Digital Comprehensive Summaries of Uppsala Dissertations
from the Faculty of Medicine 2228

Tibial Plateau Fractures

Long-term Outcomes and Conversion to Total Knee Arthroplasty

FREDRIK OLERUD

ACTA UNIVERSITATIS
UPSALIENSIS
2026

ISSN 1651-6206
ISBN 978-91-513-2725-9
urn:nbn:se:uu:diva-577031

UPPSALA
UNIVERSITET

Dissertation presented at Uppsala University to be publicly examined in Gunnesalen, Akademiska sjukhuset, Ingång 10, Uppsala, Friday, 13 March 2026 at 12:00 for the degree of Doctor of Philosophy (Faculty of Medicine). The examination will be conducted in English. Faculty examiner: Associate Professor Rasmus Elsoe (Aalborg University Hospital, department of Orthopaedic Surgery, Denmark).

Abstract

Olerud, F. 2026. Tibial Plateau Fractures. Long-term Outcomes and Conversion to Total Knee Arthroplasty. *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine* 2228. 108 pp. Uppsala: Acta Universitatis Upsaliensis. ISBN 978-91-513-2725-9.

Tibial plateau fractures (TPFs) encompass a broad spectrum of injuries, ranging from simple, undisplaced splits to complex intra-articular fracture patterns. These fractures are frequently associated with long-term sequelae, most notably post-traumatic osteoarthritis (PTOA) and eventual conversion to total knee arthroplasty (TKA). As the incidence of fragility fractures is projected to rise within expanding ageing populations, the burden of TPF-related knee degeneration is expected to increase substantially. Despite advances in internal fixation techniques, uncertainty persists regarding long-term clinical outcomes, the risk factors driving joint deterioration, and the potential role of primary arthroplasty for selected patients.

The overarching aim of this thesis was to investigate the long-term consequences of TPF, with focus on epidemiology, the progression to TKA, and the role of patient- and fracture-related characteristics in risk stratification for joint conversion. This objective was addressed through a series of longitudinal cohort studies, leveraging both single-centre clinical data and comprehensive national register-based datasets. First, national incidence patterns and mortality rates following TPF were evaluated using the National Patient Register (NPR). A single-centre cohort study linked to the Swedish Arthroplasty Register (SAR) was used to identify factors associated with subsequent TKA conversion. Subsequently, national data from the SFR were linked to the SAR to examine the association between fracture severity and TKA conversion within a large, population-based cohort. Finally, SAR data were analysed to evaluate clinical outcomes following acute TKA as a primary treatment for TPF, with these results compared against outcomes of delayed TKA performed for PTOA.

Findings from this thesis indicate that although most TPFs managed with ORIF have low TKA conversion rates, a distinct subset of patients faces an elevated risk of conversion. This high-risk group is characterised by severe fracture patterns, advanced age, and inadequate postoperative reduction. Moreover, TKA following TPF often resembles revision surgery rather than primary arthroplasty in terms of surgical complexity, implant selection, and clinical outcomes. Consequently, acute arthroplasty in carefully selected high-risk individuals may serve as a viable primary intervention with favourable results.

In conclusion, this thesis offers new insights into the trajectory from fracture to arthroplasty following TPF. The findings underscore the critical importance of achieving high-quality anatomical reduction, early stratification of patients at elevated risk of failure, and individualised decision-making regarding joint preservation versus primary arthroplasty. Collectively, these findings advance clinical understanding and provide a foundation for future research aimed at refining treatment strategies and improving long-term outcomes.

Keywords: Tibial Plateau Fractures, Knee Arthroplasty, Trauma, Lower Leg, Epidemiology

Fredrik Olerud, Department of Surgical Sciences, Orthopaedics and Handsurgery, Akademiska sjukhuset, ingång 61, Uppsala University, Uppsala, Sweden.

ISSN 1651-6206
ISBN 978-91-513-2725-9
URN urn:nbn:se:uu:diva-577031 (http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-577031)

All models are approximations. Essentially, all models are wrong, but some are useful. However, the approximate nature of the model must always be borne in mind.

-George E.P. Box

To my family, Josefin, Ilse, and Elliot

Tibial Plateau Fractures – Long-term Outcomes and Conversion to Total Knee Arthroplasty

Dissertation for PhD

Illustrations by Pontus Andersson (Pontus Art Production AB)

List of Papers

This thesis is based on the following papers, which are cited in the text by Roman numerals.

I. Olerud F, Garland A, Hailer NP, Wolf O. Incidence of Proximal Tibia Fractures: Women Have Twice the Rate and Young Women Show a Twofold Increase - a national 13-year observational study, Manuscript, Submitted

II. Olerud F, Garland A, Hailer NP, Wolf O. Risk of conversion to total knee arthroplasty after surgically treated tibial plateau fractures: an observational cohort study of 439 patients. *Acta Orthop*. 2024 May 7;95:206-211

III. Olerud F, Garland A, Hailer NP, Wolf O. Fractures with complex fracture patterns are associated with increased rate of subsequent conversion to total knee arthroplasty after a tibial plateau fracture: an observational cohort study of 12,012 patients from the Swedish Fracture Register. *Knee Surg Relat Res*. 2025 Jun 6;37(1):27.

IV. Olerud F, Garland A, W-Dahl A, Hailer NP, Wolf O. Acute or delayed total knee arthroplasty for tibial plateau fracture? An observational study from the Swedish Arthroplasty register. Manuscript, Accepted *Clin Ort Rel Res*. 2026.

Papers not part of this thesis

1. Olerud F, Olsson C, Flivik G. Comparison of Refobacin bone cement and palacos with gentamicin in total hip arthroplasty: an RSA study with two-year follow-up. Hip Int. 2014 Jan-Feb;24(1):56-62.

Contents

Abbreviations

aHR	Adjusted Hazard Ratio
AO	Arbeitsgemeinschaft für Osteosynthesefragen
A	Anterior
AP	Anteroposterior
BMD	Bone Mineral Density
CI	Confidence Interval
EQ-5D-3L	EuroQol- 5 Dimension – 3 Levels
EQ-5D-5L	EuroQol- 5 Dimension – 5 Levels
HR	Hazard Ratio
HRQoL	Health-Related Quality of Life
ICD-10	International Classification of Diseases -10th Revision
KSS	Knee Society Score
KOOS	Knee Injury and Osteoarthritis Outcome Score
L	Lateral
LCL	Lateral Collateral Ligament
LCP	Locking Compression Plate
M	Medial
MAR	Missing at Random
MCAR	Missing Completely at Random
MCID	Minimal Clinically Important Difference
MIC	Minimal Important Change
MNAR	Missing Not at Random
MCL	Medial Collateral Ligament
ORIF	Open Reduction Internal Fixation
OA	Osteoarthritis
OR	Odds Ratio
OTA	Orthopedic Traumatology Association
P	Posterior
PIN	Personal Identification Number
PTF	Proximal Tibia Fracture
PTOA	Post-traumatic Osteoarthritis
PY	Person-years
QoL	Quality of Life
RCT	Randomised Controlled Trial
ROM	Range of Motion

SCB	Statistiska Centralbyrån (‘Statistics Sweden’)
SD	Standard Deviation
SFR	Swedish Fracture Register
SAR	Swedish Arthroplasty Register
TKA	Total Knee Arthroplasty
TPF	Tibial Plateau Fracture

	Paper I	**Paper II**	**Paper III**	**Paper IV**
Type of study	Register-based cohort study	Single-centre cohort study	Register-based cohort study	Register-based cohort study
Year (publication)	2011-2023 (Submitted)	2002-2015 (2024)	2012-2023 (2025)	2014-2023 (Accepted 2025)
Aims	Description of the demographics and incidence of PTF from the NPR.	What is the conversion rate to TKA after a TPF, and what preoperative patient and fracture characteristics are associated with joint failure?	What is the conversion rate to TKA after a TPF, and what preoperative patient and fracture characteristics are associated with joint failure?	What are the long-term outcomes for acute or delayed TKA for a TPF? Reoperation/revision: causes and outcomes, and PROMs.
Population	38,053 PTF from the NPR	439 TPF, surgically treated, from Uppsala	12012 TPF from SFR	1102 TKA from SAR
Results	Epidemiological data. The incidence in 2023 was 40.1 per 100,000 person-years. Incidence increased over time, driven primarily by a rise among women.	Two-year TKA conversion was 5.2%. ‘Comminuted fractures’ (AO/OTA B3 and C3) carried a markedly higher conversion risk (6.8-fold), and residual post-reduction step-off was associated with an 8.4-fold increased risk.	Five-year conversion rate to TKA was 2.8%. Patients with more severe fractures (AO B3, C2, C3) and those aged 65–74 years had the highest risk of later TKA.	Reoperation rates were similar, but causes differed: infection predominated after delayed TKA, whereas loosening was more common after early TKA. PROMs favoured early TKA.
Clinical perspective	Information on the demographics of patients and clinicians in PTF.	Identifying fracture patterns with a higher preoperative risk of subsequent conversion to TKA.	Identifying patient groups with a higher preoperative risk of subsequent conversion to TKA.	Different complication patterns between early and delayed TKA.

Introduction

Tibial plateau fractures (TPFs) encompass a broad spectrum of injuries, ranging from simple, undisplaced splits to complex, articular patterns. These injuries pose significant challenges for clinical decision-making and surgical risk stratification. These injuries account for approximately 1% of all fractures [28] and involve the proximal tibia adjacent to the knee joint. They typically result from either high-energy mechanisms, such as traffic collisions or falls from height in the younger population, or following low-energy trauma in osteoporotic bone [28]. The primary goal in managing TPFs is to achieve a stable, congruent, and pain-free joint that supports functional ambulation. Consequently, surgical intervention is directed toward restoring articular congruity and axial alignment to facilitate early mobilisation and to minimise the risk of secondary osteoarthritis (OA).

While TPFs account for approximately 1% of all adult fractures, their incidence exceeds 8% in the elderly population. This high prevalence in older age groups underscores their classification as fragility fractures, a trend particularly evident among women [38,114,122,136]. Previous studies have demonstrated a link between lower-leg fractures and reduced bone mineral density (BMD), although this trend has not been consistently observed in men [68]. As the population ages, the incidence of TPFs is projected to rise, imposing an escalating clinical and socioeconomic burden. Given the elevated risk of fixation failure and suboptimal surgical outcomes in older adults [4,59,98,109], this trend represents a significant future challenge for orthopaedic services.

Undisplaced lateral TPFs are typically managed non-operatively through protected weight-bearing, often supplemented by functional knee bracing [100]. In contrast, unstable or displaced TPFs generally necessitate open reduction and internal fixation (ORIF), most commonly employing plate-and-screw constructs [9,13,151].

Refinements in surgical technique, including fragment-specific approaches, three-dimensional preoperative planning, and enhanced fixation via locking plates and subchondral rafting screws, have improved clinical results [45]. Furthermore, the use of bone substitutes to address voids from impacted fragments may have further optimised patient outcomes. Nevertheless, a substantial proportion of patients still suffer from debilitating post-traumatic OA (PTOA) [29,42,58,65,87,112,114]. This significant burden of long-term sequelae underscores the limitations of current treatment strategies and the need for further investigation into alternative management approaches.

TKA remains the definitive intervention for end-stage OA and, by extension, for end-stage PTOA. Earlier studies have investigated the rate of conversion to TKA following TPFs [32,129,139,150], with a 2023 systematic review of 42 studies estimating a pooled conversion rate of approximately 5% (range 0-21.9%) [50]. However, considerable uncertainty persists regarding the accuracy and consistency of 'conversion to TKA' as a clinical endpoint, primarily due to methodological heterogeneity in study design, follow-up duration, and patient selection.

A significant gap remains in understanding the specific patient and fracture characteristics that predispose to failure of initial internal fixation. While emerging evidence identifies preoperative comorbidity and fracture morphology as key risk factors for TKA conversion [7,48], management strategies for other major joints have already shifted from fixation toward primary replacement for complex articular injuries [93,105,116]. Historically, TPF fixation has been advocated as a means of establishing a stable foundation for a future TKA; however, current data indicate that TKA following failed ORIF often functions as a salvage procedure, yielding inferior outcomes compared to conventional primary TKA [60,108,134]. This disparity underscores the urgent need to reevaluate treatment paradigms for high-risk patients.

Primary TKA has been advocated as a definitive initial intervention for complex TPFs by several authors, who report promising outcomes from various single-centre case series [2,125,130,132,141,145].

For primary TKA to be considered a viable acute intervention, its potential benefits must be carefully weighed against its inherent drawbacks. Advantages, such as immediate weight-bearing and the prospect of superior functional recovery, must be balanced against increased surgical risk and the technical challenges of endoprosthesis implantation in the context of compromised bone quality or metaphyseal comminution. In such scenarios, the use of revision or tumour-style prostheses is often required, effectively restricting this treatment modality to specialised centres with the requisite expertise and resources [107].

Background

Anatomy and Biomechanics of the Knee Joint

The knee is a complex, weight-bearing, modified hinge joint that is fundamental to lower-limb stability and mobility [56]. It comprises three osseous structures—the femur, tibia, and patella—which together create two primary articulations: the tibiofemoral and patellofemoral joints. These components function in concert as a compound joint, providing the structural integrity required for weight-bearing while facilitating the extensive range of motion necessary for functional ambulation [3].

The Knee Joint

The primary articular surfaces of the knee—the femoral and tibial condyles—are inherently incongruent, making the menisci essential for improving joint stability and congruity. These two fibrocartilaginous structures include the lateral meniscus, which is smaller and nearly circular, and the medial meniscus, which is larger and semicircular [86]. Both menisci are anchored to the tibia via the cruciate ligaments and are interconnected by the transverse ligament; together, they play a critical role in load distribution, shock absorption, and secondary joint stability [3,144,159].

The menisci serve not only as intra-articular shock absorbers but also as primary stabilisers that optimise tibiofemoral congruity and facilitate complex kinematics, including gliding and rolling [148]. Following meniscal injury or excision, the loss of load-sharing capacity leads to a marked increase in contact stress on the articular cartilage, accelerating degenerative changes. This pathological progression frequently results in chronic joint pain, functional impairment, and the eventual development of PTOA [3].

Joint stability is maintained through the collective action of the knee's ligamentous, muscular, and tendinous structures. The primary stabilisers include the anterior and posterior cruciate ligaments, complemented by the medial (MCL) and lateral collateral ligaments (LCL). The collateral ligaments function as the principal constraints against abnormal varus and valgus stresses; they are relatively lax during flexion and become taut in extension to preserve coronal plane stability. In synergy with the cruciate ligaments, these structures govern joint kinematics and provide a robust defence against pathological instability [3].

The LCL is structurally more robust than its medial counterpart. It originates from the lateral femoral epicondyle and inserts onto the head of the fibula. As an extra-articular structure with no attachment to the lateral meniscus, the LCL possesses greater freedom of movement and is generally less susceptible to injury compared to the MCL [144] (Figure 1).

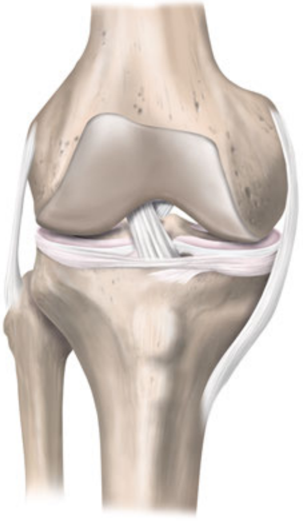

***Figure 1**. Anteroposterior (AP) view of the right knee joint with the patella removed to enhance visualisation of the collateral and cruciate ligaments, as well as the medial and lateral menisci.*

In contrast to the cord-like morphology of the LCL, the MCL is a broad, flat structure composed of distinct superficial and deep layers. It originates from the medial femoral epicondyle and inserts extensively into the medial aspect of the tibia. As an integral component of the joint capsule, the deep layer of the MCL is firmly attached to the medial meniscus; this intimate relationship increases its vulnerability to injury [3].

The anterior and posterior cruciate ligaments (ACLs and PCLs) are centrally located within the knee joint, where they intersect to form an X-shaped configuration. The ACL originates from the anterior intercondylar eminence of the tibia and inserts onto the lateral wall of the femoral notch. In contrast, the PCL extends from the posterior aspect of the tibia to the medial wall of the femoral notch. Together, these ligaments serve as primary stabilisers of the knee, preventing abnormal sagittal translation of the tibia relative to the femur and contributing significantly to rotational stability [6,44,46]

The articulating surfaces of the femur, tibia, and patella are largely covered by articular cartilage, which enables smooth, pain-free joint motion with minimal friction while also distributing load and absorbing shock. Unlike most other tissues, articular cartilage is avascular and relies on synovial fluid for its metabolic requirements. This hyaline structure is composed of a specialised extracellular matrix populated by chondrocytes, which are responsible for matrix homeostasis and limited repair [62]. Due to its limited intrinsic capacity for healing, preserving the structural integrity of the articular surface is critical for maintaining long-term joint function [36].

Biokinetics and Biomechanics

The knee is one of the most complex articulations in the human body, both anatomically and functionally. This complexity stems from the competing requirements to facilitate multi-axial mobility while maintaining structural stability. The joint accommodates an extensive range of motion and withstands substantial physiological loads through the synergy of its active and passive stabilisers[24].

While often simplified as a simple hinge joint, the knee is more accurately defined as a complex bicondylar joint with six degrees of freedom: three translational and three rotational. Translational movements include anterior-posterior, medial-lateral, and superior-inferior gliding, while rotational movements encompass flexion-extension, internal-external rotation, and abduction-adduction (varus-valgus). These sophisticated kinematics are facilitated by the inherently incongruent articular surfaces of the femur and tibia [144] (Figure 2).

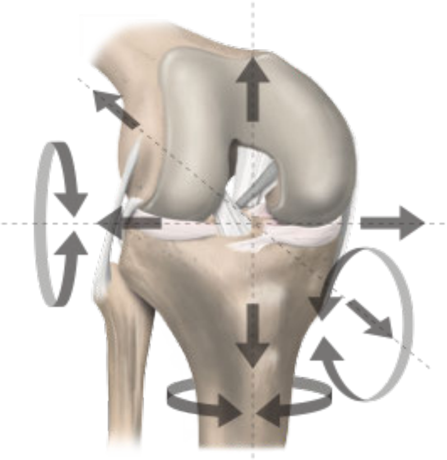

Figure 2. *Schematic representation of the knee joint illustrating its six degrees of freedom. Translational movements include anterior–posterior, medial–lateral, and superior–inferior gliding, while rotational movements comprise flexion–extension, internal–external rotation, and abduction–adduction. The incongruent articular surfaces of the femur and tibia enable this complex range of motion while maintaining joint stability.*

The physiological range of motion of the knee typically spans from 0° to approximately 140° of active flexion, while passive flexion may extend to 160°. During terminal extension, the tibia undergoes an obligatory external rotation relative to the femur, a phenomenon dictated by the joint's asymmetrical articular geometry. Known as the *screw-home movement*, this movement provides a terminal locking system that enhances joint stability during static weight-bearing [144]. Conversely, during the initial 15-20° of flexion, the tibia rotates internally to 'unlock' the joint, thereby facilitating smooth kinematic transition in a broader range of motion.

Tibial Plateau Fractures

The annual incidence of TPFs is estimated to range between ~10 and 26 cases per 100,000 persons [14,28,33,154]. These injuries typically exhibit a bimodal distribution. In younger populations, they are frequently the result of high-energy trauma, such as motor vehicle collisions or falls from significant heights. Conversely, older individuals with reduced BMD are more susceptible to TPFs caused by low-energy mechanisms, such as simple falls from a standing position or minor twisting injuries.

The mechanism of injury—whether high—or low-energy—in conjunction with the patient's intrinsic bone quality, is a critical determinant of fracture morphology and guides the subsequent management algorithm.

Aetiology of Tibial Plateau Fractures

TPFs typically result from varus or valgus forces, often coupled with significant axial loading. Historically, these injuries have been classified based on their involvement of the lateral, medial, or (bicondylar) columns, with lateral being the most prevalent. The lateral tibial condyle is particularly vulnerable to injury due to its anatomical morphology and lower BMD relative to the medial side. These fractures frequently occur under valgus or axial compression, in which the lateral femoral condyle acts as a wedge, driving into and displacing the articular surface. (Figure 3).

In contrast, medial TPFs are relatively uncommon and typically require substantial force, most often resulting from high-energy velocity trauma such as motor vehicle accidents or falls from height [85]. These high-energy mechanisms frequently produce bicondylar fractures—involving both the medial and lateral condyles—due to the magnitude of the impact and the overwhelming of the joint's structural integrity.

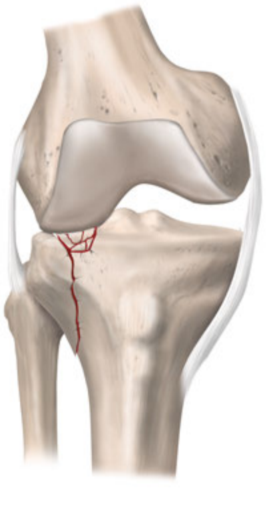

***Figure 3**. Valgus force applied to the knee joint, resulting in a lateral tibial plateau fracture, classified as Schatzker type II (AO/OTA 41B3).*

Classification of Tibial Plateau Fractures

The primary purpose of a fracture classification system is to provide a structured taxonomical framework that enhances clinical communication, documentation, and decision-making [8]. By establishing a standardised language, these systems enable clinicians to describe morphology consistently, facilitate the comparison of outcomes across diverse studies, and provide a foundation for evidence-based treatment algorithms.

While numerous classification systems have been proposed to categorise TPFs, the Schatzker [70,127] and the AO/OTA classifications [88] remain the most widely used in clinical practice. Both frameworks are instrumental in providing a standardised morphological language, thereby facilitating clinical communication and guiding surgical decision-making.

In recent years, advancements in imaging technology have facilitated the development of three-dimensional classification methods. The three-column classification system [83] was introduced to provide a more comprehensive understanding of fracture morphology and spatial orientation. Additionally, the Schatzker classification has been modified to incorporate computed tomography (CT) imaging [70], which enhances preoperative planning by allowing for precise three-dimensional visualisation of fracture topography. This adaptation ultimately improves the execution of fragment-specific surgical approaches.

While various other classification systems have been proposed, they fall outside the scope of this background chapter, as the Schatzker and AO/OTA frameworks represent the current clinical and research standards.

Schatzker Classification

Introduced in 1974 by Toronto-based traumatologist Joseph Schatzker, this system remains the gold standard for classifying tibial plateau fractures (TPFs). The classification categorises fractures into six distinct types based on anatomical location and fracture pattern [123]: The fractures are divided into six categories I-VI, with I-III being lateral condyle fractures, IV being medial, V being bicondylar and VI with meta-diaphyseal discontinuity. While clinically indispensable, the system is a two-dimensional model based on anteroposterior (AP) plain radiographs. It is important to note that the original classification does not explicitly account for the degree of placement, the extent of comminution, or posterior column involvement, factors that are often clarified today by CT imaging (Figure 4).

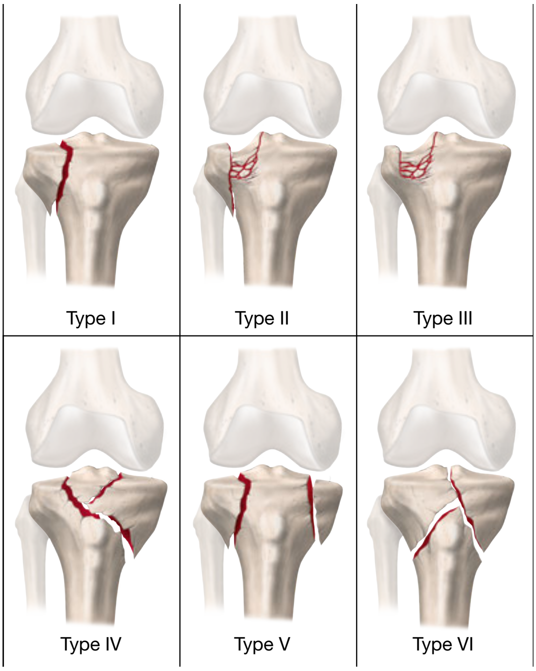

Figure 4. *The Schatzker classification of tibial plateau fractures, dividing injuries into six distinct types (I–VI). Types I–III involve lateral condyle fractures, type IV involves the medial condyle, type V represents bicondylar fractures, and type VI is characterized by metaphyseal–diaphyseal discontinuity.*

The Schatzker classification describes six main patterns of TPFs. Type I and II injuries involve split fractures of the lateral tibial condyle, with type II additionally including depression of the articular surface; both patterns are frequently associated with concomitant meniscal and ligamentous injuries. Type III fractures are characterised by an isolated articular depression and typically occur in osteoporotic bone, with a lower incidence of associated ligamentous damage. Type IV fractures affect the medial tibial condyle and may represent reduced fracture-dislocations, necessitating careful assessment for potential neurovascular injury. Bicondylar fractures are classified as type V when both condyles are involved without metaphyseal–diaphyseal dissociation, and as type VI when there is additional separation between the metaphysis and diaphysis, often with extensive comminution and bone loss.

Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) Classification

The AO/OTA classification system marked a significant milestone in the standardisation of fracture descriptions. Prior to its introduction, eponymous names and a variety of localised classification systems were commonly used, often leading to inconsistency in communication. The approach developed by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) distinguished itself by introducing a uniform framework applicable to the entire skeleton.

Initially conceived by Dr Maurice Müller and colleagues, the *Comprehensive Classification of Fractures of Long Bones* was published in English in 1990 [101] and laid the foundation for the AO/OTA system. Its uniqueness lay not in being the first classification system, but in its uniformity: it used a standardised alphanumeric code applicable to all bones and fracture types. This coding system was designed to be readily adaptable to all bones and fracture types, enabling orthopaedic surgeons to use a consistent, reproducible method for describing fractures. The coding system provides information about the bone involved, the segment of the bone, and the type of fracture.

By providing a consistent, reproducible method for describing fractures, the AO/OTA classification has become an essential tool for orthopaedic surgeons, facilitating communication, research, and treatment planning across diverse clinical settings.

The Orthopaedic Trauma Association (OTA) further refined the AO/OTA classification system in 1996, enhancing the alphanumeric coding and extending its application to additional bones and anatomical regions. Subsequent revisions in 2007 and 2018 introduced further clarifications and expansions, underscoring the ongoing commitment to standardising [88,95].

In the AO/OTA classification, the first two digits of the alphanumeric code denote the localisation of the fracture. The first number determines the localisation of bone 1-8, and the second number is the segment of the bone, 1 being the proximal end, 2 being the diaphyseal segment, and 3 being the distal. In special locations, 4-8 is also used to describe special segments of clinical importance.

The AO/OTA classification for proximal tibial fractures, labelled as 41, is structured into three primary types: Type A (extra-articular), Type B (partial articular), and Type C (complete articular) (Figure 5). This alphanumeric system provides a standardised framework for describing fracture morphology and guiding treatment strategies.

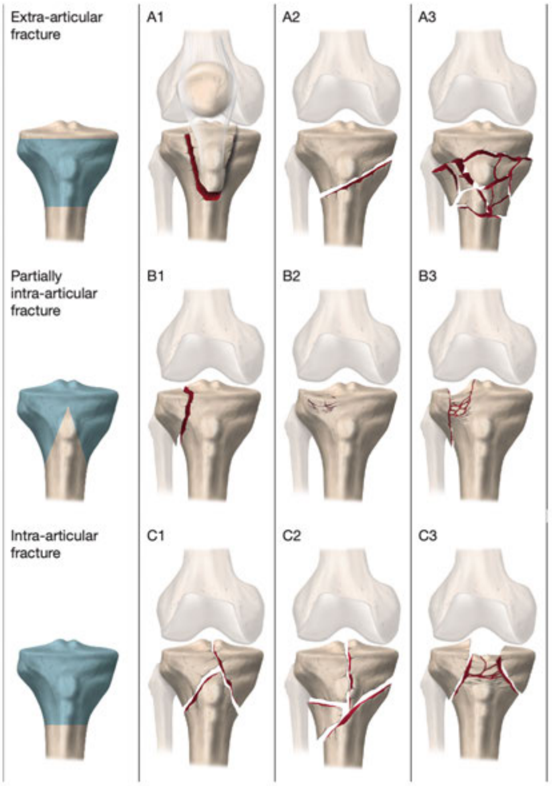

***Figure 5**. AO/OTA classification of tibial plateau fractures.*

Type A fractures are inherently extra-articular (apart from tibial spine avulsions), meaning they do not involve the tibial plateau surface. They are subdivided into three groups with group 1 covering avulsions (e.g., Segond, tibial tuberosity, ACL/PCL avulsions), group 2 including simple fractures, and group 3 involving multi-fragmentary patterns.

Type B (partial articular) and Type C (complete articular) fractures encompass TPFs, the focus of this thesis. B1 includes split fractures (lateral, medial, oblique), B2 refers to pure depressions, and B3 covers split-depression fractures. Subgroups have been added to indicate position (medial /lateral), as these fractures have different etiologies and prognoses.

Type C fractures involve complete articular disruption, with C1 having a simple metaphyseal component, C2 a multi-fragmentary metaphyseal component, and C3 featuring complex articular and metaphyseal involvement.

These fractures are further subdivided into subgroups and have several modifiers available to categorise the fracture further [95].

The Three-Column Concept

In 2010, Congfeng Luo et al. highlighted the limitations of traditional two-dimensional classification systems for TPFs, particularly in cases resulting from high-energy trauma. While the widely used Schatzker and AO/OTA classifications provide detailed descriptions of fracture morphology, they lack a true three-dimensional perspective, especially in categorising posterior rim involvement. To address this gap, Luo proposed the Three-Column Classification System, which divides the tibial plateau into three distinct anatomical columns; a medial, a lateral and a posterior column [83]

This system allows for more precise characterisation of fracture patterns, facilitates three-dimensional surgical planning, and improves the ability to tailor fixation strategies to specific fracture fragments (Figure 6).

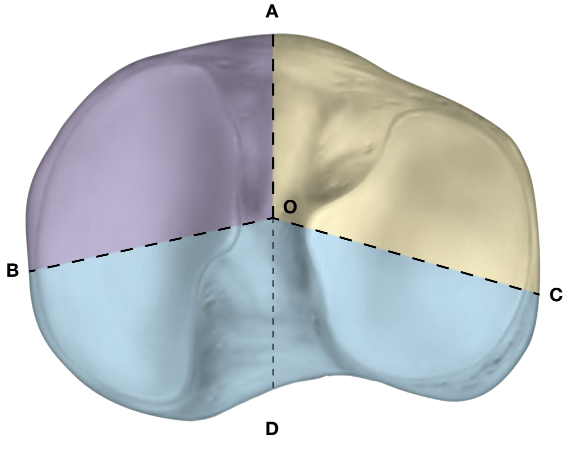

Figure 6. *The three-column concept for tibial plateau fractures. Point 0 represents the centre of the knee. The posterior column is defined by the BC, the lateral column by line AC, and the medial column by line AB.*

In the three-column system, any independent depression associated with a break in the column wall is defined as a fracture of the corresponding column. Conversely, a pure depression without wall involvement is described as a 'zero-column fracture.'

Fractures are categorised according to the number of columns involved, one, two or three. For example, a two-column fracture (L + P) refers to a split-depression fracture involving both the lateral column (L) and the posterior column (P) [149] (Figure 7).

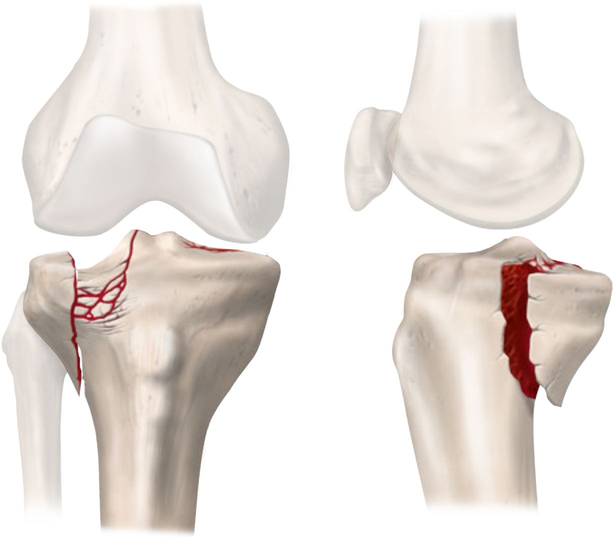

***Figure** 7. Example of a two-column fracture (L+P) according to the three-column classification system. The fracture involves both the lateral and posterior columns, illustrated in anterior-posterior (AP) and lateral radiographic views.*

Revisiting the Schatzker Classification

Following the introduction of the three-column classification system by Congfeng Luo et al., a revised Schatzker classification was proposed in 2018 to incorporate a three-dimensional perspective into the existing framework [70]. This modification aimed to address limitations of the original two-dimensional radiographic approach by better accounting for complex fracture morphologies [70]. The revision introduced the concept of a virtual equator, extending from the tip of the fibular head laterally to the posterior aspect of the insertion of the superficial medial collateral ligament (MCL). This anatomical landmark divides the tibial plateau into four distinct segments, thereby enhancing the ability to categorise posterior involvement and improving preoperative planning.

A denominator A for anterior and/or P for posterior are added to the existing classifications of unicondylar fractures. This illustrates the location of the main fracture plane in the sagittal plane to assist with plate positioning and surgical approach.

To bicondylar fractures, an AM, PM, AL, and/or PL is added to the existing classes to note the positions of the fragments.

Treatment Strategies

History of Tibial Plateau Fractures, Diagnostics, and Management

Fractures around the knee likely date back to early human history, but their recognition and treatment were limited by the absence of diagnostic tools. A major breakthrough occurred in 1896, when Wilhelm Conrad Roentgen discovered a 'new kind of rays,' leading to the development of radiography (X-ray). This innovation marked a turning point in orthopaedics, providing clinicians with a reliable method for visualising skeletal injuries and significantly advancing the diagnosis and management of TPFs [119](Figure 8).

Figure 8. *Plain anterior-posterior (AP) radiograph of a tibial plateau fracture in a 50-year-old woman after a bicycle accident, Schatzker VI, AO/OTA 41C3.*

Three major innovations profoundly shaped the development of operative fracture management, the aforementioned X-rays, the antiseptic regime established by Semmelweis in 1865, and the invention of anesthesia in 1846.

Despite significant advances in surgical techniques and concepts during the mid- to late 19th century, fracture management in the first half of the 20th century remained conservative by modern standards. Long-term immobilisation using plaster casts and skeletal traction was the predominant treatment approach. Although surgical intervention was occasionally considered, it was often avoided due to concerns about complications, such as infection, and the lack of reliable fixation methods (Figure 9).

Figure 9. *Closed reduction and external fixation of a Schatzker VI tibial plateau fracture*

A significant milestone in the treatment of fractures, including TPFs, was the establishment of the AO Foundation in 1958. Founded by Swiss surgeons Maurice E. Müller, Martin Allgöwer, Robert Schneider, and Hans Willenegger, the AO Foundation sought to improve fracture care through research, education, and the development of standardised surgical techniques.

The AO Foundation pioneered the concept of open reduction and internal fixation (ORIF), emphasising 1) anatomical reduction of fracture fragments, 2) stable fixation to allow reliable healing, and 3) early mobilisation to restore function and reduce complications. The AO's influence led to the widespread adoption of plates and screws in the management of TPFs, establishing principles that remain central to modern orthopaedic practice.

The AO Foundation's work, particularly its emphasis on biomechanical principles and fracture healing, continues to guide and advance the management of complex fractures. As surgical techniques evolved and ORIF gradually became the treatment of choice for TPFs, the need for systematic categorisation became increasingly evident. To address this, fracture classification systems were developed to tailor surgical interventions according to fracture morphology and severity [101]

The advent of advanced imaging techniques in the late 20th century—most notably CT—revolutionised fracture evaluation by allowing far more precise assessment of fracture severity.

Open Reduction Internal Fixation

The primary goal in treating a TPF is to restore anatomical alignment and joint stability, thereby enabling early mobilisation and reducing the risk of morbidity [9]. Surgical management of knee fractures has evolved considerably, with varying techniques employed since the mid-19th century.

The founding of the AO, together with subsequent advancements in surgical techniques and biomaterials, greatly expanded the range of complex fractures amenable to operative management. In the 1970s, Joseph Schatzker strongly advocated surgical treatment for TPFs. Nevertheless, the most comminuted and complex fracture patterns were often recommended for non-operative management, as the technical challenges of achieving stable fixation and the historically poor outcomes associated with surgical intervention limited the effectiveness of operative approaches [128].

Complex TPFs can be managed operatively through a variety of techniques. Today, ORIF is regarded as the gold standard for treating complex TPFs [9,13,83,151]. Advances in imaging, particularly CT, have greatly enhanced preoperative planning by enabling detailed assessment of the three-column structure of the tibial plateau. This allows surgeons to tailor fixation strategies more precisely to the unique characteristics of each fracture [70].

The aforementioned advancements in imaging have facilitated a fragment-specific approach, enabling surgeons to identify the precise fracture components requiring stabilisation during preoperative planning and to tailor operative strategies accordingly. The introduction of locking screw plate technology has further broadened surgical options, allowing effective management of comminuted fractures even in patients with markedly diminished bone quality.

Severe depression or compression fractures resulting in bone loss can now be managed using bone substitute materials to fill osseous voids, as well as with rafting screw techniques, in which screws provide structural support to the elevated articular surface during healing. Based on preoperative planning and identification of displacing forces, buttress plates or anti-glide plates are strategically applied to counteract these forces (Figure 10).

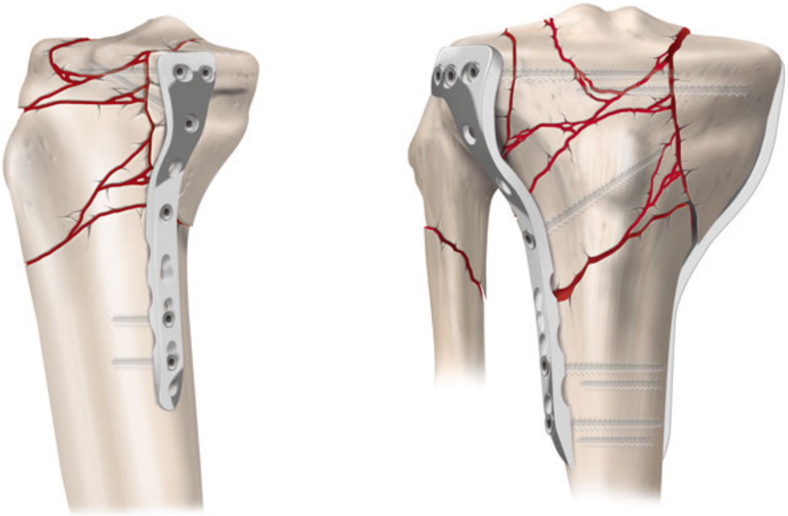

***Figure 10**. Open reduction and internal fixation of a Schatzker VI tibial plateau fracture using the LCP technique. Anteroposterior (AP) and lateral radiographic views demonstrate fixation with a posteromedial buttress plate and a lateral periarticular plate with locking screws.*

Postoperatively, weight-bearing is generally restricted for the first 6 weeks following surgery. Younger patients can often tolerate this period without weight-bearing on a comminuted articular surface, whereas older patients typically require a wheelchair to maintain mobility during recovery.

Total Knee Arthroplasty as Primary Treatment of TPF

While consensus exists regarding the management of fractures in major joints, such as the hip, elbow, and shoulder [93,105,116], no clear agreement has been reached on the optimal treatment of severely displaced TPFs, particularly in elderly patients. With an ageing population, the incidence of TPFs is anticipated to rise, highlighting the importance of re-evaluating treatment strategies for this demographic [28].

For elderly patients, achieving stable initial treatment that permits early mobilisation with immediate weight-bearing is critical to minimising complications and morbidity. Primary TKA has been reported in TPF cases under two main circumstances: complex intra-articular fractures in elderly patients with pre-existing OA, and fractures in which internal fixation is deemed hazardous [17,21,107,115]. These observations raise an important question—whether certain types of TPFs might benefit more from primary joint replacement than from the current gold standard of osteosynthesis, in which immediate weight-bearing is not always feasible.

When considering primary TKA for complex TPFs, both the advantages and disadvantages must be carefully weighed. As noted, weight-bearing is often restricted following ORIF in elderly osteoporotic patients with comminuted fractures. Prolonged immobilisation and lack of weight-bearing after major fractures have been associated with increased mortality [78,137,152,157]. Conversely, outcomes following TKA in the setting of established post-traumatic OA are significantly poorer compared to primary TKA performed for degenerative OA [60,108,134]. Nevertheless, retrospective single-centre case series of primary TKA in TPFs have reported encouraging results, including improved range of motion, Knee Society Scores (KSS), and favourable patient-reported outcome measures (PROMs) [2,145].

Primary TKA in the acute setting carries distinct risks. Metaphyseal comminution can compromise implant stability, often necessitating the use of stemmed or tumour-type components to permit early weight-bearing. Severe osteoporosis further increases technical complexity, limiting the feasibility of such procedures to high-volume centres with specialised expertise. Moreover, primary TKA as a first-line treatment has been associated with a higher incidence of complications [17,21,106,115]. A systematic review by Cochrane highlights the lack of sufficient evidence supporting TKA as a primary surgical approach for TPFs [94].

The higher risk of complications and the greater technical demands of the procedure must be weighed against the potential benefits of early weight-bearing and the reduced likelihood of revision surgery.

National Registers

In Sweden, every citizen and permanent resident is assigned a personal identification number (PIN) at birth or upon immigration. This system provides a unique opportunity to establish nationwide quality registers with exceptional completeness, thereby improving patient care. In a secondary stage, the data can be used to conduct high-quality research. The PIN also enables linkage across registers, ensuring comprehensive databases. The three national registers employed in this thesis are the Swedish Fracture Register (SFR), the Swedish Arthroplasty Register (SAR), and the National Patient Register (NPR).

The Swedish Fracture Register (SFR)

Established in 2011, the SFR is a database of fractures in Sweden that encompasses nearly all adult fractures, excluding those of the ribs and skull. The SFR collects data on injury mechanisms, fracture classification, trauma energy, treatment, reoperations, and PROMs [97,155]. The SFR provides real-time data that enables healthcare providers to benchmark performance against national averages and support research with its extensive, prospectively collected data[37]. With over 1,100,000 registered fractures to date, it serves as a unique resource. For this thesis, SFR data have served as the source of the study cohort for Study II. All 54 eligible orthopaedic departments have participated in the SFR, ensuring complete national coverage since 2021. Completeness of fracture registrations, critical for external validity, averaged 62% in 2023 for tibial fractures, with a range of 0-96% across departments [37,97].

At the time of diagnosis, the treating clinician registers the injury in the SFR. Key variables are documented, including the patient's age, date of injury, mechanism of injury, and whether the fracture is classified as open or closed. The fracture is subsequently categorised using an interactive, clickable interface. Treatment details are entered once the treatment plan has been finalised or surgery has been performed.

The SFR employs the AO/OTA 2007 classification, which specifies fracture location, type, and group for 41A1-3, 41B2-3, and 41C1-3. Additional subgroups have been introduced for 41B1 fractures (41B1.1-3) to provide a better illustration of variations in lateral contra medial split fractures (Figures 11-12).

Figure 11. *An interactive skeleton from the clickable interface in the Swedish Fracture Register (SFR), used during fracture registration.*

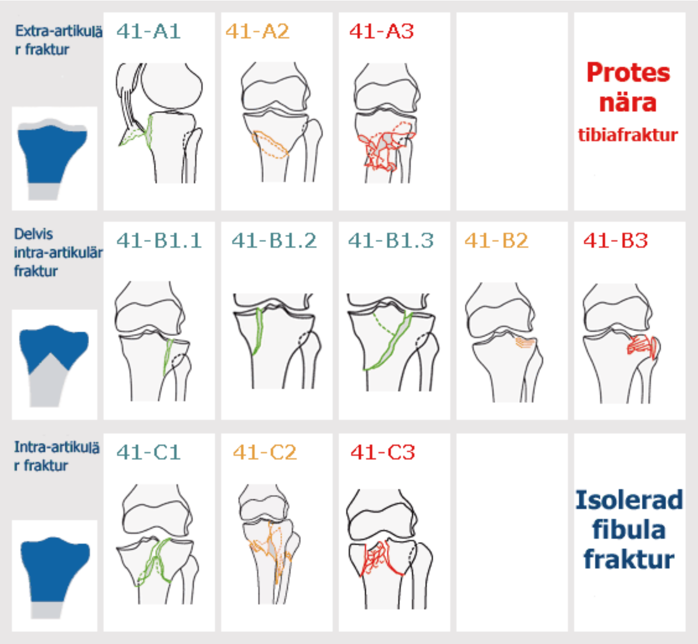

***Figure 12**. Schematic view of the clickable interface in the Swedish Fracture Register (SFR) used for classifying tibial plateau fractures.*

The Swedish Arthroplasty Register (SAR)

The SAR was established in 2020 through a merger of the Swedish Knee Arthroplasty Register (founded in 1975) and the Swedish Hip Arthroplasty Register (founded in 1979). It systematically collects nationwide data on hip and knee arthroplasties performed in Sweden, including revision surgeries. Using a standardised reporting form, the SAR documents details such as arthroplasty type, surgical technique, perioperative antibiotic prophylaxis, and patient characteristics (e.g., ASA score and BMI). PROMs are collected separately, both preoperatively and at 1 year postoperatively. The SAR achieves nearly complete national coverage, with participation from all eligible departments and a completeness exceeding 96% for primary procedures [77]. In addition to annual quality reports, the SAR provides a robust foundation for research through its large, prospectively collected cohorts.

The National Patient Register (NPR)

The NPR was established in the 1960s by the National Board of Health and Welfare to collect information on inpatients treated in public hospitals. In 1987, the register achieved nationwide coverage by including data from private hospitals. Since 2001, specialised outpatient visits have also been incorporated, and private healthcare providers became legally required to report to the register. Thus, the NPR contains comprehensive data on all inpatient and outpatient care delivered by specialised healthcare providers in Sweden since 2001. The NPR contains diagnoses, treatments and causes coded according to the Swedish edition of "International Classification of Diseases -10th revision (ICD-10) since 1997 [157–159]

The register has undergone repeated validation and demonstrates strong external validity for most diagnoses [80].

Patient-Reported Outcome Measures (PROMs)

In recent decades, healthcare systems have placed growing emphasis on incorporating the patient perspective as a key element in evaluating the quality and safety of care [89]. A major step toward achieving this has been the widespread adoption of PROMs [16,27]. PROMs are standardised questionnaires designed to capture information directly from patients about their health status, symptoms, and overall satisfaction with the care they receive. By focusing on the patient's voice, PROMs provide valuable insights that complement clinical assessments and help ensure that healthcare delivery aligns with patient needs and experiences.

Broadly, PROMs can be divided into two main categories: generic and disease-specific. Generic PROMs assess general aspects of health, such as health-related quality of life (HRQoL), mobility, and self-care. These tools are designed to be applicable across a wide range of populations and conditions, making them useful for comparisons between different patient groups. Disease-specific PROMs, of which thousands have been developed, focus on symptoms, functional limitations, and quality-of-life (QoL) impacts associated with particular conditions. They provide more targeted insights into how a specific illness or treatment affects patients' daily lives.

Sweden has been a pioneer in integrating PROMs into healthcare, with a strong emphasis on improving clinical care. This leading is largely attributed to the 1975 establishment of disease-specific national databases, known as Quality Registers (NQRs). Around the year 2000, PROMs were gradually incorporated into several of these registers, marking a significant step toward embedding the patient perspective into routine clinical evaluation and quality improvement efforts [117]

The reliability of PROMs has been suggested to be comparable to that of routinely used clinical indicators such as diastolic blood pressure or blood glucose levels [47]. A striking example is the well-documented discordance between radiographic findings of OA and patient-reported knee pain, which can occur in both directions [10]. This highlights the importance of integrating both objective assessments and patient-reported measures into clinical decision-making to ensure a more comprehensive understanding of patient health.

A major challenge in the collection and analysis of PROMs is achieving high participation rates, particularly among older adults and patients with more illnesses [63]. Inevitably, working with PROM data also involves dealing with missing responses. This has sparked ongoing debate about the most appropriate statistical and methodological approaches for handling missing data, as the chosen strategy can significantly influence the validity and reliability of findings derived from PROMs.

Understanding Missing Data in PROMs

To understand missing data more deeply, it is first necessary to identify and categorise the different types of missing values. Little and Rubin's framework is commonly used for this purpose and distinguishes three mechanisms: *missing completely at random (MCAR)*, *missing at random (MAR)*, and *missing not at random (MNAR)*.

Missing completely at random occurs when there are no systematic differences between the missing and the observed data. In other words, the probability that a value is missing is entirely independent of patient characteristics or outcomes. For example, if a radiographic assessment is unavailable because the X-ray machine malfunctioned on a given day, the missingness is random with respect to the study variables. Under MCAR, missing data do not introduce bias, although they may reduce statistical power.

Missing at random occurs when the probability of missingness depends on observed variables but not on the missing values themselves. In this case, potential bias can often be addressed through appropriate statistical adjustments. For instance, if younger patients are less likely to complete a follow-up PROM, and age is recorded for all participants, the missing data can be accounted for since the mechanism is linked to an observed variable (age). While MAR is more complex than MCAR, it is generally manageable with robust analytical methods.

Missing not at random describes situations in which systematic differences remain even after accounting for observed data. In these cases, the missingness is directly attributable to the unobserved value. For example, patients experiencing persistent knee pain after a TPF may be less inclined to respond to a PROM due to dissatisfaction or fatigue from ongoing symptoms. MNAR is the most challenging mechanism to address, as it introduces systematic bias that cannot be corrected simply by adjusting for observed variables.

Statistical tests can be applied to assess whether data are missing completely at random (MCAR). In contrast, distinguishing between missing at random (MAR) and missing not at random (MNAR) is far more challenging, as it cannot be determined solely by calculation. Instead, this distinction often relies on interpretation, debate, and the application of clinical expertise on a case-by-case basis. The complexity of distinguishing between MAR and MNAR underscores the importance of careful methodological consideration when analysing PROMs data.

While some authors argue that missing values in PROMs do not necessarily introduce bias [121,135] , others suggest that non-responders often experience worse outcomes compared to responders [34,73]. This divergence of views highlights the complexity of interpreting missing data in PROMs and emphasises the importance of carefully considering how non-response may influence study findings and clinical decision-making.

Several statistical methods are available for handling missing data; two are highlighted here. *Complete case analysis (CCA)* includes only cases with fully observed data and therefore assumes that the missingness is completely at random (MCAR). When interpreted cautiously and supported by clinical insight, this approach can be sufficient in some settings. However, its primary limitation is the potential loss of statistical power and the introduction of bias if the MCAR assumption is violated.

In other cases, *multiple imputation* can be applied [133,156] under the assumption that the data are missing at random (MAR). In brief, multiple imputation replaces each missing value with multiple plausible estimates based on observed data, creating numerous complete datasets that are analysed separately and then combined to produce overall estimates that account for uncertainty due to missingness. This approach preserves statistical power by retaining incomplete cases and yields valid inferences when the MAR assumption is reasonable.

EuroQol 5-Dimension (EQ-5D) and EuroQol-Visual Analog Scale (EQ-VAS)

The EQ-5D is a standardised measure of general health that assesses five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Responses are converted into a single index score using country-specific value sets [25], in which lower scores indicate poorer health status [25]. In addition, the EQ-VAS records self-rated health on a vertical scale ranging from 0 (worst imaginable health) to 100 (best imaginable health), providing a single quantitative measure of overall health perception [111,142]. Population-based data from large interview-based studies across various countries indicate that EQ-VAS scores in healthy individuals typically range from 71 to 79 [35,67,92].

Evolution of EQ-5D in the SAR

Before 2021, the EQ-5D-3L was used in the SAR, which has three response levels per dimension [111]. While widely adopted, the 3L version was often criticised for limited sensitivity and pronounced ceiling effects, particularly in populations with relatively good health status. These limitations reduced its ability to detect subtle differences in HRQoL across different populations [66].

Since 2021, the EQ-5D-5L has replaced the 3L version to improve sensitivity and reduce ceiling effects, demonstrating greater reliability and discriminative ability across populations. The 5L version expands each dimension to five response levels, allowing for more nuanced gradation of health states. This refinement enhances the instrument's ability to capture small but clinically meaningful changes, thereby improving both cross-sectional and longitudinal analyses [66].

Knee Injury and Osteoarthritis Outcome Score (KOOS and KOOS-12)

In our studies, knee-specific PROMs were measured using the KOOS, which assesses five domains: symptoms, pain, activities of daily living, sports and recreational function, and knee-related QoL. Scores are transformed to a 0–100 scale, where higher scores indicate better outcomes [120]. In SAR, until 2021, the 42-item comprehensive version (KOOS-42) was used. In 2021, the validated short form, KOOS-12, was introduced to reduce respondent burden while preserving robust psychometric validity [40]. The KOOS-12 generates individual domain scores for pain, function, and knee-related QoL, as well as an overall summary score [41].

Causal Inference in Observational Studies

It is important to recognise that causality is not directly observed but inferred. Causal conclusions are based on consistent associations rather than direct observation of cause and effect. Thus, we can never be certain that exposure X causes outcome Y. Instead, causation is an inference drawn from repeated co-occurrence. This limitation of inferential reasoning is relevant to both experimental and observational research [79]

All analyses in this thesis were conducted using observational, single-centre, or register-based data and should therefore be interpreted initially as estimates of association rather than as evidence of causal relationships. Observational studies are inherently susceptible to confounding, bias, and spurious correlations, particularly when shared patient-related, biological, or healthcare-related factors influence exposures and outcomes [53]. Although model adjustment was applied to reduce confounding by measured variables, unmeasured or residual confounding cannot be excluded.

Epidemiological reasoning has long distinguished between association and causation. In observational research, causality cannot be established solely through statistical association but must be interpreted in light of broader evidence. Because randomised allocation of exposure is not always ethical or feasible, epidemiologists have adopted conceptual frameworks to guide causal assessment. Most prominently, the Bradford Hill criteria, first published in 1965 [22], provide nine viewpoints—strength, consistency, temporality, biological gradient, plausibility, coherence, specificity, experiment, and analogy—that are intended not as a rigid checklist but as complementary considerations to be weighed collectively when evaluating potential causal relationships [103].

More recent methodological developments, such as target trial emulation [52], enable observational studies to approximate the design principles of a hypothetical randomised trial. This approach explicitly defines eligibility criteria, treatment strategies, time zero, and follow-up within a causal framework [39,51,53]

Accordingly, the results presented in this thesis are reported as associations unless explicitly stated otherwise. A more comprehensive discussion of potential causal relationships is provided in the General Discussion, where the findings are critically evaluated using Bradford Hill criteria and principles of target trial emulation.

Knowledge Gaps

Although some data exist on the overall frequency of conversion to TKA following TPF, important uncertainties remain. Specifically, questions persist regarding the accuracy of endpoint measurement ‘conversion to TKA’ and the methods used to capture this outcome. Moreover, there is a notable lack of research on the Swedish population, which limits the generalisability of existing findings and underscores the need for population-specific investigations.

Limited evidence exists regarding the underlying risk factors of conversion to TKA. In particular, the influence of preoperative factors—including patient demographics, comorbidities, and injury-specific characteristics—on the subsequent development of PTOA serious enough to necessitate endoprosthetic intervention remains insufficiently understood. This gap accentuates the need for further research to clarify which factors predispose patients to poor long-term outcomes following TPF.

There remains considerable debate regarding the viability and clinical applicability of TKA as a primary treatment for TPFs. The lack of robust evidence identifying patient or injury subgroups at greatest risk of developing PTOA after a TPF complicates evaluation of whether primary TKA could serve as a sustainable and clinically appropriate treatment strategy. Establishing these risk profiles is critical for guiding patient selection, informing surgical decision-making, and optimising long-term outcomes.

Evidence suggests that TKA performed as a delayed procedure after failed initial treatment yields significantly poorer outcomes than primary TKA performed for idiopathic OA. However, direct comparative studies evaluating early versus delayed TKA in the context of TPFs remain scarce, limiting the ability to draw firm conclusions regarding optimal timing of intervention.

Study Design

Study 1: A nationwide, register-based observational study examining incidence and treatment trends in Sweden between 2011 and 2023.

Study II: A single-centre observational cohort study investigating the rate of conversion to TKA following surgically treated TPFs.

Study III: A national, register-based observational cohort study using data from the SFR to examine the TKA conversion rate following a TPF.

Study IV: A register-based observational cohort study that directly compares outcomes between early and delayed TKA for TPF.

Specific Aims

The overarching aim of this thesis was to investigate the relationship between TPFs and subsequent TKA, with a focus on incidence, treatment strategies, and long-term outcomes.

Study I – Specific Aims

The objective of Study I was to assess the nationwide incidence of proximal tibial fractures in Sweden between 2011 and 2023. Specifically, we examined whether demographic shifts, particularly an ageing population, have influenced fracture incidence, and whether treatment practices have evolved over time. In addition, we analysed differences in incidence and treatment patterns across age groups and between sexes.

Study II – Specific Aims

The primary objective of Study II was to determine the rate of conversion to TKA following operatively treated TPFs in a single-centre cohort from Uppsala University Hospital. Secondary objectives were to evaluate whether preoperative fracture classification, according to the Schatzker or AO/OTA systems, was associated with the likelihood of conversion to TKA.

Additionally, we aimed to explore whether preoperative patient characteristics, such as age and sex, and postoperative reduction quality were associated with the risk of conversion to TKA.

Study III – Specific Aims

The objective of this study was to investigate the rate of conversion to TKA in a national cohort of patients with TPFs. Secondary aims were to evaluate whether fracture classification and preoperative patient and fracture characteristics were associated with the risk of conversion to TKA.

Study IV – Specific Aims

The objective of this study was to compare outcomes between acute TKA performed for TPFs and delayed TKA undertaken for fracture sequelae. Specifically, we assessed reoperation and revision rates, along with the underlying reasons for reoperation in both groups. In addition, we evaluated whether PROMs differed between primary TKA in the acute setting and delayed TKA following TPF.

Methods

Inclusion Criteria and Patient Selection

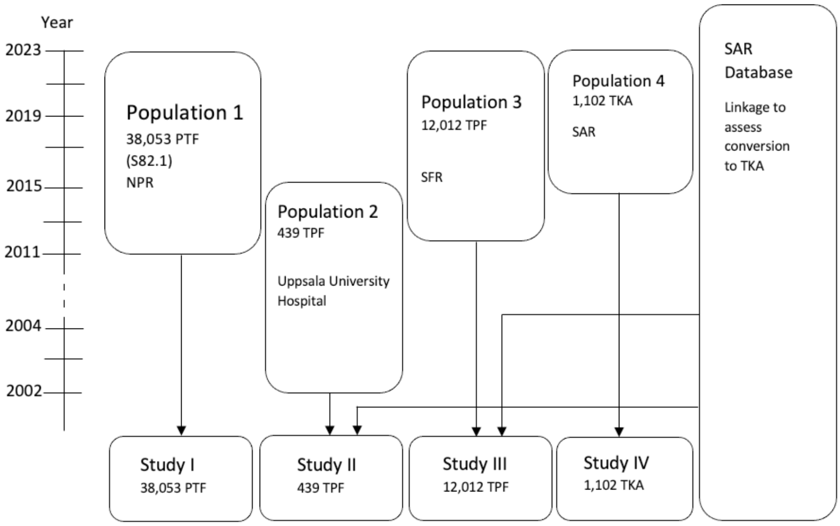

Figure 13: *Overview of data linkage and study populations**.** The diagram outlines the data sources and patient cohorts (Populations 1-4) used across the four studies (Study I–IV), highlighting the linkage to the Swedish Arthroplasty Register (SAR) to assess conversion to TKA.*

Study I – Study Population and Variables

All adult patients (>18 years of age) treated for a proximal tibial fracture in Sweden between 2010 and 2024 were identified through the NPR. Case ascertainment was based on ICD-10 codes S82.1, S82.10, and S82.11. Both inpatient and outpatient registers were included to ensure comprehensive coverage of the study population.

The following data were extracted from the NPR: age, sex, date of registration, and diagnostic and procedural codes (classified according to ICD-10). For patients with multiple hospital admissions or visits, only the first occurrence was included, as it was not possible to reliably differentiate new injuries from follow-up care related to the initial fracture. Because individuals who sustained their fracture in 2009, or earlier, could have follow-up visits recorded in 2010, this would have resulted in incorrect index dates and an overestimation of the 2010 incidence. To mitigate this, data from 2010 were excluded from incidence calculations and graphical analyses.

Study II – Study Population

All patients aged ≥18 years who were treated for TPFs at Uppsala University Hospital between 2002 and 2015 were identified in hospital records using ICD-10 codes S82.10 and S82.11. Patients who underwent surgical treatment with available pre- and postoperative radiographs were assessed for inclusion. Exclusion criteria were treatment with primary TKA and absence of a Swedish PIN, as conversion to TKA was either not applicable or could not be reliably verified.

The cohort was linked to the Swedish SAR. In cases of bilateral fractures, the second entry was excluded due to technical challenges in censoring and concerns regarding statistical dependency. Emigration and death were treated as competing events, with patients censored at the time of the event. Linkage to SAR was performed in 2017, ensuring a minimum follow-up of 2 years for all included patients.

Study III – Study Population

Data were retrieved for all patients aged ≥18 years at the time of injury who sustained a proximal tibia fracture and were registered in the SFR between 1 January 2012 and 31 December 2023. As in Study II, the cohort was linked to the SAR using unique Swedish PINs to identify conversions to TKA.

AO Type A, defined as proximal tibial fractures without intra-articular involvement, were excluded from the main analysis but retained as a control group. Patients whose initial treatment consisted of amputation, primary TKA, or arthrodesis were excluded, as conversion to TKA was not applicable in these cases.

Additional exclusions included patients with erroneous registrations, unclassifiable fractures, or missing information regarding primary treatment. In cases of bilateral fractures, the second entry was excluded due to technical issues with survival analysis and censoring, as well as concerns about statistical dependency.

Study IV – Study Population

All TKAs performed between 2014 and 2023 for the indications *acute TPF* (ICD-10: S82.0) and *fracture sequelae* (ICD-10: M84.0) were identified in the SAR. Each patient was included only once; in cases of bilateral procedures, only the first entry was retained [113].

The SAR currently provides full national coverage, with data completeness estimated at 98% for primary TKAs and 94% for revision procedures [76]. Reoperations that do not qualify as formal revisions—defined as the exchange of at least one prosthetic component—are less well defined in the register, and their reporting is likely incomplete.

Fracture Classification

Study II

Preoperative radiographs were analysed and classified according to the Schatzker [127] and AO/OTA [95] systems. All fractures were initially classified by a single observer (FO). To assess interobserver reliability, a second observer independently classified 171 fractures, and agreement was evaluated using Cohen's kappa [74,90]. Schatzker classification groups I-VI were applied, while in the AO/OTA system, location, type, and groups 41 B1-3 and 41 C1-3 were used. Due to the cohort size, neither Schatzker classification modifiers nor AO/OTA subgroups were included.

Postoperative reduction quality was assessed using the first postoperative radiograph, interpreted by a single observer. Reduction was considered inadequate if a residual joint surface step off of ≥2 mm was present on AP or lateral radiographs.

Study III

Fracture classification for each included fracture was retrieved directly from the SFR [88,97]. This approach limited the ability to assess interobserver agreement in the present study. However, a prior validation of tibia fracture classification in the SFR has demonstrated good agreement, supporting the reliability of the register data [153] (Figure 12).

Outcome Measures and Variables

Study I - Variables and Outcome Measures

From NPR, we obtained data on sex, age at the time of injury, diagnostic and procedural codes, and the index date—defined as the date of first registration in either the inpatient or outpatient register. Population data for the corresponding period were retrieved from Statistics Sweden to enable calculation of incidence rates.

The primary outcome was the incidence of proximal tibial fractures in Sweden, with temporal trends stratified by sex and age group. Secondary outcomes included the frequency of surgically treated proximal tibial fractures and changes in surgical treatment patterns over time. In addition, we evaluated the use of primary TKA in the context of proximal tibial fracture, specifically its proportion and temporal development.

Study II - Variables and Outcome Measures

Baseline information was available on laterality, sex, and age at the time of injury, together with individual pre- and postoperative radiographs. The primary outcome was the 2-year conversion rate to TKA following initial surgical treatment of TPFs. Secondary outcomes included the overall conversion rate during follow-up, as well as the associations between preoperative fracture classification (Schatzker and AO/OTA) and postoperative joint-surface reduction quality with the risk of conversion to TKA.

Study III - Variables and Outcome Measures

From the SFR, baseline data were obtained on sex, age at the time of injury, fracture classification, and treatment method.

Additional variables included injury mechanism, categorised into four groups: falls, transportation-related causes, stress fractures, and other causes. Injury type was classified as high-energy, low-energy, unknown, or not applicable.

For surgically treated cases, operating surgeon's level of experience was recorded as consultant orthopaedic trauma surgeon, consultant orthopaedic surgeon, or resident.

The primary outcome was the conversion rate to TKA at the 5 years observation point. Secondary outcomes included associations between preoperative patient and fracture characteristics and the risk of conversion to TKA at 5 years and throughout the full observation period.

Study IV - Variables and Outcome Measures

Patient data extracted from the SAR included age, sex, body mass index (BMI), and American Society of Anesthesiologists (ASA) physical status classification. Procedure-related variables comprised indication for surgery, date of operation, implant type, operative time, and complications necessitating reoperation. The dataset contained only coded case numbers, which prevented identification of individual patients; consequently, review of medical records and pre- or postoperative radiographs was not possible.

Implants were classified as primary, revision non-hinged, or revision hinged based on implant barcodes.

PROMs were available in the form of EQ-5D-3L (and later EQ-5D-5L), EQ-VAS for general health, the Knee Injury and Osteoarthritis Outcome Score (KOOS), and subsequently KOOS-12, as well as a general satisfaction score. For methodological consistency, only the EQ-VAS (a generic health measure) and KOOS-12 (knee-specific measure) were used in the main analyses. Sensitivity analyses, including the remaining PROMs, were also performed.

The primary outcome was the risk of reoperation or revision for any cause when comparing early or delayed TKA. Secondary outcomes included the risk of reoperation or revision for infection and the risk of revision for aseptic loosening.

Statistical Analyses

Study I

The incidence of proximal tibial fractures, including those managed surgically, was calculated for the period 2011–2021. Incidence rates were expressed as the number of cases per 100,000 inhabitants per year and were determined for the entire adult population. As the dataset represented complete national coverage rather than sample-based estimates, 95% confidence intervals (CIs) and other inferential statistical methods were not applied. All statistical analyses were conducted using R software (version 4.3.1)[110]

Study II

Descriptive statistics were used to characterise the study population and to determine TPF-to-TKA conversion rates at 2 years and at full follow-up.

Kaplan-Meier survival analysis was applied to estimate time to TKA, with censoring for death, expatriation, or end of the observation period.

Cox proportional hazards models were used to estimate the association between fracture classification and the risk of TKA conversion, with adjustments for age and sex.

To address limited event numbers, fractures were grouped as follows: Schatzker I-III (lateral) versus IV-VI (medial/bicondylar), and AO/OTA 41B1-3 versus 41C1-3, and a ‘complex articular’ group comprising 41B3 & 41C3 fractures. Cox models were also applied to evaluate the impact of post-operative joint-surface reduction on the risk of TKA, again adjusting for age and sex.

Interobserver agreement was assessed using Cohen’s kappa values. Group-specific values were 0.7 for the Schatzker classification and 0.64 for the AO/OTA classification. According to the categorisation by Landis and Koch [74], these values indicate substantial agreement (0.61–0.80).

All statistical analyses were performed using IBM SPSS software (version 27, IBM Corp, Armonk, NY, USA) and R software (version 4.3.1) [110].

Study III

Descriptive statistics were used to summarise the study population, including mean age (SD) and stratification into five age groups (<55, 55-64, 65-74, 75-84, ≥85 years). Conversion rates to TKA were calculated at 1, 2, and 5 years, as well as for the entire observation period. Kaplan-Meier analysis was applied to estimate cumulative event probabilities, with censoring at the end of follow-up or death. Cox proportional hazards models were used to assess the association between fracture classification and TKA conversion, reporting both unadjusted (HRs) and adjusted hazard ratios (aHRs) with 95% CIs. Additional models evaluated the influence of age, injury type, and surgeon experience. The proportional hazards assumption was tested using Schoenfeld residuals.

Sensitivity analyses were performed by grouping 41B3 and 41C3 fractures as ‘comminuted fractures.’ AO Type A fractures were used as a proxy control to compare intraarticular versus extraarticular injuries, analysed with both Cox regression and Kaplan-Meier methods.

All statistical tests were two-tailed with an alpha level of 0.05. Analyses were conducted using R software (version 4.3.1)[110].

Study IV

Descriptive statistics were used to characterise the study population. Data distributions were evaluated for normality using histograms and Q–Q plots.

Baseline characteristics were compared using Student's *t*-tests for normally distributed variables and Mann–Whitney *U* tests for non-normally distributed data. Categorical variables were analysed using chi-square tests.

Time to first reoperation was defined as the interval from the date of primary TKA to the date of the subsequent surgical procedure, with censoring at death or at the end of follow-up (31 December 2024). Descriptive summaries of all reoperations were also presented. Multivariable Cox proportional hazards models were not applied because survival curves crossed and the proportional hazards assumption was violated, as indicated by Schoenfeld residuals. Instead, adjusted odds ratios (ORs) were computed using logistic regression analyses.

Kaplan–Meier analysis was used to estimate the cumulative event probability of reoperation/revision, regardless of cause, comparing the two primary surgical indication groups: 'acute TKA' and 'delayed TKA' Analogous Kaplan-Meier analyses were performed to assess cumulative event probabilities for reoperation/revision due to infection and for revision due to aseptic loosening.

EQ-VAS PROMs were analysed as follows: EQ-VAS scores were assessed at baseline and at 1 year postoperatively, with median values presented and changes from baseline calculated. For patients who had completed the KOOS-42, items corresponding to the KOOS-12 were extracted and scored according to the KOOS-12 protocol. KOOS-12 scores were analysed at baseline, at 1 year postoperatively, and as changes from baseline for the summary score and each of the three subscales (Pain, Function, and Knee-related QoL). Mean values with 95% CIs were reported to indicate uncertainty.

Normally distributed data were compared using independent *t*-tests; non-normally distributed data were compared using Mann-Whitney U tests; and categorical variables were compared using chi-square tests. A two-tailed significance level of 0.05 was applied for all statistical tests. All analyses were performed using R software (version 4.5.2) [110].

Additional Analyses of PROMs for Study IV

Additional analyses of PROMs were conducted to explore subgroup differences and validate the robustness of the main findings. For EQ-5D, the reverse crosswalk method was applied to convert EQ-5D-3L index scores to EQ-5D-5L index scores to ensure consistency [54,61]. EQ-5D index scores were calculated at baseline and 1 year postoperatively using UK value sets, as no crosswalk algorithm exists for the Swedish value sets. Changes from baseline (Δ index) were subsequently derived from these scores. Both EQ-5D versions were also analysed separately using the available Swedish value sets.

In the main analysis, missing PROM data were handled using complete-case analysis, as responder characteristics and reoperation rates were comparable across responder status (Figure 14). Responder status was also similar between groups.

Because missing data rarely satisfy the MCAR assumption, additional sensitivity analyses were performed using multiple imputations for the KOOS-12 summary score and EQ-VAS. The outcome 'reoperation' was included as a predictor in the imputation model, as illustrated in Figure 15. Two approaches were applied: one in which imputations were restricted to cases with either preoperative or 1-year data available, and another in which all missing values were imputed. Group differences were evaluated using linear regression models adjusted for age, sex, BMI, and the corresponding preoperative score.

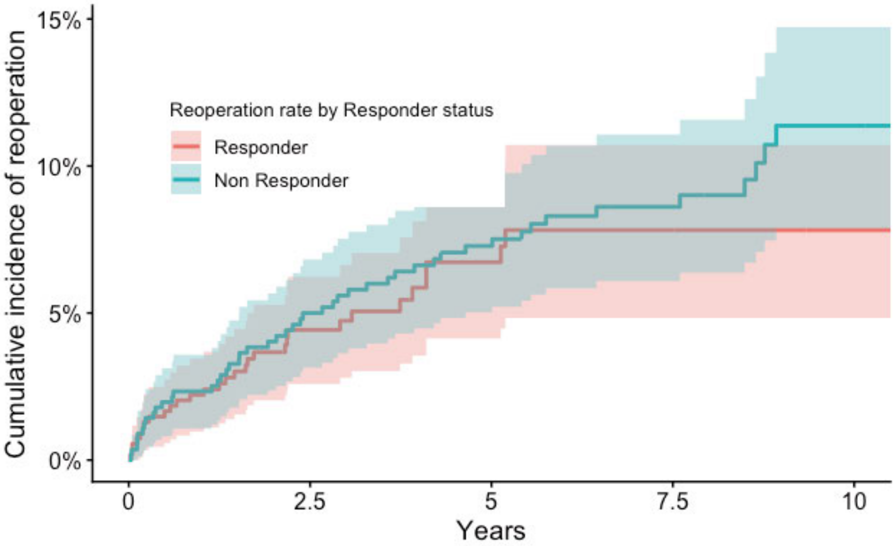

***Figure 14**. Responder status is associated with reoperation, as shown in the Kaplan-Meier plot.*

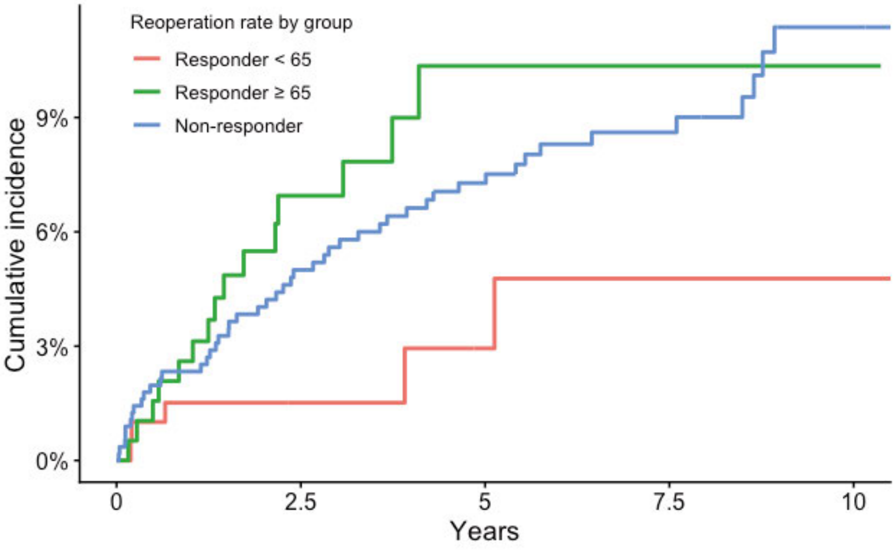

***Figure 15**. Association between responder status, reoperation, and PROM scores illustrated in a Kaplan-Meier Plot. Non-Responders (blue) showed lower incidence of reoperation compared to responders with a below-median KOOS-12 Score (<65; green). Responders with an above-median KOOS-12 score (>65; red) demonstrated the lowest incidence of reoperation over time.*

Ethical Considerations

All studies were performed in accordance with the ethical principles of the Helsinki Declaration[160,161]. Ethical approval for Study II was granted by the Regional Ethical Committee in Uppsala (Dnr 2017/245). Approval for Studies I, III, and IV was obtained from the Swedish Ethical Review Authority (Dnr 2023-06309-01 and 2024-07378-02).

Under Swedish legislation, data from national quality registers are classified as sensitive personal information and are not publicly available. Consequently, access to these data requires formal approval from the Swedish Ethical Review Authority. This research received no specific funding, and the authors declare no conflicts of interest.

Results

Study I

Study Population Characteristics

Between 2011 and 2023, a total of 38,053 cases of proximal tibial fracture were identified in the NPR. The mean age at injury was 57 years. Women accounted for 60.5% of cases, with a mean age of 61.3 years, while men comprised 39.4% of cases, with a mean age of 49.8 years (Figure 16). The mean age at injury remained stable throughout the study period.

In 2023, 3,360 proximal tibia fractures were recorded, representing 2.5% of all 139,576 fractures nationwide. This proportion was comparable to 2017, when 2,967 proximal tibia fractures (2.3%) were registered among 126,961 fractures. Data for 2011–2016 were incomplete, which precluded full temporal comparisons for those years.

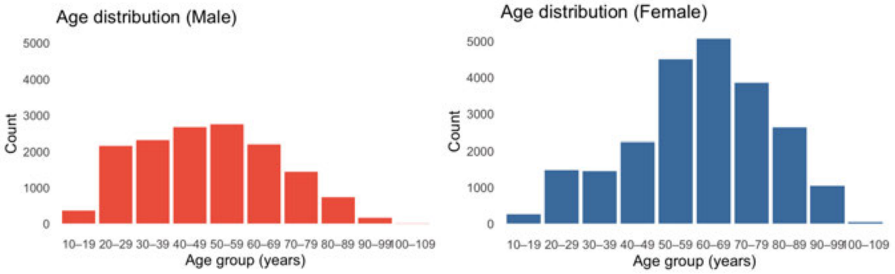

Figure 16. *Age distribution of the tibial plateau fracture population in Sweden between 2011 and 2023 (n =38053), shown separately for men (A) and women (B).*

Incidence of Proximal Tibial Fractures

The overall incidence of proximal tibial fractures in Sweden increased modestly over the study period, rising from 36.7 per 100,000 person-years in 2011 to 40.1 per 100,000 in 2023, corresponding to an 9.3% increase (Figure 17).

When stratified by sex, the incidence among men remained essentially unchanged (31.0 vs. 30.3 per 100,000 person-years), whereas women demonstrated a 18.5% increase, from 42.2 to 50.0 per 100,000 person-years.

Throughout the study period, the highest incidence rates were consistently observed among women aged ≥80 years. However, rates in this cohort declined by 18.6%, falling from 111.0 per 100,000 person-years in 2011 to 90.3 per 100,000 person-years in 2023. In contrast, the largest relative increase occurred among women aged 20–29 years, in whom the incidence doubled from 12.7 to 25.4 per 100,000 person-years during the same study period (Figure 18).

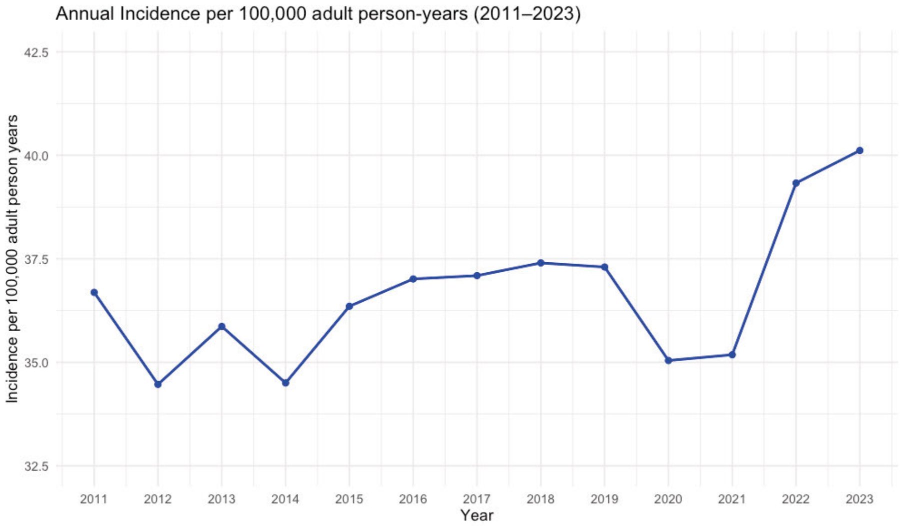

Figure 17*. Annual incidence of proximal tibial fractures in Sweden from 2011 to 2023, expressed per 100,000 person-years.*

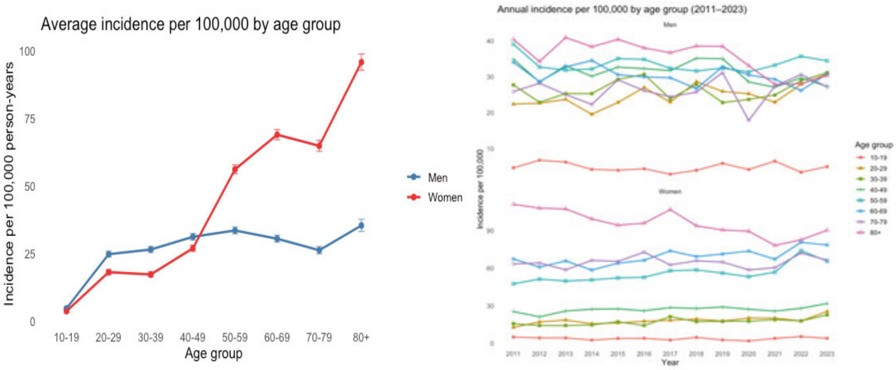

Figure 18. *Age- and sex-specific incidence rates of tibial plateau fractures in Sweden from 2011 to 2023, expressed per 100,000 person-years by age group. (a) Mean incidence across the study period, (b) Annual incidence by age-group and sex, shown separately for men (upper panel) and women (lower panel).*

Treatment

During the 13-year observation period, 11,141 patients (29.3%) underwent surgical intervention, with women comprising the majority (n = 6,716; 60.3%). The proportion of surgically managed fractures remained largely stable over time, at 29.7% in 2011 compared with 28.0% in 2023.

Among surgical techniques, plate fixation was the most frequently employed method (72.5%; *n* = 8,083), followed by intramedullary nailing (6.6%; *n* = 736), isolated screw fixation (6.5%; *n* = 726), and primary arthroplasty (4.2%; *n* = 467). Notably, the use of primary arthroplasty as the initial treatment declined markedly, from 5.6% in 2011 to 1.3% in 2023, reflecting a shift toward fixation-based management strategies (Figure 19).

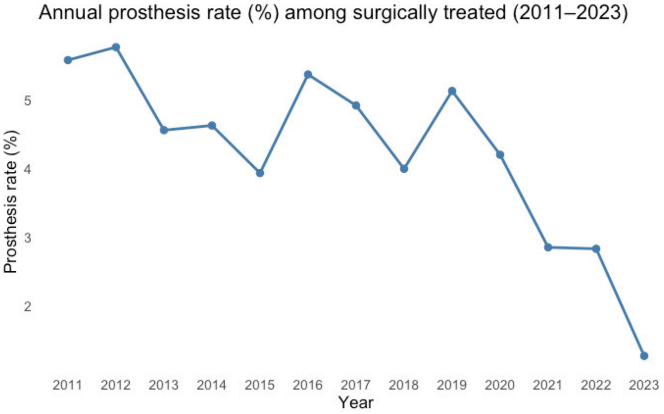

Figure 19. *Frequency and temporal trends in proximal tibial fractures treated with primary total knee arthroplasty in Sweden, 2011–2023 (*n *= 467).*

Study II

Study Population Characteristics

This study included 439 patients treated for TPFs at Uppsala University Hospital from 2002 to 2015. The cohort comprised 57% women, with a mean age of 55 years (SD ± 17).

Fracture distribution by Schatzker classification was: type I (2.7%), type II (34%), type III (9.3%), type IV (7.2%), type V (16%), and type VI (31%). By AO/OTA classification, fractures were categorised as B1 (3.5%), B2 (7.5%), B3 (49.5%), C1 (7.5%), C2 (5.0%), and C3 (27%).

For the survival analyses, 14 patients (3%) were censored: 11 due to death and 3 due to migration.

Conversion Rate to TKA

Of the 439 patients, 23 (5.2%) underwent conversion to TKA within 2 years post-surgery. Age-stratified conversion rates were 3.0% in patients aged < 55 years, 6.0% in those aged 55–64, 8.6% in those aged 65–74, and 7.1% in patients aged ≥75 years. Over the full 14-year follow-up period (mean 7.5 years), 34 patients (7.7%) required TKA.

When fracture types were merged according to the Schatzker classification, 44% of conversions occurred in types I–III and 56% in types IV–VI. By AO/OTA classification, 62% were type B and 38% type C. Adjusted models controlling for age and sex revealed no significant association between fracture type and TKA conversion overall. However, patients with complex articular fractures (AO/OTA types 41B3/41C3) faced a *6.8-fold higher risk of conversion within 2 years (95% CI: 1.6–29.2)* and a *4.8-fold higher risk over the entire follow-up period (95% CI: 1.7–13.5)* compared to those with non-complex fractures (Figure 20).

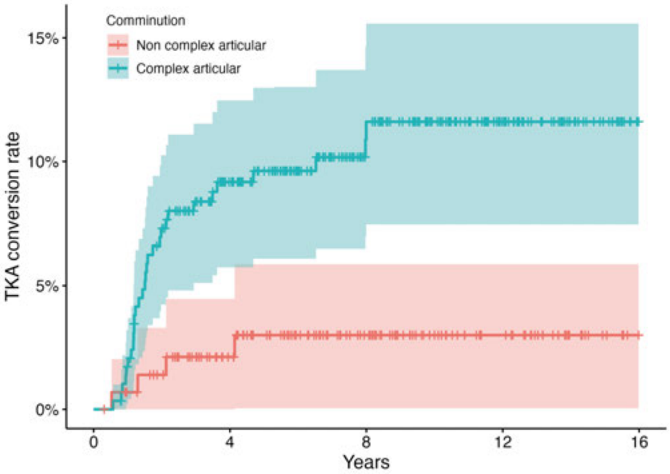

Figure 20. *Kaplan-Meier survival analysis illustrating fracture type as a risk factor for joint failure, with time to conversion to TKA shown on the x-axis. The complex articular group comprises fractures with comminuted articular surfaces (AO/OTA types 41B3 and 41C3). The shaded areas represent the 95% confidence intervals.*

Joint Surface Reduction and TKA Conversion

Inadequate joint-surface reduction was identified in 69 patients (15.6%) and was strongly associated with an increased risk of conversion to TKA. Specifically, suboptimal reduction conferred an 8.4-fold higher risk of conversion (95% CI: 3.6-19.5). Among patients with inadequate joint surface reduction, approximately 30% ultimately required conversion to TKA (Figure 21).

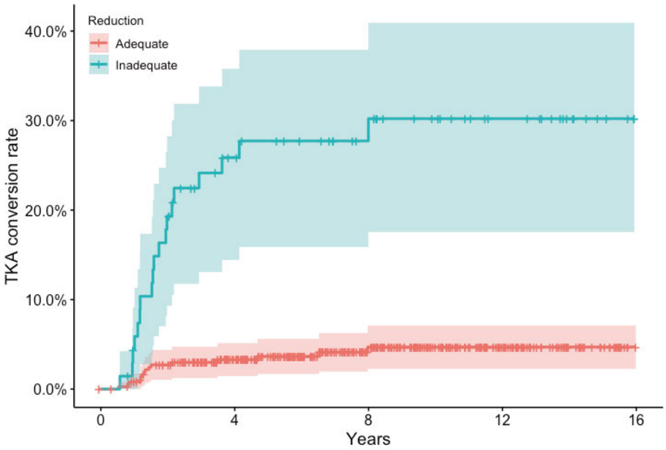

Figure 21. *Kaplan-Meier survival analysis comparing adequate (<2 mm) and inadequate (>2 mm) fracture reduction on the first postoperative radiograph following primary TPF surgery. The x-axis indicates time to conversion to TKA in years, and shaded areas denote 95% confidence intervals.*

Study III

Study Population Characteristics

Between 2012 and 2023, a total of 12,012 cases of TPFs meeting the inclusion criteria were registered in the SFR. The cohort had a mean age at injury of 56.5 (SD 18.0), and 63% of patients were female.

The distribution of fractures according to the AO/OTA classification was as follows: B1 (34%), B2 (28%), B3 (17%), C3 (12%), C1 (6%), and C2 (4%). The most frequent injury mechanisms were falls (62%), and low-energy trauma (73%; Figures 22-25).

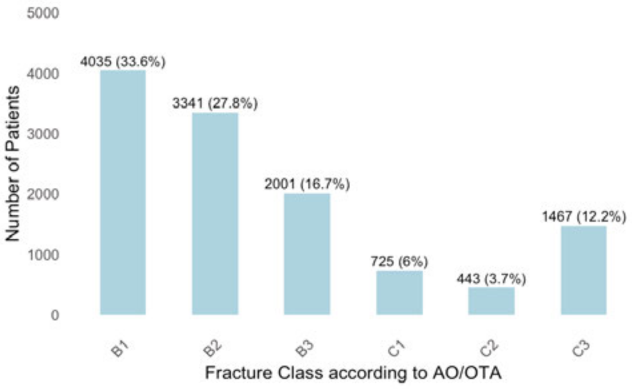

Figure 22. *Distribution of fracture classes in the study population (n = 12,012) according to AO/OTA.*

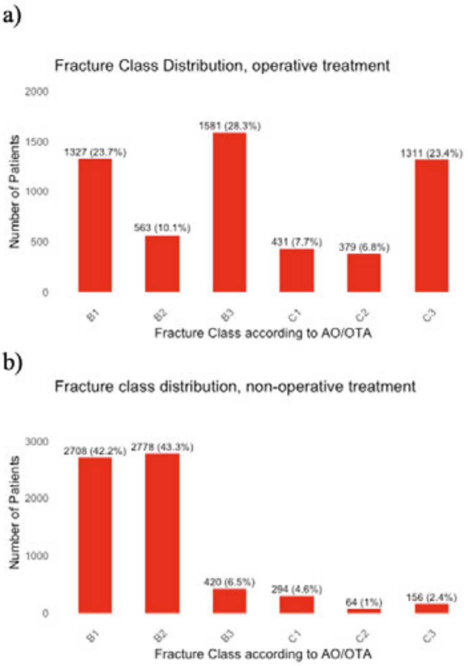

Figure 23. *Distribution of fracture classes in the study population (n = 12012), stratified by treatment modality: (a) operative and (b) non-operative.*

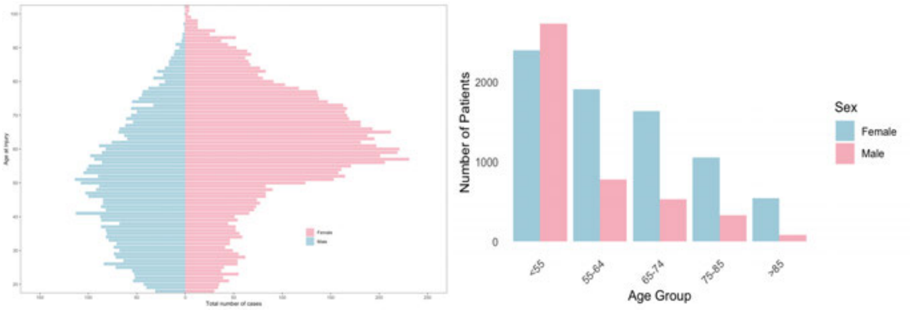

Figure 24. *Age distribution in the study population (n = 12,012) stratified by sex: (a) continuous age and (b) age group.*

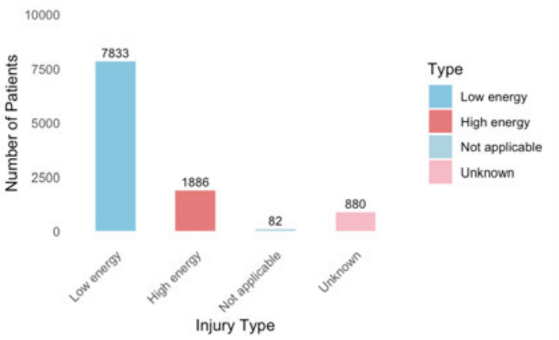

Figure 25. *Distribution of injury type in the study population (n = 12,012).*

Conversion to Total Knee Arthroplasty

During a 12-year observation period (mean follow-up, 4.2 years), 275 patients underwent TKA. The cumulative conversion rates were 0.6% at 1 year, 1.8% at 2 years, 2.8% at 5 years, and 4.2% at 12 years. When stratified by treatment approach:

Operatively treated patients demonstrated conversion rates of 0.6% at 1 year, 2.5% at 2 years, 4.1% at 5 years, and 5.1% at 12 years.

Non-operatively treated patients showed lower rates of 0.7% at 1 year, 1.2% at 2 years, 1.7% at 5 years, and 3.4% at 12 years.

(See Figures 26-28; Tables 1-3.)

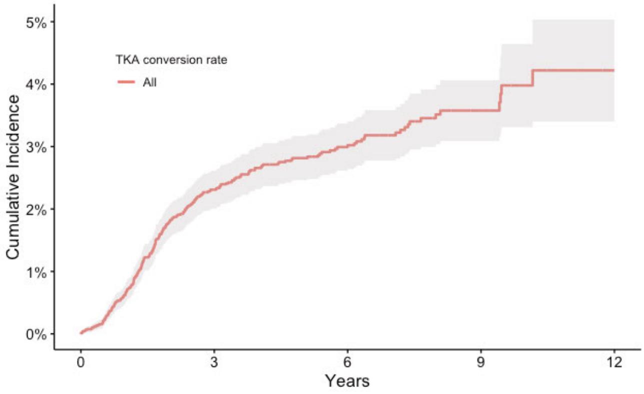

Figure 26. Kaplan-Meier curve illustrating the cumulative conversion rate to TKA over the study period. Time (years) is shown on the x-axis and cumulative percentage of conversion (failure) on the y-axis. The shaded area indicates 95% confidence intervals.

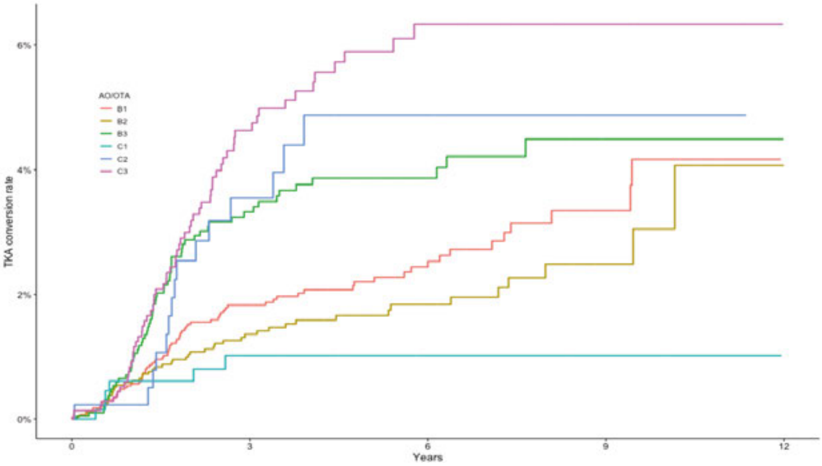

Figure 27. Kaplan-Meier curve showing the cumulative probability of conversion to TKA stratified by fracture type. The x-axis represents time to conversion (years), and the y-axis shows event probability (%).

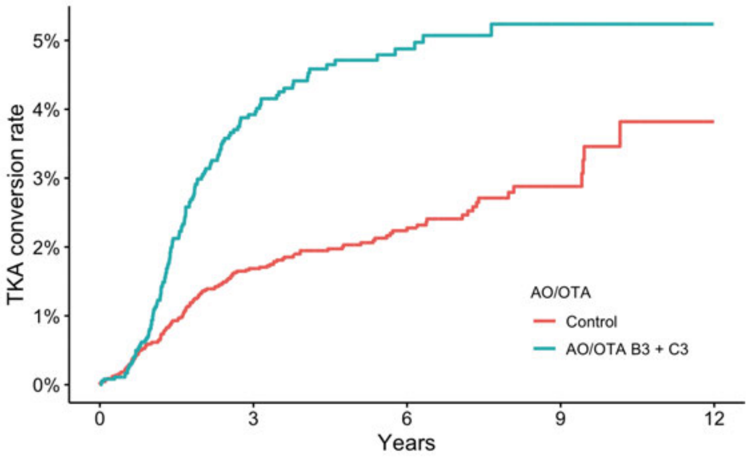

Figure 28. *Kaplan-Meier curve illustrating the cumulative probability of conversion to TKA in patients with comminuted fractures (AO/OTA types 41B3 and C3). The x-axis represents time to conversion (years), and the y-axis shows event probability (%). The control group includes AO/OTA types B1-2 and C1-2.*

Age-specific 5-year conversion rates to TKA were 1.4% in patients <55 years, 3.7% in those aged 55–64, 5.1% in the 65–74 group, 3.3% in patients aged 75–84, and 1.9% in those ≥85 years. The most pronounced risk was observed in patients aged 65–74 years *(aHR 3.7, 95% CI: 2.5–5.4)*. Complex fractures (AO/OTA types 41B3 and 41C3) were associated with a significantly higher risk of TKA (aHRs 2.1 and 3.2, respectively).

Comminuted fractures increased the risk of joint failure 2.5-fold within 5 years *(aHR=2.5, 95% CI: 1.9–3.2)* and 2.2-fold over the full follow-up period *(aHR=2.2, 95% CI: 1.7–2.8)*. In contrast, high-energy trauma did not significantly affect conversion risk *(aHR=1.3, 95% CI: 0.9–1.7)*.

For comparison, among 1,608 patients with extra-articular proximal tibial fractures, conversion rates to TKA were 0.2% at 1 year, 0.6% at 5 years, and 0.9% at 12 years. Cox regression analysis demonstrated a significantly higher risk of TKA among patients with intra-articular fractures, with an aHR of *3.3 (95% CI: 1.7-6.2)* relative to those with extra-articular fractures. (Figure 29).

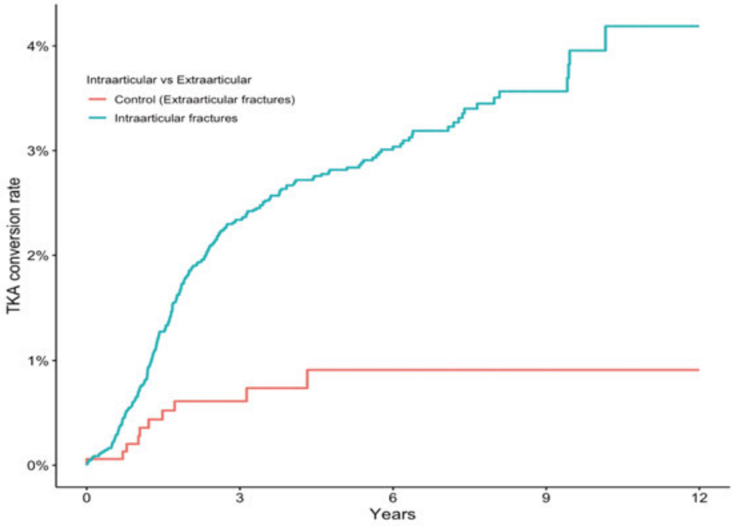

Figure 29. *Kaplan-Meier curve illustrating the cumulative risk of conversion to TKA for intra-articular fractures (AO/OTA types 41B-C; n = 12,012) compared with extra-articular fractures (AO-OTA type 41A, uninjured joint surface) as the reference group.*

Table 1. *Cumulative TKA conversion rates stratified by AO/OTA fracture classification at 1-, 2-, 5-, and 12-years of follow-up.*

Time (years)	**B1 (95% CI)**	**B2 (95% CI)**	**B3 (95% CI)**	**C1 (95% CI)**	**C2 (95% CI)**	**C3 (95% CI)**
1	0.6% (0.3 - 0.8)	0.6% (0.3 - 0.9)	0.9% (0.4 - 1.4)	0.8% (0.1 - 1.5)	0.2% (0.0 - 0.6)	1.0% (0.4 - 1.4)
2	1.5% (1.0 - 2.0)	1.1% (0.7 - 1.5)	2.9% (2.0 - 4.0)	0.8% (0.1 - 1.5)	2.4% (0.9 - 3.8)	3.1% (2.0 - 4.2)
5	2.2% (1.5 - 2.9)	1.7% (1.1 - 2.2)	3.8% (2.8 - 4.8)	1.2% (0.4 - 2.4)	4.5% (2.2 - 6.8)	6.0% (4.5 - 7.5)
12	4.1% (2.5 - 5.7)	4.1% (1.6 - 6.5)	4.5% (3.3 – 5.7)	1.2% (0.4 - 2.4)	4.5% (2.2- 6.8)	7.2% (4.8 - 9.6)

Table 2*. Adjusted hazard ratios (aHRs, 95% CI) for conversion to TKA within 5 years of initial surgery and over the full follow-up period. Stratified by comminuted fracture types and age groups. Comminuted fractures refer to AO/OTA types 41B3 and 41C3. The reference group is AO/OTA type B1 fractures and patients aged <55 years.*

Group	**5 Years aHR (95% CI)**	**12 Years aHR (95% CI)**
AO/OTA 41B3	2.1 (1.3 – 3.3)	1.7 (1.1 – 2.6)
AO/OTA 41C3	3.2 (2.0 – 5.0)	2.6 (1.7 – 3.9)
AO/OTA 41B1(reference)	—	—
Comminuted fractures	2.5 (1.9 – 3.2)	2.2 (1.7 – 2.8)
Age <55 (reference)	—	—
Age 55-64	2.8 (1.9 – 4.0)	2.5 (1.7 – 3.5)
Age 65-74	3.7 (2.5 – 5.4)	3.6 (2.5 – 5.0)
Age 75-84	2.8 (1.7 – 4.5)	2.8 (1.7 – 4.2)
Age ≥85	1.8 (0.9 – 4.3)	1.7 (0.7 – 3.8)

Table 3. *Kaplan-Meier estimates of the cumulative probability of conversion to TKA: operatively treated patients versus the overall cohort. Probabilities are presented as percentages with 95% confidence intervals (CIs) in parentheses.*

Time	**Surgically Treated Patients (Event Probability, 95% CI)**	**All Patients (Event Probability, 95% CI)**
1	0.6% (0.4 - 0.8)	0.6% (0.5 - 0.8)
2	2.5% (2.0 - 2.9)	1.8% (1.5 - 2.1)
5	4.1% (3.5 - 4.7)	2.8% (2.5 - 3.2)
12	5.1% (4.0 - 6.2)	4.2% (3.4 - 5.0)

Study IV

Study Population Characteristics

From the SAR (2014-2023), we identified 1,102 patients who underwent TKA following TPF. Of these, 152 were classified as acute TKAs and 950 as delayed TKAs. The mean age at surgery was 66.6 years (SD 11.1), and 59.6% were female (Figure 30).

Patients in the early TKA group tended to be older, have lower BMI and be more often female than those in the delayed TKA group. The distribution of the ASA class was comparable between groups. Median operative time was 100 minutes for acute TPF cases and 104 minutes for delayed TKA procedures.

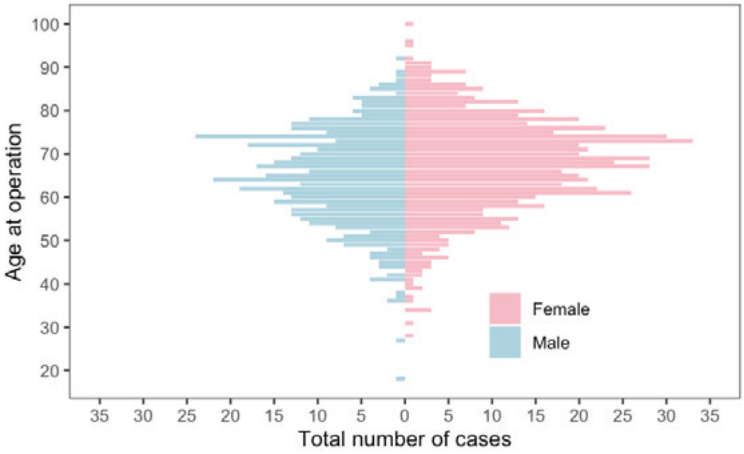

Figure 30. *Age and sex distribution of 1,102 patients who underwent total knee arthroplasty (TKA). The x-axis represents the number of cases, and the y-axis indicates patient age.*

Revision and Reoperation Rates

Among the 1,102 patients, 60 (5.4%) underwent revision surgery during a mean follow-up of 5.2 years. The cumulative revision rate was *2.6% (95% CI: 1.6–3.6)* at 2 years and *5.3% (95% CI: 4.0–6.6)* at 5 years, with no statistically significant differences observed between groups.

In the acute TKA group, the corresponding rates were *2.9% (95% CI: 0.1–5.7)* at 2 years and *7.7% (95% CI: 1.5–13.6)* at 5 years. In comparison, the delayed TKA group demonstrated rates of *2.5% (95% CI: 1.5–3.5)* and *5.1% (95% CI: 3.6–6.7)* at the same time points (Figures 31-32).

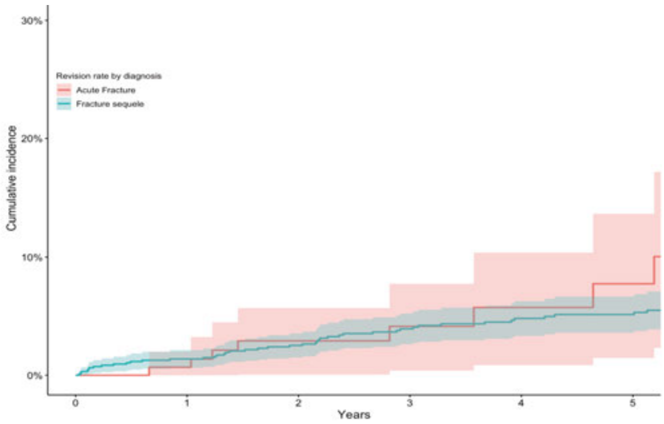

Figure 31. *Kaplan-Meier estimates of revision after total knee arthroplasty (TKA) up to 5 years (n = 1,102), stratified by indication for primary surgery: acute tibial plateau fracture (TPF) (n = 152) or fracture sequelae (n = 950). The x-axis shows years of follow-up and the y-axis shows cumulative incidence with 95% confidence intervals (CIs).*

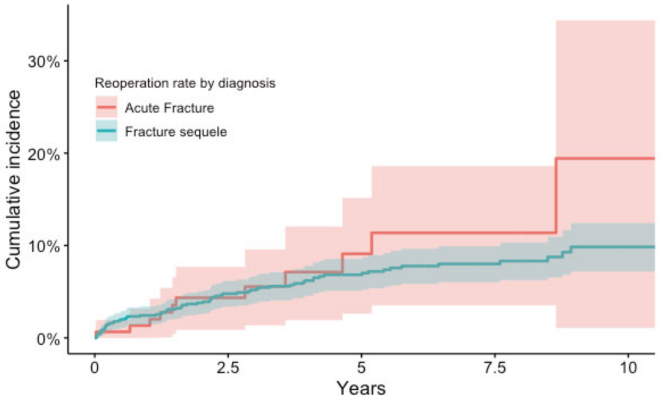

Figure 32. *Kaplan-Meier estimates of reoperation (any cause and type) after total knee arthroplasty (TKA; n = 1102), stratified by indication for primary surgery: acute tibial plateau fracture (TPF; n =152) or fracture sequelae (n = 950). The x-axis shows years of follow-up and the y-axis shows cumulative incidence with 95% confidence intervals (CIs).*

A total of 78 patients (7.1%) underwent reoperation for any cause during follow-up. The cumulative reoperation rates were *3.9% (95% CI: 2.7–5.1)* at 2 years and *7.0% (95% CI: 5.4–8.6)* at 5 years, with no significant differences between groups.

In the acute TKA group, reoperation rates were *4.3% (95% CI: 0.9–7.7)* at 2 years and *9.1% (95% CI: 2.6–15.2)* at 5 years, compared with *3.8% (95% CI: 2.6–5.0)* and *6.8% (95% CI: 5.1–8.6)* in the delayed TKA group. Reoperations were most frequently performed for instability in the acute TKA group, whereas infection, stiffness, or patellofemoral complaints predominated in the delayed TKA group. Infection accounted for 40.3% of reoperations in the delayed TKA group and 9.1% in the acute TKA group, whereas prosthesis loosening was the leading cause in acute cases (Figure 33).

No significant differences in the risk of reoperation or revision (any cause) were observed at the chosen level of statistical significance (Table 4).

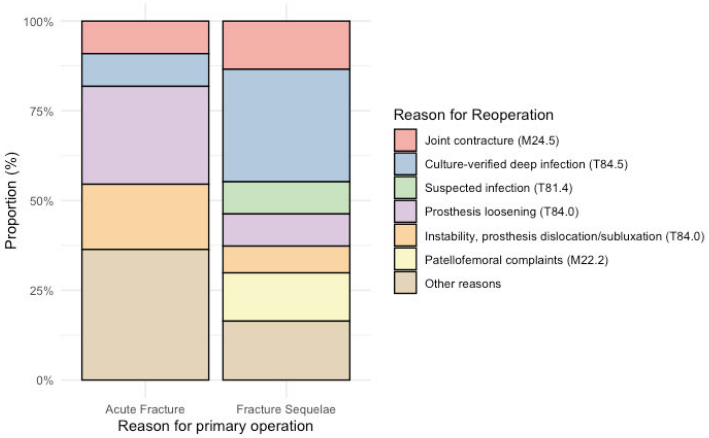

Figure 33*. Reasons for reoperation (any cause; n =78), stratified by indication for primary surgery. Data are presented as a stacked bar chart.*

Patient-Reported Outcomes

The overall non-response rate, defined as the proportion of individuals who did not complete any questionnaire, was 51%. Depending on the specific PROM instrument and time point, complete data were available for 22–44% of patients (Table 5). Response rates were generally consistent across groups; however, patients who underwent reoperation were less likely to respond compared with those who did not.

Baseline EQ-VAS and KOOS-12 scores did not differ significantly between groups. At 1 year, patients in the acute TKA group reported superior outcomes on EQ-VAS (mean *80.0*, 95% CI: *70.0–80.0*) compared with the delayed TKA group (mean *70.0*, 95% CI: *66.5–70.5*). Similarly, KOOS-12 Pain, QoL, and summary scores were statistically significantly higher in the acute TKA group. Improvements from baseline to 1 year were also greater in the acute TKA group across these subscales (Table 6).

Exploratory Analyses of PROMs

In the sensitivity analysis of EQ-5D index values, baseline scores were lower in the early TKA group compared with the delayed group *(0.55 vs 0.66, ns)*.

EQ-5D index values were calculated using the reverse crosswalk method to convert EQ-5D-3L to EQ-5D-5L scores. At 1 year, the early group demonstrated a higher mean EQ-5D index (0.90 vs 0.83; p = *0.022)*. The mean change from baseline (Δ index) was also greater in the early group *(0.22 vs 0.15)*, though this difference did not reach statistical significance.

A post hoc sensitivity analysis using multiple imputation (m = 100) and a linear regression model adjusted for age, sex, BMI, and preoperative score produced comparable estimates across imputation strategies (Table 7). For EQ-VAS, adjusted mean differences ranged from *3.1 (95% CI: –2.7 to 8.9)* to *8.1 (95% CI: 0.3–15.8)*. For KOOS-12, adjusted mean differences ranged from *8.0 (95% CI: 1.7–14.3)* to *13.4 (95% CI: 4.6–22.1)*.

Table 4*: Adjusted Odds of Revision/Reoperation*

Outcome	**OR**	**95% CI (lower)**	**95% CI (upper)**	**P-value**
Reoperation (any cause)	0.756	0.378	1.510	0.4270
Revision (any cause)	0.675	0.314	1.452	0.3150
Reoperation due to infection	3.660	0.481	27.846	0.2100
Revision due to infection	3.040	0.397	23.275	0.2840
Revision due to loosening	0.214	0.047	0.967	0.0451*

Table 5. *Response rates by individual PROMs*

Measure	Timepoint	Group	
		Early (n=152)	**Delayed (n = 950)**
EQ-VAS	Baseline	40 (26.3%)	318 (33.5%)
	1 year	69 (45.4%)	374 (39.4%)
	Complete data	30 (19.7%)	233 (24.5%)
KOOS-12	Baseline	33 (21.7%)	267 (28.1%)
	1 year	60 (39.5%)	330 (34.7%)
	Complete data	24 (15.5%)	197 (20.7%)
Non-responders		80 (52.6%)	463 (48.7%)

Baseline - preoperative, 1-Year - 1 year follow-up, Complete data - Patients with both measurements

Table 6. *Patient-reported outcome measures (PROMs) at baseline, 1 year, and change from baseline (Δ), by indication group*

PROM (95% CI)	Early TKA	Delayed TKA	P-value
EQ-VAS (median, 95% CI)			
Baseline	70.0 (57.5–72.5)	60.0 (57.5–62.5)	ns
1 year	80.0 (70.0–80.0)	70.0 (66.5–70.5)	0.017
Δ (change)	10.7 (1.4–20.0)	7.8 (4.8–10.8)	ns
KOOS Pain (mean, 95% CI)			
Baseline	36.0 (31.2–40.8)	35.7 (33.7–37.7)	ns
1 year	75.4 (69.0–81.7)	68.8 (66.1–71.4)	0.03
Δ (change)	46.1 (35.1–57.1)	36.1 (32.8–39.6)	ns
KOOS Function (mean, 95% CI)			
Baseline	40.1 (31.4–48.7)	40.9 (38.6–43.2)	ns
1 year	74.3 (68.7–79.9)	68.8 (66.4–71.3)	ns
Δ (change)	38.8 (27.2–50.4)	29.8 (26.4–33.2)	ns
KOOS Quality of life (mean, 95% CI)			
Baseline	19.9 (15.7–24.1)	17.6 (16.0–19.3)	ns
1 year	65.1 (58.1–72.1)	53.1 (50.2–56.1)	0.0018
Δ (change)	55.6 (46.4–64.8)	36.7 (33.3–40.3)	<0.001
KOOS Summary score (mean, 95% CI)			
Baseline	32.0 (26.8–37.2)	31.5 (29.8–33.1)	ns
1 year	71.3 (65.2–77.3)	63.7 (61.2–66.1)	0.01
Δ (change)	46.8 (37.0–56.7)	34.3 (31.3–37.3)	0.017

***Table** 7. Adjusted linear regression results comparing complete case analysis and multiple imputation (m=100).*

	Imputations	*Estimated difference in means between groups at 1 year*	*95% Confidence Interval*	*p-value*
EQ-VAS	None (complete case analysis)	8.1	0.3, 15.8	0.04
	One time point	7.6	1.4, 13.7	0.01
	Non-Responders	3.1	-2.7, 8.9	0.2
KOOS-12	None (complete case analysis)	13.4	4.6, 22.1	< 0.01
	One time point	9.0	2.7, 15.3	< 0.01
	Non-Responders	8.0	1.7, 14.3	0.01

Linear regression model: Outcome score ~ Group + Age + Sex + BMI + Preoperative score

One Time Point: Excluded non-responders, only imputed for those who were only missing one value

Non-Responders: Did not exclude non-responders; imputed for all individuals that missed data points

Discussion

Summary of Findings

The incidence of TPFs in Sweden has increased modestly over the past decade, largely driven by higher rates among women across all age groups. Although the proportion of surgically treated cases remained relatively stable, treatment modalities shifted, with a slight decline in the use of primary arthroplasty. These observations require cautious interpretation given the study's inherent methodological limitations.

The rate of subsequent conversion to TKA following TPF remains relatively low. Discrepancies in conversion rates between Study II and Study III likely reflect their differing inclusion criteria: Study II was limited to patients treated surgically at a single centre, whereas Study III encompassed a nationwide cohort from the SFR, including both operative and non-operative cases. In Study II, the TKA conversion rate was *5.2%* at 2 years, notably higher than the *1.8%* observed in the broader Study III cohort. However, among surgically isolated patients in Study III, the conversion rate was *2.5%*. Despite these variations in incidence, both studies identified fracture comminution as a significant risk factor for conversion to TKA.

In Study II, postoperative radiographs were available for analysis, revealing a strong association between inadequate postoperative reduction and an increased risk of subsequent conversion to TKA. This relationship may be influenced by initial fracture severity and comminution, which can limit the surgeon’s ability to achieve accurate anatomical reduction.

Because studies directly comparing outcomes after early versus delayed TKA following TPF are lacking, Study IV specifically examined these two approaches with respect to revision and reoperation rates, underlying causes, and PROMs. No statistically significant differences were observed in the cumulative incidence of revision or reoperation between the groups; however, the wide confidence intervals highlight considerable uncertainty and limit the interpretability of these findings. The causes of reoperation differed by indication, with infection more frequently reported in the delayed group and prosthesis loosening more common in the acute group. Patients treated acutely also more often required revision-type implants, reflecting distinct technical challenges between the two settings. Importantly, PROMs at 1 year postoperatively were significantly better in the acute fracture group.

Demographics

In Study I, the cohort was identified using the NPR, which has very high completeness (>99%) and strong validity, making it representative of the entire Swedish population [80] . Unlike Studies II and III, where fracture classification was available through radiographic assessment or the SFR, such information was not available through the NPR dataset. Because the ICD-10 code used in the NPR does not distinguish between extra-articular proximal tibial fractures and TPFs [162–164], Study I includes all proximal tibial fractures without differentiation by fracture type. However, restricting inclusion to AO/OTA type A fractures alone does not fully explain the discrepancy in cohort size observed during the same period. In the NPR, 35,278 proximal tibial fractures were identified between 2012 and 2023, compared with 15,603 cases recorded in the SFR. This difference may be partly attributable to the gradual implementation and increasing completeness of the SFR over the observation period. While the SFR offers more granular data on injury characteristics, fracture classification, treatment, and mortality, its stepwise implementation and lower completeness compared to the NPR impact the total case numbers [37].

The local cohort examined in Study II was drawn from Uppsala University Hospital, a large regional centre that receives referrals for severe and complex cases from across central Sweden. Consequently, fracture severity in this cohort was substantially higher than in the national cohort of Study III. Comminuted fractures (AO/OTA types 41B3 and 41C3) accounted for 66.5% of all surgically treated cases in the local cohort, compared with 29% in the national cohort. This discrepancy in fracture severity partially explains the difference in conversion rates observed between the two studies, as both studies demonstrate a strong association between fracture comminution and subsequent conversion to TKA. Previous research has likewise shown that the risk of PTOA increases with the severity of the fracture [65]. Apart from fracture severity, the two study groups were similar in age, although the national cohort included a higher proportion of women. However, neither of our Cox models revealed an association between sex and the risk of conversion to TKA. Previous studies on the demography of TPFs have reported similar distributions, with men predominantly sustaining these fractures ≤ 50 years due to high-energy trauma, and a gradual shift toward women being more affected in older age, primarily due to potential osteoporosis and low-energy falls [28,33,154].

In Study IV, the cohort was identified through the SAR and comprised 152 patients who underwent TKA as the primary treatment for an acute TPF. By contrast, in Study I, primary TKA was evaluated as a secondary outcome when examining treatment trends, with 338 TKAs performed for proximal tibial fractures identified between 2014 and 2023. Thus, within the same time frame, the SAR cohort included considerably fewer cases (n = 152) than those recorded in Study I (n = 338). A potential explanation for this discrepancy is that simply excluding 2010 from the statistical analyses in Study I was insufficient to avoid capturing follow-up visits or subsequent surgical procedures related to non-union or post-traumatic symptoms. The observed rate of TKA could still have been overestimated due to potential miscoding, whereby procedures for non-union or post-traumatic conditions were incorrectly registered under the fracture diagnosis code S82.1.

Incidence of Proximal Tibial Fractures in Sweden

The incidence of fragility fractures in Sweden has increased over time [18,81,138]. Our findings mirrored this trend for proximal tibial fractures. Study I aimed to determine the contemporary national incidence of proximal tibia fractures over a 13-year period. In 2023, the incidence was 40.1 per 100,000 person-years (30.3 for men and 50.0 for women), which appears to be the highest reported incidence to date in the literature and aligns with expectations of increasing fragility fractures in an aging population. Earlier research based on local or smaller cohorts reported lower incidence estimates, including 13.3 per 100,000 person-years in Edinburgh [28], increasing proportions in a Turkish cohort [15], 22.3 per 100,000 person-years in a single-centre German study [19], and 26.9 per 100,000 in a Swedish regional study [154]. Comparable findings were reported in a national Belgian study (29 per 100,000 person-years [55], while a multicentre German study observed an incidence of 28.7 per 100,000 person-years with a 9% increase over time [123] , which aligns with our findings.

The temporal trend in our cohort showed a gradual rise in incidence, with a notable dip during 2020–2021, likely attributable to the COVID-19 pandemic. This pattern is consistent with similar reports for TPFs and ankle fractures [20,124]. Sex-specific analyses revealed no increase among men, who were generally younger at injury, potentially reflecting high-energy mechanisms and risk-taking behaviours. In contrast, incidence increased among women, particularly within the fragility-related age spectrum, supporting the bimodal fracture pattern hypothesis. The steepest relative increase occurred among women aged 20–29 years, possibly reflecting shifts in injury mechanisms or risk exposure in younger generations.

Conversion to Total Knee Arthroplasty

Numerous studies have investigated the presence of radiographic PTOA following TPFs, with reported proportions ranging from 17% to 73% depending on the study design [29,42,58,65,87,112,114]. For bicondylar fractures, even higher rates have been observed. However, we believe that the conversion rate to TKA provides a more accurate measure of post-traumatic knee function and symptoms than radiographic OA. Our studies demonstrated 5-year conversion rates ranging from 2.8% to 7.7%, depending on follow-up duration and whether nonoperatively managed fractures were included. A large number of recent studies have reported conversion rates ranging from 0% to 21.9%[5,7,30,32,45,48,58,72,75,87,104,108,112,129,131,139,143,146,150]. A 2023 systematic review found an average conversion rate of 5.1%, increasing to 6.3% when considering only surgically treated TPFs [50].

However, despite these data, uncertainty remains regarding the TKA endpoint due to difficulties identifying all patients who underwent conversion. Conducting these studies in Sweden offers a significant advantage, as the SAR provides a unique means of determining the TKA endpoint [77]. Although the overall conversion rate to TKA remains low, certain fracture or patient characteristics may be associated with a higher risk. While conversion rates are well documented across populations, the factors influencing progression remain less clear. Large registry-based studies often lack detailed patient and fracture information, whereas smaller single-centre studies may lack statistical power or face endpoint uncertainties. In contrast, studies investigating these factors often lack sufficient statistical power or face uncertainties in converting to the TKA endpoint due to small single-centre reports. [7,30].

Studies II and III were conducted with the hypothesis that fracture classification, age, and sex would be pivotal in predicting conversion to TKA. Study II found no significant association between individual fracture classes and conversion. However, comminuted fractures (AO/OTA 41B3 and 41C3) were significantly associated with conversion (*aHR = 6.8 (1.6–29.2)*). Although this cohort included 439 patients, only 23 conversions were observed at the 2-year follow-up, limiting the ability to draw firm conclusions from subgroup analyses.

An additional advantage of Study II was the availability of both pre- and postoperative radiographs, enabling assessment of reduction quality. Inadequate reduction was strongly associated with conversion to TKA (*aHR = 8.4; 95% CI: 3.6–19.5*). This analysis was conducted separately rather than as an adjustment, as postoperative reduction is not available preoperatively and therefore lacks clinical utility in the acute setting. Furthermore, reduction quality is inherently dependent on preoperative fracture displacement and comminution.

In Study III, a national cohort from the SFR was analysed. This cohort was pseudonymised, which prevented access to pre- and postoperative radiographs; however, fracture classification data were available within the register [97]. Among 12,012 patients, including 275 conversions, comminuted fractures were found to be strongly associated with conversion to TKA. This was evident both for individual fracture types (*aHR for 41B3 = 2.1, 95% CI: 1.3–3.3; aHR for 41C3 = 3.2, 95% CI: 2.1–5.0*) and when combined (*aHR = 2.5, 95% CI: 1.9–3.2*).

Potential factors that could not be adjusted for in our studies, but are likely to influence conversion rates, include preoperative OA and the degree of osteoporosis at the time of injury. OA may act as a confounder in the indication for TKA, whereas osteoporosis affects both the extent of comminution and the stability of fixation, as well as the ability to maintain reduction once weight-bearing is initiated. The challenge of fixation failure in elderly, osteoporotic patients is well recognised, with surgical outcomes in this group being significantly worse [4,59,98,109]. Consequently, primary TKA rather than ORIF has recently been proposed as a treatment option for this patient population [125,158].

Several studies have compared TKA performed for idiopathic OA with TKA following PTOA. Although TKA for PTOA has been shown to improve pain and function in symptomatic patients [91,126], it has also been associated with higher complication risks [69,134], increased reoperation rates [69,126], and poorer functional outcomes [82,134] compared with TKA for idiopathic OA. A recent meta-analysis comparing acute and delayed TKA for TPFs reported that primary TKA in the acute fracture setting was linked to lower complication rates and superior functional outcomes; however, none of the included studies directly compared patients with acute or delayed TKA [84]. In Study IV, which directly examined acute versus delayed TKA following TPF, no statistically significant differences were observed in overall revision or reoperation rates. Notably, the causes of reoperation differed between groups: in the acute TKA cohort, reoperations were more often due to prosthetic loosening or instability, whereas prosthetic joint infection was four times more common in the delayed group (40.3% vs. 9.1%).

In addition to revision and reoperation outcomes, PROMs provided further insight into intergroup differences. Baseline EQ-VAS and KOOS-12 scores were comparable across cohorts. At 1 year postoperatively, the acute TKA group demonstrated significantly superior outcomes on the EQ-VAS, the KOOS-12 subscales Pain and Knee-Related Quality of Life, and the KOOS-12 summary score. Moreover, improvements from baseline to 1 year were greater in the acute TKA group across these KOOS-12 domains. For KOOS-12, a change of 15 points is typically considered the minimally important change (MIC), and 11 points is regarded as the minimal clinically important difference (MCID)[31]. In our cohort, 96% of patients in the acute TKA group and 83% in the delayed TKA group achieved or exceeded the 11-point MCID. When applying the 15-point MIC threshold, 92% of patients with acute fractures and 78% of patients with fracture sequelae met this criterion. These findings suggest that the observed differences are not only statistically significant but also clinically meaningful at the individual patient level**.**

Taken together with the reoperation profiles described above, these findings suggest that although revision and overall reoperation rates were comparable, acute TKA may provide more favourable patient-reported functional outcomes and QoL than delayed procedures. Nevertheless, these results should be interpreted with caution, given the low response rate (51% non-responders) [118].

Missing Data in PROMs

To evaluate the potential impact of missing data, a post hoc sensitivity analysis was performed using multiple imputation *(m = 100)* and a linear regression model adjusted for age, sex, BMI, and preoperative score. As shown in Table 7, the estimated differences in mean scores between groups at 1 year were consistent across all imputation approaches, indicating that the results were robust to the handling of missing data. Three methods were compared: 1) a complete-case analysis, including only participants with complete data, 2) a 'one-time point' imputation excluding non-responders but imputing for individuals missing a single measurement, and 3) a 'non-responder' imputation incorporating all individuals with missing data points. For EQ-VAS, the adjusted mean difference between groups ranged from *3.1 (95% CI: –2.7 to 8.9)* with non-responder imputation to *8.1 (95% CI: 0.3–15.8)* in the complete-case analysis. Corresponding estimates for KOOS-12 ranged from *8.0 (95% CI: 1.7–14.3)* to *13.4 (95% CI: 4.6–22.1)*. These findings confirm that the observed group differences remained stable across analytic strategies.

The Role of Fracture Classification Systems

Fracture classification systems play a pivotal role in evidence-based medicine, guiding health policy and informing the development of clinical practice guidelines. They are widely applied in the construction of treatment recommendations and in the evaluation of research [64]. The primary purpose of such systems is to provide a standardised framework that enhances understanding, facilitates communication, ensures consistent documentation, and supports clinical decision-making in the management of fractures [8].

For a fracture classification system to have clinical utility, it must be both simple and reproducible, enabling consensus in categorisation and thereby ensuring high interobserver reliability. Additionally, the categories should demonstrate clear clinical relevance—either by guiding treatment principles, delineating distinct prognoses, or identifying specific complications and associated injuries.

Numerous fracture classification systems have been developed to evaluate and categorise TPFs [23,43,96]. The most widely used are the Schatzker and AO/OTA classifications [70,102], although concerns have been raised regarding their reproducibility and accuracy [71,147]. The Hohl-Moore classification, first described by Hohl in 1967 and later revised by Moore in 1981 [57,99], was introduced to accommodate fracture patterns not encompassed by the Schatzker system. The earliest classification system, proposed by Marchand, identified three basic fracture types: split, depression, and combined. Building on this foundation, the Duparc and Ficat classification, introduced in 1960 and revised in 1990 and 2013, expanded these categories to provide greater clinical detail [43].

With the adoption of CT imaging as a standard component of preoperative assessment of TPFs, the need for three-dimensional classification systems became evident. The Khan classification, introduced in 2000, and the three-column concept proposed by Congfeng Luo and colleagues in 2010, were developed to address this requirement [71,83]. Subsequent revisions and extensions to existing classification systems have incorporated three-dimensionality [70,95,149]. However, these modifications have generated numerous subgroups and modifiers, which in turn reduce reproducibility and limit clinical relevance. Excessive subclassification risks undermining the fundamental purpose of these systems: to provide simplicity, consistency, and practical clinical applicability [26].

Despite the wide range of available classification systems, a persistent limitation remains: they describe fracture morphology but fail to adequately capture fracture severity. For example, a Schatzker II split-depression fracture may present with either a 4 mm or a 25 mm depression, representing substantial variability in joint surface involvement and bone loss. This shortcoming raises concerns about the ability of current systems to convey clinically relevant information to the treating surgeon. In Studies II and III, we hypothesised that the degree of comminution and fracture severity would influence prognosis and outcomes. While this hypothesis was supported, the observed effect was less pronounced than expected, likely reflecting the inherent limitations of existing classification systems.

Unfortunately, fracture classification data were not available for either Study I or Study IV. Incorporating such information in additional sub-analyses could have provided deeper insight and may have helped to explain variations in outcomes within the study population.

Association or Causation

The studies included in this thesis are based on retrospective local and nationwide registry data and are therefore inherently observational. While such a design enables the inclusion of large, representative cohorts and confers high external validity, it also raises important questions regarding causal inference. The key outcomes analysed—such as the influence of fracture severity on long-term joint outcomes and the comparison of early versus delayed TKA—are the result of a multifactorial interplay of biological, mechanical, and healthcare-related determinants. Therefore, although we demonstrate strong associations between fracture severity and subsequent TKA, as well as differences related to treatment timing, establishing whether these associations are causal requires careful evaluation.

Application of the Bradford Hill Criteria

*Strength***.** In studies II and III, fracture severity—as categorised by the AO/OTA and Schatzker classification systems—was strongly associated with an increased risk of conversion. Across multiple analyses, markedly elevated HRs were observed (e.g., complex articular fractures with aHR of 6.8 and 2.5). The magnitude of these associations, while potentially subject to residual confounding, provides compelling initial support for a causal relationship.

Consistency. Across the studies included in this thesis, the findings were coherent: fracture severity consistently correlated with an increased likelihood of conversion to TKA. Moreover, these results are consistent with previous literature documenting the development of PTOA and the elevated risk of TKA following intra-articular knee fractures [49].

Specificity. Demonstrating specificity is challenging, as TPFs do not uniformly lead to TKA, and TKA may also result from degenerative OA or other knee pathologies. In addition, a range of individual-level factors and comorbidities (e.g., obesity, smoking, pre-existing cartilage degeneration, and chronic inflammatory conditions) can independently predispose to TKA.

Thus, while the presence of a TPF clearly elevates risk, it represents only one of several pathophysiological pathways leading to joint replacement. Adjusting for potential confounders within the data enhances the specificity of the observed associations.

Temporality. In Studies II and III, TPF exposure was documented prior to the outcome. In the time-to-event analyses, this strict maintenance of temporality minimised the risk of reverse causality. Establishing temporal order is a fundamental prerequisite for causal inference, and it represents one of the strongest methodological advantages of the register-based cohort design employed throughout this thesis.

Biological gradient. A clear dose-response relationship was observed across several analyses: fractures classified as more severe were consistently associated with higher conversion rates to TKA. This gradient strengthens the argument for a structural causal chain, in which greater intra-articular damage accelerates post-traumatic joint degeneration and ultimately increases the likelihood of joint replacement.

Plausibility. There is strong biological plausibility supporting a causal explanation. TPFs disrupt the articular surface, impair load transmission, and may result in chondral damage, chronic instability, and altered joint biomechanics. These pathological changes are well-established risk factors for post-traumatic OA, which often culminates in TKA. Furthermore, numerous biomechanical and imaging studies have documented progressive cartilage deterioration following intra-articular fractures [29,42,58,65,87,112,114], thereby reinforcing the plausibility of a causal link.

*Coherence***.** The observed associations are coherent with broader clinical understanding and align with established biological and clinical principles. Clinicians frequently witness post-traumatic degeneration following TPFs, and the elevated requirement for secondary procedures—including TKA—is widely recognised in clinical practice. This coherence between empirical findings and clinical experience reinforces the credibility of a causal interpretation.

Experiment. Ideal experimental evidence is inherently lacking, as random assignment of individuals to sustain a fracture is neither feasible nor ethical. An RCT directly comparing early versus delayed arthroplasty would, in principle, provide the most rigorous evidence and remains a warranted avenue for future research. In the absence of such trials, alternative methodologies, such as target trial emulation, offer promising strategies for approximating experimental reasoning in observational datasets [39,53].

Analogy. Analogous clinical scenarios provide supportive evidence. Other intra-articular fractures, such as those affecting the proximal humerus, the elbow, or the femoral neck [93,105,116], demonstrate similar patterns of post-traumatic degeneration that frequently culminate in surgical intervention. These parallels reinforce the plausibility of a causal relationship between TPFs and subsequent TKA.

Severity of TPFs and Progression to Arthroplasty

Severity emerged as a key determinant of long-term outcomes in this thesis. More complex TPFs were consistently associated with an increased risk of conversion to TKA. This hierarchical risk pattern reinforces both the biological gradient and plausibility criteria, suggesting that greater intra-articular disruption leads to irreversible cartilage damage and altered joint mechanics, thereby initiating a degenerative cascade. Nonetheless, fracture severity may also correlate with unmeasured confounders, such as surgeon experience, rehabilitation quality, or patient-specific factors, which must be acknowledged when interpreting these associations.

Early versus Delayed TKA: Causation or Confounding by Selection?

A further question arises regarding outcomes of early versus delayed TKA following TPF. Patients undergoing early arthroplasty may represent those with severely damaged joints or complex fracture patterns for whom reconstructive surgery is unlikely to be successful. Conversely, delayed arthroplasty may reflect initial preservation efforts in younger patients or fractures with characteristics more amenable to reconstructive efforts. Therefore, differences in outcomes between early and delayed TKA could be partially attributed to confounding by indication. While we report differences in outcome trajectories across timing groups, we cannot definitively ascertain whether timing per se influences prognosis or merely reflects underlying clinical complexity.

Strengths and Limitations

The primary strength across all studies is the substantial sample size, providing the necessary statistical power to detect meaning clinical associations. In Study 1, the use of nationwide NPR data—encompassing both inpatient and outpatient care—ensures virtually complete population coverage of proximal tibia fractures in Sweden. Given the NPR's high validity and completeness, the reported incidence rates are highly likely to represent true national figures rather than regional variations, thereby enhancing the generalisability of the findings.

Several limitations must be acknowledged. First, comorbidity data (e.g., diabetes, osteoporosis) were unavailable, restricting the ability to account for patient-related risk factors that may influence fracture risk or treatment selection. Second, ICD-10 coding does not differentiate among subtypes of proximal tibial fractures, even though fracture morphology is likely to affect both treatment strategies and long-term outcomes.

Injury misclassification may still have occurred, even after excluding the 2010 injury year to minimise the risk of follow-up visits being misclassified as new events. Misapplication of fracture diagnosis codes (e.g., S82.1) for procedures addressing non-union or post-traumatic conditions could have contributed to an overestimation of TKA rates. In addition, the NPR does not capture laterality, making it impossible to distinguish between refractures and contralateral injuries and potentially leading to undercounting.

Mortality data were not available in our dataset for Study I, preventing assessment of competing risks or survival following a proximal tibia fracture. Previous studies have reported elevated standardised mortality ratios of 1.7-2.3 in elderly patients with such fractures [12], consistent with patterns observed in other fragility fractures of the hip, pelvis [81], and proximal humerus [11]. These findings highlight the need to regard proximal tibia fractures not only as markers of skeletal fragility but also as potential indicators of overall frailty.

The data collection methods and stratification by preoperative patient and injury characteristics were major strengths of Studies II and III. Study II comprised 439 patients, a smaller cohort compared with larger observational register-based studies previously conducted by Wasserstein et al., Elsoe et al., Vestergaard et al., and Tapper et al. [32,140,146,150]. Nevertheless, a notable strength of study II was the availability of both pre- and postoperative radiographs, enabling detailed radiographic assessment.

Wasserstein et al. utilised hospital billing codes from Ontario, Canada, to identify patients and track subsequent conversion to TKA. In this study, neither pre- nor postoperative characteristics were investigated. Furthermore, the TKA endpoint remains subject to uncertainty, as procedures performed outside Ontario were not captured; additionally, the laterality of the TKA could not be confirmed [150]. Elsoe et al. and Vestergaard et al. used the Danish Patient Register, which identifies fractures and conversions via ICD codes. However, this administrative dataset lacks granular fracture or injury characteristics, and surgical laterality remains unavailable[32,146]. Tapper et al. employed the Finnish

Hospital Discharge Register and encountered the same data shortcomings as the previous studies [140].

In study III, fractures were identified using the SFR. A primary advantage of the SFR, as discussed earlier in this thesis, is the granularity of its data regarding fracture morphology and injury characteristics, coupled with direct reporting of both primary and secondary (if registered) interventions. When supplemented by linkage to the SAR for additional information on prospective conversions not captured in the SFR, the accuracy of endpoint measurement is substantially reinforced, leaving little uncertainty regarding its validity.

Previous studies investigating the impact of fracture classification and severity on TKA conversion have often been limited by small cohort sizes or ambiguity regarding the definition of the TKA endpoint [7,30,129]. Assink et al [7]. conducted a multicentre study involving 862 patients with operatively treated TPFs, in which rigorous preoperative radiograph measurements were performed. However, the endpoint 'conversion to TKA' was assessed through a mailed query— 'Do you still have your native knee? '—which yielded only a 55% response rate, thereby restricting the reliability of conclusions regarding the true conversion rate.

Study II included 439 patients; however, the low number of conversions within the first two postoperative years limited the statistical power to establish a definitive association between fracture type and TKA conversion. Additionally, neither the injury mechanism nor patient comorbidities were evaluated. Notably, many patients were younger than 55 years, a cohort in which surgeons are generally more hesitant to perform early TKA due to concerns regarding long-term implant longevity.

Study III employed a substantially larger national cohort; however, the absence of a single observer to classify all fractures introduces some uncertainty regarding data accuracy. Both studies are observational in nature and therefore subject to inherent limitations, including the potential influence of unidentified confounders. Important key potential confounders, including smoking status, BMD, and pre-existing OA, were not captured in our dataset. Consequently, we were unable to adjust to these factors, which may have led to residual confounding, as they may have influenced both the exposures and outcomes.

Study IV provides novel insight by directly comparing early and delayed TKA following fracture—an evaluation not previously conducted in a nationwide setting. Nonetheless, several limitations should be acknowledged. While revisions were clearly defined and reliably captured, other reoperations are reported less consistently in the SAR and may be underrepresented. The classification of revision and reoperation is based on whether the procedure involved insertion, exchange, or removal of prosthetic components. Given that the distributions of revisions and other reoperations were similar across groups, the risk of major bias is considered low.

Confounding by indication remains a potential concern, as primary TKA in the acute fracture setting is uncommon and likely reflects selective surgical decision-making influenced by unmeasured clinical factors. In addition, no minimum follow-up duration was applied. Although 329 of 1,102 patients had less than 2 years of follow-up, the mean follow-up time was 5.2 years. Importantly, previous studies indicate that most complications occur during the early postoperative period, suggesting that the majority of clinically relevant events were nonetheless captured [1].

Conclusion

This thesis provides an epidemiological perspective on TPFs, including trends, treatment strategies, and the risk of progression to TKA. The incidence of TPFs in Sweden has increased modestly over the past decade, particularly among women in both younger and older age groups, while rates of surgical management have remained stable. Despite the rising fracture burden, conversion to TKA following ORIF remains relatively uncommon.

Failure risk was not influenced by sex or trauma mechanism but was strongly associated with joint surface comminution and advanced age. The importance of achieving adequate articular surface reduction was highlighted by the finding that insufficient reduction increased the likelihood of later TKA more than eightfold. Nevertheless, no fracture type or classification demonstrated a 5-year conversion rate exceeding 12%, indicating that most patients do not ultimately require arthroplasty.

Taken together, these results suggest that while certain factors are linked to an increased risk of failure, a clearly defined subgroup that consistently benefits from primary TKA in the acute setting remains to be established.

A novel key contribution of this thesis is the direct comparison of acute versus delayed TKA following fracture within a nationwide cohort. While overall revision and reoperation rates were comparable between the two approaches, their underlying causes differed: prosthetic loosening and instability were more frequent after acute TKA, whereas prosthetic joint infection was more common after delayed procedures. Importantly, patients who underwent acute TKA reported superior general health and knee-related outcomes, including reduced pain and improved QoL, suggesting that surgical timing may influence functional recovery in selected cases.

The overall findings of this thesis indicate that while most TPFs can be successfully managed with ORIF, certain patient- and fracture-related characteristics are associated with an increased risk of subsequent TKA. Factors such as fracture comminution, age-related bone quality, and reduction quality influence long-term outcomes; however, these alone do not justify a systematic shift toward primary arthroplasty. Nonetheless, the favourable functional outcomes observed following early TKA in selected patient groups support a more individualised, risk-stratified approach to surgical decision-making in the acute setting.

The findings of this thesis underscore the importance of optimising fracture management, stratifying high-risk patients at an early stage, and mitigating the clinical sequelae that lead to arthroplasty. Concurrently acknowledging that a subset of patients may inevitably progress to TKA highlights the need for refined decision-making regarding reconstruction versus acute arthroplasty. As Bradford Hill emphasised, scientific conclusions should be based on the weight of evidence rather than deferred indefinitely in pursuit of absolute certainty. In this spirit, although causation in TPF outcomes cannot be established with complete certainty, the accumulated evidence is sufficient to guide clinical practice and provides a meaningful foundation for future research aimed at refining causal understanding and improving patient care.

Future research should focus on improving risk stratification by integrating radiographic, clinical, and patient-related factors to better identify individuals at increased risk of failure following ORIF. Defining such a subgroup helps determine which patients may benefit from primary TKA at the time of injury, thereby enabling more individualised treatment strategies and improving long-term outcomes.

A logical next step would be the design of a RCT comparing ORIF with primary TKA in elderly patients with TPFs. Eligible participants should present with sufficient articular comminution and depression to justify consideration of TKA as a primary treatment option. In an initial trial setting, it may be prudent to limit inclusion to Schatzker type II and III fractures, thereby reducing the likelihood of requiring highly constrained implants such as tumour or hinged prostheses.

However, such a trial cannot feasibly be conducted within a register-based RCT framework, as existing fracture classification systems are too crude to ensure sufficiently precise inclusion criteria. Instead, such an investigation would require a multicentre prospective design, involving institutions with established expertise in both complex fracture fixation and primary TKA for TPFs.

Sammanfattning

Frakturer i övre delen av skenbenet, så kallade tibiaplatåfrakturer, är allvarliga knäskador som kan variera från enkla sprickor till mycket komplexa ledengagerande frakturer. Dessa skador drabbar både yngre personer efter högenergivåld, till exempel trafikolyckor, och äldre personer efter fall i vardagen. På längre sikt kan frakturerna leda till bestående besvär i knät, framför allt i form av ledförslitning – artros, vilket i vissa fall gör att patienten senare behöver en knäprotes.

I takt med att befolkningen blir allt äldre förväntas antalet benskörhetsrelaterade frakturer öka, vilket innebär att även problemen med knäledsartros efter tibiaplatåfrakturer sannolikt kommer att bli allt vanligare. Trots förbättrade operationsmetoder finns det fortfarande osäkerhet kring vilka patienter som löper störst risk att utveckla svåra knäbesvär och i förlängningen behöva en knäprotes.

Syftet med denna avhandling var att studera de långsiktiga konsekvenserna av tibiaplatåfrakturer, med särskilt fokus på hur ofta patienter senare behöver opereras med knäprotes och vilka faktorer som påverkar denna risk. Studierna bygger på både kliniska patientmaterial och stora nationella register, däribland Patientregistret, Svenska Frakturregistret och Svenska Ledprotesregistret.

I **studie I** undersökte vi förekomsten av frakturer i övre delen av skenbenet i Sverige. Vi använde socialstyrelsens Patientregister för att få fram hur vanlig denna diagnos är. Vi ville även ta reda på om behandlings-algoritmerna har ändrats över tid. Det visade sig att frakturer i övre delen av skenbenet har ökat senaste 10 åren, men hur dessa behandlas i vardagen är väsentligen oförändrat.

I **studie II och III** undersökte vi – med hjälp av en lokal och en nationell kohort, från Svenska Frakturregistret – hur ofta en tibiaplatåfraktur leder till efterföljande knäprotes. Vi undersökte även hur patient- och fraktur-karaktäristika påverkar risken för att utveckla svåra knäbesvär som kräver knäprotesförsörjning. Vi fann att mer komplexa frakturer och stigande ålder var associerade med en ökad risk för senare knäprotes.

I **studie IV** använde vi oss av Svenska Ledprotesregistret för att identifiera patienter som blivit opererade med en knäprotes som primär behandling av en tibiaplatåfraktur. Dessa jämfördes med patienter som blivit behandlade med ledbevarande metoder som sedan på grund av svåra knäbesvär behövt byta sin knäled. Vi fann att riskerna för om operation eller revision ej skilde sig mellan dessa grupper, men att komplikationsprofilen skilde sig något. Knäprotesoperationer som första behandlingsval hade fler sena revisioner på grund av proteslossning – medan sena knäprotesoperationer hade fler revisioner på grund av infektion.

Resultaten visar att de flesta patienter som opereras med plattor och skruvar får ett gott långsiktigt resultat utan behov av knäprotes. Samtidigt finns en tydlig högriskgrupp bestående av äldre patienter med svåra frakturer. Hos dessa patienter är risken för senare protesoperation betydligt högre. Avhandlingen visar också att en knäprotes efter en tidigare fraktur ofta är mer komplicerad än en vanlig protesoperation och liknar mer en revisionsoperation. För vissa noggrant utvalda patienter kan därför en tidig protesoperation redan vid frakturtillfället vara ett rimligt behandlingsalternativ.

Sammanfattningsvis bidrar avhandlingen med ny kunskap om hur knäskador efter tibiaplatåfrakturer utvecklas över tid. Resultaten betonar vikten av god kirurgisk teknik, tidig identifiering av högriskpatienter och individanpassade behandlingsbeslut för att förbättra patienternas långsiktiga livskvalitet.

Acknowledgements

Olof Wolf
My main supervisor and arguably the busiest orthopaedic surgeon on the planet. How you manage to combine clinical work, research, supervision of multiple PhD students, teaching, and leadership roles such as Director of the Swedish Fracture Register and Chair of the Swedish Orthopaedic Trauma Society is truly remarkable. I have so much to thank you for. From our first meeting many years ago to the finalization of my thesis, you have always been there to answer my questions. Regardless of how trivial they may have seemed, you consistently shared your experience in a timely, constructive, and generous manner.

You have been a true inspiration to me, and for that I am deeply grateful. Thank you also for your patience and for allowing me to set the pace of the studies. Supervising a PhD student is no easy task, and even more so when we are not based in the same city. In summary, thank you for guiding me into the world of research.

Nils Hailer
My professor and co-supervisor. I am deeply grateful for all your support throughout the course of my studies. Thank you for your relentless pursuit of excellence — for those moments when I was convinced the manuscript was ready for submission, only for you to identify every remaining inconsistency, ambiguity, and loose end with the precision of a bloodhound. Everything you touch genuinely seems to improve. Thank you for always being so positive and for consistently finding the upside in every situation — it has been a tremendous source of motivation for a tired PhD student.

Anne Garland
My co-supervisor and boss. I have a great deal to thank you for, not only for your guidance throughout my academic journey but also for your mentorship in clinical practice. You have been a true inspiration to me, demonstrating that working at a small regional hospital such as Visby does not limit the opportunity to conduct meaningful research or contribute to the advancement of orthopaedics in Sweden. You have also played a pivotal role by being close at hand; when distance has precluded regular interaction with my other supervisors, you have been there to keep me on track.

It has been an honour working with you for more than a decade, and I am truly saddened to see you leave.

Annette W-Dahl
Co-author and expert on the Swedish Arthroplasty Register. Thank you for an excellent collaboration and for your invaluable contribution to Study IV.

Tönu Saartok
My first head of department in orthopaedics. Thank you for recognising my potential and for giving me the opportunity all those years ago. Your leadership and strong commitment to scientific research have truly inspired me and guided me along both my clinical and academic paths.

John Eliasson
My mentor and colleague. Without you, I would not be here. Your positivity, humility, and immense, seemingly inexhaustible knowledge continue to guide me every day. You encourage people to be the best they can be, and always with a smile on your face. Thank you for everything.

To all my **colleagues at Ortopedkliniken, Visby**, I would like to thank each and every one of you. I spend most of my waking hours working alongside you. Without the camaraderie, laughter, and enjoyment I share with all of you, I would never have had the energy to complete this journey.

Leslie Shaps
Thank you for your thorough and speedy proofreading of my thesis. I am deeply grateful for the time you devoted to improving its readability.

Pontus Andersson
Your illustrations are truly outstanding. Without your assistance, this thesis would have been far less engaging. Thank you.

Mattias Rydberg
Truest of friends, I have shared the better part of my adult life with you, and for that I am truly grateful. From sharing all my passions and embarking on magnificent journeys, to being a true inspiration in combining clinical work, academia, and social life — thank you for always being there, and for all the adventures still to come. GOLFE!

John Hutchins
From our first meeting in Visby 13 years ago, we found each other right from the start — even though you are from the “backside” of Sweden. You have been a true friend and later, through what can only be described as excellent matrimonial coordination, we managed to marry into the same family. From

being colleagues to maintaining our weekly phone calls to keep each other updated on the state of things, we have never drifted apart.

Marcus, Niklas, Christian, Jonathan and **Erik**
Friends from medical school and my trusted golf crew. I truly look forward to reviving our annual golf trips.

Hampus, Lars and **Arvid**
Long time friends and travel companions. I look forward to exploring new castles, bathing in lochs and sharing a dram with you. Sláinte!

Björn and **Marie**
Thank you, my dearest aunt and uncle, for taking me in and making your home my second home during those never-ending PhD courses. It truly made the process of this doctorate much easier and more joyful.

Lars and **Kristin**
My in-laws. Thank you for always making me feel part of your family from the very beginning. Thank you, Lars, for nurturing my DIY side and for helping me with all my carpentry and building projects. Thank you both for the invaluable support you provide in caring for my children — without you, there would be no thesis.

Sven Olerud
Grandfather and role model, your contributions to orthopaedics aside, I will always remember the sawbones and screw prototypes in your study in Länna, as well as your kindness and unwavering interest in our lives and pursuits.

Lotta Olerud
My dear little sister. Thank you for always being there for me, and for the loving way you are with my children. I have you to thank for keeping my wits sharp throughout the years.

Per Olerud
My father and role model — my greatest supporter. Orthopaedic surgeon and PhD. Even though I tried to resist, I have followed in your footsteps. Thank you for your support over the years, and for pushing me to focus on my studies in my teenage years. I would probably have excelled regardless, but it is the thought that counts.

Ulrika Swenman Olerud
My dearest mother — a role model as well, you have always been there for me. As an orthopaedic surgeon and hand surgeon, one might think my path was set from the very beginning. However, your ability to balance work and

family life has truly been an inspiration and a motivation for me to pursue this career. Thank you also for taking such wonderful care of my children and for helping me find the time to finalise this thesis. “Fammo” is an absolute favourite.

Josefin
My lovely wife. The apple of my eye and the mother of my children. Thank you for being you. You truly are my everything. Thank you for carrying the load and giving me the time to attend all those conferences and spend all those late nights writing. Without you, this thesis would never have been completed. And thank you for being the best mother imaginable to our children.

Ilse and Elliot
My wonderful children, you are the light of my life. I love you both.

References

1. Abdel, M. P. *et al.* Total Knee Arthroplasty in Patients With a Prior Tibial Plateau Fracture: A Long-Term Report at 15 Years. *Journal of Arthroplasty* **30**, 2170–2172 (2015).
2. Abdelbadie, A., El-Hennawy, A. & Sallam, A. Primary Total knee Arthroplasty: A Viable Surgical Option for Complex Tibial Plateau Fractures in Elderly. *Journal of Knee Surgery* **33**, 496–503 (2020).
3. Affatato, S. Biomechanics of the knee. in *Surgical Techniques in Total Knee Arthroplasty (TKA) and Alternative Procedures* 17–35 (Elsevier Ltd, 2015). doi:10.1533/9781782420385.1.17.
4. Ali, A. M., El-Shafie, †m & Willett, †k M. *Failure of Fixation of Tibial Plateau Fractures*. http://journals.lww.com/jorthotrauma (2002).
5. Ali, A. M., El-Shafie, M. & Willett, K. M. Failure of fixation of tibial plateau fractures. *J. Orthop. Trauma* **16**, 323–329 (2002).
6. Amis, A. A., Gupte, C. M., Bull, A. M. J. & Edwards, A. Anatomy of the posterior cruciate ligament and the meniscofemoral ligaments. *Knee Surgery, Sports Traumatology, Arthroscopy* **14**, 257–263 (2006).
7. Assink, N. *et al.* Radiographic Predictors of Conversion to Total Knee Arthroplasty After Tibial Plateau Fracture Surgery: Results in a Large Multicenter Cohort. *Journal of Bone and Joint Surgery* **105**, 1237–1245 (2023).
8. Audigé, L., Bhandari, M., Hanson, B. & Kellam, J. *A Concept for the Validation of Fracture Classifications*. http://journals.lww.com/jorthotrauma.
9. Barei, D. P. *et al.* Functional outcomes of severe bicondylar tibial plateau fractures treated with dual incisions and medial and lateral plates. *Journal of Bone and Joint Surgery* **88**, 1713–1721 (2006).
10. Bedson, J. & Croft, P. R. The discordance between clinical and radiographic knee osteoarthritis: A systematic search and summary of the literature. https://doi.org/10.1186/1471-2474-9-116 (2008) doi:10.1186/1471-2474-9-116.
11. Bergdahl, C., Wennergren, D., Möller, M. & Ekelund, J. Mortality after a proximal humeral fracture. *Bone and Joint Journal* **102-B**, 1484–1490 (2020).

12. Bergh, C., Wennergren, D., Möller, M. & Brisby, H. Fracture incidence in adults in relation to age and gender: A study of 27,169 fractures in the Swedish Fracture Register in a well-defined catchment area. *PLoS One* **15**, e0244291 (2020).
13. Biggi, F., Di Fabio, S., D'Antimo, C. & Trevisani, S. Tibial plateau fractures: Internal fixation with locking plates and the MIPO technique. *Injury* **41**, 1178–1182 (2010).
14. Bilge, O. The Epidemiology of Adult Fractures According to the AO/OTA Fracture Classification. *Turkish Journal of Trauma and Emergency Surgery* **28**, 209–216 (2020).
15. Bilge, O. *et al.* The epidemiology of adult fractures according to the AO/OTA fracture classification. *Ulus. Travma Acil Cerrahi Derg.* **28**, 209–216 (2022).
16. Black, N. Patient reported outcome measures could help transform healthcare. *BMJ (Online)* **346**, (2013).
17. Bohm, E. R., Tufescu, T. V. & Marsh, J. P. The operative management of osteoporotic fractures of the knee: To fix or replace? *Journal of Bone and Joint Surgery - Series B* **94 B**, 1160–1169 (2012).
18. Borgström, F. *et al.* Fragility fractures in Europe: burden, management and opportunities. https://doi.org/10.1007/s11657-020-0706-y doi:10.1007/s11657-020-0706-y.
19. Bormann, M. *et al.* Changing patterns in the epidemiology of tibial plateau fractures: a 10-year review at a level-I trauma center. *European Journal of Trauma and Emergency Surgery* **49**, 401–409 (2023).
20. Bormann, M. *et al.* [Influence of the COVID-19 pandemic on fracture epidemiology exemplified by tibial plateau fractures]. *Unfallchirurgie (Heidelberg, Germany)* **126**, 967–974 (2023).
21. Boureau, F. *et al.* Does primary total knee arthroplasty for acute knee joint fracture maintain autonomy in the elderly? A retrospective study of 21 cases. *Orthopaedics and Traumatology: Surgery and Research* **101**, 947–951 (2015).
22. Bradford Hill, A. The Environment and Disease: Association or Causation? *Section of Occupational Medicine* 295–300 (1965).
23. Brunner, A., Horisberger, M., Ulmar, B., Hoffmann, A. & Babst, R. Classification systems for tibial plateau fractures; Does computed tomography scanning improve their reliability? *Injury* **41**, 173–178 (2010).
24. Burgess, I. C., Kolar, M., Cunningham, J. L. & Unsworth, A. Development of a six station knee wear simulator and preliminary wear results. *http://dx.doi.org/10.1243/0954411971534665* **211**, 37–47 (1997).
25. Burström, K. *et al.* Swedish experience-based value sets for EQ-5D health states. *Quality of Life Research* **23**, 431–442 (2014).

26. Charalambous, C. P. *et al.* Inter and intra-observer variation of the Schatzker and AO/OTA classifications of tibial plateau fractures and a proposal of a new classification system. *Ann R Coll Surg Engl* **89**, 400–404 (2007).
27. Churruca, K. *et al.* Patient-reported outcome measures (PROMs): A review of generic and condition-specific measures and a discussion of trends and issues. *Health Expectations* **24**, 1015–1024 (2021).
28. Court-Brown, C. M. & Caesar, B. Epidemiology of adult fractures: A review. *Injury* **37**, 691–697 (2006).
29. DeCoster, T. A., Nepola, J. V & El-Khoury, G. Y. Cast brace treatment of proximal tibia fractures. A ten-year follow-up study. *Clin. Orthop. Relat. Res.* 196–204 (1988).
30. Donovan, R. L. *et al.* Epidemiology and outcomes of tibial plateau fractures in adults aged 60 and over treated in the United Kingdom. *Injury* **53**, 2219–2225 (2022).
31. Eckhard, L. *et al.* Minimal important change and minimum clinically important difference values of the KOOS-12 after total knee arthroplasty. *Knee* **29**, 541–546 (2021).
32. Elsoe, R., Johansen, M. B. & Larsen, P. Tibial plateau fractures are associated with a long-lasting increased risk of total knee arthroplasty a matched cohort study of 7,950 tibial plateau fractures. *Osteoarthritis Cartilage* **27**, 805–809 (2019).
33. Elsoe, R. *et al.* Population-Based Epidemiology of Tibial Plateau Fractures. *Orthopedics* **38**, e780–e786 (2015).
34. Emberton, M. & Black, N. Impact of Non-response and of Late-response by Patients in a Multi-centre Surgical Outcome Audit. *Iratmanonal Journal for Quality in Health Cart* **7**, 47–55 (1995).
35. Emrani, Z., Akbari Sari, A., Zeraati, H., Olyaeemanesh, A. & Daroudi, R. Health-related quality of life measured using the EQ-5D-5 L: Population norms for the capital of Iran. *Health Qual. Life Outcomes* **18**, 1–8 (2020).
36. Fox, A. J. S., Bedi, A. & Rodeo, S. A. The Basic Science of Articular Cartilage: Structure, Composition, and Function. https://doi.org/10.1177/1941738109350438 (2009) doi:10.1177/1941738109350438.
37. Frakturregistret, S. *Årsrapport 2024*. www.frakturregistret.se.
38. Frattini, M., Vaienti, E., Soncini, G. & Pogliacomi, F. Tibial plateau fractures in elderly patients. *Chir. Organi Mov.* **93**, 109–114 (2009).
39. Fu, E. L. Target Trial Emulation to Improve Causal Inference from Observational Data: What, Why, and How? *Journal of the American Society of Nephrology* **34**, 1305–1314 (2023).

40. Gandek, B., Roos, E. M., Franklin, P. D. & Ware, J. E. Item selection for 12-item short forms of the Knee injury and Osteoarthritis Outcome Score (KOOS-12) and Hip disability and Osteoarthritis Outcome Score (HOOS-12). *Osteoarthritis Cartilage* **27**, 746–753 (2019).
41. Gandek, B., Roos, E. M., Franklin, P. D. & Ware, J. E. A 12-item short form of the Knee injury and Osteoarthritis Outcome Score (KOOS-12): tests of reliability, validity and responsiveness. *Osteoarthritis Cartilage* **27**, 762–770 (2019).
42. Gaudinez, R. F., Mallik, A. R. & Szporn, M. Hybrid external fixation of comminuted tibial plateau fractures. *Clin. Orthop. Relat. Res.* **328**, 203–210 (1996).
43. Gicquel, T. *et al.* Tibial plateau fractures: Reproducibility of three classifications (Schatzker, AO, Duparc) and a revised Duparc classification. *Orthopaedics and Traumatology: Surgery and Research* **99**, 805–816 (2013).
44. Girgis, F. G., Marshall, J. L. & Al Monajem, A. R. S. The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. *Clin. Orthop. Relat. Res.* **No. 106**, 216–231 (1975).
45. Gonzalez, L. J., Hildebrandt, K., Carlock, K., Egol, K. A. & Konda, S. R. Patient function continues to improve over the first five years following tibial plateau fracture managed by open reduction and internal fixation. *Bone and Joint Journal* **102 B**, 632–637 (2020).
46. Gray, H. & Bannister, L. *Gray's Anatomy: The Anatomical Basis of Medicine and Surgey*. (Churchill Livingstone, London, 1995).
47. Hahn, E. A. *et al.* Precision of health-related quality-of-life data compared with other clinical measures. *Mayo Clin. Proc.* **82**, 1244–1254 (2007).
48. Hansen, L., Larsen, P. & Elsoe, R. Characteristics of patients requiring early total knee replacement after surgically treated lateral tibial plateau fractures—A comparative cohort study. *European Journal of Orthopaedic Surgery and Traumatology* **32**, 1097–1103 (2022).
49. Haslhofer, D. J., Kraml, N., Winkler, P. W., Gotterbarm, T. & Klasan, A. Risk for total knee arthroplasty after tibial plateau fractures: a systematic review. *Knee Surgery, Sports Traumatology, Arthroscopy* **31**, 5145–5153 (2023).
50. Haslhofer, D. J., Kraml, N., Winkler, P. W., Gotterbarm, T. & Klasan, A. Risk for total knee arthroplasty after tibial plateau fractures: a systematic review. *Knee Surgery, Sports Traumatology, Arthroscopy* vol. 31 5145–5153 Preprint at https://doi.org/10.1007/s00167-023-07585-8 (2023).
51. Hernán, M. A. & Robins, J. M. Using Big Data to Emulate a Target Trial When a Randomized Trial Is Not Available. *Am. J. Epidemiol.* **183**, 758–764 (2016).

52. Hernán, M. A. & Robins, J. M. *Causal Inference: What If.* https://www.hsph.harvard.edu/miguel- (2024).
53. Hernán, M. A., Wang, W. & Leaf, D. E. Target Trial Emulation: A Framework for Causal Inference from Observational Data. *JAMA* **328**, 2446–2447 (2022).
54. Hernández Alava, M., Pudney, S., Wailoo, A. & Wailoo ajwailoo, A. Estimating the Relationship Between EQ-5D-5L and EQ-5D-3L: Results from a UK Population Study Key Points for Decision Makers. *Pharmacoeconomics* **41**, 199–207 (123AD).
55. Herteleer, M., Van Brandt, C., Vandoren, C., Nijs, S. & Hoekstra, H. Tibial plateau fractures in Belgium: epidemiology, financial burden and costs curbing strategies. *European Journal of Trauma and Emergency Surgery* **48**, 3643–3650 (2022).
56. Hirschmann, M. T. & Müller, W. Complex function of the knee joint: the current understanding of the knee. *Knee Surgery, Sports Traumatology, Arthroscopy* **23**, 2780–2788 (2015).
57. Hohl M. Tibial Condylar Fractures. *J Bone Joint Surg Am.* **49**, 1455–67 (1967).
58. Honkonen, S. E. Degenerative Arthritis After Tibial Plateau Fractures. *J. Orthop. Trauma* **9**, 273–277 (1995).
59. Honkonen, S. E. Indications for Surgical Treatment of Tibia1 Condyle Fractures. *CLINICAL ORTHOPAEDICS AND RELATED RESEARCH Number* **302**, 199–205.
60. Houdek, M. T. *et al.* Posttraumatic Total Knee Arthroplasty Continues to Have Worse Outcome Than Total Knee Arthroplasty for Osteoarthritis. *Journal of Arthroplasty* **31**, 118–123 (2016).
61. Van Hout, B. *et al.* Interim scoring for the EQ-5D-5L: Mapping the EQ-5D-5L to EQ-5D-3L value sets. *Value in Health* **15**, 708–715 (2012).
62. Hunziker, E. B., Quinn, T. M., Hä, H.-J. & Mü, M. E. Quantitative structural organization of normal adult human articular cartilage. *Osteoarthritis Cartilage* **10**, 564–572 (2002).
63. Hutchings, A., Neuburger, J., Grosse Frie, K., Black, N. & Van Der Meulen, J. Factors associated with non-response in routine use of patient reported outcome measures after elective surgery in England. https://doi.org/10.1186/1477-7525-10-34 (2012) doi:10.1186/1477-7525-10-34.
64. Irving, M., Eramudugolla, R., Cherbuin, N. & Anstey, K. J. A Critical Review of Grading Systems: Implications for Public Health Policy. *Eval. Health Prof.* **40**, 244–262 (2017).
65. Jagdev, S. S., Pathak, S., Kanani, H. & Salunke, A. Functional outcome and incidence of osteoarthritis in operated tibial plateau fractures. *Archives of Bone and Joint Surgery* **6**, 508–516 (2018).

66. Janssen, M. F., Gouke, •, Bonsel, J. & Luo, N. Is EQ-5D-5L Better Than EQ-5D-3L? A Head-to-Head Comparison of Descriptive Systems and Value Sets from Seven Countries. https://doi.org/10.1007/s40273-018-0623-8 (2018) doi:10.1007/s40273-018-0623-8.
67. Jiang, R., Janssen, M. F. B. & Pickard, A. S. US population norms for the EQ-5D-5L and comparison of norms from face-to-face and online samples. *Quality of Life Research* **30**, 803 (2020).
68. Kanis, J. A. *et al.* The burden of osteoporotic fractures: A method for setting intervention thresholds. *Osteoporosis International* **12**, 417–427 (2001).
69. Kester, B. S., Minhas, S. V., Vigdorchik, J. M. & Schwarzkopf, R. Total Knee Arthroplasty for Posttraumatic Osteoarthritis: Is it Time for a New Classification? *J. Arthroplasty* **31**, 1649-1653.e1 (2016).
70. Kfuri, M. & Schatzker, J. Revisiting the Schatzker classification of tibial plateau fractures. *Injury* **49**, 2252–2263 (2018).
71. Khan, R. M. S., Khan, S. H., Ahmad, A. J. & Umar, M. Tibial plateau fractures: A new classification scheme. *Clin. Orthop. Relat. Res.* **375**, 231–242 (2000).
72. Kim, J. K., Hwang, K. T., Soh, H. S., Shon, O. J. & Park, K. C. Comparison of tibial plateau fracture surgical outcomes between young and elderly patients: are outcomes really poorer in the elderly? *Arch. Orthop. Trauma Surg.* **142**, 2419–2427 (2022).
73. Kornvig, S., Jakobsen, T. H., Gromov, K., Timm, S. & Varnum, C. Patient-reported outcomes may be 'missing not at random' in hip and knee arthroplasty. *Bone and Joint Journal* **108 B**, 46–53 (2026).
74. Landis, J. R. & Koch, G. G. The Measurement of Observer Agreement for Categorical Data. *Biometrics* **33**, 159 (1977).
75. Lapidus, O., Linder, M., Barenius, B. & Lapidus, L. J. Total knee arthroplasty following surgical treatment of tibial plateau fractures – A retrospective cohort study. *Knee* **50**, 27–32 (2024).
76. Ledprotesregistret, S. Årsrapport 2024.
77. Ledprotesregistret, S. & W-dahl, A. *Årsrapport 2021.* (2021).
78. Leer-Salvesen, S. *et al.* Does time from fracture to surgery affect mortality and intraoperative medical complications for hip fracture patients? An observational study of 73 557 patients reported to the Norwegian hip fracture register. *Bone and Joint Journal* **101-B**, 1129–1137 (2019).
79. Lucas, R. M. & Mcmichael, A. J. *Public Health Classics Association or Causation: Evaluating Links between 'Environment and Disease'. Bulletin of the World Health Organization* vol. 83 http://www.jrsm.org (2005).
80. Ludvigsson, J. F. *et al.* External review and validation of the Swedish national inpatient register. *BMC Public Health* **11**, 450 (2011).

81. Lundin, N. *et al.* Epidemiology and mortality of pelvic and femur fractures-a nation-wide register study of 417,840 fractures in Sweden across 16 years: diverging trends for potentially lethal fractures. *Acta Orthop.* **92**, 323–328 (2021).
82. Lunebourg, A. *et al.* Lower function, quality of life, and survival rate after total knee arthroplasty for posttraumatic arthritis than for primary arthritis. *Acta Orthop.* **86**, 189 (2015).
83. Luo, C., Sun, H., Zhang, B. & Zeng, B. F. Three-column fixation for complex tibial plateau fractures. *J. Orthop. Trauma* **24**, 683–692 (2010).
84. Makaram, N. S., Param, A., Clement, N. D. & Scott, C. E. H. Primary Versus Secondary Total Knee Arthroplasty for Tibial Plateau Fractures in Patients Aged 55 or Over-A Systematic Review and Meta-Analysis. *J. Arthroplasty* **39**, 559–567 (2024).
85. Malik, S., Herron, T., Mabrouk, A. & Rosenberg, N. Tibial Plateau Fractures. *Orthopedic Trauma Call for the Attending Surgeon* 211–222 (2023) doi:10.1201/9781003525493-28.
86. Mameri, E. S. *et al.* Review of Meniscus Anatomy and Biomechanics. https://doi.org/10.1007/s12178-022-09768-1 doi:10.1007/s12178-022-09768-1.
87. Manidakis, N. *et al.* Tibial plateau fractures: Functional outcome and incidence of osteoarthritis in 125 cases. *Int. Orthop.* **34**, 565–570 (2010).
88. Marsh, J. L. *et al.* Fracture and Dislocation Classification Compendium - 2007, Orthopaedic Trauma Association Classification, Database and Outcomes Comitee. *J. Orthop. Trauma* **21**, S1–S6 (2007).
89. Marshall, S., Haywood, K. & Fitzpatrick, R. Impact of patient-reported outcome measures on routine practice: A structured review. *J. Eval. Clin. Pract.* **12**, 559–568 (2006).
90. Mary McHugh. Interrater reliability: the kappa statistic. *Biochem. Med. (Zagreb).* **3**, 276–82 (2012).
91. Massin, P. *et al.* Total knee replacement in post-traumatic arthritic knees with limitation of flexion. *Orthopaedics and Traumatology: Surgery and Research* **97**, 28–33 (2011).
92. McCaffrey, N., Kaambwa, B., Currow, D. C. & Ratcliffe, J. Health-related quality of life measured using the EQ-5D-5L: South Australian population norms. *Health Qual. Life Outcomes* **14**, 1–12 (2016).
93. McKee, M. D. *et al.* A multicenter, prospective, randomized, controlled trial of open reduction-internal fixation versus total elbow arthroplasty for displaced intra-articular distal humeral fractures in elderly patients. *J. Shoulder Elbow Surg.* **18**, 3–12 (2009).
94. Mcnamara, I. R. *et al.* Surgical fixation methods for tibial plateau fractures. *Cochrane Database of Systematic Reviews* **2015**, (2015).

95. Meinberg, E. G., Agel, J., Roberts, C. S., Karam, M. D. & Kellam, J. F. Fracture and Dislocation Classification Compendium-2018. *J. Orthop. Trauma* **32**, S1–S170 (2018).
96. Millán-Billi, A., Gómez-Masdeu, M., Ramírez-Bermejo, E., Ibañez, M. & Gelber, P. E. What is the most reproducible classification system to assess tibial plateau fractures? *Int. Orthop.* **41**, 1251–1256 (2017).
97. Möller, M. *et al.* The Swedish Fracture Register – ten years of experience and 600,000 fractures collected in a National Quality Register. *BMC Musculoskelet. Disord.* **23**, (2022).
98. Moore, T. M., Patzakis, M. J. & Harvery, J. P. Tibial Plateau Fractures_Definition, Demographics, Treatment Rationale, and Long-Term Results of Closed Traction Management or Operative Reduction. *J. Orthop. Trauma* **1**, 97–119 (1987).
99. Moore, T. Fracture-dislocation of the knee. *Clin Orthop Relat Res* **156**, 128–140 (1981).
100. Mthethwa, J. & Chikate, A. A review of the management of tibial plateau fractures. *Musculoskelet. Surg.* **102**, 119–127 (2018).
101. Müller, M. E., Koch, P., Nazarian, S. & Schatzker, J. The Comprehensive Classification of Fractures of Long Bones. *The Comprehensive Classification of Fractures of Long Bones* https://doi.org/10.1007/978-3-642-61261-9 (1990) doi:10.1007/978-3-642-61261-9.
102. Müller, M. E., Nazarian, S. & Koch, P. Classification AO des fractures. *Classification AO des fractures* https://doi.org/10.1007/978-3-662-06263-0 (1987) doi:10.1007/978-3-662-06263-0.
103. Nowinski, C. J. *et al.* Applying the Bradford Hill Criteria for Causation to Repetitive Head Impacts and Chronic Traumatic Encephalopathy. *Front. Neurol.* **13**, 938163 (2022).
104. Ochen, Y. *et al.* Long-term outcomes after open reduction and internal fixation of bicondylar tibial plateau fractures. *Injury* **51**, 1097–1102 (2020).
105. Olerud, P., Ahrengart, L., Ponzer, S., Saving, J. & Tidermark, J. Hemiarthroplasty versus nonoperative treatment of displaced 4-part proximal humeral fractures in elderly patients: A randomized controlled trial. *J. Shoulder Elbow Surg.* **20**, 1025–1033 (2011).
106. Parratte, S. *et al.* Primary total knee arthroplasty in the management of epiphyseal fracture around the knee. *Orthopaedics and Traumatology: Surgery and Research* **97**, (2011).
107. Parratte, S., Ollivier, M. & Argenson, J. N. Primary total knee arthroplasty for acute fracture around the knee. *Orthopaedics and Traumatology: Surgery and Research* **104**, S71–S80 (2018).
108. Pinter, Z. *et al.* Outcomes of knee replacement in patients with post-traumatic arthritis due to previous tibial plateau fracture. *European Journal of Orthopaedic Surgery and Traumatology* **30**, 323–328 (2020).

109. Prall, W. C. *et al.* Radiological Outcome Measures Indicate Advantages of Precontoured Locking Compression Plates in Elderly Patients With Split-Depression Fractures to the Lateral Tibial Plateau (AO41B3). *Geriatr. Orthop. Surg. Rehabil.* **12**, (2021).
110. R Core Team. R: A Language and Environment for Statistical Computing. Preprint at (2023).
111. Rabin, R. & De Charro, F. EQ-5D: A measure of health status from the EuroQol Group. *Ann. Med.* **33**, 337–343 (2001).
112. Rademakers, M. V., Kerkhoffs, G. M. M. J., Sierevelt, I. N., Raaymakers, E. L. F. B. & Marti, R. K. Operative treatment of 109 tibial plateau fractures: Five- to 27-year follow-up results. *J. Orthop. Trauma* **21**, 5–10 (2007).
113. Ranstam, J. *et al.* Statistical analysis of arthroplasty data. II. Guidelines. *Acta Orthop.* **82**, 258–267 (2011).
114. Rasmussen, P. S. Tibial condylar fractures. Impairment of knee joint stability as an indication for surgical treatment. *J. Bone Joint Surg. Am.* **55**, 1331–50 (1973).
115. Ries, M. D. Primary arthroplasty for management of osteoporotic fractures about the knee. *Curr. Osteoporos. Rep.* **10**, 322–327 (2012).
116. Rogmark, C. & Leonardsson, O. Hip arthroplasty for the treatment of displaced fractures of the femoral neck in elderly patients. *Bone and Joint Journal* **98B**, 291–297 (2016).
117. Rolfson, O., Kärrholm, J., Dahlberg, L. E., Garellick, G. & Surgeon, O. Patient-reported outcomes in the Swedish Hip Arthroplasty Register RESULTS OF A NATIONWIDE PROSPECTIVE OBSERVATIONAL STUDY. **93**, (2011).
118. Rolfson, O. *et al.* Patient-reported outcome measures in arthroplasty registries Report of the Patient-Reported Outcome Measures Working Group of the Inter-national Society of Arthroplasty Registries Part II. Recommendations for selection, administration, and analysis. *Acta Orthop.* **87**, 9–23 (2016).
119. Rontgen, W. K. On A New Kind of Rays. *Science (1979).* **3**, 227–231 (1896).
120. Roos, E. M., Roos, H. P., Lohmander, L. S., Ekdahl, C. & Beynnon, B. D. Knee Injury and Osteoarthritis Outcome Score (KOOS) - Development of a self-administered outcome measure. *Journal of Orthopaedic and Sports Physical Therapy* **28**, 88–96 (1998).
121. Ross, L. A. *et al.* Loss to patient-reported outcome measure follow-up after hip arthroplasty and knee arthroplasty patient satisfaction, associations with non-RESponse, and maximizing returns. *Bone Jt. Open* **3**, 275–283 (2022).
122. Rozell, J. C., Vemulapalli, K. C., Gary, J. L. & Donegan, D. J. Tibial Plateau Fractures in Elderly Patients. *Geriatr. Orthop. Surg. Rehabil.* **7**, 126–134 (2016).

123. Rupp, M. *et al.* The Incidence of Fractures Among the Adult Population of Germany: An Analysis From 2009 Through 2019. *Dtsch. Arztebl. Int.* **118**, 665 (2021).

124. Rydberg, E. M., Möller, M., Ekelund, J., Wolf, O. & Wennergren, D. Does the Covid-19 pandemic affect ankle fracture incidence? Moderate decrease in Sweden. *Acta Orthop.* **92**, 381–384 (2021).

125. Sabatini, L. *et al.* Primary total knee arthroplasty in tibial plateau fractures: Literature review and our institutional experience. *Injury* **54**, S15–S23 (2023).

126. Saleh, H., Yu, S., Vigdorchik, J. & Schwarzkopf, R. Total knee arthroplasty for treatment of post-traumatic arthritis: Systematic review. *World J. Orthop.* **7**, 584 (2016).

127. Schatzker J. Compression in the surgical treatment of fractures of the tibia. *Clin Orthop Relat Res.* **Nov-Dec**, 220–39 (1974).

128. Schatzker, J. & Tile, M. *The Rationale of Operative Fracture Care.* (Springer-Verlag Berlin Heidelberg Gmbh, Berlin Heidelberg, 1987).

129. Scott, B. L., Lee, C. S. & Strelzow, J. A. Five-Year Risk of Conversion to Total Knee Arthroplasty After Operatively Treated Periarticular Knee Fractures in Patients Over 40 Years of Age. *Journal of Arthroplasty* **35**, 2084-2089.e1 (2020).

130. Scott, C. E. H., Davidson, E., Macdonald, D. J., White, T. O. & Keating, J. F. Total knee arthroplasty following tibial plateau fracture: A matched cohort study. *Bone and Joint Journal* **97-B**, 532–538 (2015).

131. Shimizu, T. *et al.* Geriatric tibial plateau fractures: Clinical features and surgical outcomes. *Journal of Orthopaedic Science* **21**, 68–73 (2016).

132. Softness, K. A., Murray, R. S. & Evans, B. G. Total knee arthroplasty and fractures of the tibial plateau. *World Journal of Orthopaedics* **8**, 107–114 (2017).

133. Sterne, J. A. C. *et al.* Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. https://doi.org/10.1136/bmj.b2393 doi:10.1136/bmj.b2393.

134. Stevenson, I., McMillan, T. E., Baliga, S. & Schemitsch, E. H. Primary and Secondary Total Knee Arthroplasty for Tibial Plateau Fractures. *Journal of the American Academy of Orthopaedic Surgeons* **26**, 386–395 (2018).

135. Stirling, P. H. C. *et al.* Nonresponder bias in hand surgery: analysis of 1945 cases lost to follow-up over a 6-year period. *Journal of Hand Surgery: European Volume* **47**, 197–205 (2022).

136. Su, E. P., Westrich, G. H., Rana, A. J., Kapoor, K. & Helfet, D. L. Operative Treatment of Tibial Plateau Fractures in Patients Older Than 55 Years. *Clin. Orthop. Relat. Res.* **421**, 240–248 (2004).

137. Sundkvist, J. *et al.* Epidemiology, classification, treatment, and mortality of adult femoral neck and basicervical fractures: an observational study of 40,049 fractures from the Swedish Fracture Register. *J. Orthop. Surg. Res.* **16**, (2021).
138. Svedbom, A. *et al.* Osteoporosis in the European Union: a compendium of country-specific reports. https://doi.org/10.1007/s11657-013-0137-0 doi:10.1007/s11657-013-0137-0.
139. Tapper, V. S., Pamilo, K. J., Haapakoski, J. J., Toom, A. & Paloneva, J. Risk of total knee replacement after proximal tibia fracture: a register-based study of 7,701 patients. *Acta Orthop.* **93**, 179–184 (2022).
140. Tapper, V. S., Pamilo, K. J., Haapakoski, J. J., Toom, A. & Paloneva, J. Risk of total knee replacement after proximal tibia fracture: a register-based study of 7,701 patients. *Acta Orthop.* **93**, 179–184 (2022).
141. Tapper, V., Toom, A., Pesola, M., Pamilo, K. & Paloneva, J. Knee joint replacement as primary treatment for proximal tibial fractures: analysis of clinical results of twenty-two patients with mean follow-up of nineteen months. *Int. Orthop.* **44**, 85–93 (2020).
142. Teni, F. S. *et al.* Inequality and heterogeneity in health-related quality of life: findings based on a large sample of cross-sectional EQ-5D-5L data from the Swedish general population. *Quality of Life Research* **31**, 697–712 (2022).
143. Timmers, T. K., van der Ven, D. J. C., de Vries, L. S. & van Olden, G. D. J. Functional outcome after tibial plateau fracture osteosynthesis: A mean follow-up of 6years. *Knee* **21**, 1210–1215 (2014).
144. Vaienti, E., Scita, G., Ceccarelli, F. & Pogliacomi, F. Understanding the human knee and its relationship to total knee replacement. *Acta Biomed* **88**, 6–16 (2017).
145. Vermeire, J. & Scheerlinck, T. Early primary total knee replacement for complex proximal tibia fractures in elderly and osteoarthritic patients. *Acta Orthop. Belg.* **76**, 785–793 (2010).
146. Vestergaard, V., Becic Pedersen, A., Borbjerg Hare, K., Morville Schrøder, H. & Troelsen, A. Knee Fracture Increases TKA Risk after Initial Fracture Treatment and throughout Life. in *Clinical Orthopaedics and Related Research* vol. 478 2036–2044 (Lippincott Williams and Wilkins, 2020).
147. Wahlquist, M., Iaguilli, N., Ebraheim, N. & Levine, J. Medial tibial plateau fractures: a new classification system. *J Trauma* **63**, 1418–1421 (2007).
148. Walker, P. S. & Erkman, M. J. The role of the menisci in force transmission across the knee. *Clin. Orthop. Relat. Res.* **No. 109**, 184–192 (1975).
149. Wang, Y. *et al.* Updated Three-Column Concept in surgical treatment for tibial plateau fractures - A prospective cohort study of 287 patients. *Injury* **47**, 1488–1496 (2016).

150. Wasserstein, D., Henry, P., Paterson, J. M., Kreder, H. J. & Jenkinson, R. Risk of Total Knee Arthroplasty After Operatively Treated Tibial Plateau Fracture. *Journal of Bone and Joint Surgery* **96**, 144–150 (2014).
151. Weil, Y. A., Gardner, M. J., Boraiah, S., Helfet, D. L. & Lorich, D. G. Posteromedial supine approach for reduction and fixation of medial and bicondylar tibial plateau fractures. *J. Orthop. Trauma* **22**, 357–362 (2008).
152. Welford, P. *et al.* The association between surgical fixation of hip fractures within 24 hours and mortality: A systematic review and meta-analysis. *Bone and Joint Journal* **103 B**, 1176–1186 (2021).
153. Wennergren, D. *et al.* High reliability in classification of tibia fractures in the Swedish Fracture Register. *Injury* **47**, 478–482 (2016).
154. Wennergren, D. *et al.* Epidemiology and incidence of tibia fractures in the Swedish Fracture Register. *Injury* **49**, 2068–2074 (2018).
155. Wennergren, D., Ekholm, C., Sandelin, A. & Möller, M. The Swedish fracture register: 103,000 fractures registered. *BMC Musculoskelet. Disord.* **16**, (2015).
156. White, I. R., Royston, P. & Wood, A. M. Multiple imputation using chained equations: Issues and guidance for practice. *Stat. Med.* **30**, 377–399 (2011).
157. Wolf, O., Mukka, S., Ekelund, J., Möller, M. & Hailer, N. P. How deadly is a fracture distal to the hip in the elderly? An observational cohort study of 11,799 femoral fractures in the Swedish Fracture Register. *Acta Orthop.* **92**, 40–46 (2020).
158. Wong, M. T., Bourget-Murray, J., Johnston, K. & Desy, N. M. Understanding the role of total knee arthroplasty for primary treatment of tibial plateau fracture: a systematic review of the literature. *Journal of Orthopaedics and Traumatology* **21**, (2020).
159. Zhang, L. *et al.* Knee Joint Biomechanics in Physiological Conditions and How Pathologies Can Affect It: A Systematic Review. *Applied Bionics and Biomechanics* vol. 2020 Preprint at https://doi.org/10.1155/2020/7451683 (2020).
160. World Medical Association declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA* vol. 310 2191–2194 Preprint at https://doi.org/10.1001/jama.2013.281053 (2013).
161. *WMA DECLARATION OF HELSINKI-ETHICAL PRINCIPLES FOR MEDICAL RESEARCH INVOLVING HUMAN PARTICIPANTS GENERAL PRINCIPLES.*
162. ICD-10-SE Del 1 – Internationell statistisk klassifikation av sjukdomar och relaterade hälsoproblem – Systematisk förteckning – Svensk version 2025 – Del 1 (3) - Socialstyrelsen. https://www.socialstyrelsen.se/publikationer/icd-10-se-del-1--internationell-statistisk-

klassifikation-av-sjukdomar-och-relaterade-halsoproblem--systematisk-forteckning--svensk-version-2025--del-1-3-2025-1-9321/.

163. ICD-10-SE Del 2 – Internationell statistisk klassifikation av sjukdomar och relaterade hälsoproblem – Systematisk förteckning – Svensk version 2025 – Del 2 (3) - Socialstyrelsen. https://www.socialstyrelsen.se/publikationer/icd-10-se-del-2--internationell-statistisk-klassifikation-av-sjukdomar-och-relaterade-halsoproblem--systematisk-forteckning--svensk-version-2025--del-2-3-2025-1-9322/.

164. ICD-10-SE Del 3 – Internationell statistisk klassifikation av sjukdomar och relaterade hälsoproblem – Systematisk förteckning – Svensk version 2025 – Del 3 (3) - Socialstyrelsen. https://www.socialstyrelsen.se/publikationer/icd-10-se-del-3--internationell-statistisk-klassifikation-av-sjukdomar-och-relaterade-halsoproblem--systematisk-forteckning--svensk-version-2025--del-3-3-2025-1-9323/.

Acta Universitatis Upsaliensis

Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine 2228

Editor: The Dean of the Faculty of Medicine

Distribution: publications.uu.se
urn:nbn:se:uu:diva-577031

ACTA UNIVERSITATIS
UPSALIENSIS
2026