to be directly discharged home (Bozic et al. 2010). However, shorter LOS has been coupled with a higher likelihood of discharge to an EICF (Paterson et al. 2010). In line with this, we found hospital volume to be inversely related to the rate of discharge home after TKR (II).

Two earlier fast-track studies from the Netherlands and Norway reported no change in the proportion of patients discharged to their own homes after the introduction of a fast-track protocol, the rate remaining at about 80% (den Hartog et al. 2015, Winther et al. 2015). In our study, the rate of discharge home increased after fast-tracking after both THR (71% to 75%) and TKR (66% to 75%), but the increase was only statistically significant for TKR. Compared to other study hospitals, fast-tracking did not result in a higher discharge destination rate to home (III, IV). However, we also found (III, IV) that the proportion of patients at home 1 week after surgery increased significantly after fast-tracking. This is a new finding, as no previous studies have reported on this issue. We believe that this is an even more important measure than the rate of discharge home, as discharging patients home too early can lead to early readmissions to hospital or to rehabilitation centers, and therefore such patients cannot truly be said to have returned home.

6.5 READMISSION

The unscheduled readmission rate is commonly used as an indicator in evaluating the outcome of arthroplasties, despite criticism of its use as a basis for assessing quality of care (Weissman et al. 1999, Jimenez-Puente et al. 2004). The reliability of the readmission coding in databases has also been disputed (Keeney et al. 2012). However, the readmission rate has been used as a key performance indicator (Courtney et al. 2003, Adeyemo and Radley 2007). Hospital readmissions after THR and TKR are a massive economic burden on the healthcare system, especially when due to procedure-related complications such as infection, dislocations and periprosthetic fractures (Kurtz et al. 2017). A systematic review found the readmission rate after THR to be 5.6% within 30 days and 7.7% within 90 days (Ramkumar et al. 2015). A recent study on a Finnish high-volume hospital reported unplanned readmission rates of 6.5% within 30 days and 8% within 90 days after TKR (Saku et al. 2018).

A number of earlier studies have evaluated the correlation between hospital volume and readmissions after THR and/or TKR and have arrived at conflicting results (Kreder et al. 1998, Judge et al. 2006, SooHoo et al. 2006a, 2006b, Bozic et al. 2010, Cram et al. 2011b, Mäkelä et al. 2011a). However, in the more recent studies higher provider volume has been reported to be associated with lower readmission rates (Paxton et al. 2015, Chen et al. 2016, Kurtz et al. 2016, Laucis et al. 2016, Wilson et al. 2016, D'Apuzzo et al. 2017, Courtney et al. 2018). In the absence of a uniform categorization of hospital volume and owing to variation in the definition of readmissions across studies, it is difficult to draw firm conclusions on this issue. However, according to two recent studies, a meaningful hospital volume threshold for minimizing readmissions would be at least 236 TKRs annually (Wilson et al.

2016, D'Apuzzo et al. 2017). The correlation between LOS and readmissions is controversial: short LOS has been coupled with a higher rate of readmissions or no change in readmission (Husted et al. 2010b, Cram et al. 2011a, 2012, Vorhies et al. 2011, 2012, Keeney et al. 2012, Wolf et al. 2012, Paxton et al. 2015, Ricciardi et al. 2017). In our studies (I, II), the patients operated in the very-high-volume hospitals had a lower probability for readmission within 14 and 42 days of discharge after TKR and within 42 days of discharge after THR than those operated in the low-volume hospitals. This latter finding after THR (I) is contrary to the previous finding reported by Mäkelä et al. (2011a) for Finland. In our study, hospitals were grouped somewhat differently. Some of the hospitals classified by Mäkelä et al. (2011a) as very-high-volume hospitals were in the high- or medium-volume hospital groups in our study. According to our studies (I, II) the savings from shorter LOS in the very-high-volume hospitals were not cancelled out by a potentially higher rate of readmissions.

Comparison of readmission rates between fast-track studies is difficult. As in hospital volume studies, definitions of readmission vary between studies as also do the diagnoses that are included. Moreover, some complications may be treated in an outpatient setting in one hospital and during readmission in another. Unlike in our studies (III and IV), readmissions to other hospitals have not been included in all the previous fast-track studies. The readmission rate within 90 days after fast-track THR has been reported to be between 8.6% and 10.9%, and after TKR to be between 8.3% and 8.9%, with no increase after implementing the protocol (Husted et al. 2010b, 2016, den Hartog et al. 2013, Jørgensen et al. 2013b, Glassou et al. 2014, Winther et al. 2015). Although we included all events that required care in any hospital and in any ward, our finding of a 6% 42-day readmission rate after TKR with no increase after fast-tracking is in line with previous fast-track reports (IV) (Jørgensen et al. 2013b, Husted et al. 2016). However, we found that the readmission rate after THR increased from 3.1% to 8.3% within 42 days after fast-track implementation (III). This increase was mainly due an increase in infections and mechanical complications, also potentially causing the need for revision (III).

There is some evidence, including from our studies (I, II), that the number of readmissions after THR and TKR operations can be reduced by centralizing these operations to higher volume hospitals and no evidence that lower volume hospitals would perform better on this issue. Further studies are needed to draw firm conclusions on meaningful thresholds for the volume-readmission relationship in THR and TKR. Fast-track protocols do not appear to increase complication or revision rates after TKR (IV). However, it is possible that a learning curve also exists in process standardization, causing more readmissions and revisions after THR in the early stage after a change of protocol (III).

6.6 REVISION

Both a systematic review of the risk factors for revision of THR and two subsequent register studies found an association between low surgeon volume and risk for revision but no association between hospital volume and risk for revision (Katz et al. 2012, Prokopetz et al. 2012, Cossec et al. 2017). The reason for this may be that surgeon procedure volume is a stronger predictor of revisions, and hence masks the effect of hospital volume. This would be in line with the finding that higher surgeon procedure volume has been found to be associated with lower risk of revisions (Bozic et al. 2010, Paterson et al. 2010). In the recent, and largest, register study by Glassou et al. (2016), the authors found that low-volume hospitals with 50 or fewer operating procedures per year had an increased risk for revision after cemented THR. In our study (I), no association was observed between hospital volume and risk for revision after THR. We did not conduct separate analyses for cemented THRs.

Data on the association between hospital volume and revision is more conflicting for TKR than THR. Some studies have found hospital volume predictive of revision after TKR (Kreder et al. 2003, Judge et al. 2006, Manley et al. 2009, Paterson et al. 2010, Badawy et al. 2013, Jeschke et al. 2017) while others have not (Shervin et al. 2007, Bozic et al. 2010). Higher hospital volume has reported to be associated with lower risk for revision after unicondylar knee replacements (Baker et al. 2013, Badawy et al. 2017). In our study (II), the very-high-volume hospitals had fewer revisions than the medium-volume and high-volume hospitals after TKR. However, there was no significant difference between the very-high-volume and low-volume hospitals. In Finland, some of the higher volume surgeons also operate in low-volume (private) hospitals, while more demanding cases are unlikely to be treated in low-volume hospitals. Thus, this factor may also partly explain this result.

We also acknowledge some other limitations in our volume-revision association analyses (I, II). Only a subgroup of patients with unilateral THR or TKR (70% of patients in Study I and 79% of patients in Study II) was included in our analyses of revisions. Patients with bilateral THR or TKR may have a different risk for revision. However, no practical difference has been reported between the results of analyses of solely unilateral compared to both uni- and bilateral revisions (Robertsson and Ranstam 2003, Lie et al. 2004). It might be that other determinants, such as volume per surgeon, surgical technique, patient characteristics (including others than those included in our study), process standardization and type of prosthesis are more important factors influencing revision risk, and therefore should be taken into account in efforts to estimate the real effect of hospital volume on revisions.

The revision rate within 90 days after fast-track THR has been reported to be between 1.4% and 2.9% and after fast-track TKR between 1.4 and 2% (Husted et al. 2008, den Hartog et al. 2013, Glassou et al. 2014). Winther et al. (2015) reported revision rates of 2.9% after fast-track THR and 3.3% after fast-track TKR within the first post-operative year. An earlier study raised the possibility of an association between an elevated infection-related revision risk after THR and the introduction of a fast-track protocol (Amlie et al. 2016). In contrast to previous studies (den Hartog et al. 2013, Glassou et al. 2014), the 1-year revision rate after fast-track THR in our study (I) showed a non-significant increase from 1.8% to 5.5% after the introduction of a fast-track protocol. Our finding of a 2.3% revision rate within one year after fast-track TKR is a little lower than that reported by Winther et al. (2015) and the finding of no significant increase after fast-tracking is in line with the previous report by Glassou et al. (2014)(IV).

We believe that the trend towards a higher revision rate after fast-track THR was associated with other factors, rather than fast-track THR per se (III). For example, we enhanced operating theater efficiency simultaneously with fast-track implementation. Enhancing operation theater efficiency may at first induce an unnecessary feeling of hurry, which could also cause complications. However, this enhanced efficiency did not affect the results after TKR to the same degree. It is likely that the higher revision rate after fast-track THR was due to the introduction of a new implant (uncemented stem) simultaneously with the switch to fast-tracking. The learning curve associated with the use of a new implant stem can potentially cause complications at the beginning (Peltola et al. 2013). In addition, before the year 2011, we mainly used MOM implants with a larger head; these implants have been associated with a lower dislocation rate (Haughom et al. 2016).

6.7 MUA

While hospitals are under pressure to shorten LOS, there is fear that reducing LOS may lead to an increase the incidence of MUA. Therefore, we also evaluated the association between MUA and LOS in Study II, and found no association between short LOS and an increase in the rate of MUA. No previous studies have examined the effect of hospital volume on the incidence of MUA. Our data showed no clear association between hospital volume and rate of MUA. A large register study reported MUA rates of about 3% within 180 days after unilateral TKR (Meehan et al. 2017). Husted et al. (2015) reported a MUA rate of 2.2% within one year after fast-track TKR and Wied et al. (2015) a MUA rate of 5.8% with a median post-operative period of 169 days. Our finding of 5.9% is in line with the latter result. However, comparing MUA rates between studies is difficult as the cause of MUA is multifactorial and the criteria for MUA differ between hospitals. No increase in the rate of MUA after fast-tracking has been reported, which is in line with our Study IV results (Husted et al. 2015, Wied et al. 2015).

6.8 MORTALITY

Death after TKR is relatively rare event and not always surgery-related (Jørgensen et al. 2017). Ninety-day mortality after THR in Sweden fell from 1.1% to 0.7% over the period 1999-2012 (Cnudde et al. 2018). Associations between higher hospital volume and lower mortality have been reported after both THR and TKR (SooHoo et al. 2010, Singh et al. 2011, Wilson et al. 2016). We did not evaluate mortality in our volume studies (I, II). A fast-track program has been found to be associated with a significant or nearly significant reduction in mortality after TKR and THR (Malviya et al. 2011, Savaridas et al. 2013, Khan et al. 2014). However, mortality risk has not declined for patients with a comorbidity burden at the time of surgery (Glassou et al. 2017). We found (III, IV) 1-year mortality rates of 1.1% after THR and 0.7% after TKR with no increase after fast-tracking. This is a little lower than the 1-year mortality of 1.3% after THR and TKR reported by Savaridas et al. (2013). Other studies have reported 90-day mortality rates of 0.2%-0.5% after fast-track THR and TKR (Husted et al. 2010b, Malviya et al. 2011, Khan et al. 2014, Glassou et al. 2017, Jørgensen et al. 2017).

6.9 FUTURE CONSIDERATIONS

LOS, LUIC, and possibly readmissions, can be reduced by centralizing TJR operations to higher volume hospitals. However, centralizing must take into account all areas of quality (safe, effective, patient-centered, accessible, efficient and equitable). A hospital volume of over 100 has been found to be associated with better patient satisfaction (Katz et al. 2003). However, centralizing can have also a negative effect on patient accessibility and hence patient satisfaction, since it can result in a geographically unreasonable distance between patients and providers. Patient access to treatment for complications (revisits, readmissions and revisions) can also be more problematic where distances from hospitals are long. Thus, from the patient´s point of view, this may not always be a patient-centered approach to providing TJR operations. Patient satisfaction and patient experience measures should be administered before and after centralizing as they provide information on how acceptable, equitable and patient-centered TJR processes are. Even if TJRs are centralized, patients should be offered a choice in selecting the hospital for their TJR as this has a positive effect on satisfaction (Losina et al. 2005).

LOS and LUIC can also be shortened by fast-tracking. A fast-track protocol does not appear to increase complication or revision rates after TKR. However, we found that the main reason for the higher readmission rate after THR was an increase in infections and mechanical complications. An earlier study also raised the possibility of an association between an elevated infection-related revision risk after THR in the early stage after the introduction of a fast-track protocol (Amlie et al. 2016). Therefore, implementing fast-tracking requires careful work and outcomes must be closely monitored. Patient satisfaction following fast-track TJR has been found to be good (Jones et al. 2014, Specht et al. 2015). However, the questionnaires used in these studies have rarely been validated using an accepted validation method. Further studies on the effect of fast-track TJR on patient experience and satisfaction with properly validated questionnaires are therefore needed. At least in our institution, short stay after TKR has resulted in an increase in opioid prescriptions for patients on discharge home. The possible development of opioid addiction among these patients is a matter of concern. Thus, it is important that the national recommendations on the prescription of opioids is strictly followed (Munsterhjelm et al. 2017). Another important future research topic is the need of thromboprophylaxis after fast-track TJR. Early mobilization and short LOS could have changed the need for aggressive thromboprophylaxis (Jorgensen et al. 2013).

Patient satisfaction is most important issue when centralizing or implementing fast-track protocols. However, from the organizational perspective it is also very important to keep personnel satisfied. In this way the organization can remain attractive for professionals in the field and also provide patients with the best possible care.

7 Summary and conclusions

Average LOS and LUIC after THR and TKR can be shortened not only by centralizing operations to higher volume hospitals, but also by fast-tracking. However, cut-off above which hospital volume ceases to have an effect and whether such a cut-off remains the same over time is not known. There is some evidence that the number of readmissions after THR and TKR operations and number of revisions after TKR operations can be reduced by centralizing these operations to higher volume hospitals. A fast-track protocol does not appear to increase complication or revision rates after TKR.

Further studies are needed on how surgeon volume, hospital volume and fast-tracking interact. In addition, more information is needed on effect of hospital volume and fast-tracking on patient-related outcomes, experience and satisfaction measures.

The results of the present study allow the following conclusions:

1. In Finland, hospital volume is inversely associated with LOS and LUIC both after THR and TKR. Thus, potential exists to reduce LOS and LUIC in hospitals performing a smaller volume of hip and knee replacements. There are fewer readmissions within 42 days after THR and TKR in very-high-volume hospitals than in low-volume hospitals. Lower hospital volume is not associated with a higher revision rate after THR and not unambiguously associated with a higher revision rate after TKR.

2. Process standardization by fast-tracking offers an opportunity to reduce LUIC and LOS. Short LOS appears not to be coupled with increased readmission or revision rates after TKR. Mortality rates after THR and TKR remain unchanged after fast-tracking after both THR and TKR.

3. In Finland, hospital volume is inversely related to the rate of discharge home after TKR. Thus, re-evaluation of patient discharge to EICFs is needed in the higher volume hospitals. However, the larger the hospital volume, the shorter the average LOS and LUIC. Fast-tracking can result in an increased discharge rate to home despite shortened LOS after TKR. The proportion of patients at home 1 week after surgery can be increased by fast-tracking.

4. Average LOS and LUIC can be shortened by centralizing TKR operations to higher volume hospitals or by fast-tracking without increasing the MUA rate.

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KONSTA PAMILO

Total hip and knee replacement are the gold standard treatments for severe osteoarthritis refractory to conservative treatment. The incidence and prevalence of these procedures are expected to increase markedly in the future. Due to the potentially severe complications and high economic impact associated with these procedures, efforts to minimize the risks and to optimize perioperative efficiency are necessary. This doctoral dissertation study evaluates the effect of hospital procedure volume and implementation of fast-tracking on outcomes after arthroplasty.

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