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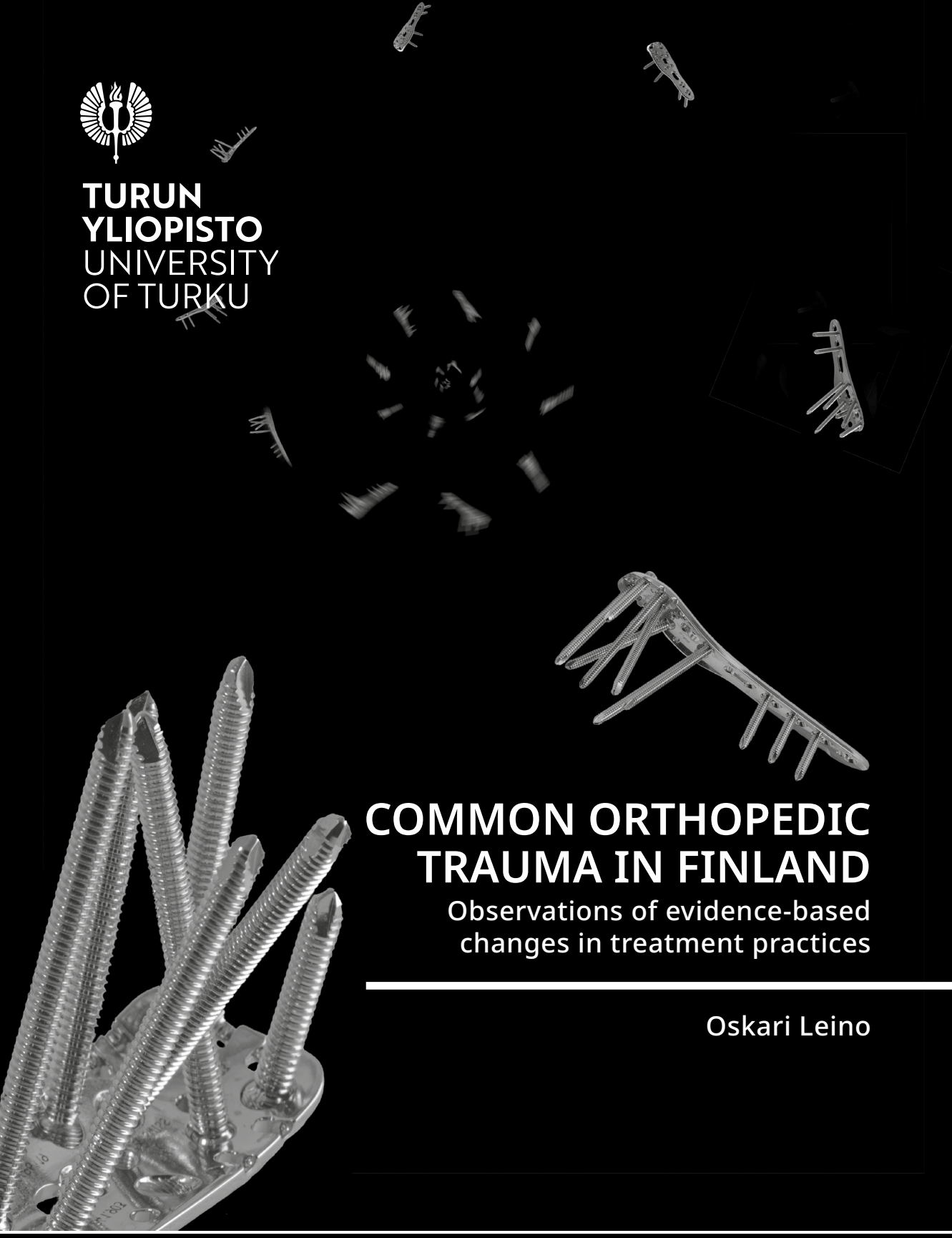

COMMON ORTHOPEDIC TRAUMA IN FINLAND

Observations of evidence-based changes in treatment practices

Oskari Leino

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA – SER. D OSA – TOM. 1938 | MEDICA – ODONTOLOGICA | TURKU 2025

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"First, do no harm"
In the spirit of the Hippocratic Oath

To my family

UNIVERSITY OF TURKU
Faculty of Medicine
Orthopedics and Traumatology
OSKARI LEINO: Common orthopedic trauma in Finland – Observations of evidence-based shifts in treatment practices
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ABSTRACT

Proximal humerus fractures (PHFs), Achilles tendon ruptures (ATRs), and hip fractures are common orthopedic traumas that have been the focus of increasing clinical research in recent decades. Comparative evidence favors nonoperative treatment for PHFs and ATRs, while arthroplasty with cemented stems is recommended for most femoral neck fractures. Arthroplasty has also become more widely studied in PHF management.

The aim of this doctoral thesis was to examine changes in the incidence and treatment of these injuries in Finland over the past two decades, with emphasis on how treatment practices have adapted to emerging evidence-based medicine. Data were obtained from the National Hospital Discharge Register and the National Register of Primary Health Care Visits.

The findings show that the incidence of PHFs and ATRs has risen, whereas hip fracture incidence has remained relatively stable. There has been a clear, evidence-based shift toward nonoperative management of PHFs and ATRs, and for femoral neck fractures, from internal fixation (IF) to cemented arthroplasty. In trochanteric fractures, the dynamic hip screw has been largely replaced by cephalomedullary nails. In operative treatment of PHFs, reverse shoulder arthroplasty has become more common in relation to IF and hemiarthroplasty. These changes parallel international trends, despite a lower level of evidence in their favor. A strong national consensus amongst hospital districts was also evident in PHF treatment.

These injuries impose a substantial health and economic burden. Awareness of national incidence trends is crucial for planning health care resources, and treatment must be both standardized and effective, particularly given the challenges of the ongoing Finnish health care reform. In this field of orthopedic trauma, Finnish treatment practices have, with good consensus, developed in the right direction as defined by current medical scientific evidence.

KEYWORDS: Proximal humerus fracture, Achilles tendon rupture, Hip fracture, Incidence, Nonoperative treatment, Internal fixation, Arthroplasty, Evidence-based medicine

TURUN YLIOPISTO
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TIIVISTELMÄ

Olkaluun yläosan murtumien, akillesjänteen repeämien ja lonkkamurtumien hoidosta on 2000-luvulla julkaistu lukuisia satunnaistettuja vertailevia tutkimuksia sekä näihin perustuvia meta-analyysejä. Tulokset puoltavat ensimmäisten kahden vamman osalta useimmiten konservatiivista hoitoa. Reisiluun kaulan murtumista tulisi nykytietämyksen mukaan yhä suurempi osa hoitaa sementillisillä tekonivelratkaisuilla. Myös olkamurtumien hoito käänteistekonivelellä on ollut aktiivisen tutkimuksen kohteena.

Tämän väitöstutkimuksen tavoitteena oli selvittää näiden vammojen ilmaantuvuuden ja hoitokäytäntöjen muutoksia Suomessa kahden viime vuosikymmenen aikana sekä arvioida hoitolinjojen kehittymistä suhteessa näyttöön perustuvaan lääketieteeseen. Tutkimusaineisto kerättiin valtakunnallisista Terveyden ja hyvinvoinnin laitoksen hoitoilmoitusrekisterin Hilmo- ja Avohilmo-tietokannoista.

Tulokset osoittavat, että Suomessa akillesjänteen repeämien ja olkaluun yläosan murtumien ilmaantuvuus on lisääntynyt, kun toisaalta lonkkamurtumien ilmaantuvuus on pysynyt tasaisena. Akillesjänteen repeämiä ja olkaluun yläosan murtumia on hoidettu lisääntyvissä määrin konservatiivisesti. Reisiluun kaulan murtumien sisäinen kiinnitys on vähentynyt ja yhä useammat potilaat on hoidettu sementillisillä tekonivelratkaisuilla. Nämä muutokset hoidossa ovat linjassa vahvan lääketieteellisen tutkimusnäytön kanssa. Sarvennoisten alueen lonkkamurtumien hoidossa ydinnaulaus on pitkälti syrjäyttänyt liukuruuvi-levy implantin käytön ja leikatuissa olkaluun yläosan murtumissa olan käänteistekonivel on yleistynyt levytykseen ja osatekoniveleen nähden, mukaillen kansainvälisiä trendejä. Olkaluun yläosan murtumien alueellisia eroja tarkasteltaessa hoitolinjojen konsensus sairaanhoitopiirien välillä on ollut pääsääntöisesti hyvä.

Väitöskirjassa käsiteltävät vammat ovat erittäin yleisiä ja ne yhdessä muodostavat merkittävän sairastavuustaakan, sekä yhteiskunnallisen kuluerän. Ilmaantuvuuden kehityksen selvittäminen on tärkeää terveydenhuollon resursointia suunniteltaessa ja tarjoamamme hoidon tulisi olla mahdollisimman vakioitua ja tehokkaaksi todettua. Julkisen terveydenhuollon haasteiden myötä hoidon vaikuttavuus on noussut keskeiseksi, ajankohtaiseksi käsitteeksi. Yhteenvetona voi todeta, että tällä ortopedian saralla toteutettu hoito on valtakunnallisesti kehittynyt tutkimustiedon osoittamaan oikeaan suuntaan.

AVAINSANAT: Olkaluun yläosan murtuma, Akillesjänteen repeämä, Lonkkamurtuma, Ilmaantuvuus, Konservatiivinen hoito, Leikkaushoito, Näyttöön perustuva lääketiede

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Abbreviations

AO/OTA	Arbeitsgemeinschaft für Osteosynthesefragen/ Orthopedic Trauma Association
AP	Anterior-posterior
ATR	Achilles tendon rupture
AVN	Avascular necrosis
BMI	Body mass index
CMN	Cephalomedullary nail
CROM	Clinician Reported Outcome Measure
CS	Constant score
CT	Computed tomography
DAIR	Surgical debridement, antibiotics, and implant retention
DASH	Disabilities of the arm, shoulder and hand
DHS	Dynamic hip screw
ECM	Extracellular matrix
FAR	Finnish arthroplasty register
FNS	Femoral neck system
FOS	Functional outcome score
GH	Glenohumeral
HA	Hemiarthroplasty (hip)
IF	Internal fixation
IM	Intramedullary
ISp	Infraspinatus
MCID	Minimal clinically important difference
MRI	Magnetic resonance imaging
NHDR	National Hospital Discharge Register
PFN	Proximal femoral nail
PHF	Proximal humerus fracture
PJI	Prosthetic joint infection
PHCR	Register of Primary Health Care visits
PROM	Patient reported outcome measure
RCT	Randomized controlled trial

ROM	Range of motion
RSA	Reverse shoulder arthroplasty
SHA	Shoulder hemiarthroplasty
SHS	Sliding hip screw
SSc	Subscapularis
SSp	Supraspinatus
TM	Teres minor
THA	Total hip arthroplasty
THL	National Institute for Health and Welfare
TSA	Total shoulder arthroplasty
US	Ultrasonography
10^5	100,000 person-years

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Leino OK, Lehtimäki KK, Mäkelä K, Äärimaa V, Ekman E. Proximal humeral fractures in Finland: trends in the incidence and methods of treatment between 1997 and 2019. Bone Joint J. 2022 Jan;104-B (1):150-156. doi: 10.1302/0301-620X.104B1.BJJ-2021-0987.R1. PMID: 34969281.

II Leino O, Keskinen H, Laaksonen I, Mäkelä K, Löyttyniemi E, Ekman E. Incidence and Treatment Trends of Achilles Tendon Ruptures in Finland: A Nationwide Study. Orthop J Sports Med. 2022 Nov 8;10(11):23259671221131536. doi: 10.1177/23259671221131536. PMID: 36389616; PMCID: PMC9647260.

III Leino OK, Forsbacka N, Laaksonen IE, Mäkelä KT, Matilainen M, Ekman EM. Changing treatment of hip fractures in Finland. Arch Orthop Trauma Surg. 2024 Aug;144(8):3469-3478. doi: 10.1007/s00402-024-05462-8. Epub 2024 Aug 28. PMID: 39196404; PMCID: PMC11417085.

IV Roivas IA, Leino OK, Lehtimäki KK, Matilainen M, Ekman E. Proximal humeral fractures in Finland: regional differences in incidence and methods of treatment. J Shoulder Elbow Surg. 2025 Apr;34(4):1081-1087. doi: 10.1016/j.jse.2024.08.027. Epub 2024 Oct 11. PMID: 39396609.

1 Introduction

Proximal humerus fractures (PHFs), Achilles tendon ruptures (ATRs), and hip fractures comprise a significant proportion of the injuries treated in our health care system. Although incidence rates of these injuries have been reported globally, studies reporting national incidences over periods longer than a few years have been sparse. In Finland, the statutory national health care registries have long collected and stored data on patient encounters, making it possible to analyze and report national incidence data and trends covering several decades.

The prior lack of general consensus regarding the optimal treatment of these injuries has made them an area of interest in clinical research over the past few decades, and the volume of comparative evidence regarding their optimal treatment has thereafter grown substantially. Nonoperative treatment of most PHFs and ATRs has been proven to lead to comparable clinical outcomes without the risks associated with surgery. (Meulenkamp et al. 2021, H. H. G. Handoll et al. 2022) In femoral neck fractures, we now know that arthroplasty with cemented stems leads to fewer reoperations compared to internal fixation and use of cementless stems. (Cecilia Rogmark et al. 2014) There are global trends toward increased use of reverse shoulder arthroplasty for PHFs and use of cephalomedullary nailing for trochanteric hip fractures, following growing reports of promising clinical outcomes. (Anglen and Weinstein 2008, McLean et al. 2019, Wahlsten et al. 2021)

When this research project was being planned, information on whether these findings had been followed by changes in clinical practice during the last two decades, was not available. In contrast, the latest reports on Finnish treatment trends conflicted with the available evidence, such as increasing use of plate osteosynthesis for PHFs and of cementless stems in hip hemiarthroplasty. (T. T. Huttunen, Launonen, et al. 2012, Hongisto et al. 2014) Previous national epidemiological data on Finnish PHFs was limited to elderly females and patients treated operatively. (Kannus et al. 2017) Similarly, data on hip fracture incidence was restricted to patients aged >50, without analyses of specific fracture types or operations performed. (Kannus et al. 2018) There were no previous national studies reporting ATR incidence, although one study covered operatively treated ATRs in Finland from 1987 to 2011, during which a substantial overall increase in operative

treatment was followed by a decline in the very final years of the study. (V. Mattila et al. 2015)

The aim of this doctoral thesis was to update the incidence data on these injuries among the entire adult population of Finland using the National Hospital Discharge Register (NHDR) and, for the first time, to combine it with data from the Finnish Register of Primary Health Care visits (PHCR), as we suspected that many of these injuries were diagnosed and treated outside of hospital. Equally, our aim was to investigate how treatment methods have changed over the last two decades, including age subgrouping, with special interest in how the development of current treatment methods compare with available medical evidence.

2 Review of the Literature

2.1 The Finnish health care registers

The NHDR is maintained by Finland's National Institute for Health and Welfare (THL). Founded in 1967, the register requires mandatory data reporting from all public and private hospitals in Finland. The coverage and validity of the NHDR have been found to be good, especially in the field of orthopedic trauma. (V. M. Mattila et al. 2008, Sund 2012, T. T. Huttunen et al. 2014) The last of these referenced studies concentrated on pertrochanteric hip fractures, and concluded that diagnosis codes were placed correctly in 96% of cases when radiographs were used as reference, and procedural coding had a coverage of 98%.

The PHCR, similarly maintained by THL, receives data on all patient encounters within the public primary health care system (health care centers) in Finland, and it has been in use since 2011. Both registers belong to the larger Care Register for Health Care. The registers contain data on age, sex, domicile, external cause of injury, type of injury, primary and secondary diagnoses, type of hospital (public or private), duration of hospital stay, and possible operations performed during the hospital stay. Although data reporting is thorough, certain key variables such as sidedness of injury are not obligatorily reported to the registers.

Data obtained from these registers may be used for research purposes purposes, subject to strict legislative regulation and approval of a research permit by the relevant authorities. All data obtained from the registers are anonymized and must be filed securely by the researcher(s). The studies in this thesis are based on a study permit granted by THL prior to the entry into force of the Secondary Use Act of 2019, which aims to better enable efficient and secure processing of data in the provision of health care. The handling of research permits has since been transferred from THL to the Finnish Social and Health Data Permit Authority Findata, which operates in conjunction with THL but separately from the institute's other activities. www.thl.fi, www.findata.fi

2.2 Proximal humerus fractures

2.2.1 Relevant anatomy

The bony anatomy of the proximal humerus consists of the humeral head with its cartilaginous surface, the anatomical and surgical necks, the greater and lesser tuberosities, and the metaphysis continuing to the proximal diaphysis. The humeral head forms half of the glenohumeral (GH) joint, and the glenoid fossa of the scapula forms the other half (Fig. 1a.). The GH joint is one of the most mobile and unstable joints in the human body, comparable to a golf ball on a tee. (Thompson 2010) The stability of the GH joint arises partly from the joint capsule and glenoid labrum, which enhances stability by making the glenoid surface more concave, but more importantly from the function of the four rotator cuff muscles: the subscapularis (SSc), supraspinatus (SSp), infraspinatus (ISp), and teres minor (TM). These originate from the surface of the scapular wing and attach to the lesser and greater tuberosities of the humerus (Fig. 1b.). Moreover, the stability and function of the entire shoulder and subsequently the arm rely on the function of the five shoulder girdle muscles (trapezius, levator scapulae, rhomboideus, serratus anterior, and pectoralis minor), which attach the scapula and clavicle to the trunk. The only true articulation between the trunk and the arm is the relatively small sternoclavicular joint; all other stability is provided by soft tissue and the dynamic stabilization of the shoulder girdle muscles known as the scapulothoracic joint.

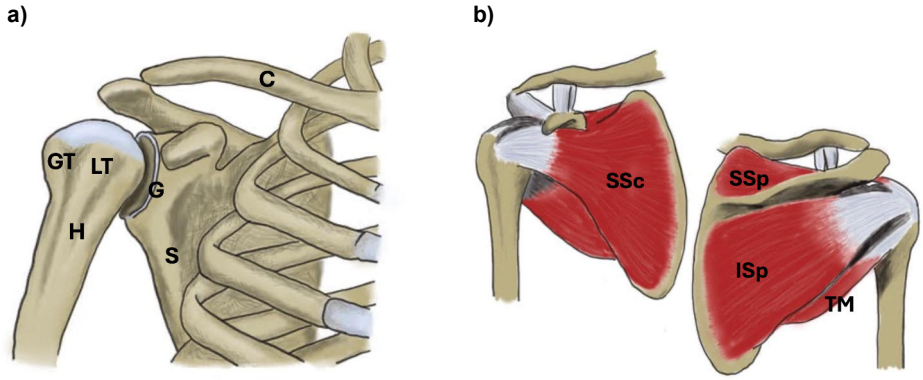


Figure 1. **a)** Bony anatomy of the shoulder. (H = Humerus, LT = Lesser tuberosity, GT = Greater tuberosity, S = Scapula, C = Clavicle, G = Glenoid fossa and labrum) **b)** Anatomy of the rotator cuff. (SSp = Supraspinatus, ISp = Infraspinatus, SSc = Subscapularis, TM = Teres Minor) Illustration by Marketta Hormia (MH).

The function and stability of the shoulder joint are compromised in PHFs due to the loss of normal alignment and stability of the tuberosities and/or humeral head in relation to the humeral shaft. The external rotators, the ISp and TM, tend to dislocate the greater tuberosity posteriorly and the SSp superiorly, while the SSc dislocates the lesser tuberosity anteriorly. If the structure of the tuberosities and surgical neck is interrupted, the humeral head may become impacted into the metaphysis, rotate into valgus or varus, or even dislocate anterior to the glenoid. Alongside this, fracture lines tend to dislocate due to the forces exerted by the muscles attached to the metaphysis and humeral shaft, especially the deltoid and pectoralis muscles (Fig. 2a). (Kiviranta and Järvinen 2012) The main blood supply to the proximal humerus is provided by the anterior and posterior circumflex arteries originating from the axillary artery (Fig. 2b). The blood supply can be interrupted in displaced fractures of the surgical neck, potentially leading to nonunion or avascular necrosis (AVN) of the humeral head.

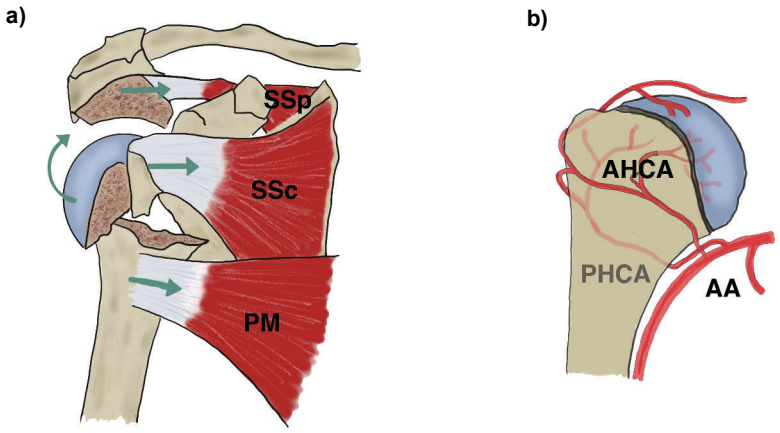


Figure 2. **a)** Dislocating forces. (SSp = Supraspinatus, SSc = Subscapularis, PM = Pectoralis major) **b)** Vascular supply of the proximal humerus. (AHCA = Anterior humeral circumflex artery, PHCA = Posterior humeral circumflex artery, AA = Axillary artery). Illustration by MH.

2.2.2 Epidemiology

2.2.2.1 Clinical significance

PHFs are common injuries seen daily in hospital emergency rooms. Like hip and wrist fractures, PHFs often result from falls from standing height and are associated with advanced age and osteoporosis. These three injuries (hip, wrist, and PHFs) are,

in descending order, the most common frailty fractures, predominantly affecting elderly females. Like hip fractures, PHFs have been shown to be a predictor of mortality. (Palvanen et al. 2006, Bergdahl et al. 2020)

2.2.2.2 Incidence rates in literature

Previous epidemiological reports of PHF incidence vary, with some presenting overall incidences and others reporting age- and sex-adjusted incidences. The reported overall PHF incidence varies between 28 and 121.9 per 100,000 person-years (10^5). Sex-adjusted incidences vary between 28 and 106 per 10^5 for men, and from 78 to 711 per 10^5 for women, depending on age grouping. (S. H. Kim, Szabo, and Marder 2012, Kannus et al. 2017, Sumrein et al. 2017, Court-Brown et al. 2018, McLean et al. 2019) Studies concentrating on elderly age groups report significantly higher incidences, for example as high as 711 per 10^5 in Australian women aged >85. (McLean et al. 2019) As Launonen noted in his doctoral thesis (A. P. Launonen 2015), overall incidences of PHFs are not directly comparable between different regions or even across different time periods within the same region, due to possible differences/temporal changes in population structures, especially among elderly individuals and in sex distribution. In countries such as Finland, with a growing elderly population, PHF rates have been predicted to rise substantially based on incidence rates available at the time. (Palvanen et al. 2006)

2.2.2.3 Previous Finnish studies

Two articles on PHF incidence based on NHDR data have been previously published. (T. T. Huttunen, et al. 2012, Kannus et al. 2017) Kannus concentrated on elderly females aged 80+ and reported that the incidence in this population increased to 304 per 10^5 in 1995, remaining stable thereafter until 2015. Huttunen concentrated on operatively treated PHFs and discovered that the incidence of such treatments increased markedly between 1997 and 2009. A third Finnish article on PHF incidence (A. P. Launonen et al. 2015) was based on a cohort of patients treated in a mid-sized town and reported an overall, unadjusted, incidence of 82 per 10^5, and sex adjusted incidences of 114 vs. 47 per 10^5 for females vs. males, respectively. The mean incidence during the five-year period increased significantly with age, rising from 39 per 10^5 in females aged 40–49 to 379 per 10^5 in females aged 80+, with a corresponding increase in males from 31 to 232 per 10^5 in the same age groups.

2.2.3 Imaging

Basic radiographs of the shoulder form the basis of PHF diagnostics. A shoulder trauma radiograph series consists of an anterior-posterior (AP) projection and scapular Y or lateral projection. An axillary projection is often helpful for deciphering the position of the humeral head in relation to the glenoid. (Fig. 3.)

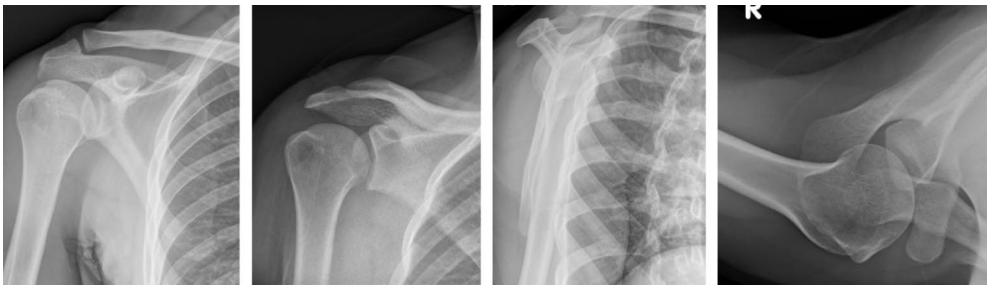


Figure 3. AP, AP oblique, Y, and axillary projections in a trauma radiograph series of a normal shoulder. Source: Turku University Hospital radiology archive.

Computed tomography (CT) scans are currently widely available and a helpful tool in evaluating the exact morphology of complex and displaced PHFs when the positions of the tuberosities or the humeral head are uncertain, or a possible head-split is suspected based on plain radiographs. The most important role of CT is in preoperative planning. Magnetic resonance imaging (MRI) is seldom indicated in PHFs and is mainly used for assessing the rotator cuff when no bony injury is detectable on radiographs.

2.2.4 Classifications

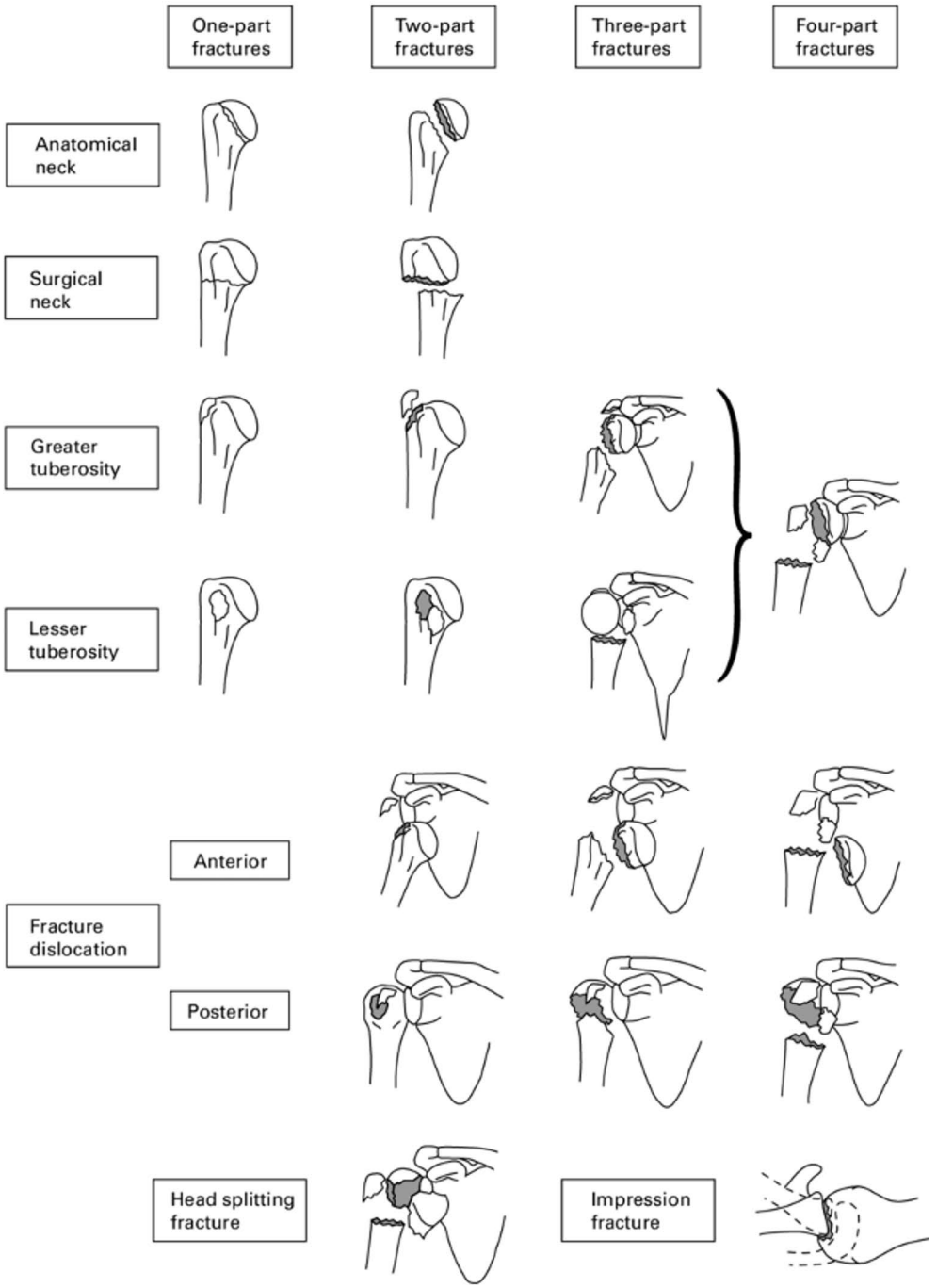
2.2.4.1 The Neer classification

Neer developed a classification system for PHFs in the 1960s, based on the location of the main fracture line and the number of displaced fragments (dislocation between fragments >1 cm or angulation >45°) (Front and Neer, 1970) (Fig. 4a). This four-part model of PHFs has been shown to adequately describe the pathoanatomy of the fracture and enable grouping of similar fracture patterns in a matter that predicts outcome. (Chelli et al. 2022)

2.2.4.2 The AO/OTA classification

Another widely used classification is the AO/OTA (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association) system, which divides all fractures into subgroups based on whether the fracture is extra-articular unifocal (A), extra-articular bifocal (B), or intra-articular (C). Each group is further subdivided based on the degree of displacement, ranging from nondisplaced to severely displaced or dislocated. (Meinberg et al. 2018) (Fig. 4b)

a)


One-part fractures
Two-part fractures
Three-part fractures
Four-part fractures
Anatomical neck
Surgical neck
Greater tuberosity
Lesser tuberosity
Fracture dislocation
Anterior
Posterior
Head splitting fracture
Impression fracture

b)

Figure 4. **a)** The Neer classification; **b)** AO/OTA classification. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.surgeryreference.aofoundation.org.

2.2.4.3 Comparison of classification systems

The purpose of classification systems for fractures is to enable clinicians and researchers to easily and repeatably discuss specific fracture morphologies and to propose and test morphology-specific treatments. Of the two systems above, the Neer classification has been considered more reliable in terms of inter-observer agreement. (Majed et al. 2011) Despite this, even specialized shoulder surgeons disagreed with article authors in a third of the cases when deciphering the Neer classification in de-identified radiographs of PHFs in the authors' manuscripts. (Chelli et al. 2022) An optimal classification system is thought to be one that guides

clinical treatment by differentiating which fractures can be treated nonoperatively and which ones warrant a specific surgical procedure. In clinical practice, the distinction between a two-part fracture of the surgical neck from a multi fragmented fracture is important. The former has generally been considered a candidate for osteosynthesis, whereas the latter may in some cases warrant treatment with arthroplasty. This distinction has been shown to be quite reliable in the eyes of experienced shoulder surgeons. (B. O. Sumrein et al. 2018)

2.2.5 Nonoperative treatment

2.2.5.1 Immobilization

Nonoperative treatment of PHFs generally consists of initial immobilization in a sling that supports the elbow and forearm against the chest or abdomen. Different types of sling are used, ranging from a simple collar and cuff to more constrained and supported constructs with swaths and braces around the chest. No specific sling type has been shown to be superior, nor is it generally possible to meaningfully reduce the degree of fracture displacement using particular postures (i.e., shoulder abduction or external rotation). There is slight evidence suggesting a possible benefit of early mobilization compared to delayed mobilization in nonoperatively treated PHFs. (H. H. G. Handoll et al. 2022) (Fig. 5.)

Figure 5. Different types of shoulder slings/braces. Mosaic of copyright-free images. Source: www.google.com

2.2.5.2 Rehabilitation

The duration of initial immobilization should be as short as possible, as it is mainly intended as pain relief. Immediate mobilization of unaffected joints is important, and passive early mobilization of the affected joint is recommended from 2–3 weeks, starting with passive pendulum movements followed by assisted movements with range of motion up to the shoulder level. Usually, progressive resistance exercises are introduced from week 6, with progression as pain permits. Radiographs are usually obtained before starting resistance exercises to confirm radiological evidence of ongoing fracture consolidation. The role of physiotherapy is considered crucial in

rehabilitation, although the evidence supporting this assumption, for instance evidence comparing self-exercises versus conventional physiotherapy, and tele-rehabilitation versus face-to-face rehabilitation, is of very low certainty. (H. H. G. Handoll et al. 2022, Østergaard et al. 2024)

2.2.5.3 Underlying principles and biology of fracture healing

The duration of immobilization and the progression of mobilization and exercises are based on the healing and stabilization of bone following a fracture. Following the initial inflammatory phase induced by the fracture hematoma and inflammatory response of the first 1–3 weeks, the reparative phase begins. During this phase, mesenchymal stem cells differentiate into chondroblasts and osteoblasts, forming a soft elastic callus of fibrous tissue and cartilage over the fracture line. This process provides partial stability of the fracture, allowing resistance-free movement during the following few weeks. Osteoblasts continue to produce woven bone within the callus, leading to additional stability and stiffness through ossification of the callus. Ossification is partially stimulated by micromovement and the stress caused by passive and assisted movements of the limb. As ossification progresses and the reparative phase is followed by the remodellation phase starting roughly 1.5 months following the fracture, normal stressing of the bone stimulates the differentiation of woven bone into normal lamellar bone by modulating osteoblast and osteoclast activity. (Thompson 2010, Li and Stocum 2014) (Fig. 6.)

Figure 6. Stages of fracture healing. (From left to right: Hematoma & inflammation, Cellular differentiation, Reparative phase with woven bone formation, and Remodellation to lamellar bone) Illustration by MH.

2.2.5.4 Indications

Nondisplaced or minimally displaced PHFs tend to heal well without surgical interventions. (Maier et al. 2014, Jawa and Burnikel 2016, H. H. G. Handoll et al.

2022) In displaced fractures, nonoperative treatment is generally indicated for patients who are not surgical candidates. In addition to fracture morphology, several other factors influencing the choice of nonoperative treatment include patient age, general medical condition, concurrent injuries, hand dominance, and bone quality.

2.2.6 Operative treatment

2.2.6.1 Internal fixation

2.2.6.1.1 Indications

In general, relatively young patients with good overall health and bone quality, who sustain Neer two-, three-, or four-part fractures, or greater tuberosity fractures with more than 5 mm of dislocation, are treated with internal fixation (IF). IF is performed using an appropriate implant in accordance with AO/OTA principles of fracture management. As PHFs are intra-articular or periarticular fractures, the aim is to achieve anatomical reduction and absolute stability of the fracture. (Buckley et al. 2018)

2.2.6.1.2 Choice of implant

IF is most often performed with locking plate fixation. Modern locking plates, such as the Philos plate manufactured by Synthes, have revolutionized fracture treatment since their introduction in the early 2000s (Figs. 7a, 8). These plates have been associated with superior stability and fewer complications compared to previous generation conventional plating (so-called T-plates), closed reduction and percutaneous pinning, or intramedullary nailing of the proximal humerus; locking plates, through their screw design, form a 3D angular stable construct with superior resistance to torque and shear stress compared to intramedullary nails, pins, or conventional plates. (Haidukewych 2004) Due to this angular stability, locking plates have been recommended for the treatment of fractures in osteoporotic bone, as the stability of the construct is less dependent on the integrity of the bone with which the screws engage. This may explain the observed increase in use of operative treatment for PHFs during the first decade of this century. (T. T. Huttunen et al. 2012) Next-generation intramedullary nails have since been introduced, featuring multiple variably angled proximal locking screws that provide angular stability comparable to that of locking plates (Fig 7b).

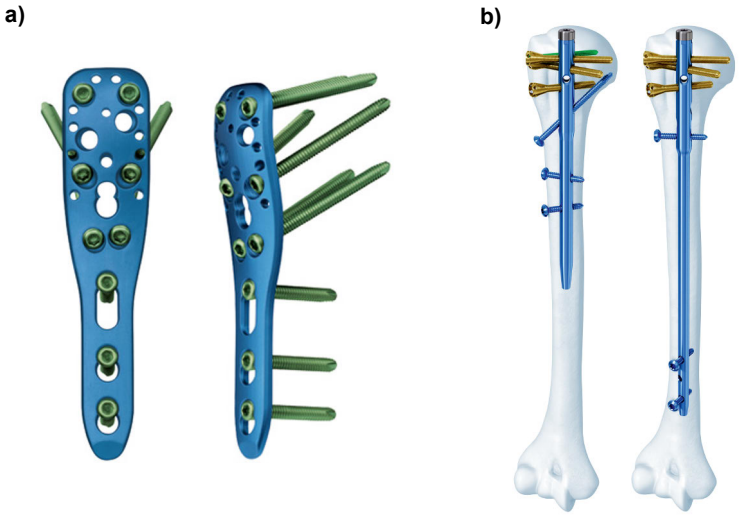


Figure 7. **a)** The Philos plate by Synthes; **b)** The Multiloc nail by Synthes. Copyright DePuy Synthes, Switzerland. Source: Trauma innovation, jnjmedtech.com

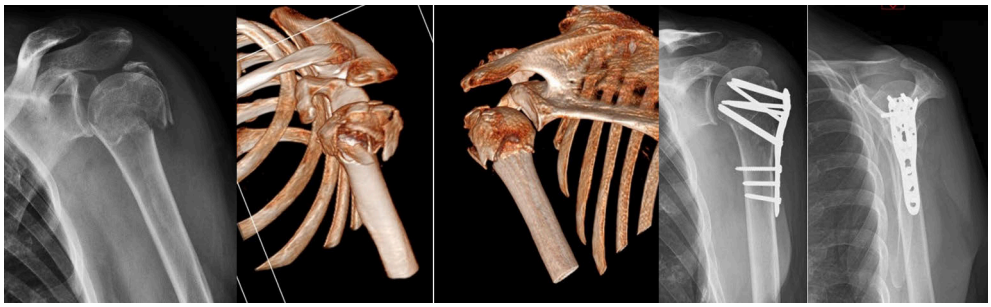


Figure 8. Pre- and post-operative radiographs of a 57-year-old man with a plated PHF. Author's own radiograph archive.

2.2.6.1.3 Complications

The goal of IF is to achieve stable contact and, ideally, compression between anatomically reduced fracture fragments. In extremely comminuted fractures, this may be hard to achieve; without the angular stable constructs described above, loss of reduction in the early postoperative weeks is possible, potentially leading to secondary displacement. This, or an initial malreduction, can lead to malunion or nonunion of the fracture. Malunion of the tuberosities may cause dysfunction of the rotator cuff, and varus misalignment between the humeral head and shaft can further restrict movement restriction through mechanical impingement against the acromion. In contrast, valgus misalignment is better tolerated. (Maier et al. 2014) These characteristics of malunion are mechanistic concepts that do not necessarily have clinical relevance in the context of elderly patients. Nonunion can present as

persistent pain, muscle weakness, and restricted motion following internal fixation. Nonunion is defined as doubtful bony bridging between fracture fragments on a CT scan. (Hak et al. 2014) Severely displaced two-part fractures of the surgical neck are at particular risk of nonunion and AVN, due to distruption of the circumflex arteries. (Maier et al. 2014)

Differentiating the causes of persistent symptoms following a PHF, such as delayed union, malunion, or something else, is challenging, as some degree of capsulitis with associated stiffness and pain is always triggered by shoulder trauma. Overall, rehabilitation after PHFs is a lengthy process. Plate breakage or cut-out is usually a sign of nonunion or AVN rather than a hardware-related issue. Nonetheless, hardware-related complications are still possible: proper positioning of implants is important, as plates or screws placed too cranially may impinge on or interfere with the rotator cuff, and screws engaging the articular surface can cause gradual destruction of the GH joint. Screws perforating the joint are a common complication after plating and require removal during revision surgery. There are reports of reoperation rates due to screw perforation ranging from 14% to 19%. (Maier et al. 2014) Surgical site infections are classified as superficial or deep, with the latter requiring surgical debridement and possible removal of hardware.

A recent meta-analysis (Oldrini et al. 2022) pooled available data on complications following IF of PHFs using the PHILOS plate. The overall complication rate was 23.8% and the overall reoperation rate 10.5%. The most important complications leading to reoperation, in order of frequency, were: cut-out (rate 2.2, 13.4% of reoperations), AVN (1.9, 11.9%), subacromial impingement (1.7, 10.3%), other failure (0.6, 3.5%), deep infection (0.4, 2.5%) non-union (0.3, 2.0%), and other fixation loss (1.8, 6.3%). The nerve injury rate was 0.7 (2.4% of all complications).

2.2.6.2 Arthroplasty

2.2.6.2.1 Indications

In cases of three- or four-part fractures in elderly patients with poor bone quality, arthroplasty is preferrable to IF if surgical treatment is deemed necessary. This is due to the high the risk of AVN, nonunion, and hardware complications (Gavaskar et al. 2022). Younger patients with severely comminuted fractures involving significant destruction of the humeral head are rare, and IF is usually attempted first; arthroplasty is considered a salvage option if this fails.

2.2.6.2.2 Implant types

Shoulder hemiarthroplasty (SHA), in which the humeral head is replaced with a prosthetic component, has been used in PHFs and shoulder osteoarthritis since the 1950s (Neer, Brown, and McLaughlin 1953, Neer 1955, Brand 2011) (Figs. 9a, 11.). SHA relies on the integrity of the rotator cuff to function. The challenge of rotator cuff deficiency leading to superior humeral head migration prompted the development of total shoulder arthroplasty (TSA) in the 1970s using constrained designs or reversed anatomy designs. This ultimately led to the development of the first contemporary reverse shoulder arthroplasty (RSA) design by Grammont in 1985. (Flatow and Harrison 2011) (Fig. 9b, 10.) In RSA, the ball and socket anatomy of the GH joint are reversed, leading to the displacement of the center of rotation medially and distally. The torque lever arm of the deltoid muscle is changed making it able to take over movement normally provided by a functioning rotator cuff. RSA has inherent stability compared to an anatomic design, provided by the relative lowering of the humerus and tensioning of the deltoid muscle and the compressive forces from the deltoid's action on the bearing surface. It also has a larger bearing surface with increased concavity and complementing convexity compared to an anatomic design. RSA has since become the standard surgical treatment for cuff tear arthropathy. However, in PHF cases, the use of SHA has continued into recent years. In fracture-related SHA, prosthetic function depends not only on the integrity of the rotator cuff, but also on the ossification of the tuberosities (to which the cuff tendons attach) with the humeral stem. In clinical practice, tuberosity ossification has proven to be unpredictable, and as most patients are elderly, underlying rotator cuff deficiency is often present. In comparison, RSA is inherently more stable due to its design, and its function is less dependent on tuberosity ossification. (Boileau et al. 2006, Stechel et al. 2010)

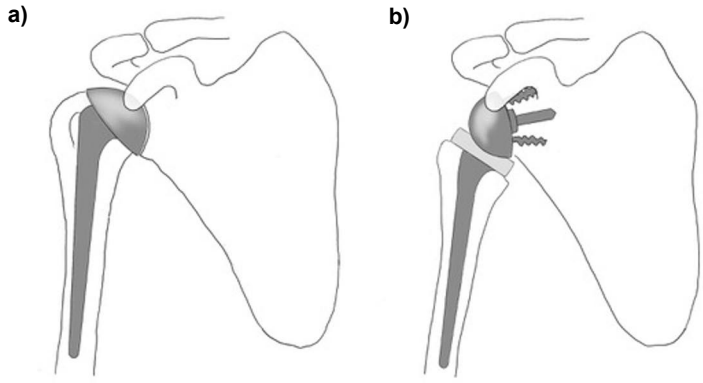


Figure 9. Conceptual illustration **a)** Shoulder hemiarthroplasty; **b)** Reverse shoulder arthroplasty. Illustration by MH.

Figure 10. Pre- and post-operative radiographs of a 73-year-old woman with a fracture RSA. Author's own radiograph archive.

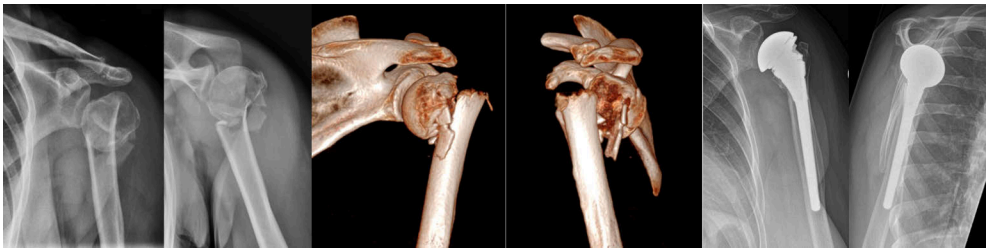


Figure 11. Pre- and post-operative radiographs of a 53-year-old man with a fracture SHA. Courtesy of Dr. Juha Kukkonen.

2.2.6.2.3 Complications and considerations

Arthroplasty of a large joint is always a major surgerical procedure and carries inherent risks. The most common and feared complication is prosthetic joint infection (PJI). Although infection rates following shoulder arthroplasty are generally low, RSA performed for various indications has been shown to carry a higher risk of PJI compared to anatomical TSA and SHA. Other risk factors associated with elevated PJI risk are male sex, previous shoulder surgery, and younger age (<75 years). (Kunutsor et al. 2020) A study based on the Nordic Arthroplasty Register Association (NARA) reported a 10-year cumulative revision rate due to infection of 1.4% for all shoulder arthroplasties, 3.1% for RSA, and 8.0% for male RSA patients. When assessing indications for surgery, fracture RSA had a slightly elevated relative PJI risk of 1.60 (95% confidence interval (CI) 1.07 to 2.38), and RSA for fracture sequelae carried a higher risk of 2.96 (CI 1.81 to 4.84). (Moeini et al. 2019)

On an individual level, an infection is a devastating complication requiring one or more revision surgeries and prolonged courses of antibiotics. An early postoperative or acute hematogenic PJI can often be managed with urgent surgical debridement, antibiotics, and implant retention (DAIR). Still, if this fails, or in cases of late/chronic infections, removal of the prosthesis is the only course of action. A new prosthesis may be implanted during a later procedure (two-stage revision) or

during the same surgery (one-stage revision), with current evidence supporting the latter as often adequate and yielding better functional outcomes. (Belay et al. 2020) Obesity, diabetes, and other risk factors known to predispose patients to infection must be considered when evaluating a patient for arthroplasty. Elective arthroplasty patients typically undergo dental health screenings and have time to optimize any chronic conditions, such as diabetes, prior to surgery. This is not possible in acute PHF cases.

Another complication of shoulder arthroplasty is dislocation, which may arise due to suboptimal implantation of the components. A pooled dislocation rate of 1–5% following primary RSA for any indication has been reported in recent meta-analyses. RSA due to PHF sequelae carries a higher risk of dislocation with a collective dislocation rate of 40% (16 out of 40 patients spanning three studies). Other risk factors associated with instability are SSc deficiency, younger age, male sex, and a BMI over 30 (Loucas et al. 2022, Olson et al. 2022). Patients with neurological conditions such as Parkinson's disease are also at risk of developing instability and are considered by many surgeons to be contraindicated for RSA. Some patients with a PHF suffer an acute axillary nerve injury and need to be identified, as RSA depends on the function of the deltoid muscle. These nerve injuries are often neuropraxic and heal over time, making RSA a viable option later if difficult symptoms persist.

Aseptic loosening of prosthetic components is a late complication and often a sign of latent infection. Cutibacterium acnes (formerly Propionibacterium acnes) is a low-virulence, often latent pathogen that can cause acute or chronic infection in a shoulder endoprosthesis. Diagnosing PJI in the shoulder is clinically challenging due to the frequent absence of classical signs of infection, but guidance from the 2018 Consensus Meeting on Orthopedic Infections helps in assessing suspected infection and determining optimal treatment. (Garrigues et al. 2019) PHF patients are typically elderly and have comorbid conditions, making them especially vulnerable to infections. When evaluating an elderly PHF patient for arthroplasty, in addition to the indications mentioned above, the clinician must assess the patient's capacity to overcome potential complications and thoroughly discuss them with the patient.

2.2.7 Current evidence in treatment of PHFs

In 2001, a Cochrane Database systematic review (Gibson, Handoll, and Madhok 2001) found that scientific evidence regarding the optimal treatment of PHFs was sparse, despite the rapidly increasing use of locking plate fixation. Since then, the topic has become a focus of significant interest in clinical research. Randomized controlled trials (RCTs) have shown no benefit of operative treatment of displaced PHFs with locking plates compared to nonoperative treatment in the elderly, based

on functional outcome scores. (Olerud et al. 2011b, Fjalestad et al. 2012, Rangan et al. 2015, H H Handoll et al. 2017, A. P. Launonen et al. 2019, A. P. Launonen et al. 2023, Gracitelli et al. 2025)

Similarly, comparison of SHA with nonoperative treatment has not demonstrated significant advantages in favor of SHA. (Olerud et al. 2011a, Boons et al. 2012, A. P. Launonen et al. 2023) More recent studies comparing SHA and RSA have found that RSA delivers more consistent clinical outcomes and less need for revision surgery. (Cuff and Pupello 2013, Sebastiá-Forcada et al. 2014, Vall et al. 2022) The use of RSA for various indications has increased significantly in recent years, according to implant registry data. (Harjula et al. 2018, McLean et al. 2019) In the Nordic countries, RSA numbers for PHFs have followed a similar upward trend. (Lehtimäki et al. 2020) As noted by Brorson, what is needed is not more studies, but better studies comparing RSA with nonoperative treatment. (Brorson 2022) The level of evidence remains low, especially concerning the widespread use of RSA for PHFs. (H. H. G. Handoll et al. 2022)

2.3 Achilles tendon ruptures

2.3.1 Relevant anatomy

The primary muscles of the posterior compartment of the calf are the soleus and gastrocnemius, both of which perform plantar flexion of the foot. The soleus originates from the posterior surface of the proximal fibula and the soleal line of the tibia, while the gastrocnemius originates from the medial and lateral condyles of the femur. These two muscles share a common insertion on the calcaneus through the calcaneal or Achilles tendon (Fig. 12a). The tendon divides proximally into the anterior gastrocnemius aponeurosis and the posterior soleus aponeurosis, which together form the musculotendinous junctions (Fig. 12b). The Achilles tendon is the thickest tendon in the human body. It is twisted in such a way that, at its distal attachment, tendon fibers from the soleus aponeurosis insert predominantly medially, while fibers from the gastrocnemius aponeurosis insert laterally. (Thompson 2010) The tendon is thinnest approximately four to five centimeters proximal to its insertion, which is the area most prone to rupture. This area is also the least vascularized, supplied primarily by the peroneal artery, whereas the proximal and distal areas are supplied by the posterior tibial artery (Fig. 12c). The calf muscles are innervated by the tibial nerve, but the most important neural structure to consider during surgical exposure is the sural nerve, which lies superficial to the tendon and is at risk of injury.

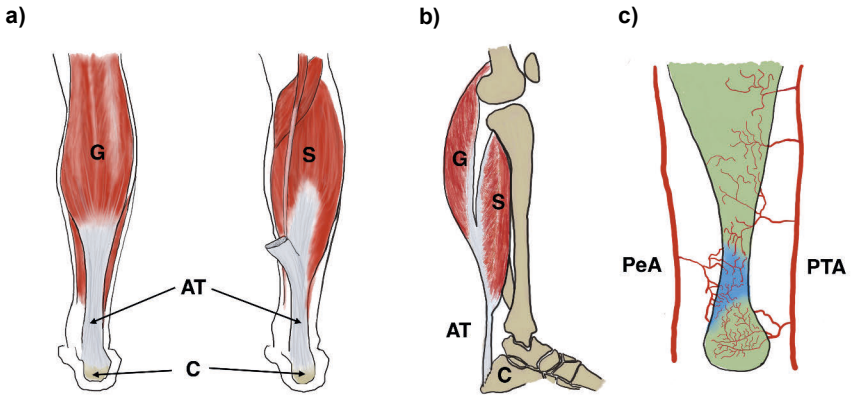


Figure 12. a) Dorsal anatomy of the calf, showing the muscles of the superficial dorsal compartment. (S= Soleus, G = Gastrocnemius, AT = Achilles tendon, C = Calcaneus) **b)** Sagittal view. **c)** Vascular supply. (PeA = Peroneal artery, PTA = Posterior tibial artery) Illustration by MH.

2.3.2 Trauma mechanism and pathoanatomy

ATRs have classically been associated with predominantly middle-aged males participating in recreational sports. The typical trauma mechanism involves a forceful exertion with plantar flexion of the foot, resulting in rupture of the tendon. Patients often describe an audible pop and/or a sensation of something hitting the calf. As with tendon ruptures in general, the presence of pre-existing tendinosis or underlying tendon pathology is considered a prerequisite for tendon failure due to strain in the absence of high-energy trauma. Tendinosis is a chronic pathology of tendon tissue, thought to result from repetitive strain causing microtrauma and a sustained inflammatory response over a long period of time. (Darrieutort-Laffite et al. 2024) This inflammatory response does not result in adequate healing of the tendon (see next chapter) but rather leads to replacement of the normal well-organized type I collagen-rich extracellular matrix (ECM) with type III collagen and scar tissue. This results in thickening, altered elasticity, and diminished tensile strength, making the tendon more prone to rupture from loading.

2.3.2.1 Principles of tendon healing

A rupture in tendon tissue induces a biological response comparable to that seen in bone fractures. The process begins with an acute 1–5-day inflammatory phase, during which a blood clot forms and necrotic tissue is cleared. This is followed by a proliferative phase of up to eight weeks, during which fibroblasts are activated to produce type III collagen and other components of the ECM, forming a scar between the tendon ends. At this point, controlled mechanical loading, such as early passive

or assisted motion, stimulates fibroblast activity; however, excessive stress may disrupt the healing process. This is followed by the remodeling phase, which extends over several months. During this phase, the ECM reorganizes, becomes less cellular and vascular, and type III collagen is replaced by type I collagen, which has greater tensile strength. Progressive loading promotes ECM reorganization and gain of tensile strength. (Kiviranta and Järvinen 2012, Darrieutort-Laffite et al. 2024)

2.3.3 Epidemiology

The incidence of ATRs has been increasing globally since the turn of the century. (Erickson et al. 2014, T. Huttunen et al. 2014, Lantto et al. 2015, Ganestam et al. 2016, Sheth et al. 2017) Reports also suggest that the classical patient profile has become more heterogeneous, with a notable increase in ruptures among elderly patients. This may reflect increased participation in sporting activities among the elderly population. Previously published incidence rates are discussed in greater detail in the discussion section of the thesis.

2.3.4 Diagnostics

An ATR is typically diagnosed clinically, based on a typical patient history and physical examination. A palpable or even visible gap in the tendon may be present. The Thompson test is used to assess for a complete ATR by squeezing the calf muscles with the knee flexed to 90° (patient supine or sitting). In an intact tendon, squeezing causes contraction and plantarflexion of the foot, indicating a negative result. A positive Thompson test indicates a complete ATR, and further diagnostic testing or imaging is seldom required. (Kiviranta and Järvinen 2012) However, in cases with atypical history and findings, imaging with either ultrasonography (US) or MRI may be helpful.

2.3.5 Nonoperative treatment

Nonoperative treatment of an ATR is thought to rely on achieving initial apposition of the torn tendon ends to enable adequate scarring across the rupture. This is achieved by positioning and immobilizing the foot in roughly 30° of plantar flexion, known as the equinus position. Traditionally, an equinus cast was applied for the initial weeks of treatment, followed by a cast in a neutral position for up to five weeks or more post-injury, with prolonged limited weight-bearing. Contemporary nonoperative treatment is mainly performed with an ankle-foot orthosis, permitting early controlled ankle mobilization within a controlled safe range of motion (ROM) and protected weight-bearing; this reflects the growing understanding of tendon healing principles. (Kiviranta and Järvinen 2012) Several commercial ankle-foot

orthoses are available (Fig. 13). Modern orthoses are often air-filled to ensure adequate fit and stability, and special sole designs have been developed to enable as normal a gait as possible. Some orthoses use removable heel wedges to allow a gradual decrease from equinus to neutral position as healing progresses. Others rely on adjustable ROM settings that control the degree of dorsiflexion and permit early free plantarflexion.

A concern in nonoperative treatment is to prevent elongation of the tendon and exclude the presence of a clear palpable gap between the torn tendon ends. Ruptures that initially present with a clear gap between the tendon ends in equinus (either palpable or confirmed by US) have been considered unsuitable for nonoperative treatment. It should be noted that, as the tendon typically fails through loading (fraying rather than a clean laceration), distinguishing the tendon ends from the surrounding hematoma can be challenging on US, making accurate assessment of the gap length difficult.

Several examples of contemporary nonoperative treatment protocols have been published. (Hutchison et al. 2015, Costa et al. 2020) Generally, the first two weeks post-injury are restricted to 30° plantarflexion with partial weight bearing or weight bearing as tolerated; the following two weeks to 15–30° plantarflexion with weight bearing as tolerated; and the final two weeks to 0–30° plantarflexion using an orthosis. Physiotherapy begins with strengthening of the proximal muscles, followed by mobilization exercises within the permitted ROM, isometric muscle strengthening and, as healing progresses, isotonic exercises with progression based on pain tolerance. As this active rehabilitation continues and time has passed well to the remodeling phase of tendon healing, performing these excercises relatively painlessly, with good coordination and strength comparable to the uninjured side are considered essential before returning to high demant or contact sports (so-called return to play criteria).

Figure 13. Equinus cast (left) and examples of different ankle foot orthoses used to treat ATRs. Mosaic of copyright-free images. Source: www.google.com

2.3.6 Operative treatment

Operative treatment of an ATR is performed by suturing the torn tendon ends together. The role of surgery is essentially to bring together the torn tendon ends and bridge the gap between them. Surgery is followed by a rehabilitation and immobilization protocol similar to that used in nonoperative treatment. Surgery is typically performed through a longitudinal incision placed dorsally directly over the tendon path or slightly medially to avoid damaging the sural nerve. Mini-invasive techniques have been described involving small incisions through which the torn tendon ends are retrieved for suturing, and even arthroscopic procedures have been developed. (Erickson et al. 2015, Deng et al. 2017) Common suture techniques include the Bunnel, Kessler, or Krackow bundle. The torn peritenon should be reconstructed around the sutured tendon, and the wound meticulously closed. Operative treatment is generally followed with a similar rehabilitation protocol as described in the previous chapter.

2.3.7 Complications

Complications following treatment of ATRs can be roughly divided in two categories: re-rupture following nonoperative treatment and surgery-related complications following operative treatment.

Reruptures following nonoperative treatment are an issue, but with the evolution of nonoperative treatment protocols, re-rupture rates are significantly lower. Elongation of the tendon during healing can be considered a complication of ATRs, previously mostly associated to those treated nonoperatively. Elongation may lead to diminished strength in plantar flexion of the foot, something that can be troublesome for elite athletes or those partaking in high-demand sports, which has been used as a reasoning for operative treatment. Current studies have shown that elongation is in fact an issue affecting both nonoperatively and operatively treated ATRs. (Cramer et al. 2021, Kosiol et al. 2023)

Surgical site infections and wound healing problems following operative treatment are common. (Meulenkamp et al. 2021, Seow et al. 2021) Factors influencing this risk should always be considered in patient selection, such as smoking, cooperativeness and comorbidities like diabetes, vascular conditions, and medications affecting wound healing. Sural nerve injury is a rarer complication of surgery. Although risk of wound-related complications may be lower with mini-invasive techniques, the sural nerve may be at greater risk without proper visualization and dissection. All in all, thorough communication of these risks and their consequences is key when discussing treatment options with the patient.

2.3.8 Current evidence

The optimal treatment method for ATRs has been widely studied in recent years. Results from numerous RCTs comparing operative and nonoperative treatment have been pooled into several meta-analyses (Soroceanu et al. 2012, Van der Eng et al. 2013, Erickson et al. 2015, Deng et al. 2017, Ochen et al. 2019, Reda et al. 2020, Meulenkamp et al. 2021, Seow et al. 2021). Nonoperative treatment is associated with a greater risk of re-rupture (risk ratio ranging from 0.27 to 0.43 in favor of surgery (Ochen et al. 2019, Seow et al. 2021)), whereas operative treatment is associated with surgery-related complications (overall complication risk ratio ranging from 2.76 to 6.06 in favor of nonoperative treatment (Ochen et al. 2019, Seow et al. 2021)), especially infections (risk ratio ranging from 3.43 to 6.69 (Reda et al. 2020, Seow et al. 2021)), thromboembolic events, and sural nerve damage. However, unlike the risks associated with open surgery, the risk of re-rupture has been disputed, and some conflicting interpretations have been presented in the meta-analyses mentioned above.

Operative treatment was previously considered superior to nonoperative treatment, as re-ruptures were a frequent concern with nonoperative care (Jones, Khan, and Carey Smith 2012). Nonoperative treatment, historically comprised of rigid cast immobilization and limited weight-bearing, has evolved alongside advancing knowledge of tendon healing principles into a functional rehabilitation strategy, with early protected ROM and early weight-bearing. In their RCT comparing operative and functional nonoperative treatment of ATRs, Willits et al. (Willits et al. 2010) found no difference in re-rupture risk in favor of operative treatment. Wallace, Heyes, and Michal (Wallace, Heyes, and Michael 2011) published similar findings in their RCT the following year.

A 2012 meta-analysis pointed out the advantage of early ROM, showing that nonoperative treatment incorporating this approach carried no greater risk of re-rupture compared with operative treatment. (Soroceanu et al. 2012) Another 2013 meta-analysis concluded that rehabilitation with early weight-bearing led to lower re-rupture rates, with no difference between operatively and nonoperatively treated patients. (Van der Eng et al. 2013) Some later meta-analyses interpreted the evidence on re-rupture rates in favor of operative treatment, highlighting the advantages of minimally invasive techniques and the potential for earlier return to work compared with nonoperative care. (Erickson et al. 2015, Deng et al. 2017, Reda et al. 2020) Others, on the other hand, have found the difference in re-rupture risk between treatment groups to be small compared with the greater overall complication risk associated with surgery (1.6% vs. 3.3%, respectively). These findings support the view that when contemporary protocols are used (excluding prolonged cast immobilization), the risk of re-rupture is probably no different between treatment groups. (Ochen et al. 2019, Meulenkamp et al. 2021) The

importance of careful individualized risk-benefit assessment between treatment options alongside shared decision-making has been highlighted in the two studies cited above. It should be noted that all these meta-analyses are based on RCTs that are quite heterogeneous in their methodology and rehabilitation protocols for nonoperative and operative treatments. A large portion of the RCTs date back to the first decade of the twenty-first century or earlier, when functional nonoperative treatment had not yet become mainstream. Detailed and validated functional nonoperative treatment protocols have later been described, such as those used in the UK-based SMART protocol (Hutchison et al. 2015) and the UKSTAR multicenter RCT (Costa et al. 2020).

2.4 Hip fractures

2.4.1 Relevant anatomy

The bony anatomy of the proximal femur consists of the femoral head, femoral neck, the medial calcar area at the base of the neck and lesser trochanter, the lesser and greater trochanters, and the metaphysis extending into the proximal diaphysis. The femoral neck–shaft angle, or inclination, ranges from 125° to 135°, and the femoral neck has an anteversion angle of 8–14° relative to the axis of the femoral condyles at the knee. The femoral head is roughly two-thirds spherical and is covered by hyaline cartilage. It articulates with the cartilage-surfaced acetabulum to form the hip joint, which is the largest ball-and-socket joint in the human body. (Thompson 2010) (Fig. 14a).

The hip joint allows rotational movement in three planes, with the center of the femoral head serving as the pivot point: flexion–extension, abduction–adduction, and internal and external rotation. The rim of the acetabulum is lined with a fibrocartilaginous labrum, analogous to the glenoid fossa of the shoulder joint. In the hip, the labrum extends beyond the equator of the ball joint to provide extra stability. Due to this deep, enclosed socket structure, and especially the tough and tight joint capsule, the hip is inherently a very stable joint. The joint capsule originates from the edges of the acetabulum, the labrum, and the transverse ligament of the acetabular notch. It attaches to the femur anteriorly along the intertrochanteric line, superiorly and inferiorly at the base of the neck, and posteriorly at the intertrochanteric crest. The anterior portion of the capsule is taut and thick, whereas the inferior and posterior portions are thin and loose. (Fig. 14b)

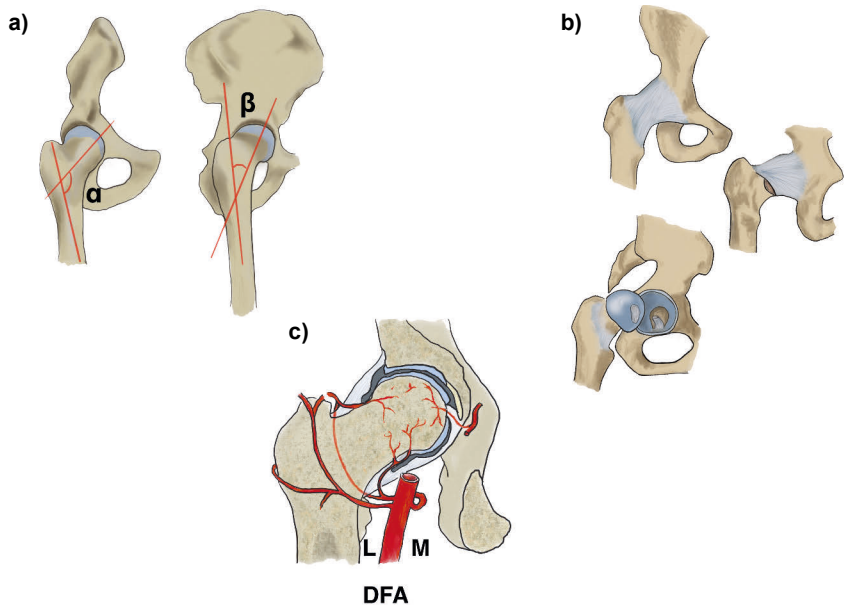


Figure 14. a) Bony anatomy of the proximal femur and hip joint. (α = inclination angle, β = anteversion angle) **b)** Joint capsule, acetabular fossa and labrum. **c)** Vascular supply of the proximal femur. (DFA = Deep Femoral Artery, M = Medial circumflex artery, L = Lateral circumflex artery) Illustration by MH.

In hip fractures, the joint capsule serves as an anatomical boundary distignuising intracapsular fractures, which involve the femoral neck, from extracapsular fractures affecting the trochanteric region of the femur. The blood supply to the proximal femur is provided by the medial (posterior) and lateral (anterior) circumflex arteries, which originate from the deep femoral artery. The ligamentum teres, connecting the femoral head to the acetabular fossa, contains an artery supplying the femoral head, but its role is mainly limited to adolescence. In adults, the circulation of the femoral head depends on the circumflex arteries, as the femoral neck lacks a periosteal blood supply. (Fig. 14c) These anatomical features explain the relatively poor ossification potential and AVN risk associated with femoral neck fractures compared to trochanteric fractures.

2.4.2 Epidemiology

2.4.2.1 Clinical significance

As described in the previous chapter, hip fractures are mainly fragility fractures that affect the elderly population. Patients are typically in declining health and physical condition. Sustaining a hip fracture delivers a crippling blow, leading to further

incapacity and loss of independence in activities of daily living. Rehabilitation is a lengthy and strenuous process, and patients are at high risk of institutionalization or death during recovery. (Karampampa et al. 2015, Dyer et al. 2016, Katsoulis et al. 2017) The socioeconomic impact of hip fractures is significant, and every effort should be made to enable patients to return to their preceding level of independence. Another important objective is to ensure that treatment is as optimal as possible, avoiding complications, especially those leading to reoperations.

2.4.2.2 Previous studies

Hip fracture incidence has declined in the Nordic countries and the USA, and, similar to PHFs, elderly women are most commonly affected. In Finland, hip fracture incidence in patients aged >49 years increased substantially from 1970 to 1997, after which it declined until 2016, from 537.9 to 344.1 per 10^5 for women and from 256.5 to 194.7 per 10^5 for men. This decrease was most evident in the age groups 65 and older. The mean age of the patients increased from 74.7 to 82.2 for women and from 70.2 to 77.3 for men. (Kannus et al. 2018). A similar decline in incidence was observed in Denmark between 1997 and 2017, where the incidence of hip fractures decreased, especially among elderly female patients, whereas the reduction in men was more modest. (Wahlsten et al. 2021) In the USA, hip fracture incidence in patients aged >64 increased between 1986 and 1995 (from 964.2 to 1050.9 per 10^5 for women and from 392.4 to 456.6 per 10^5 for men), followed by a 24.5% decrease to 793.5 per 10^5 for women and a 19.2% decrease to 369.0 per 10^5 for men. Again, the decrease was most pronounced in patients aged >74, especially those aged >84. (Brauer et al. 2009)

2.4.3 Imaging

A basic hip trauma radiograph forms the foundation of diagnostics and includes a pelvis and/or hip AP view and a hip lateral view (Fig. 15). In hip fractures, this is often sufficient to determine the appropriate treatment. A calibration sphere should be included in the radiographs to enable preoperative planning of surgery. If there is doubt regarding the presence of a suspected fracture, a CT scan should be performed to confirm or rule it out. CT is also helpful in determining whether a femoral neck fracture extends into the trochanteric region. MRI is seldom indicated in suspected acute hip fractures as CT is faster and often better available, but MRI is useful for ruling out a stress fracture of the femoral neck, acetabular labral pathology, and for the differential diagnosis of nonspecific bony lesions on X-ray images.

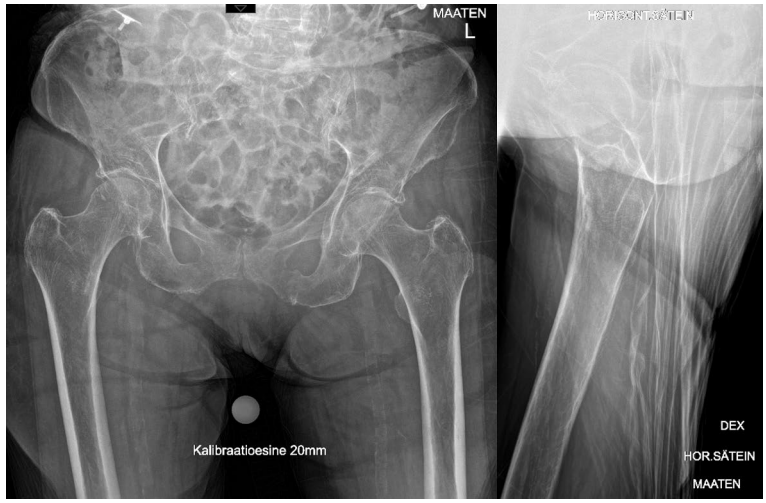


Figure 15. Trauma series radiographs of an intact hip in an 86-year-old female; pelvis AP and right hip lateral view. Source: Turku University Hospital radiology archive.

2.4.4 Classifications

2.4.4.1 Femoral neck fractures

The Garden classification divides fractures of the femoral neck into two undisplaced and two displaced types: Type I (incomplete or valgus impacted), Type II (complete and undisplaced), Type III (complete and partially displaced), and Type IV (complete and fully displaced) (Kazley et al. 2018). This classification is based on AP radiographs and does not consider lateral or sagittal alignment. (Fig. 16a).

The Pauwels Classification, published in 1935, describes the inclination of the fracture line. As with the Garden classification, it is based only on an AP radiograph. It divides fractures into three types: Type I (inclination 0–30°), Type II (30–50°), and Type III (>50°) (Fig. 16b). In minimally inclined and valgus-impacted fractures, compressive forces are predominant, whereas in Type III fractures, shearing and varus forces predominte, making them more prone to displacement. Although the Pauwels classification was introduced before the advent of modern hip arthroplasty and IF techniques, it has played a role in their development and remains relevant in determining fracture stability when planning surgical treatment and assessing whether a stress fracture is suitable for nonoperative treatment. (J. Bartoníček 2001)

The AO/OTA classification divides femoral neck fractures (31B) into three types depending on the location of the fracture line, and into 1–3 subgroups describing fracture morphology, similar to the two classifications above. (Meinberg et al. 2018) (Fig. 16c.)

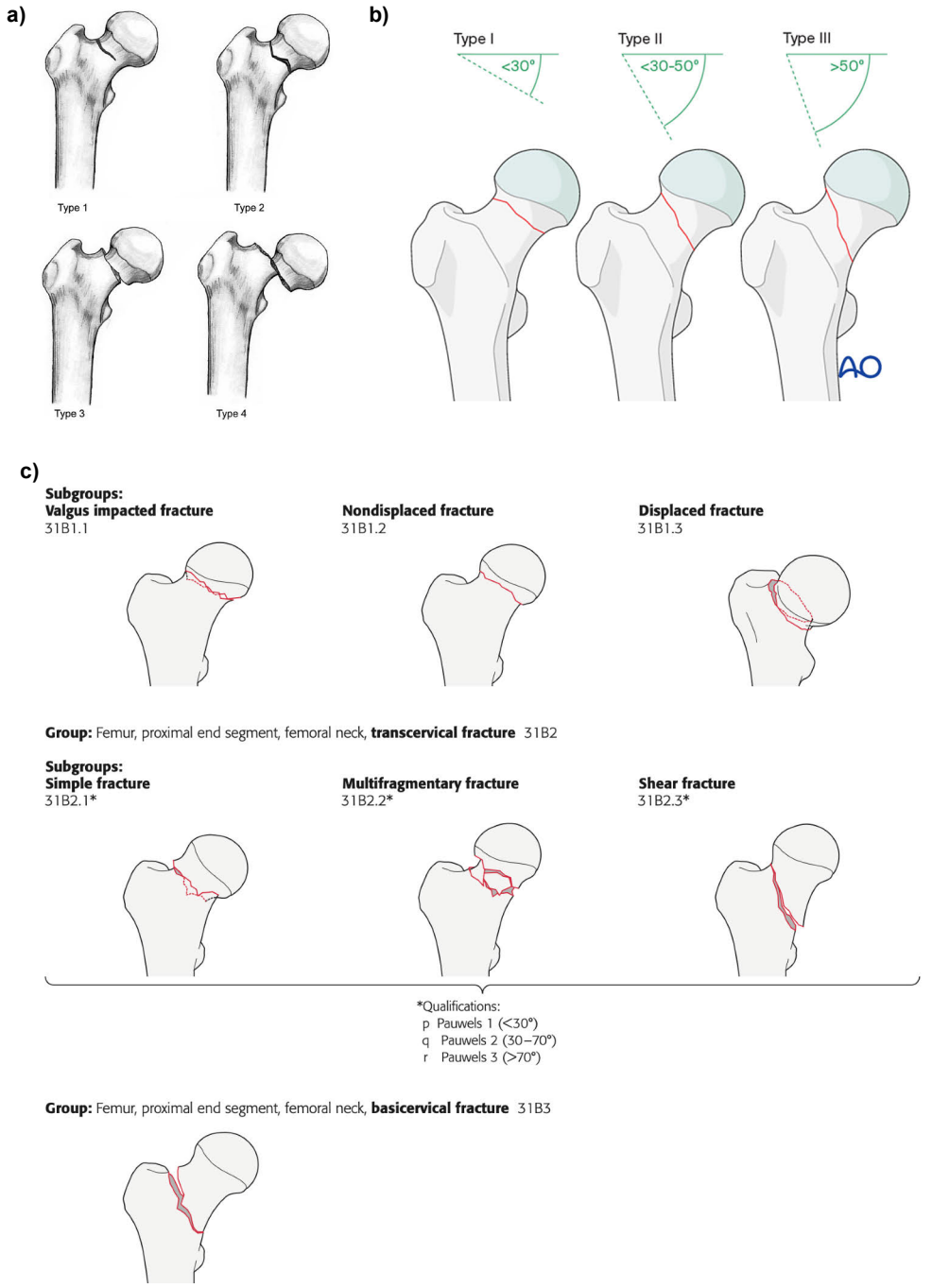


Figure 16. a) Garden classification; **b)** Pauwels classification; **c)** AO/OTA classification of femoral neck fractures. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.surgeryreference.aofoundation.org.

All of the classifications above are based on AP-view radiographs. The role of sagittal alignment in femoral neck fractures has also been studied, and a posterior tilt of >20° in Garden Type I and II fractures has been shown to be a reliable predictor of increased reoperation risk (Palm et al. 2009, Honkanen et al. 2021) (Fig. 17)

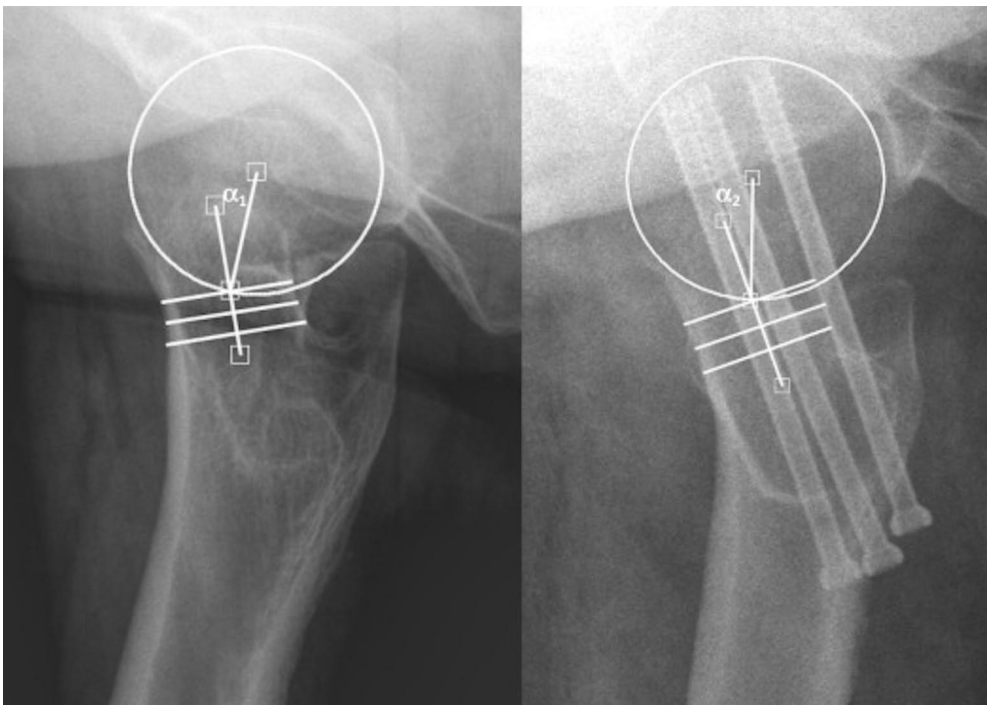


Figure 17. Posterior tilt. Alpha angle, pre- and post-operative radiographs. Reprinted with permission from Honkanen et al. (2021)

2.4.4.2 Trochanteric fractures

Fractures of the trochanteric region are classified as either stable fractures, which resist compressive medial forces when reduced, and unstable fractures, which collapse into varus or medial displacement of the shaft. The AO/OTA classification (Fig. 18.) divides fractures of the trochanteric region into three types and corresponding subgroups based on the degree of displacement and instability. (Meinberg et al. 2018)

Severe comminution, especially of the calcar area or the posteromedial cortex, reverse obliquity of the fracture line, subtrochanteric extension of the fracture, and insufficient thickness (i.e., incompetence) of the lateral femoral wall are associated with instability. A lateral wall thickness of less than 20.5 mm is considered

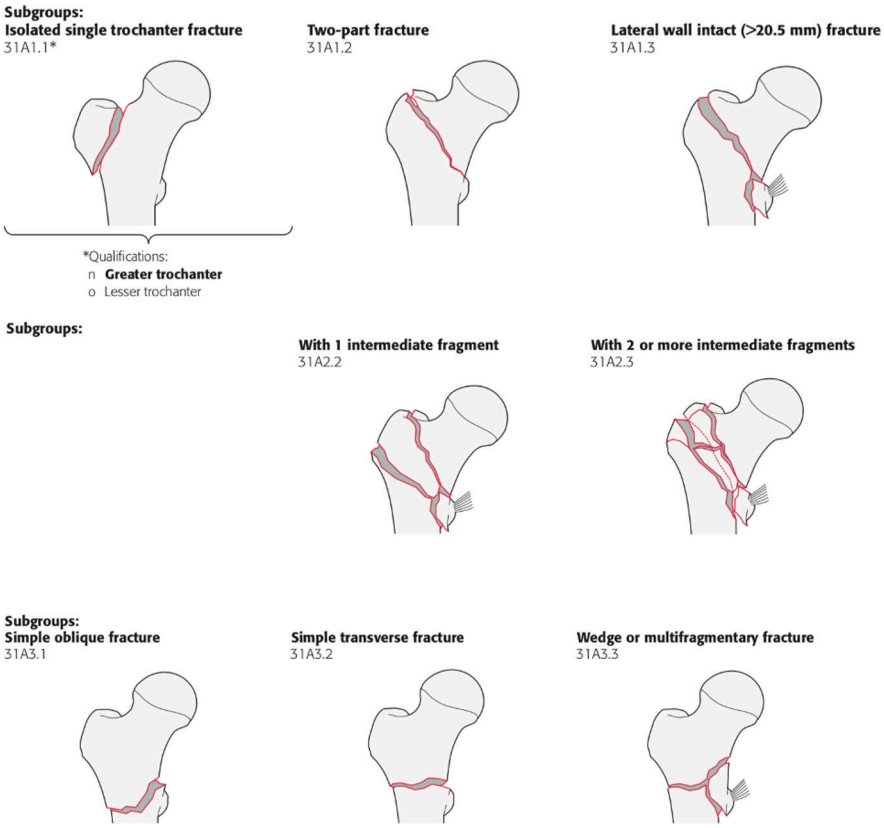


Figure 18. AO/OTA classification of fractures of the trochanteric region. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.surgeryreference.aofoundation.org.

incompetent, leaving the fracture unstable after reduction. (Hsu et al. 2013) (Fig. 19a)

Continuation of a proximal femoral fracture from the lesser trochanter up to 5 cm distally (or down to the femoral isthmus) is considered a subtrochanteric fracture. (Meinberg et al. 2018) The Fielding classification (Fig. 19b) divides fractures of the subtrochanteric area into three types based on the distance from the lesser trochanter. Type 1 fractures, affecting the level of the lesser trochanter, are the most common. Type 2 fractures extend 2.5 cm distally and Type 3 up to 5 cm distally from the lesser trochanter. Loizou et al. reviewed different proposed classifications of subtrochanteric fractures and concluded that, despite differences between them, the 5 cm definition described above is the most useful. (Loizou et al. 2010)

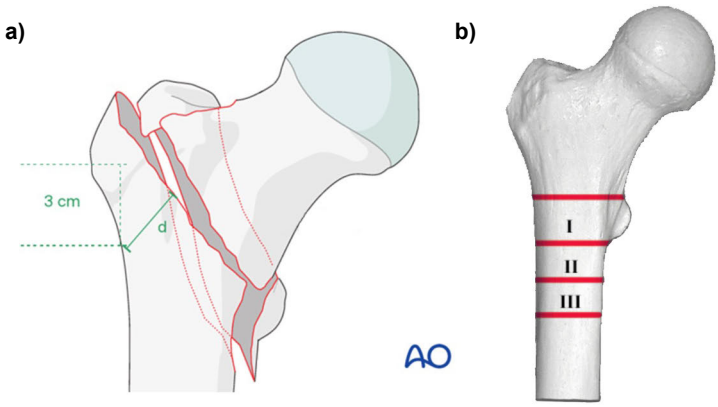


Figure 19. a) Lateral wall thickness (d). **b)** The Fieldings classification. Copyright AO Foundation, Switzerland. Source: AO Surgery Reference, www.surgeryreference.aofoundation.org.

2.4.5 Treatment of hip fractures

2.4.5.1 Internal fixation

2.4.5.1.1 Indications

2.4.5.1.1.1. Femoral neck fractures

Due to the risk of nonunion and AVN in displaced femoral neck fractures, IF of a femoral neck fracture is best indicated in nondisplaced and minimally displaced fractures. Even in cases of displaced fractures, IF is usually considered in young adults. The reoperation risk of up to one-in-four patients, as described later in chapter 2.4.6.1, is considered justified for the sake of possibly preserving a healthy hip joint. Anatomical reduction is crucial in these cases and may be achieved either from a separate anterior approach or from the lateral approach used for placing the implant. The risk of AVN increases with the degree of displacement and amount of manipulation required to achieve reduction. Common IF options for femoral neck fractures include fixation with cannulated screws, a sliding hip screw with plate (SHS), or an intramedullary (IM) nail. Screw fixation is generally used for subcapital and transcervical fractures, whereas basicervical fractures benefit from the extra stability provided by the two other fixation methods. (Buckley et al. 2018)

2.4.5.1.1.2. Trochanteric fractures

IF is the standard treatment for trochanteric fractures. As with femoral neck fractures, reduction of a displaced fracture is important, and especially varus

malalignment and disruption of the calcar and femoral neckline should be addressed. Different types of implants have been described, but IM nailing and SHS are currently the most commonly used methods. The use of fixed-angled blade plates and proximal femoral locking plates has become marginal in the primary fixation of femoral neck and trochanteric fractures, although their use is still described in AO/OTA manuals. (Buckley et al. 2018)

2.4.5.1.2 Implants

2.4.5.1.2.1. Screw fixation

Screw fixation with cannulated screws perpendicular to the fracture line (Fig. 20) is indicated in nondisplaced or valgus-impacted femoral neck fractures. Closed reduction of a displaced fracture may be attempted, but the reduction should be anatomic; if this cannot be achieved, open reduction is required. A minimum of three partial threaded cannulated screws are used to achieve compression across the fracture line. The screws should be parallel to each other to enable compression both during IF and postoperatively, as the dynamic compression of the fracture line may continue under axial loading as part of the healing process. The screws should be positioned as far apart as possible within the femoral neck in an inverted triangle or diamond configuration. Correct positioning of the inferior/calcar screw is essential. (Lindequist and Törnkvist 1995, Gurusamy, Parker, and Rowlands 2005)

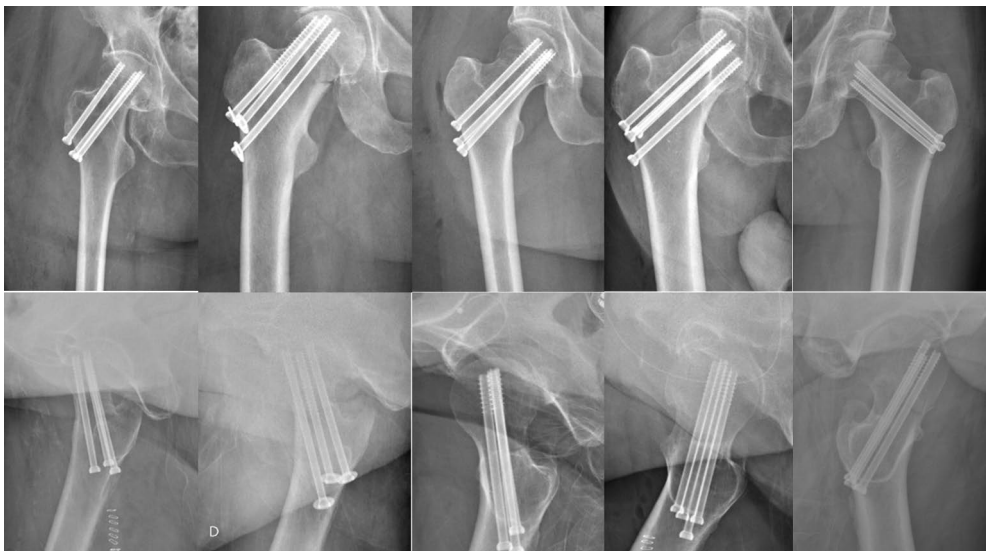


Figure 20. Post-operative AP (top row) and lateral (bottom row) radiographs of five femoral neck fractures treated with screw fixation at Turku University Hospital in 2019–2022 (mean age 67 years, range 52–82). Source: Turku University Hospital radiology archive.

2.4.5.1.2.2. Sliding hip screw with plate

This implant consists of a lateral side plate that is firmly screwed to the lateral side of the femur distal to the fracture, and a single screw or blade aligned with the femoral neck, crossing the fracture line and engaging the proximal side (Fig. 21). The screw or blade is free to slide along its axis through a barrel within the plate, permitting dynamic compression of the fracture line during axial loading, hence the name “sliding hip screw”. The first implant using this design was introduced by Ernst Pohl in 1951 and patented in the USA in 1952. Despite its German origin, later development of the implant continued in the USA. The device became known as the Richards Classic Hip Screw, and the first clinical results of its use were published in 1964. In Europe, use of the implant did not become widespread, as it did not fit the concept of stable internal fixation favored by AO/OTS at the time. This changed by the turn of the 1980s, as hardware-related issues with other widely used fixation devices were identified mostly in trochanteric fractures. (Jan Bartoníček and Rammelt 2014) AO and Synthes later introduced their own version

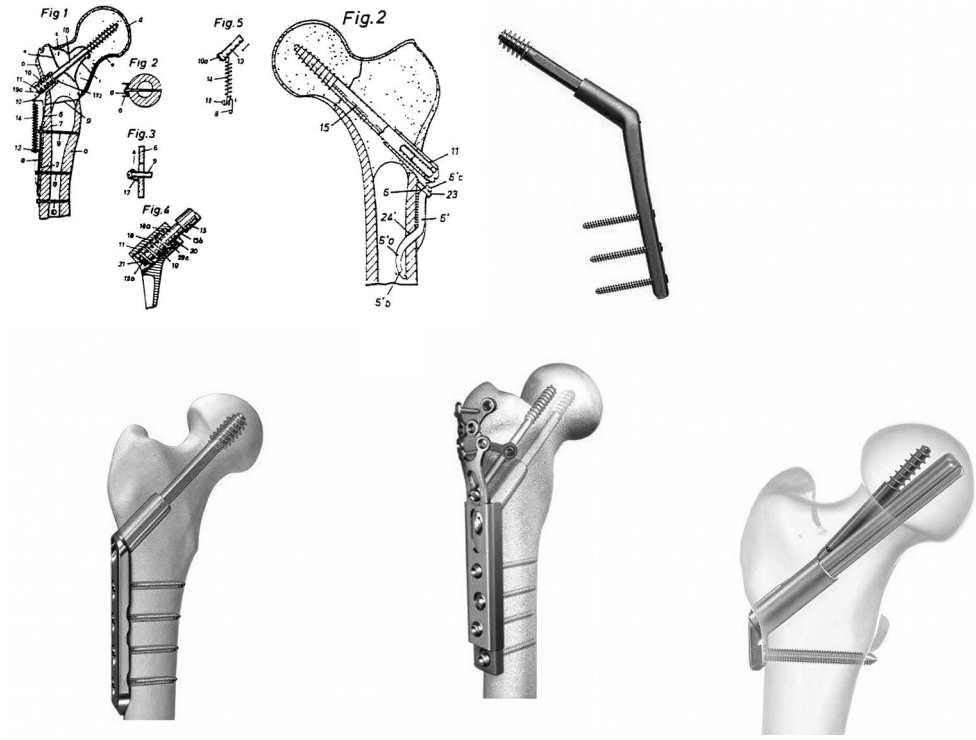


Figure 21. Implants based on the sliding hip screw with plate design. Top left: Ernst Pohl’s original patent. Top right: the Richards Classic Hip Screw. Bottom left: the Dynamic Hip Screw (DHS) by Synthes. Bottom center: the locking trochanter stabilization plate with DHS by Synthes. Bottom right: the Femoral Neck System (FNS) by Synthes. Mosaic of copyright-free images. Source: www.google.com0

of the device, the Dynamic Hip Screw (DHS), which is indicated for trochanteric fractures, as well as for basicervical fractures (Figs. 21 and 22). A DHS version with a locking trochanter stabilization plate has also been developed, intended for more unstable fracture types. A further current development of the DHS is the Femoral Neck System (FNS), which is only indicated for femoral neck fractures (Figs. 21 and 23). It features a similar sliding blade (or bolt) and plate design but also has an antirotation screw that enhances rotational stability, especially in transcervical and subcapital fractures.

Figure 22. Pre- and post-operative radiographs of a pertrochanteric fracture treated with DHS (male aged 22). Author's own radiograph archive.

Figure 23. Top row: Pre- and post-operative radiographs of a femoral neck fracture treated with the FNS (female aged 54); Bottom row: Follow-up radiographs at 6 weeks and 8 months postoperatively, showing impaction, loss of offset, union of the fracture, and subsequent revision to arthroplasty at 16 months due to persistent symptoms. Author's own radiograph archive; courtesy of Dr. Matti Seppänen.

2.4.5.1.2.3. Intramedullary nail

IM nails used in the proximal femur typically consist of a nail introduced antegrade into the medullary canal through the area of the greater trochanter, and a screw or blade passing through the nail, which is driven from the lateral femoral cortex into the femoral head. Due to this construct, these nails are referred to as cephalomedullary nails (CMNs) (Fig. 24). The screw/blade is angularly stable relative to the nail, but, as with the SHS, it allows for dynamic compression of the fracture line. The first implant with this basic construct, the "Y-nail" was described by Pohl in the 1940s (Jan Bartoníček and Rammelt 2014). Subsequent versions derived from this design led to the introduction of the Gamma nail in 1988 (Kempf et al. 2014), which has since become the most widely used CMN, followed by second-, third-, and fourth-generation variants by Stryker in 1997, 2006, and September 2022 (Figs. 22 and 24). AO/OTA and Synthes later introduced their own version, the Proximal Femoral Nail (PFN), and its derivatives. Comparable, further developed implants are also available from other manufacturers, such as the Trigen nail by Smith & Nephew.

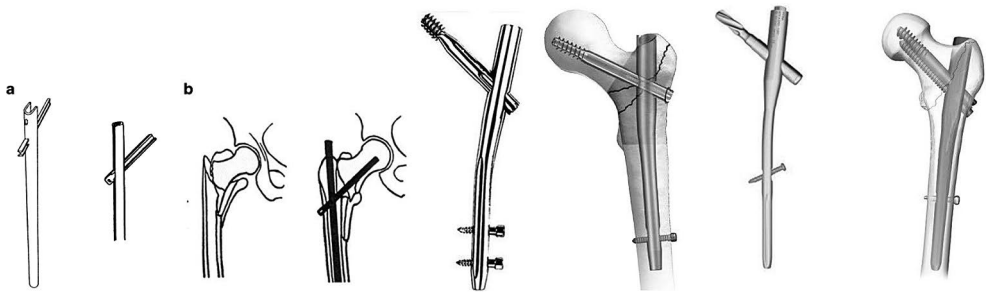


Figure 24. Different cephalomedullary nails from left to right: Pohl's "Y-nagel", the first-generation Gamma nail, the Gamma3 nail, the Proximal Femoral Nail Antirotation (PFNA), and the Trigen nail. Mosaic of copyright-free images. Source: www.google.com.

CMNs are primarily indicated for trochanteric fractures, but like the SHSs, they may also be used in basicervical fractures. CMNs have been associated with superior mechanical stability compared to SHSs due to the difference in varus torque strain on the implant. (Buckley et al. 2018) (Fig. 25a) An important measurement in both CMN and SHS implantation is the tip-apex distance (the distance from the tip of the screw/blade to the apex of the femoral head curvature), which is determined and summed from AP and lateral radiographs. A tip-apex distance of less than 25 mm is necessary, as greater distances have been associated with implant failure through cut-out. (Baumgaertner et al. 1995, John et al. 2019) (Fig. 25b)

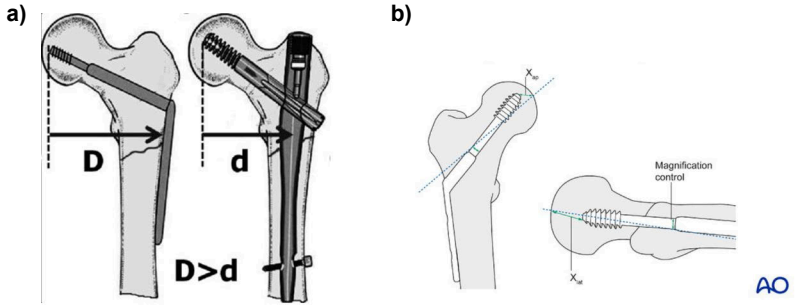


Figure 25. a) Comparison of a SHS and CMN demonstrating the difference in distance between the femoral neck screw tip in relation to the nail or plate, affecting torque stresses on the implant; **b)** Measurement of the tip-apex distance: x=x(AP) + x(Lat). Source: AO Surgery Reference, www.surgeryreference.aofoundation.org.

Figure 26. a) Top radiographs, first row: Pre- and post-operative images of a pertrochanteric fracture (male age 93) treated with a short Gamma 3 nail. Top radiographs, second row: Follow-up radiographs at 6 weeks showing dynamic compression of the fracture line and dislocation of a trochanter tip fragment. **b)** Bottom radiographs: Pre- and post-operative and 6-week follow-up images of a subtrochanteric fracture (female 92 years) treated with open reduction, a Dall-Miles cable, and a long Gamma 3 nail. Author's own radiograph archive.

2.4.5.1.3 Complications of IF

Alongside direct surgical complications such as blood loss, thromboembolic events, injury to nearby nerves or blood vessels, and surgical site infections, implant-related complications arise in this area of the body due to the high loads transmitted through the proximal femur. Treatment of a hip fracture with IF relies on consolidation of the bone through anatomically accurate and stable fixation of the fracture. Nonunion or AVN of the femoral head is a known complication following IF of femoral neck fractures, and it is more strongly influenced by the fracture pattern and displacement than by the fixation method itself.

Hardware failure in the form of screw cut-out or nail/plate breakage follows instability caused by the severity of the fracture, possible malreduction, and/or malalignment of the fracture during surgery, and less often from quality issues with the hardware itself. Delayed union and nonunion typically lead to implant failure, as the implants are not strong enough to withstand the stresses of prolonged full weight-bearing. Persistent pain and secondary displacement of the fracture during follow-up may be warning signs of imminent failure. Alongside optimal reduction and fixation of the fracture, the risk of nonunion can be reduced if the fracture hematoma and soft tissues connecting to the bone are left undisturbed during surgery. This and the possible ossification-inducing effect of medullary reaming may be considered potential advantages of IM nailing over plating of the proximal femur.

2.4.5.2 Arthroplasty

2.4.5.2.1 Brief history and implant types

The first descriptions of hip arthroplasties in the 1890s were hemiarthroplasties (HAs), using implants carved from ivory used to treat hip joints destroyed by tuberculosis. Later, attempts at interpositional arthroplasty and HAs fabricated from glass (mould arthroplasty) were followed by the first implants based on steel alloys and the first total hip arthroplasty (THA) with an acetabular component. In 1935, Smith-Petersen described his results with mold arthroplasty for hip fractures as follows: “Complications of fractured hips—A total of fifty cases have been operated for non-union, aseptic necrosis, and dead heads. The results are very satisfactory and compare favourably with those obtained in malum coxae senilis.” (Smith-Petersen 2006, Learmonth, Young, and Rorabeck 2007) The THA with a metal-on-polyethylene bearing described by Sir John Charnley in 1961 is considered the first modern hip arthroplasty. His work popularized the procedure and the use of polymethyl methacrylate cement for the fixation of the components. (Charnley 1961)

All later implants, including modern cementless hip arthroplasty components, have been developed and tested against the gold standard set by Charnley's design.

2.4.5.2.2 Indications

Hip arthroplasty is indicated for fractures as first-line treatment when the risk of nonunion and joint destruction with IF is high, which is the case in most femoral neck fractures, especially displaced ones. Another indication is as a salvage procedure after failed IF. The use of primary arthroplasty in trochanteric fractures is rare, as it requires a revision stem due to the disruption of the normal calcar osseous anatomy required by standard stems, but it remains an option in some cases. (J. T. Kim et al. 2018) Younger patients benefit from efforts at preserving the hip joint, whereas elderly patients benefit from early mobilization, weight-bearing, and minimizing the risk of complications and reoperations.

HA is mainly considered for femoral neck fractures in elderly and sedentary patients. Definite osteoarthritis of the hip joint or rheumatoid arthritis is considered a contraindication for HA. Patients with questionable cooperation due to conditions such as dementia or alcoholism, neurological disorders such as Parkinson's disease, or spinal disorders affecting sagittal balance of the spine and pelvis, may be better treated with HA rather than THA, as the latter is more prone to dislocation. (Florschutz et al. 2015)

THA is primarily indicated for displaced femoral neck fractures in older adults where the risk of failure of IF is considered high. THA is also used as a salvage procedure after failed IF. Although HA is generally considered as good a choice as THA for fitter elderly patients, the use of fracture THA has been increasing globally. (Miller et al. 2014, Bartels et al. 2018)

2.4.5.2.3 Implant positioning and attachment

Hip arthroplasty begins with a preoperative planning template based on a radiograph with a calibration object. Preliminary sizing of the implant and planning of implantation depth are key to restoring the anatomy of the hip joint. A posterior or anterolateral (Hardinge) approach is used to open the hip joint, depending on the surgeon's preference. An anterior approach has been described but is less widely used. The fracture is exposed, the femoral head exarticulated, and the medullary canal broached to the appropriate implant stem size. The anteversion of the stem is important for a successful outcome in terms of stability, with an anatomic or slightly exaggerated anteversion preferred in HA. (Fig. 27)

Figure 27. Pre- and post-operative radiographs and preoperative planning template of a femoral neck fracture (male age 75) treated with cemented HA. Author's own radiograph archive.

In THA, a combined anteversion of 40° between the stem and acetabular component is considered optimal, taking into account local soft tissue and bony landmarks. (Remes et al. 2022) The development of modern cross-linked polyethylene liners has greatly reduced the risk of acetabular component loosening. As a result, the use of cemented acetabular components in THA across all indications has declined, and today cementless acetabular components with porous coatings are predominantly used, as indicated by reports from international arthroplasty registers (AOANJRR 2024, FAR).

The stem is either impacted into the femur to achieve a press-fit (cementless HA or THA) or cemented. The term cemented THA refers to a THA in which both the stem and acetabulum are fixed with cement, whereas the term hybrid THA refers to a procedure in which the stem is cemented but the acetabular component is not. (Fig. 28)

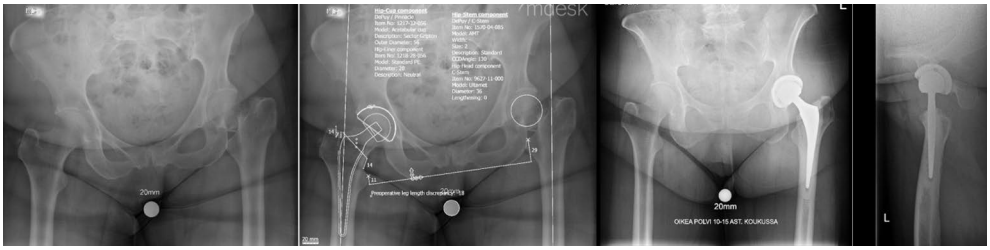


Figure 28. Pre- and post-operative radiographs and preoperative planning template of a femoral neck fracture (female age 61) treated with hybrid THA. Author's own radiograph archive.

2.4.5.2.4 Complications and considerations in arthroplasty

A PJI is a devastating, possibly life-threatening complication requiring revision surgery and prolonged intravenous courses of antibiotics. PJI risk following elective hip arthroplasty is approximately 1%. Known risk factors are advanced age, high body mass index (BMI) (the risk doubling in patients with BMI >35 and increasing four-fold with BMI >40 (Lübbeke et al. 2016)), male sex, comorbidities such as

diabetes and rheumatoid arthritis, smoking, previous hip surgery, and revision arthroplasty. Arthroplasty due to fracture, rather than osteoarthritis, is also associated with a higher infection risk. (Yli-Kyyny et al. 2014, Dale et al. 2020) Minimizing the risk of infection in an elective arthroplasty setting is important and includes optimizing chronic conditions, screening for underlying infections, promoting weight loss in obese patients, and advising smoking cessation. However, these preventive measures are not possible in the acute setting of a hip fracture. The management of hip PJI similar to that of shoulder PJI, as described in the previous chapter. The burden of a two-stage PJI revision may be even more devastating for hip patients, as it affects their ability to ambulate.

Instability or luxation tendency after hip arthroplasty should be considered when deciding between HA and THA. Due to its larger head diameter, HA offers greater inherent stability compared to the typical bearing couples used in THA. The use of bipolar components (consisting of an inner head and outer cup on the femoral head component allowing for two axes of movement) reduces the risk of luxation in THA and may be considered for patients with comorbidities or conditions predisposing them to instability. The posterior surgical approach has been associated with a greater risk of instability compared to the lateral approach, especially in fracture cases. (Rogmark et al. 2014, Gausden et al. 2021, Chen et al. 2022)

Periprosthetic fractures can occur either intraoperatively or later, typically following an accident. While rehabilitation of a hip fracture focuses in part on fall prevention, only the risk of intraoperative fractures can be influenced during primary surgery; avoiding the use of cementless stems has been shown to reduce the risk of intraoperative fractures. (Rogmark et al. 2014, Gausden et al. 2021) A periprosthetic fracture around the femoral stem most often requires revision surgery, either with IF or implantation of a revision stem, depending on the stability of the existing stem. As mentioned earlier, aseptic loosening of components has become a marginal phenomenon in hip arthroplasty following the introduction of modern cross-linked polyethylene liners. Nowadays, gradual loss of bone stock and loosening of components are more likely to indicate a latent PJI, and revision surgery should be planned with this in mind.

2.4.6 Current evidence in the treatment of hip fractures

2.4.6.1 Femoral neck fractures

Due to the risk of avascular necrosis of the femoral head in displaced femoral neck fractures, IF is generally recommended primarily for nondisplaced or minimally displaced fractures. (Kazley et al. 2018) IF has been compared with arthroplasty, which has demonstrated more predictable outcomes and fewer reoperations, even in cases of nondisplaced fractures in the elderly. (Xu et al. 2017, Bartels et al. 2018,

Dolatowski et al. 2019, Richards et al. 2020) A recent Swedish study reported that one in 10 patients aged >59 treated with IF for nondisplaced fractures required revision to arthroplasty within five years. (Lagergren J et al. 2022) Other studies report reoperation rates ranging from 18% (Slobogean et al. 2015) to as high as 27% (Bartels et al. 2018) after IF. A 2016 review concluded that arthroplasty should be the treatment of choice for elderly patients, (C. Rogmark and Leonardsson 2016) a conclusion further reinforced by a recent Cochrane review. (S. R. Lewis, Macey, Stokes, et al. 2022) Given that the proportion of younger patients with high-energy trauma mechanisms is negligible, it is safe to say that most femoral neck fractures should be treated with arthroplasty.

There is growing evidence supporting the use of cemented stems for elderly patients in both HA and THA. The advantages of cemented stems in hip arthroplasty include a lower risk of periprosthetic fractures and fewer infection complications, based on large register datasets. (C. Rogmark et al. 2014, Yli-Kyyny et al. 2014, Dale et al. 2020) Cementless HA has been associated with a higher risk of revision than cemented HA, even when infection is ruled out as the cause. (Kristensen et al. 2020, Okike et al. 2020) These risk differences may be even more pronounced in fracture patients, who are typically elderly and have more comorbidities compared to elective THA patients. A recent British multicenter study comparing cemented with cementless HA demonstrated a significantly better quality of life alongside a decreased risk of periprosthetic fracture in patients treated with cemented HA. (Fernandez et al. 2022) Despite this, some Finnish reports indicate increasing use of cementless stems in older fracture patients. (Hongisto et al. 2014)

When comparing THA with HA in fracture surgery, better functional outcomes and lower revision rates have been reported in favor of THA, despite a slightly higher risk of dislocation. (Florschutz et al. 2015) Dislocation risk can be reduced by avoiding a posterior approach and using bipolar components in selected cases. (Gausden et al. 2021, Chen et al. 2022) It has been suggested that THA should be preferred for patients aged <80 with a life expectancy of more than four years, and considered for those who are ambulatory without assistive devices and expected to maintain independence in activities of daily living for at least two years. (D. P. Lewis et al. 2019, “NICE Hip Fracture: Management” 2023) However, some argue that possible differences in outcomes are clinically nonsignificant. (Parker and Cawley 2019, Ekhtiari et al. 2020, S. R. Lewis, Macey, Parker, et al. 2022) Regardless, there are reports of increasing use of THA for hip fractures. (Miller et al. 2014, Bartels et al. 2018)

2.4.6.2 Trochanteric fractures

IF with either DHS or CMN is the standard primary treatment for trochanteric fractures. A recent Cochrane review pooling data from studies comparing outcomes

of DHS and CMNs concluded that, in fragility fractures, CMNs are associated with a lower risk of infection and nonunion, while DHS carries a lower risk of implant-related fractures, an advantage that has persisted despite the evolution of CMN designs. Although there is evidence available regarding these clinically relevant outcomes, evidence regarding Patient Reported Outcome Measures (PROMs) remains limited. (S. R. Lewis, Macey, Gill, et al. 2022)

The choice between short and long CMNs in relation to fracture type has been a subject of ongoing debate, but fractures affecting the subtrochanteric area have generally been considered to warrant fixation with a long (or medium-long) nail. The AO/OTA trauma reference guide recommends long nails in these cases. (Buckley et al. 2018) There are reports of increased operation time and blood loss when using long nails. In vitro analyses have not shown long nails to be biomechanically superior compared to short ones in subtrochanteric fractures, and it could be that the number and positioning of distal locking screws are more important than nail length. (Chantarapanich and Riansuwan 2022) While it is clear that long nails provide extra stability in fractures with distal subtrochanteric extension compared to short nails, the Cochrane review concluded that no advantage or disadvantage could be shown in favor of long nails over short ones in extracapsular hip fractures. (S. R. Lewis, Macey, Gill, et al. 2022)

2.5 Evidence based medicine and clinical practice

2.5.1 Levels of evidence

Medical research evidence is ranked by its reliability and ability to minimize bias. This hierarchy of study designs is often depicted as a pyramid: At the top are systematic reviews and meta-analyses, which combine data from multiple high-quality studies (Cochrane systematic reviews are among the most validated of these). Next come RCTs, which with their randomized-controlled design, and ideally blinding, are considered the gold standard for testing interventions. Large observational medical register studies (such as the studies in this thesis) typically fall under prospective cohort studies and provide valuable real-world evidence, especially for long-term or rare outcomes. Below are case-control studies, which compare individuals with and without a condition, and cross-sectional studies, which examine data at a single point in time. At the base are case reports and expert opinions, which offer clinical insights but carry the highest risk of bias. It is important to understand that all these study settings have inherent characteristics that yield strengths and weaknesses. These should be kept in mind when critically appraising individual research articles. (Straus et al. 2018)

2.5.2 The role of register studies

Like clinical trials, register studies form one of the bases of contemporary orthopedic and trauma research. Register studies provide evidence that complements that of RCTs. Systematically reported data to registers over long periods of time enable longitudinal monitoring of epidemiology, clinical practice, outcomes and quality of care across entire populations. (Straus et al. 2018) Health care registers such as the NHDR allow precise estimation of the incidence (number of new cases in a population over a specific time) and prevalence (number of new and existing cases at a particular point in time) of conditions such as fractures or osteoarthritis. Data of performed operations make it possible to monitor trends in treatment methods and more detailed information from implant registers such as the FAR make it possible to monitor implant survival and complication rates and outcome variables and further derive risk estimates and prognostic models of treatments. The retrospective and observational nature of register studies introduces confounding and bias, especially if one is trying to determine causality. Confounding by indication occurs when treatment selection is influenced by patient factors that also affect outcome. Further, temporal confounding may occur in studies spanning several years when population characteristics, evolving surgical techniques and implant designs influence outcome seperately from the studied intervention. Information bias arises from errors in coding or entry of data leading to possible misclassificastion of exposures or outcomes. In contrast, the selection bias of RCTs, mostly due to the systematic exclusion and randomization of patients to optimize internal validity, is generally not a similar issue in register studies. This makes their external validity, meaning representativeness of and applicability to real life, better in comparison. (Schwartz et al. 2015)

2.5.3 Outcome measures in orthopedic clinical research

Outcome measures are needed to evaluate the quality and efficacy of the treatment provided and to enable comparative research. Historically, outcome measures reported in the literature have been vague descriptions of “excellent, fair or poor” clinical results, and evaluated from the clinician’s point of view. Clinician-Reported Outcome Measures (CROMs) include objective variables such as ROM of the affected joint, radiological evidence of fracture union, and complication or reoperation rates following a specific treatment. However, despite consistent results in these variables, clinical manifestations and patient experiences may vary significantly.

Today, the patient’s role has shifted from that of a passive recipient of medical care to an active participant, making subjective perceived health and symptom outcome in the form of PROMs an important outcome variable of medical care.

These are typically structured as questionnaires combining aspects such as perceived pain, incapacity, and general satisfaction with care. Several different limb- and joint-specific outcome scores are now commonly used in clinical practice.

Examples of relevant outcome measures in the treatment of PHFs and shoulder disorders in general include the Disabilities of the Arm, Shoulder and Hand (DASH) score, the Oxford Shoulder Score and the Constant Score (CS). For hip fracture treatment, the Harris Hip Score and the EuroQol five-dimension three-level questionnaire scoring instrument are commonly employed. In the context of ATRs, the most referenced measure is the Achilles Tendon Total Rupture Score. The visual analog scale is widely used as an orthopedic PROM. (Goudie, Macdonald, and Robinson 2022, Hoeffner et al. 2022, Kjærvik et al. 2024) As the studies in this thesis cover several injury types and do not directly report or compare outcome measures, these scores are not discussed in further detail here.

Key variables measuring the quality of outcome measurement tools include validity (how well the outcome measure captures what it is intended to measure), reliability or repeatability (the consistency of results when measurements are repeated under the same conditions), and responsiveness (the ability of an instrument to detect change). (Streiner, Norman, and Cairney 2015) Another important concept is the Minimal Clinically Important Difference (MCID), which refers to the smallest change in a score that the patient perceives as real and/or significant. For instance, in PHFs, the MCID for the DASH score (spanning from 0 = *no disability* to 100 = *maximum disability*) has been approximated at 8.1–13.0 points, and for the CS (spanning 0-100 in the opposite direction) at 5.4–11.6 points. (Van De Water et al. 2014, Dabija and Jain 2019)

2.5.4 From evidence to clinical practice

Medical evidence filters into clinical practice in a chaotic pattern. Studying this, what is essentially a collective behavioral change amongst a pool of clinicians, is challenging. In their article “Which study outcomes change practice” Sepehri and Slobogean describe the phenomenon followingly: “The lag from translational research to clinical practice has been estimated to be between 10 and 30 years. The development of research into practice has been described as occurring in two phases; phase 1 refers to conversion of basic science research into clinical research and phase 2 refers to the translation of clinical studies into the practice. Clinicians play an essential role in phase 2, which entails objectively appraising prior as well as novel research literature and determining whether the evidence warrants implementing changes to their current practice.” (Sepehri and Slobogean 2020) This time span of 10 to 30 years is obviously a broad approximation.

As the amount of contiunously published orthopedic research continues to increase, surgeons currently often rely on the outcomes of key prominent studies to inform clinical decision making. For instance, the widely acknowledged ProFHER trial regarding PHFs, published in 2015, was followed by up to 50% of British surgeons having changed their practice due to the findings according to a survey two years later. (Rangan et al. 2015, Jefferson et al. 2017) Another study, focusing on which research study characteristics were more likely to influence orthopedic surgeons in their clinical decision-making, reported that an RCT study setting (followed by meta-analyses and then systematic reviews) and a sample size of more than 100 were most likely to influence decision-making. Other influential factors were the reputation of the investigators and the perceived quality of the journal whereas economic impact, industry and patient influence were less influential. (de SA et al. 2015)

Promising new ideas and sensational breakthroughs get widespread attention, which may prompt clinicians to adopt new, even experimental treatments based on promising clinical results. This is not without risk, as occasionally demonstrated, for example, in the introduction and ensuing problems with metal-on-metal bearing surfaces in THA. This discovery, originally from Australian implant register reports, is testament to the power of large observational register studies in identifying rare adverse outcomes in a large population. (AOANJRR, 2011) Following dramatic failures such as this, or as other comparative evidence emerges favoring certain treatments over others, shifts in treatment practices are observed. A widely cited humoristic description of this trajectory is Scott's parabola, which illustrates the rise and fall of a surgical teqhnique: What begins as a promising idea, developing into a standard treatment following wide-spread enthusiasm, is eventually reduced to boxes of redundant implants taking up shelf space in forgotten corners of surgical departments. (Fig. 29).

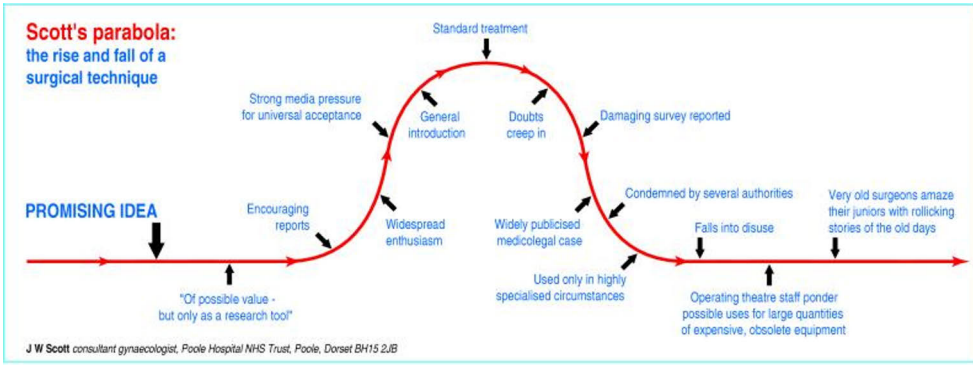


Figure 29. Scott's parabola. Copyright © 2001, BMJ.

3 Aims

1. To determine the incidence of proximal humerus fractures in Finland over the past two decades, and to examine the treatment methods used, including age-specific subgroups, with particular focus on how treatment methods have evolved in line with emerging scientific evidence.
2. To determine the incidence of Achilles tendon ruptures in Finland over the past two decades, and to examine the treatment methods used, including age-specific subgroups, with particular focus on how treatment methods have evolved in line with emerging scientific evidence.
3. To determine the incidence of hip fractures in Finland over the past two decades, and to examine the treatment methods used, including age-specific subgroups, with particular focus on how treatment methods have evolved in line with emerging scientific evidence.
4. To investigate regional differences in the incidence and treatment of proximal humerus fractures during the same period.

4 Materials and Methods

4.1 Patients

All studies were based on data from the National Hospital Discharge Register, and Studies I, II, and IV also utilized data from the Register of Primary Health Care Visits. The study population included skeletal mature individuals aged 16 years or older residing in Finland. Ethical approval and the study permit were granted by the Finnish Institute for Health and Welfare (www.thl.fi, under permit number THL/2266/5.05.00/2019).

4.1.1 Study I

The NDHR and PHCR databases were searched for all records with a primary or secondary (International Classification of Diseases, ICD-10) diagnosis code S42.2 *Fracture of upper end of humerus* between 1 January 1997 and 31 December 2019. The NDHR was further queried for records with ICD-10 code S42.2 combined with surgical procedure codes from the NCSP (Nordic Classification of Surgical Procedures): NBJ60 (humerus nail fixation), NBJ62 (humerus plate fixation), NBJ64 (humerus fixation with screws, nails, or absorbable implants), NBJ91 (other humerus fracture operation), NBB10 (shoulder hemiarthroplasty), NBB15 (shoulder bipolar hemiarthroplasty), or NBB20 (total shoulder arthroplasty). This was done to identify both nonoperatively and operatively treated patients in both primary health care and hospital settings across Finland. All duplicate cases between the NDHR and PHCR data were identified and excluded. To ensure accurate incidence calculations of acute PHFs, all subsequent records with diagnosis code S42.2 occurring within one year from the first included record, as well as all records classified as control visits, were excluded. All records with a combined diagnosis code referring to a pathological fracture, fracture sequelae, or complication of previous surgery were also excluded. See flow chart (Fig. 30).

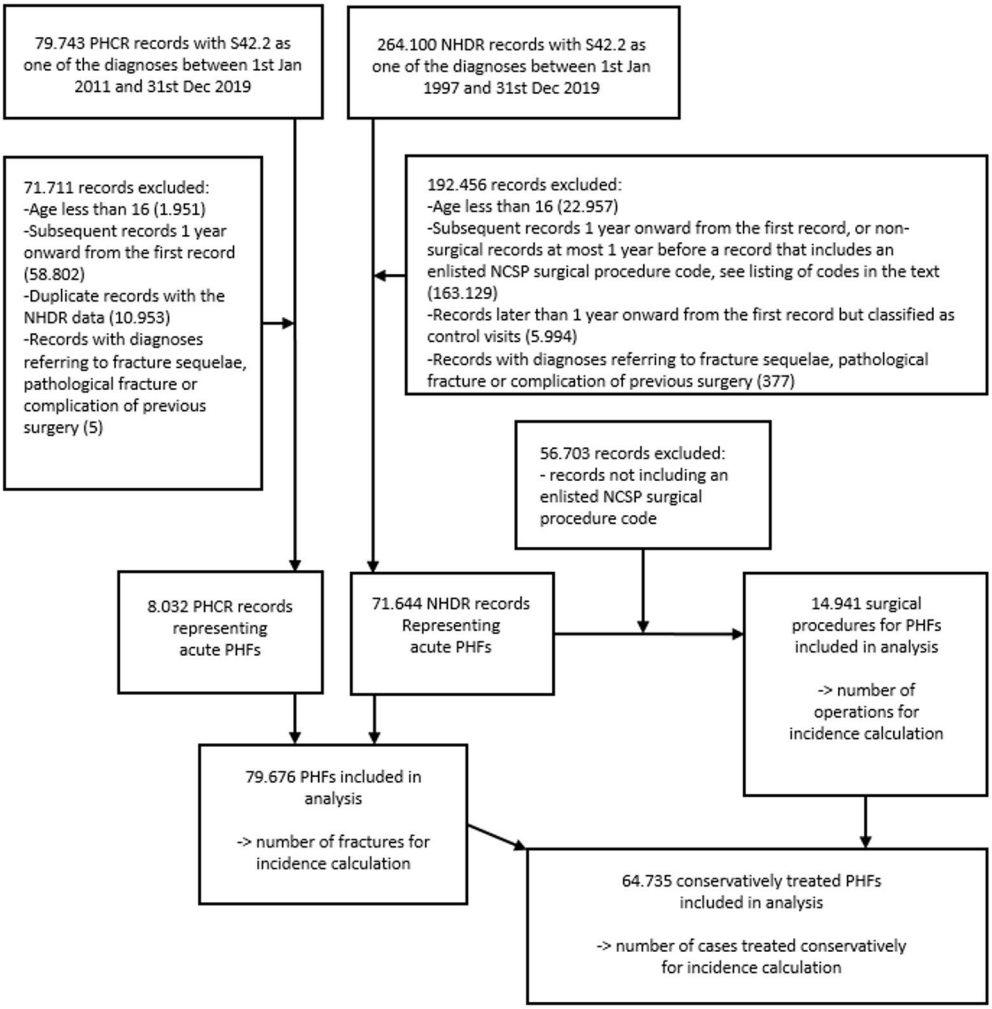


Figure 30. Exclusion flowchart in Study I.

4.1.2 Study II

The databases were searched for all records with a primary or secondary diagnosis code S86.0 *Injury of Achilles tendon* between 1 January 1997 and 31 December 2019. The NHDR was also searched for all records with the NCSP procedural code NHL10 *Suture or reinsertion of Achilles tendon*. This was done to identify all nonoperatively and operatively treated patients in both primary health care centers and hospitals in Finland. All duplicate cases between the two registers were excluded. All subsequent records with diagnosis code S86.0 were excluded so as to include only acute ATRs for the incidence calculations. Only records with operative

treatment performed within 30 days of injury were included in the operative treatment incidence calculation to reflect the first-hand choice of operative treatment and exclude treatment of ATR sequelae or salvage of failed nonoperative treatment. See flow chart (Fig. 31).

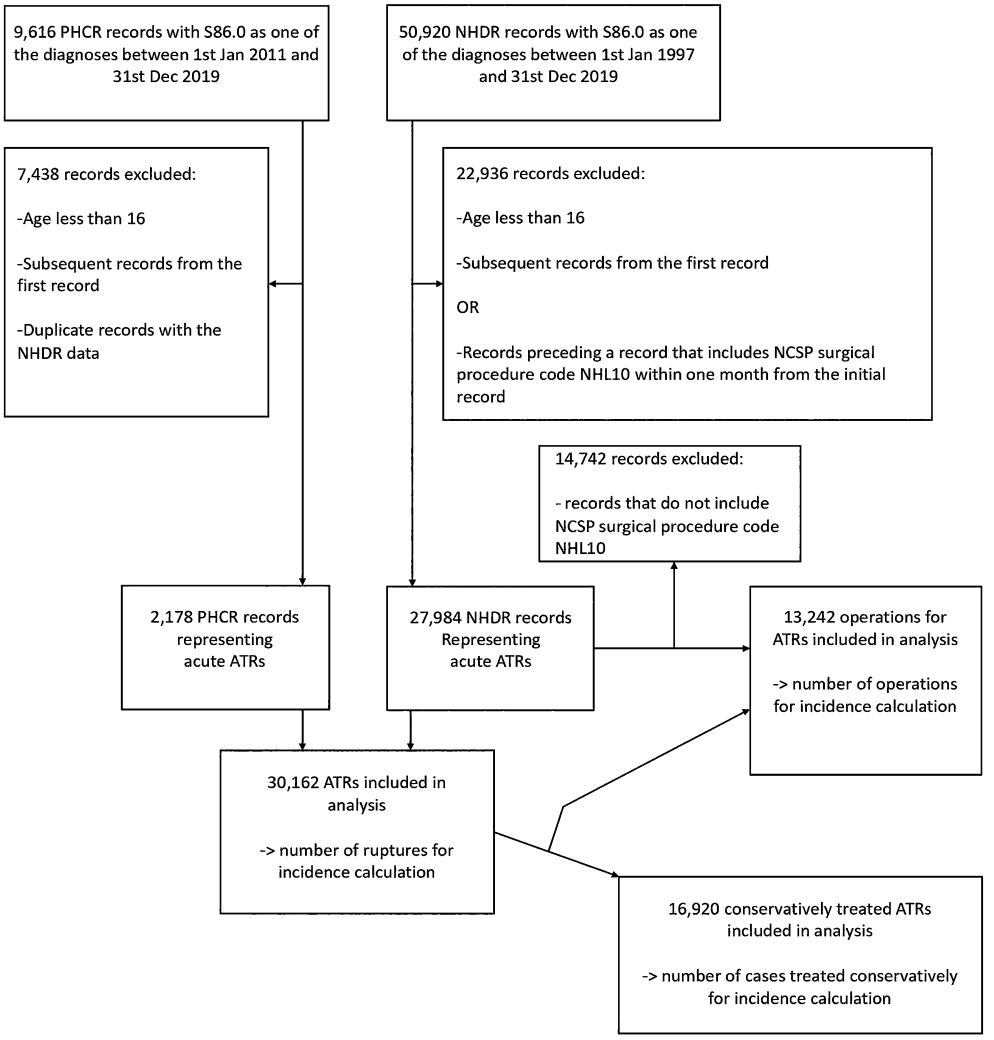


Figure 31. Exclusion flowchart in Study II.

4.1.3 Study III

The database was searched for all records with diagnosis codes S72.0 *Femoral neck fracture*, S72.1 *Pertrochanteric femoral fracture*, and S72.2 *Subtrochanteric*

femoral fracture from 1 January 1997 to 31 December 2018. Exclusion of records was performed to identify and include only records with a primary surgical operation due to an acute hip fracture. See exclusion flow chart (Fig. 32) and table of included and excluded diagnosis and NCSP codes (Table 1).

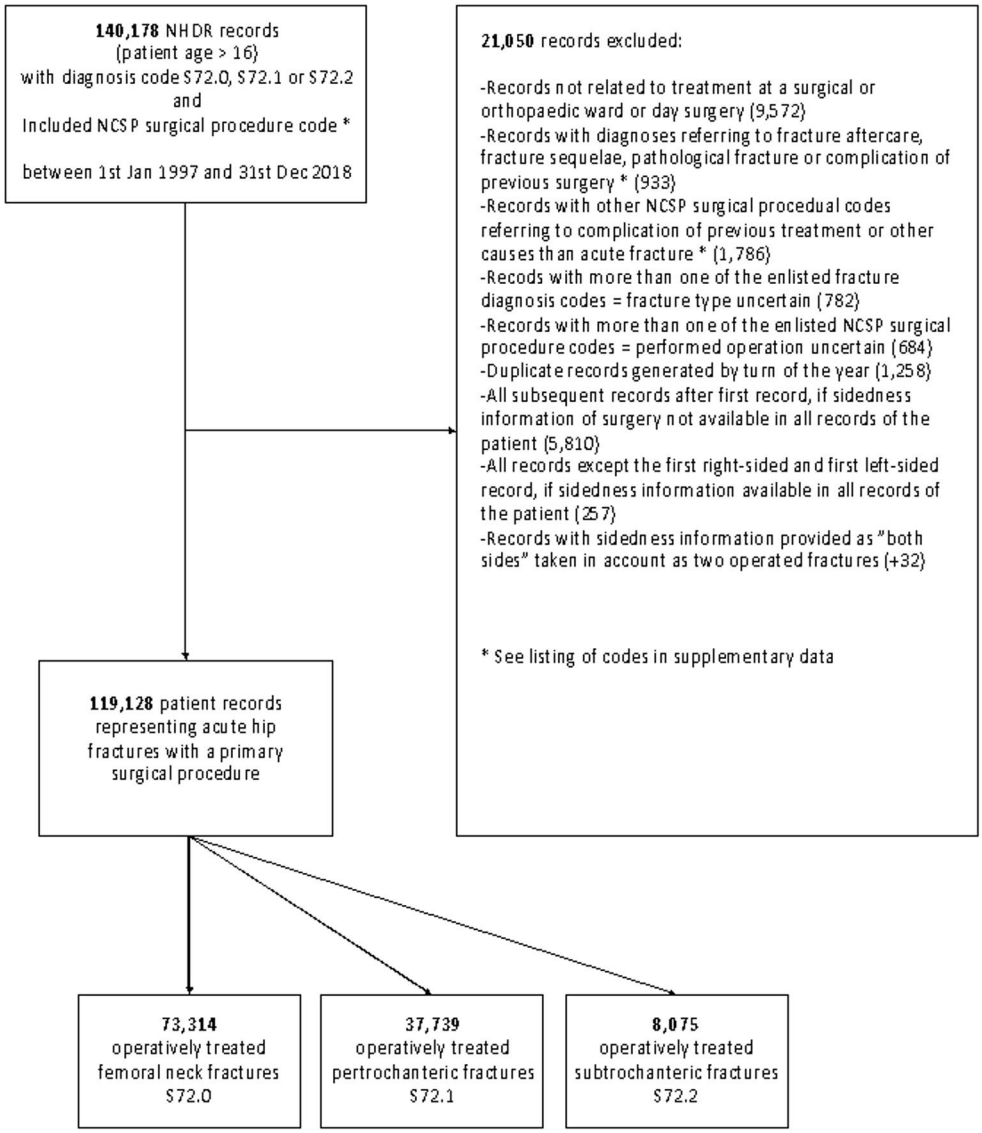


Figure 32. Exclusion flowchart in study III.

Table 1. Included and excluded ICD-10 and NCSP codes in Study III.

Included NCSP (Nordic Classification of Surgical Procedures) procedural codes

NCSP procedural codes:

NFB10 Primary partial prosthetic replacement of hip joint not using cement
NFB20 Primary partial prosthetic replacement of hip joint using cement
NFB30 Primary total prosthetic replacement of hip joint not using cement
NFB40 Primary total prosthetic replacement of hip joint using hybrid technique
NFB50 Primary total prosthetic replacement of hip joint using cement
NFB60 Demanding prosthetic replacement of hip
NFB99 Other primary prosthetic replacement of hip joint
NFJ50 Internal fixation of fracture of neck of femur with nail or screw
NFJ52 Internal fixation of fracture of upper femur with screws and side plate
NFJ54 Internal fixation of fracture of upper femur with intramedullary nail
NFJ60 Internal fixation of fracture of other parts of femur with intramedullary nail

ICD-10 Diagnosis and NCSP procedural codes leading to exclusion of record:

ICD-10 Diagnosis codes:

M84.0 Malunion of fracture
M84.1 Nonunion of fracture [pseudarthrosis]
M84.2 Delayed union of fracture
M84.3 Stress fracture, not elsewhere classified
M84.4 Pathological fracture, not elsewhere classified
M90.7 Fracture of bone in neoplastic disease
M96.6 Fracture of bone following insertion of orthopedic implant, joint prosthesis, or bone plate
T81.0 Hemorrhage and hematoma complicating a procedure, not elsewhere classified
T81.3 Disruption of operation wound, not elsewhere classified
T81.4 Infection following a procedure, not elsewhere classified
T81.58 Acute reaction to foreign substance accidentally left during a procedure
T81.7 Vascular complications following a procedure, not elsewhere classified
T81.8 Other complications of procedures, not elsewhere classified
T81.9 Unspecified complication of procedure
T84.0 Mechanical complication of internal joint prosthesis
T84.1 Mechanical complication of internal fixation device of bones of limb
T84.2 Mechanical complication of internal fixation device of other bones
T84.3 Mechanical complication of other bone devices, implants, and grafts
T84.4 Mechanical complication of other internal orthopedic devices, implants and grafts
T84.5 Infection and inflammatory reaction due to internal joint prosthesis
T84.68 Infection and inflammatory reaction due to internal fixation device [any site]
T84.7 Infection and inflammatory reaction due to other internal orthopedic prosthetic devices, implants, and grafts
T84.8 Other complications of internal orthopedic prosthetic devices, implants, and grafts
T84.9 Unspecified complication of internal orthopedic prosthetic device, implant, and graft
T93.1 Sequelae of fracture of femur

NCSP procedural codes:

NFU00 Removal of partial prosthesis from hip joint
NFU20 Removal of internal fixation device from femur
NFU99 Removal of other implant from hip joint or femur
NFC20 Secondary implantation of hip prosthesis
NFC30 Repair of hip prosthesis by bone transplant to femur
NFC40 Repair of hip prosthesis by bone transplant to acetabulum
NFC50 Repair of hip prothesis by bone transplant to femur and acetabulum
NFJ84 Refixation of fracture of femur
NFJ86 Late operation for fracture of femur to promote bone formation

4.1.4 Study IV

Study IV used the same exclusion protocol as Study I (Fig. 36), after which the PHFs and operations were organized according to the hospital district of the patient. Cases in which the hospital district data were not available were excluded.

4.2 Methods

The outcome variables were the incidences of PHFs, ATRs, and hip fractures, and the incidences of different surgical procedures performed to treat them, categorized by age, sex, and study year. The overall incidences and age- and sex-adjusted incidences were calculated based on the annual adult population size obtained from Statistics Finland (Statistics Finland: Population structure). Because the calculations were based on the entire population rather than cohort-based estimates, there was no need to calculate 95% confidence intervals.

In Study II, the difference in the treatment methods of ATRs between sexes was analyzed using the chi-square test. Statistical reporting was performed using SAS software, Version 9.4 of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA).

In Study III, the significance of trends in all incidences was assessed using the Mann-Kendall test (R-software package Trend, version 1.1.6). The chi-square test was used to assess differences in the proportions of cemented HA and IF for surgical neck fractures in the two oldest age groups, as well as differences in incidences between age groups and sexes. P-values of 0.05 or lower were considered statistically significant.

In Study IV, the incidences were calculated based on the annual adult population size of the hospital district in question, as provided by Statistics Finland. Statistical analysis was performed using R software (version 4.2.2, R Core Team, Vienna, Austria) with the packages ggplot2 (version 3.4.0, Springer-Verlag, New York, NY, USA) and mapsFinland (version 0.1.1, mapsFinland: Maps of Finland).

5 Results

5.1 Proximal humerus fractures (Study I)

A total of 79,676 PHFs were identified. Of these fractures, 8,032 were registered only in the PHCR and treated nonoperatively in primary health care centers. Over the 23-year study period, the overall incidence of PHFs rose from approximately 60 per 10^5 to 104.9 per 10^5. The incidence rose in both sexes. In 2019, the incidence for women (146.6 per 10^5) was more than twice that for men (61.5 per 10^5), and the age-adjusted incidence in the 80+ age group was 405.1 per 10^5, which is almost four times the overall incidence. (Figs. 33a and b).

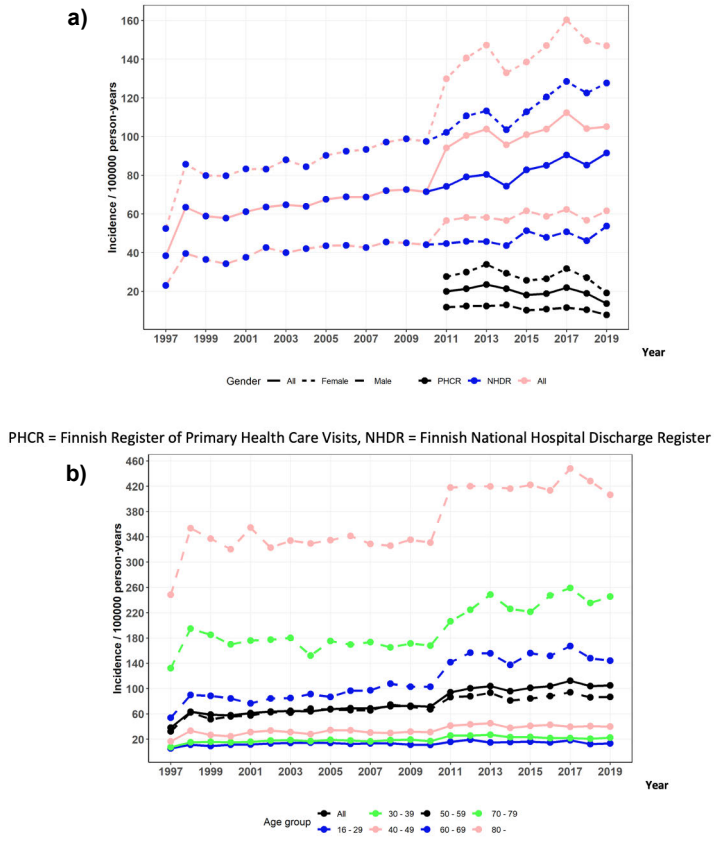


Figure 33. a) Incidence of PHFs by year and sex. **b)** Incidence of PHFs by year and age group.

During the study period, a total of 14.941 surgical operations were performed for PHFs, whereas 64,735 PHFs were treated nonoperatively. In 2019, the overall incidence of surgical treatment for PHFs was 13.2 per 10^5 (604 surgical operations), compared to an overall nonoperative treatment incidence of 92.1 per 10^5 (4,222 PHFs treated nonoperatively). The incidence of nonoperative treatment mirrored that of PHFs by age group in general and was markedly higher in the two oldest age groups (Fig. 34a). The overall incidence of surgical treatment increased during the first half of the study period and decreased during the latter half (Fig. 34b). These trends were evident in both sexes. In the 60+ age group, the use of osteosynthesis and especially plate fixation increased significantly during the first half of the study period but decreased in the latter half (Fig. 35a). In this same age group, the use of SHA increased almost three-fold during the first half of the study period. In contrast, during the latter half, TSA replaced SHA as the most commonly performed arthroplasty for PHFs (Fig. 35b).

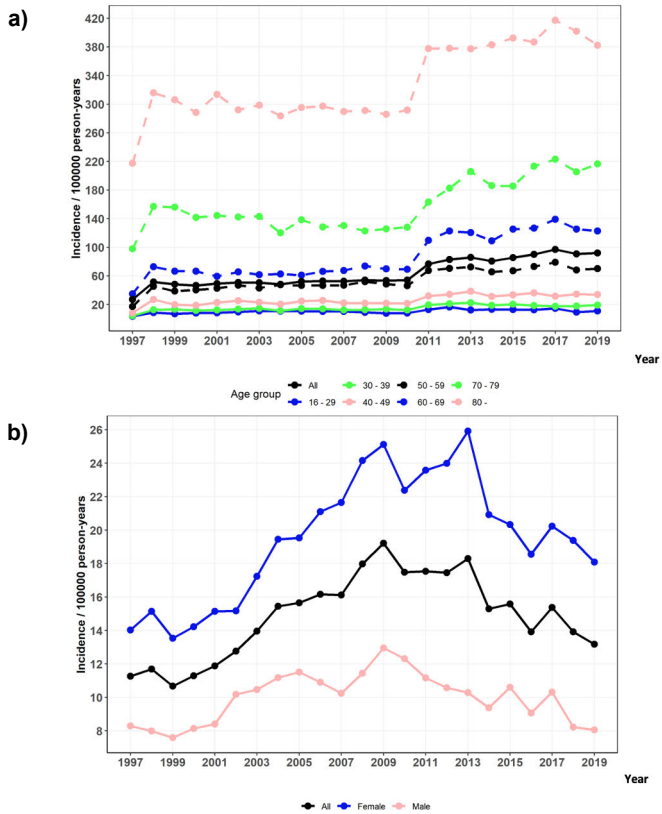


Figure 34. a) Incidence of nonoperative treatment by year and age group. **b)** Incidence of operative treatment by year and sex.

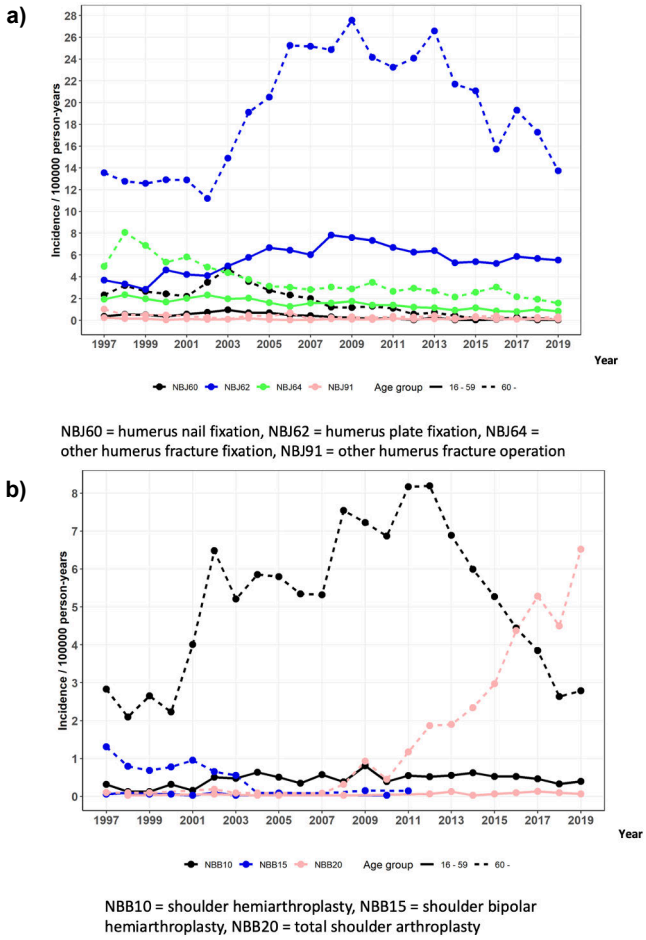


Figure 35. a) Incidence of IF by year, type, and age group. **b)** Incidence of arthroplasty by year, type, and age group.

5.2 Achilles tendon ruptures (Study II)

A total of 30,162 acute ATRs were registered in the NHDR and PHCR over the 23-year study period. Of these cases, 13,242 (44%) were treated operatively and 16,920 (56%) nonoperatively. Of the total number of cases, 2,178 were treated nonoperatively in primary health care centers and registered only in the PHCR. The overall incidence of ATRs increased from 17.3 per 10^5 in 1997 to 32.3 per 10^5 in 2019 (Fig. 36a). The rise in incidence occurred mainly during the first half of the study period, leveling off during the latter half. The incidence of ATRs rose in both sexes across the study period. ATRs were most frequent in men (22,735 cases, 75% of all cases) and in the age group of 30–49 years. In 1997, the incidences were 28.6 and 6.76 per 10^5 for men and women, respectively. In 2019, the incidence for men

was almost three times that of women, with 48.8 compared to 16.6 per 10^5, respectively.

The mean age of the patients was 44 years (SD 12.6, range 16–91) among operatively treated and 53 years (SD 16.3, range 16–101) among nonoperatively treated patients. The age-adjusted incidence of ATRs increased in every age group during the study period, but most significantly in the 70+ age group (from 6.1 to 30.1 per 10^5) (Fig. 36b.).

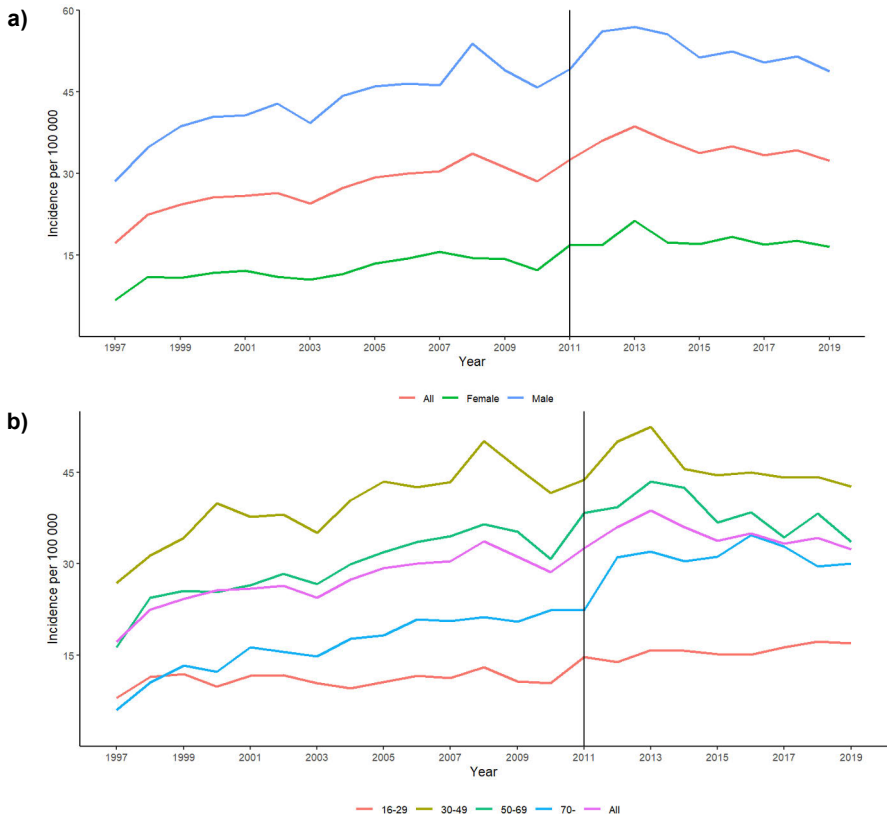


Figure 36 **a)** Overall and sex-adjusted incidences of ATRs. **b)** Age-adjusted incidence of ATRs.

The incidence of nonoperative treatment increased considerably (from 3.7 to 27.5 per 10^5), whereas the incidence of operative treatment declined (from 13.6 to 4.9 per 10^5) over the study period (Fig. 37a). The drop in operative treatment incidence occurred from 2008 onwards and was observed across all age groups (Fig. 37b). There was a statistically significant difference in the treatment method of ATRs between sexes over the study period: men were treated operatively more often (47%) than women (36%) ($p < 0.0001$).

The most reported injury mechanisms were sports injuries (7,279 cases), recreational injuries (5,082 cases), and domestic accidents (1,522 cases).

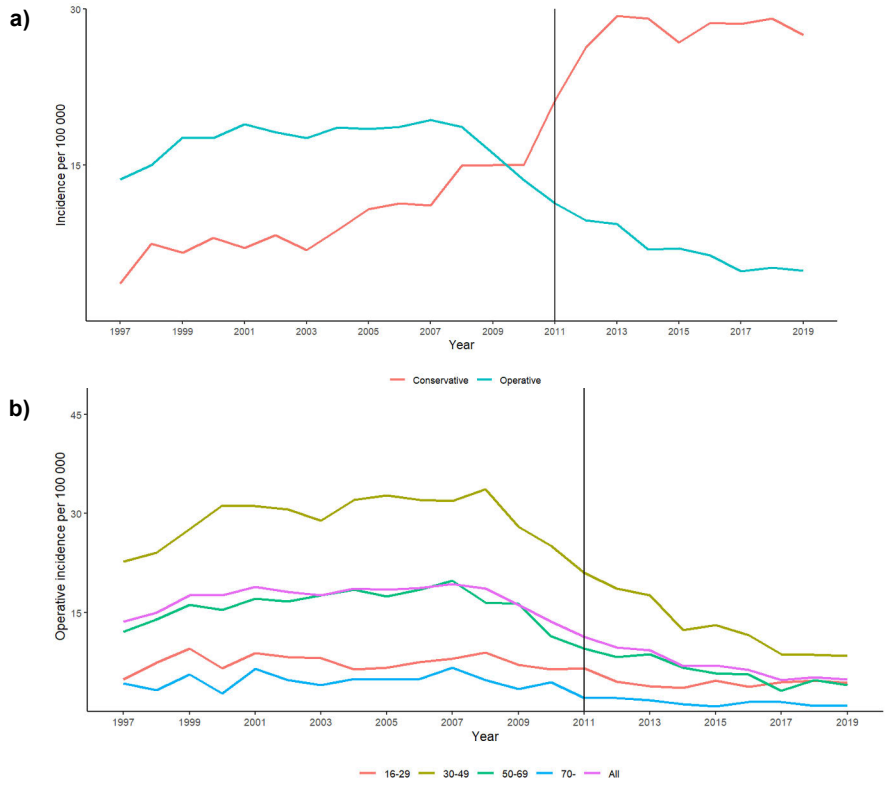


Figure 37. a) Incidence of nonoperative and operative treatment of ATRs. **b)** Age-adjusted incidence of operative treatment of ATRs.

5.3 Hip fractures (Study III)

We identified 119,128 patient records representing acute hip fractures with a primary surgical procedure. These included 73,314 femoral neck fractures (61.5%), 37,739 pertrochanteric fractures (31.7%), and 8,075 subtrochanteric fractures (6.8%). Between 1997 and 2018, no significant change was detected in the overall incidence of these fractures (Mann- Kendall test p = 0.5, indicating no significant trend). The incidences per 10^5 in 1997 and 2018 were: all operatively treated hip fractures 127.0 vs. 128.3; femoral neck fractures 80.4 vs. 77.7; pertrochanteric fractures 38.5 vs. 42.8; and subtrochanteric fractures 8.13 vs. 7.85, respectively. (Fig. 38a). The incidence was higher in the elderly age groups and among women in these groups (all p-values for comparisons between age groups and between sexes in the two oldest age groups <0.001). For instance, while the unadjusted incidence of all operatively treated hip

fractures in 2018 was 128.3 per 10^5, the 2018 incidence in patients aged 16–39 was 2.2 per 10^5 (women 0.8 / men 3.5), 18.8 per 10^5 in patients aged 40–59 (w 12.8 / m 24.7), 160.1 per 10^5 in patients aged 60–79 (w 177.8 / m 140.3), and 1,189.4 per 10^5

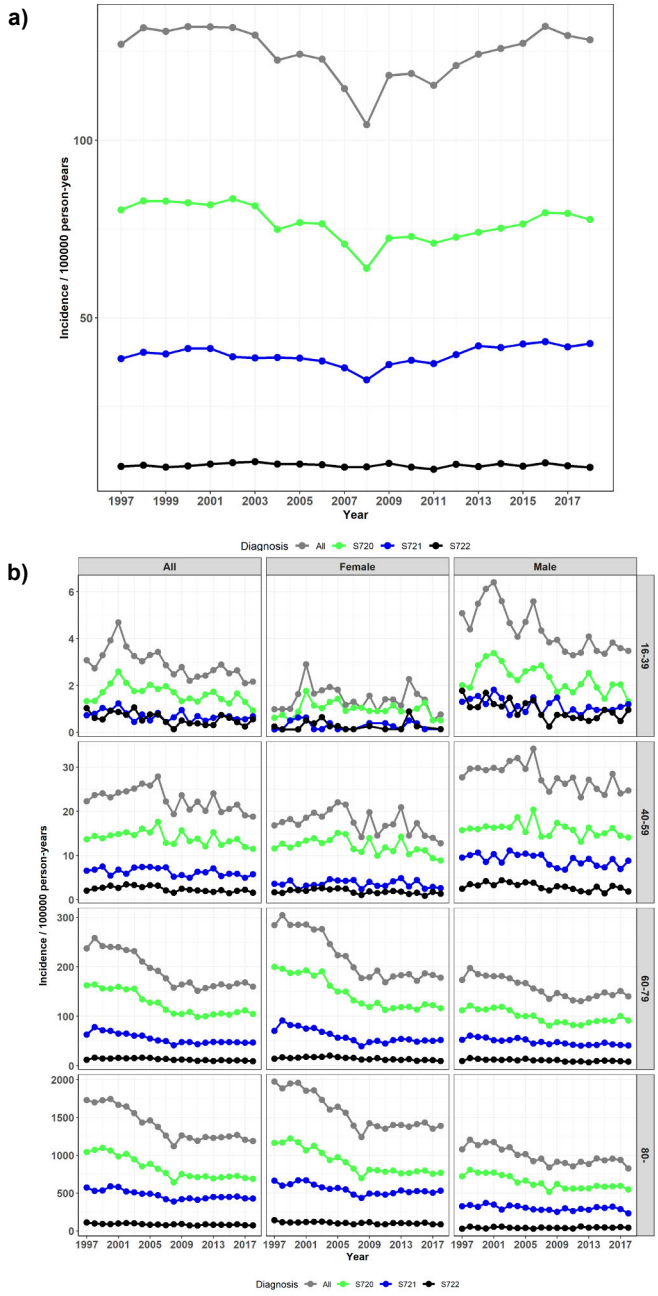


Figure 38. a) Incidence of hip fractures by diagnosis. **b)** Incidence of hip fractures by diagnosis, sex, and age group.

in patients over 79 (w 1,389.5 / m 824.7). The incidence of all operatively treated hip fractures declined in the two oldest age groups during the first half of the study period. In 1997, the incidences in patients aged 60–79 and >79 years were 237.0 per 10^5 (w 284.2 / m 173.5) and 1,728.3 per 10^5 (w 1,971.7 / m 1,079.4), respectively. (Fig. 38b). The trend was significant from 1997 to 2008 ($p < 0.001$ in both age groups), but not from 2008 to 2018 ($p = 0.4$ and $p = 0.8$, respectively).

5.3.1 Treatment of femoral neck fractures

A total of 44,813 cemented HAs, 7,946 cementless HAs, 1,504 hybrid THAs, 2,154 cementless THAs, 8,118 screw fixations, and 4,595 DHS fixations were performed to treat femoral neck fractures. In 1997–2018, the incidence of cemented HA increased from 41.1 to 59.9 per 10^5 ($p = 0.091$), and hybrid THA increased from 0.56 to 5.93 per 10^5 ($p < 0.001$), while cementless HA decreased from 13.3 to 1.2 per 10^5 ($p = 0.018$). The incidence of cementless THA increased from 0.66 per 10^5 in 1997, peaking at 4.40 per 10^5 in 2010 (1997 to 2010 trend $p = 0.003$), then decreased to 2.12 per 10^5 in 2018 (2010 to 2018 trend $p = 0.001$). The use of screw fixation decreased from 12.5 to 2.7 per 10^5 ($p < 0.001$), and DHS fixation from 7.35 to 2.06 per 10^5 ($p < 0.001$) (Fig. 39). For differences in treatment methods between age groups, see Table 2.

The shift toward cemented stems was clear in patients aged >59, whereas the treatment methods remained more heterogeneous in younger patients. In the 16–39 age group, the incidences of all other arthroplasties were largely 0, with a few sporadic years showing incidences up to 0.18 per 10^5 (mean incidence for all types: 0.01), while the cementless THA incidence was more consistent, ranging between 0 and 0.19 per 10^5 (mean 0.08). Even though the change in incidence of cemented HA did not quite reach statistical significance in the general population, in the 60–79 age group, there was a statistically significant difference in the proportion of patients treated with cemented HA in 1997 (46%) compared to 2018 (64%) ($p < 0.001$). In the same age group, there was a corresponding statistically significant decrease in the proportion of IF patients in 1997 (29%) compared to 2018 (10%) ($p < 0.001$). The same was true for the >79 age group (cemented HA in 1997 and 2018: 60% vs. 90% ($p < 0.001$); IF in 1997 and 2018: 19% vs. 6% ($p < 0.001$)).

5.3.2 Treatment of pertrochanteric fractures

A total of 17,917 short IM nailings, 16,625 DHS fixations, 1,308 screw fixations, 1,050 arthroplasties, and 839 long IM nailings were performed for pertrochanteric fractures. The incidence of DHS use for pertrochanteric fractures decreased between 1997 and 2018 from 25.6 to 4.8 per 10^5 ($p < 0.001$), and that of short IM nails increased from 6.8 to 34.2 per 10^5 ($p < 0.001$) (Figure 40, Table 2).

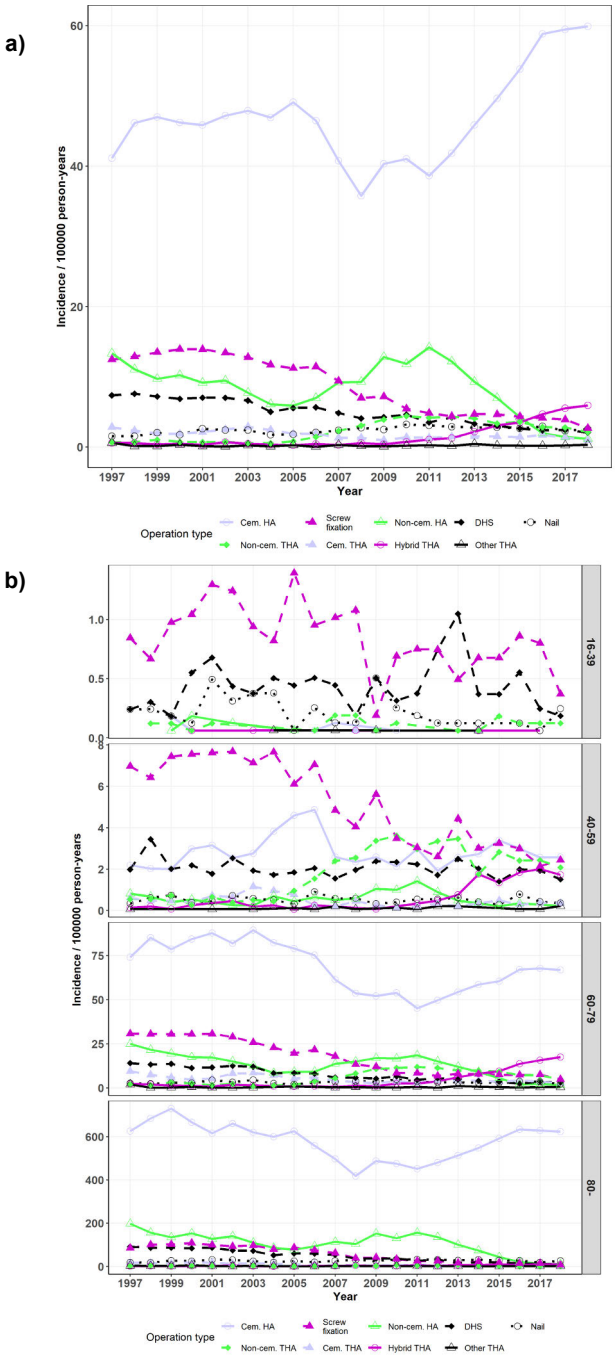


Figure 39. a) Incidence of operations performed for femoral neck fractures by operation type and **b)** age group.

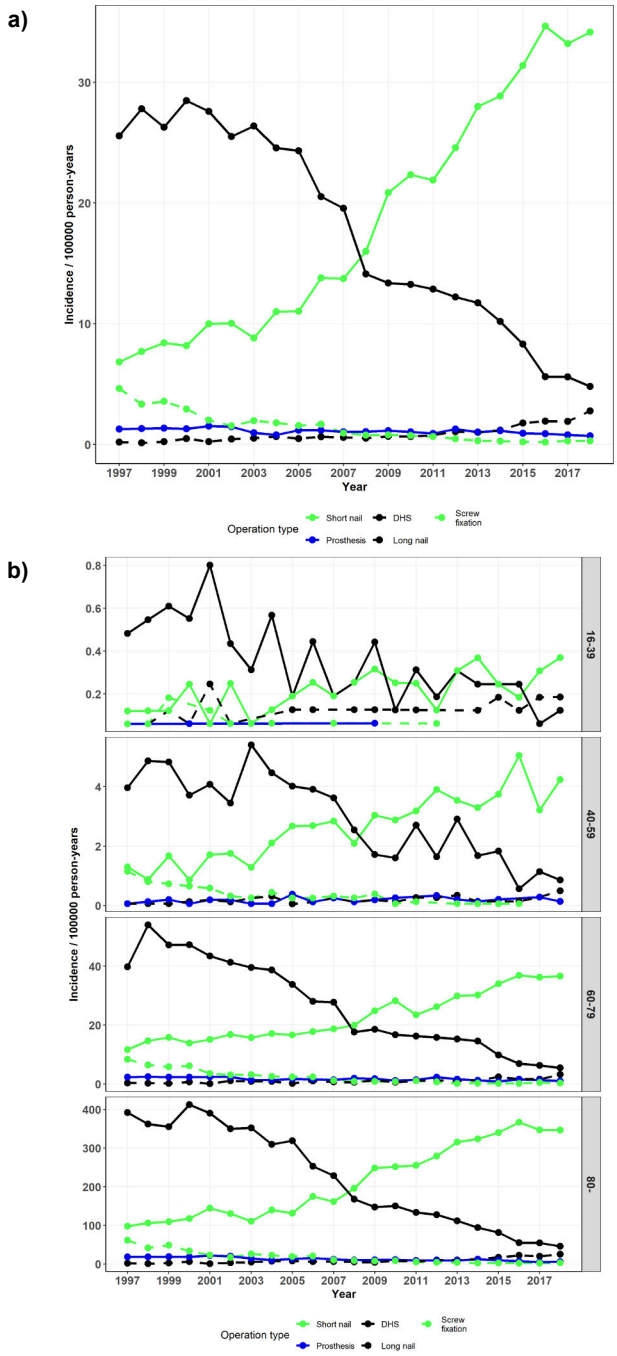


Figure 40. a) Incidence of operations performed for pertrochanteric fractures by operation type and **b)** age group.

Table 2. 1997 and 2018 incidences of operation types by age group. (HA = Hemiarthroplasty, DHS = Dynamic Hip Screw, THA = Total Hip Arthroplasty, Cem. = Cemented)

	Incidence / 100,000 person-years									
Operation type	all		age 16-39		age 40-59		age 60-79		age 80-	
	1997	2018	1997	2018	1997	2018	1997	2018	1997	2018
Femoral neck fractures										
Cem. HA	41.1	59.9	0	0	2.19	2.58	74.1	66.8	626	623
Screw fixation	12.5	2.7	0.84	0.37	6.98	2.44	30.8	4.9	85.4	6.7
Non-cem. HA	13.3	1.2	0	0	0.82	0.22	24.9	1.7	198	10
DHS	7.35	2.06	0.24	0.19	1.98	1.51	14.1	3.1	91.4	10.4
Nail	1.53	2.54	0.24	0.25	0.34	0.36	2.68	2.23	19.1	26.4
Non-cem. THA	0.66	2.12	0	0.12	0.55	2.08	2.07	5.01	1.19	1.00
Cem. THA	2.82	0.96	0	0	0.62	0.36	9.49	2.78	17.3	1.3
Hybrid THA	0.56	5.93	0	0	0.14	1.72	2.31	17.48	1.19	9.04
Other THA	0.56	0.15	0	0	0.07	0.22	1.95	0.48	4.18	2.01
Pertrochanteric fractures										
Short nail	6.8	34.2	0.12	0.37	1.30	4.24	11.7	36.6	98	346
DHS	25.6	4.8	0.48	0.12	3.97	0.86	39.8	5.5	392	46
Screw fixation	4.62	0.28	0.06	0	1.16	0	8.40	0.32	61.5	3.0
Prosthesis	1.27	0.72	0.06	0	0.07	0.14	2.31	1.03	18.5	6.0
Long nail	0.19	2.78	0	0.19	0.07	0.50	0.37	3.26	2.39	25.4
Subtrochanteric fractures										
Short nail	3.14	4.70	0.18	0.12	0.89	0.86	4.6	5.4	44.8	44.5
DHS	3.94	0.20	0.66	0	0.82	0	5.96	0.24	53.7	2.0
Screw fixation	0.58	0.04	0.06	0	0.14	0	0.97	0.08	7.76	0.33
Prosthesis	0.24	0.18	0	0	0.07	0.22	0.49	0.32	2.99	0.33
Long nail	0.22	2.73	0.12	0.43	0.14	0.50	0	2.78	3.0	25.4

5.3.3 Treatment of subtrochanteric fractures

A total of 5,231 short IM nailings, 1,326 DHS fixations, 1,136 long IM nailings, and 227 arthroplasties were performed for subtrochanteric fractures. The incidence of these fractures treated with short IM nails increased between 1997 and 2018 from 3.14 to 4.70 per 10^5 ($p = 0.063$), and those treated with DHS decreased from 3.94 to 0.20 per 10^5 ($p < 0.001$). The incidence of long IM nails increased toward the end of the study period from 0.22 to 2.73 per 10^5 ($p < 0.001$), with the most pronounced increase in the >79 age group (Fig. 41, Table 2).

The use of arthroplasty for pertrochanteric and subtrochanteric fractures remained marginal (trend $p = 0.063$ and $p < 0.001$, respectively) throughout the period (numbering 1,050 for pertrochanteric and 227 for subtrochanteric fractures), with respective incidences ranging between 0.72 and 1.53 per 10^5 (mean 1.10) and between 0.11 and 0.39 per 10^5 (mean 0.24) (Figs. 40, 41, and Table 2).

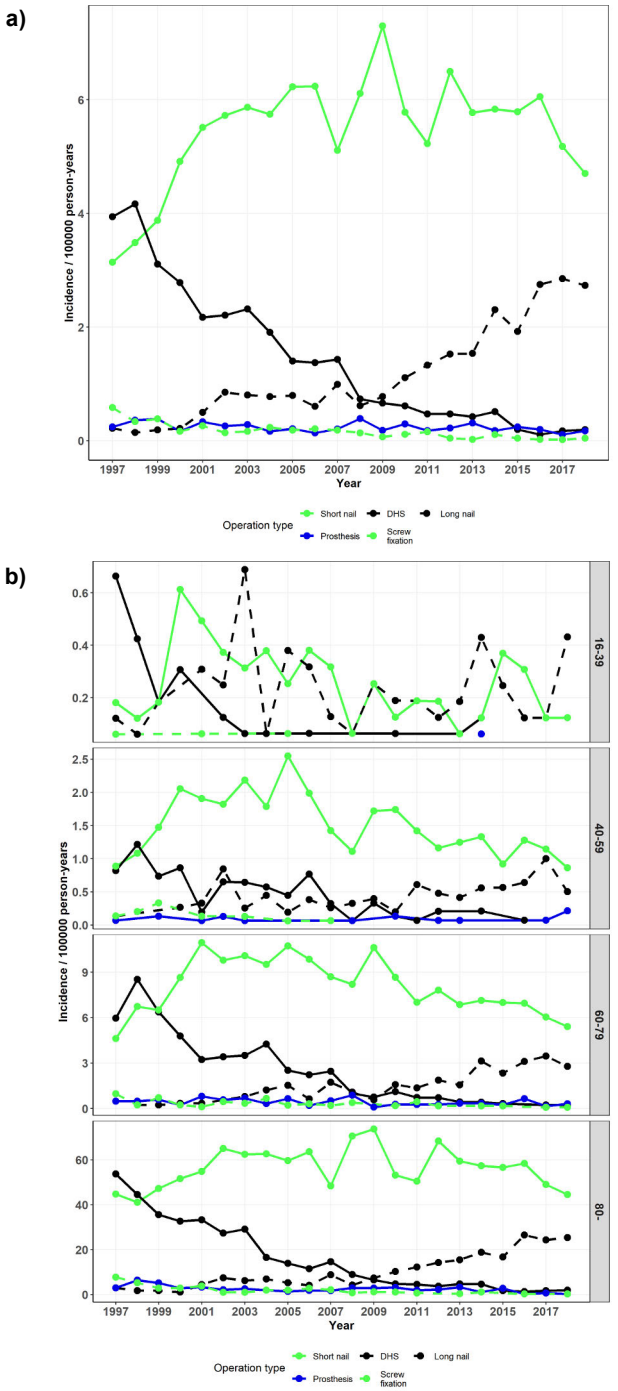


Figure 41. a) Incidence of operations performed for subtrochanteric fractures by operation type and **b)** age group.

5.4 Regional differences in incidence and treatment of proximal humerus fractures (Study IV)

In this study, we identified 79,053 PHFs, of which 64,117 were treated nonoperatively and 14,936 operatively. A total of 12,521 IFs and 2,415 arthroplasties were performed to treat PHFs. The mean age of PHF patients ranged from 64.7 years in Helsinki and Uusimaa to 69.6 years in East Savo. The proportion of patients aged 65 and older was lowest in Helsinki and Uusimaa, with 54.5%, and highest in Vaasa, with 66.6%. During 1997–2019, the mean incidence of PHFs across Finland was 78.9 per 10^5, ranging from 61.4 per 10^5 in Åland to 97.7 per 10^5 in East Savo. (Fig. 42 a). The incidence of nonoperative treatment corresponded closely to the fracture incidence per hospital district (Fig. 42 b). The incidence of operative treatment was highest in Central Ostrobothnia, at 20.2 per 10^5, and lowest in Åland, at 3.7 per 10^5 (Fig. 42 c).

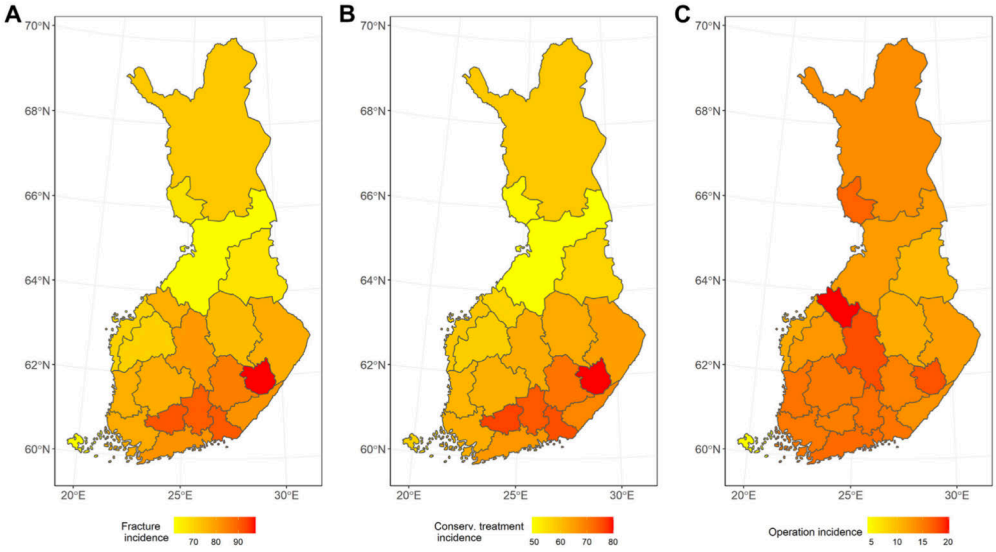


Figure 42. a) Incidence by hospital district; **b)** Nonoperative treatment by hospital district; **c)** Operative treatment by hospital district.

When examining the data in 10-year intervals, there is a clear trend toward more nonoperative treatment in 2018 compared to 1998 and 2008 (Fig. 43). The use of IF was generally highest in 2008. At the beginning of the study period, the highest incidence of IF was in Central Ostrobothnia (26.1 per 10^5, n = 16), but this declined thereafter. In contrast, IF rates in East Savo increased (from 4.8 to 30.4 per 10^5, n = 2 & 11) between 1998 and 2018. Nationally, SHA was the most common arthroplasty type in 2008, but was replaced by TSA by 2018. The highest

2008 SHA incidence was recorded in Central Ostrobothnia (9.7 per 10^5, n = 6), followed by Kymenlaakso (6.8 per 10^5, n = 10). The highest TSA incidences in 2018 were in Vaasa (5.1 per 10^5, n = 7), followed by Pirkanmaa (3.6 per 10^5, n = 16) and Central Ostrobothnia (3.2 per 10^5, n = 2). In Southwest Finland, 10 TSAs were performed, making it the second highest by number but with an incidence of 2.5 per 10^5.

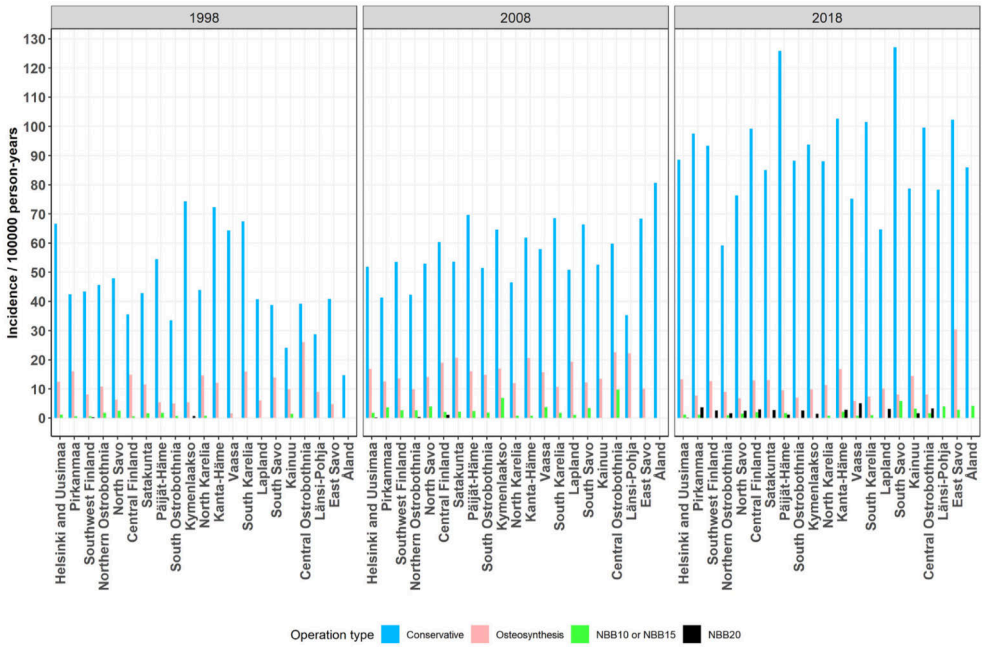


Figure 43. Incidence of treatment methods by hospital district in 1998, 2008, and 2018. (NBB10 = Shoulder hemiarthroplasty, NBB15 = Bipolar shoulder hemiarthroplasty, NBB20 = Total shoulder arthroplasty)

6 Discussion

6.1 Injury incidence rates

Studies I, II, and IV are the first national studies that combine data from both the NHDR and PHCR registers. There have been no previous studies on orthopedic trauma based on PHCR data. The 2011 increases in PHF and ATR incidences and the incidence of nonoperative treatment coincided with the introduction of the PHCR. These rises are, in fact, due to the registration of injuries that have previously been left unregistered in the NHDR. These patients were diagnosed and treated nonoperatively at primary health care centers and were never admitted to a hospital or a hospital outpatient clinic for their injuries. It is obvious that previous incidence studies based only on hospital discharge register data or hospital records have underestimated incidence rates of PHFs, ATRs, and other injuries that do not always require hospitalization.

6.1.1 Proximal humerus fractures

In Study I, we discovered that the Finnish incidence of PHFs increased steadily. Two previous studies based on Finnish NHDR data have addressed this topic. Kannus et al. (Kannus et al. 2017) published an article focusing on the rising incidence of PHFs in the elderly female population aged 80 years and older. The PHF incidence rose as high as 304 per 10^5 by 1995 and remained stable for the rest of the study period until 2015. Our data show a similar plateau in this female age group until 2011, when the PHCR was introduced. However, the age-adjusted incidence for this period is higher, at approximately 400 per 10^5. We believe that this discrepancy is due to differences in the data exclusion protocols of the two studies: Kannus, for example, excluded fractures with high-energy injury mechanisms from the NHDR data. Another NHDR study (T. T. Huttunen et al. 2012) focused on the incidence of surgical treatment for PHFs rather than fracture incidence. The study highlighted the rising trend in surgical treatment, especially plate fixation, of PHFs between 1987 and 2009, even in the elderly patient population. Our findings from 1997–2009 are consistent with those reported in the study.

Sumrein et al. (B. O. Sumrein et al. 2017) published a study on the incidence and treatment of PHFs in the Swedish population between 2001 and 2012. The Swedish hospital discharge register resembles the Finnish NHDR in its data collection principles, but as is the case with NHDR, it does not cover primary health care data. The Swedish trends in overall incidence and sex-specific incidences resemble those of the NHDR data, although the Finnish incidence is systematically lower. This difference was also noted by Sumrein et al. in their study compared to previous Finnish PHF studies, and a study from the US, where incidence was roughly 50% lower compared to Sweden. The reason for the higher incidence in the Swedish population remains unclear. The overall incidence in Sweden rose from 92.7 to 121.9 per 10^5 during the study period; in contrast, the overall incidence in the NHDR data increased from 61.0 to 71.9 per 10^5 over the same period. The surgical treatment rate in Sweden closely mirrors that observed in Finland: overall surgical incidence continued to rise until 2010, followed by a plateau phase in both populations before the clear decline demonstrated in the current study. It is conceivable that similar influences following the introduction of the Philos plate were in power in Sweden at the time, and it would be interesting to see if current trends also align.

On a global scale, a national study on PHF incidence from the United States (S. H. Kim, Szabo, and Marder 2012) reported an unadjusted incidence of 61 per 10^5 and a sex-adjusted incidence of 78 per 10^5 for females, based on fractures diagnosed in emergency departments in 2008. The incidence curve rose exponentially with age in the female population. A British study (Court-Brown et al. 2018) compared the incidences of several fractures, including PHFs, between 2000 and 2010 in Scottish patients. The incidence rose in patients aged 65 and older; in 2010, it was 355.7 and 139.6 per 10^5 for females and males, respectively. An Australian study (McLean et al. 2019) reported an increase in the overall incidence of PHFs between 2008 and 2017, from 28.5 to 45.7 per 10^5. In the age group of women older than 85, the incidence rose as high as 711.8 per 10^5. Our results are comparable with findings from all the above-mentioned studies.

Study IV found regional variation in the incidence of PHFs, with a low of 61.4 per 10^5 in Åland, and a high of 97.7 per 10^5 in East Savo. It seems that a higher incidence of PHFs is concentrated in Eastern Finland. The etiology of this regional variation is unclear. Patient factors related to falls and bone fragility, such as age, overall health status, and polymedication, may be possible contributors. (Lee, Dargent-Molina, and Bréart 2002) For example, comprehensive data show that North-Eastern Finland bears a greater morbidity burden compared to South-Western Finland. (Puska 2010)

6.1.2 Achilles tendon ruptures

ATR incidence increased in the Finnish population during the period of Study II, especially in the older age groups. This is in line with international reports of increasing ATR incidence in the 2000s. (Erickson et al. 2014, T. Huttunen et al. 2014, Lantto et al. 2015, Ganestam et al. 2016, Sheth et al. 2017) The Nordic countries are well represented in this area of study, but although there are published results from Danish and Swedish national registers, there have been no previous studies covering the national incidence of ATRs in Finland.

Lantto et al. (Lantto et al. 2015) published an article on ATR incidence based on a cohort of 515 patients treated in Oulu, Finland, from 1979 to 2011. There was an almost 10-fold increase in the incidence of ATRs, rising from 2.1 to 21.5 per 10^5 in 2011. Our findings from the first half of our study period were comparable. During the second half of our study period, the increase in ATR incidence seemed to plateau. A coinciding similar trend has been shown in recent Japanese national register data from 2010 to 2017. (Yamaguchi et al. 2021) Huttunen et al. (T. Huttunen et al. 2014) studied the incidence of ATRs and their treatment methods in Sweden between 2001 and 2012; here, the ATR incidence rose in both sexes in the Swedish population, increasing from 47.0 to 55.2 per 10^5 and from 12.0 to 14.7 per 10^5 for males and females, respectively. Ganestam et al. (Ganestam et al. 2016) published a similar study based on data from the Danish population between 1994 and 2013. The overall ATR incidence rose from 26.95 to 31.17 per 10^5 in Denmark. The overall and sex-adjusted incidences in these two studies are comparable to those observed in the Finnish population during the overlapping time periods. The more pronounced rise in incidence in the elderly age groups compared with younger ones is evident in all three Nordic countries, and may be due to the aging population increasingly taking part in high-demand sports and activities. This trend aligns with reports from the UK, the rest of Europe, North America, and Asia. (Maffulli et al. 1999, Ho et al. 2017)

6.1.3 Hip fractures

In Study III, we found that, apart from a significant decline in the elderly age groups during the first half of the study period, the incidence of hip fractures remained relatively constant. The fractures in Study III most often affected elderly women, whereas younger patients were predominantly men, a finding that mirrors previous international epidemiological studies. The decrease in operatively treated hip fracture incidence in the two oldest age groups during the first half of the study period corresponds to previously reported age-adjusted incidences of hip fractures from Finland by Kannus et al. and aligns with other epidemiological studies reporting a decreasing hip fracture incidence, especially among the elderly female population, as described in the literature review in chapter 2.4.2.2. (Brauer et al.

2009, Kannus et al. 2018, Wahlsten et al. 2021) One possible explanation for the decreasing hip fracture incidence might lie in the increasing number of elderly patients who have underwent a previous THA; these patients suffer periprosthetic fractures instead of hip fractures. For instance, the 2010 prevalence of THA in the entire US population was 0.83%, reaching 5.69% for patients aged 80-89 years. (Kremers et al. 2015) However, based on our data it appears that this decline of hip fracture incidence has since leveled off in Finland.

There was an inexplicable decrease in hip fracture incidence in 2008 (Fig. 38) apparent for both femoral neck and pertrochanteric fractures. This dip was mostly driven by a decrease in femoral neck fracture incidence in females aged > 79. At the time of the publication of study III, we could not identify any clear explanation for this decrease. Only later, when processing the same hip fracture data for a regional analysis similar to that performed in study IV, for a study yet unpublished, could we identify anomalous NHDR coding regarding the specialty of care provided, as the explanation for this finding. Roughly one half of the patients treated in the hospital district of Southwest Finland in 2007 – 2013, and a small portion of patients treated in Helsinki and Uusimaa in 2008 had this anomalous coding, which led to the exclusion of their records (see the first exclusion criteria in the exclusion flow chart of study III, Fig. 32). This is a concrete example of the effect of information bias in register data as described in chapter 2.5.2. When this anomaly in coding was adjusted for, the observed decrease in incidence was no longer apparent.

Finally, when considering the overall implications of the trends in hip fracture incidence, it should be noted, that despite decreasing or stable incidence rates, hip fracture numbers are increasing due to the growing elderly population in Finland and comparable developed countries.

6.2 Treatment

6.2.1 Proximal humerus fractures

Study I determined that the incidence of operative treatment of PHFs, especially IF with plate osteosynthesis, decreased in Finland. This was mostly replaced with nonoperative treatment. Arthroplasty for PHFs remained marginal in comparison, but a clear shift was the replacement of SHA with TSA. In Study IV, we found that despite some expected regional variation between hospital districts, there were no fundamental differences in the proportions of treatment methods. The results show that the trends in nonoperative treatment incidence for PHFs align with the overall trends of PHF incidence, as both have increased in most hospital districts, mirroring the findings of Study I.

Anatomic TSA is most unlikely used for PHFs in Finland; however, during the study period, both RSA and anatomic TSA shared the same NCSP procedure code (NBB20). Distinct NCSP coding for anatomic TSA (NBB21) and RSA (NBB22) have only very recently been added. As such, it was impossible to differentiate RSAs from anatomic TSAs based solely on NHDR data. Doing so would require cross-referencing with data from the Finnish Arthroplasty Register (FAR), which was not a part of our study design. Moreover, the coverage of the FAR has been shown to be relatively poor concerning shoulder arthroplasty (Harjula et al. 2018). Reliable coding of shoulder arthroplasty types in the FAR has only been available since 2004. Despite mandatory reporting of shoulder arthroplasty, data submission has been much more sporadic than for knee and hip arthroplasty, even in recent years. In the above-mentioned study by Harjula et al., which compared the coverage of the NHDR and the FAR between 2004 and 2015, the annual coverage of the FAR varied between 74% and as low as 45%. The indication for arthroplasty could be identified in 89% of cases, with acute fracture accounting for 21% of all arthroplasties, remaining stable throughout the study period. The overall incidence of shoulder arthroplasty increased from 9 to 21 per 10^5. While the use of hemiarthroplasty decreased substantially, the use of TSA and RSA increased during that period by 500% and 4.500%, respectively. These findings align with the trends observed in the results of Study I. Regardless of whether or not we interpret the available evidence to be in favor of RSA, there are numerous reports of its increasing use for PHFs. Finnish and Australian implant registry data show a steady rise in RSA use for various indications, with a corresponding decline in HA use. (Harjula et al. 2018, McLean et al. 2019) In the Nordic countries, RSA procedures for PHFs have followed the same upward trajectory. (Lehtimäki et al. 2020) This trend of increasing RSA use and its commercial significance is made obvious in the contiunuously lenghtening rows of implant manufacturers exhibitions at shoulder surgery congresses.

Study IV showed that among operatively treated PHFs, IF was widely used across Finnish hospital districts whereas HA and RSA incidences varied more across districts. IF is generally available and in the hands of a large group of orthopedic surgeons whereas arthroplasty is performed by a limited number of surgeons and hospitals. An interesting question is whether shoulder specialists, with their full repertoire and experience in treatment of PHFs and PHF sequelae, are more prone to the influence of current literature than other orthopedic and trauma surgeons who concentrate on osteosynthesis in general. Another interesting note is that although the incidences in study IV, including those of arthroplasty, were reported according to the hospital district of the patient, we know that arthroplasty for PHFs is centralized to specialized institutions in Finland. For instance in 2018, to our knowledge, no arthroplasties for PHFs were performed at Central Osthrobothnia

Central Hospital or at Lapland Central Hospital; these surgeries were performed at Oulu University Hospital despite being registered to the hospital districts of the patients. We made a listing of the hospitals for patients who had undergone arthroplasty for a PHF in 1997 – 2019 and most arthroplasties were performed in the five university hospitals in Finland, and a smaller amount in four larger central hospitals (Jyväskylä in Central Finland, Lahti in Päijät-Häme, Vaasa in Vaasa hospital district and Seinäjoki in Southern-Pohjanmaa, in receding order by operation numbers). Only few cases were treated in smaller or private hospitals. In these cases, the patients were referred to arthroplasty units for treatment evaluation. One might question, if patients referred to a specialized unit for operative consultation might be more prone to end up treated operatively compared to patients treated in units where shoulder arthroplasty is readily available as an option. Are all patient related issues concidered and shared decision making principles adhered to in a similar way? When a patient has travelled a long way and is already here, why not operate?

The ProFHER trial of 2008–2011, a British multi-center RCT, showed no difference in clinical outcomes between operatively and nonoperatively treated patients with displaced PHFs at 5-year follow-up. (Rangan et al. 2015, H H Handoll et al. 2017) As with all study designs, ProFHER has its limitations. For example, fractures were treated with either IF or SHA based on the surgeon's preference. Regardless, the trial has been widely acknowledged and discussed, and its influence on clinical practice has been a further area of study. A 2017 survey revealed that approximately half of all British surgeons had changed their practice because of the trial's findings (Jefferson et al. 2017). We look forward to the results of ongoing trials and being able to provide more evidence-based care for our PHF patients. One of these trials, the ProPHER-2 trial, will compare outcomes of RSA, HA, and nonoperative treatment of PHFs. Another, the Nordic DeltaCon trial, will compare the results of nonoperative treatment versus RSA for PHFs. (A. Launonen et al. 2019, Rangan et al. 2023) Hopefully these, as well as other future studies, will deliver answers to the remaining open questions, especially those concerning the use of arthroplasty for PHFs.

In light of these above-mentioned studies and an updated Cochrane review of 2022 (H. H. G. Handoll et al. 2022), there is high-certainty evidence supporting a more nonoperative line of treatment for displaced PHFs. Similar to the British survey findings, our perception is that the use of locking plates, and operative treatment in general, has gradually declined in clinical practice, while arthroplasty has gained popularity in Finland. Our findings confirm both trends.

6.2.2 Achilles tendon ruptures

The incidence of operative treatment of Finnish ATRs declined from 13.6 to 4.9 per 10^5 over the study period. A shift towards more nonoperative treatment was observed in all age groups. In Sweden and Denmark, operative treatment rates have been declining since around 2005. (T. Huttunen et al. 2014, Ganestam et al. 2016) A coinciding declining trend of operative treatment in 2010 – 2019 has even been seen in the USA, spanning all age groups. (Wilder et al. 2023) Mattila et al. (V. Mattila et al. 2015) reported that the incidence of operative treatment of ATRs in Finland rose steadily between 1987 and 2011, from 11.1 and 2.5 per 10^5 to 20.5 and 4.2 per 10^5 for men and women, respectively. This rise peaked from 2007 to 2008, followed by signs of an impending decline. We have now verified that this drop in the operative treatment of ATRs has continued, and we have demonstrated that it represents a real change in practice, rather than a possible simultaneous decline in ATR incidence. This change in treatment principle aligns with reported international trends and current literature cited in the literature review chapter 2.3.8, which have shown that compared to operative treatment, nonoperative treatment provides comparable functional outcomes, with only a slightly increased re-rupture risk and without the complications associated with surgery.

6.2.3 Femoral neck fractures

Our results in Study III show that between 1997 and 2018, the use of IF significantly decreased in Finnish patients, especially those aged >59. Similar findings have been reported from Denmark during 1997–2017, where the use of IF decreased from 48% to 25% of all operatively treated femoral neck fractures in patients aged 60+. (Wahlsten et al. 2021) In Finland, the use of screw fixation decreased even in younger patients. This trend may in part be explained by a relative increase in arthroplasty and DHS use in this age group. Another possible explanation is the introduction of novel implants such as the FNS, which is offered as an alternative to DHS or screw fixation. The NCSP system does not currently differentiate between the DHS and FNS, but because the FNS was introduced in 2018, there were few, if any, fractures treated with FNS included in the study.

Previous Finnish reports of increasing use of cementless stems in older fracture patients conflicted with available evidence on the subject. (Hongisto et al. 2014) According to our data, this rise was short-lived, as the use of cementless HA has significantly decreased. The use of hybrid THA gained popularity especially in patients aged 60–79, but also in younger patients aged 40–59. These younger fracture patients differ from elective THA patients, as alcoholism and other conditions associated with higher risks of hip fracture and surgical complications are common, thereby influencing the choice of treatment method. In this age group, the first-hand

choice for elective THA patients with good bone quality is a cementless stem. (Bunyoz et al. 2020)

There are reports of increasing use of THA for hip fractures in the US and in European countries such as Norway. (Miller et al. 2014, Bartels et al. 2018) According to Miller et al., the use of THA among all operations performed for femoral neck fractures in patients aged <65 increased in the US from 1.4 to 13.1% during 1999–2011. We see a corresponding trend of increasing THA use in patients aged 40–59, where, based on current data, cementless and hybrid THA use grew from 5% to 33% of all operations performed for femoral neck fractures during 1997–2018. In Finland, the use of cemented THA has become increasingly rare thanks to the advances in acetabular polyethylene liner technology (highly cross-linking and use of vitamin E) leading to decreased risk of aseptic loosening of cementless acetabular components, as indicated by the FAR. (FAR)

6.2.4 Trochanteric fractures

The use of DHS decreased markedly in Finland, while that of short IM nails increased. Both trends were statistically significant. The figures crossed in 2008–2009 and the trend continued thereafter. The trend was similar but less apparent in the youngest patients, which may be due to the far lower incidence in this population (the absolute numbers of operations were small in age group 16–39, with 124 DHSs and 76 short IM nails during the entire period) and perhaps the preference of avoiding the trochanter-tip mutilating entry of IM nails. A clear reason for this trend cannot be pointed out, but traditions and customs and perhaps an effort to standardize equipment in clinics, as well as surgeon's preference and/or interpretation of the available evidence probably play a role. The A trend of favoring IM nails has also been observed in the US, where in 1999–2006, the IM nailing rate of intertrochanteric fractures increased from 3% to 67%. (Anglen and Weinstein 2008) In Denmark, the choice of implant in trochanteric fractures also shifted toward IM nailing in 1997–2017. (Wahlsten et al. 2021) In Sweden, however, in cases of simple 31-A1 trochanteric fractures, DHS was still more commonly used (65%) compared to short IM nails (28%). (Mattisson, Bojan, and Enocson 2018)

Our finding that subtrochanteric femoral fractures were largely treated with short IM nails is interesting. This may be partially explained by the inter-observer variation of fracture classification as per- and intertrochanteric or subtrochanteric, a subject we sometimes find ourselves debating in radiograph meetings. Some of these subtrochanteric fractures are most likely in fact pertrochanteric. The AO/OTA classification of femoral fractures separates fractures of the trochanteric area into stable and unstable subtypes, guiding the decision between implant choices. However, the inter-observer reliability of this classification and other fracture

classification systems of the trochanteric area has been questioned. It has been suggested, that when discussing trochanteric fractures in literature, we should adhere to only using the three upper AO/OTA fracture categories A31-A1, A2 and A3 instead of their underclasses to optimize reproducibility. (Schipper et al. 2001) Another explanation might be the use of medium-length nails, such as the 240–280 mm-long Proximal Femoral Nail Antirotation by Synthes, which is indicated for "high subtrochanteric fractures" according to the manufacturer. The NSPC system divides IM nailing of the femur into two categories: NFJ54 (Intramedullary Nailing of Upper Femur) and NFJ60 (Intramedullary Nailing of Femur). These procedural codes are quite ambiguous and might further explain our findings. Mattisson, Bojan, and Enocson (Mattisson, Bojan, and Enocson 2018) reported in their study based on the Swedish Fracture Register that in patients treated between January 2014 and December 2016, 56% of AO/OTA 31-A2 fractures were treated with short nails, 33% with DHS, and 9% with long nails, whereas in cases of 31-A3 fractures, 27% were treated with short nails, 12% with DHS, and 60% with long nails.

There are global reports describing the use and results of hip arthroplasty as first-hand treatment for pertrochanteric and subtrochanteric fractures. (J. T. Kim et al. 2018, Xie and Zhou 2020) In Finland, as expected, the use of primary arthroplasty was marginal in these fractures but still existent. Despite the trend test indicating a statistically significant change in cases of subtrochanteric fractures, this cannot, in our view, be interpreted as a change in clinical paradigm due to the very small number of procedures. We suspect that the incidence might be even smaller, as some periprosthetic fractures of the proximal femur may have been miscoded as proximal femur fractures, despite our efforts to screen out such cases based on additional diagnosis and procedural codes in the records.

6.3 Strengths and limitations of the present studies

The most important strength of these nationwide studies is that they include the entire population of Finland. Secondly, Studies I, II, and IV also included data from primary health care patients, making them more representative of real-world pratice compared to previous studies relying solely on hospital registers. The cover and validity of the registers has been studied and found to be good as described in chapter 2.1.

There are also several limitations to the studies due to their retrospective and observational design and reliance on administrative databases. The quality of the data derived from registers is only as good as the quality of data reported to them. A consequence of this led to the erroneous exclusion of certain records as described in chapter 6.1.3. Identifying acute injuries and their treatment from the vast quantity of patient records required extensive exclusion procedures, as described in the

Materials and Methods section. Data on injury classification other than ICD-10 codes or more specific patient-related issues were not available. This is important, as we can only report what has been done, not the reasoning behind it. The observed changes in treatment methods are interpreted under the assumption that patient-related characteristics other than age and sex remained relatively stable over the study period. We look forward to future studies from countries with high-quality fracture registers, such as Sweden, where national, fracture-specific data have been collected for over a decade, which will hopefully provide answers to this issue. (Möller et al. 2022)

Records in which the exact diagnosis code or possible surgical procedure codes were not clearly ascertainable were excluded. The NHDR and PHCR do not register the laterality of injury, which necessitated the exclusion of injuries of the opposite side. We also found that external cause of injury codes and codes categorizing patient encounters as primary or control visits were often lacking. In cases where patients had multiple recorded encounters over a period of several years, these records had to be manually reviewed to exclude duplicate injuries. Especially hip fracture diagnosis codes often lingered in subsequent patient records, probably reflecting the comorbidity and disability (i.e., health care visits) that follow this devastating injury, especially in the elderly. Accordingly, we decided to include only the first recorded operatively treated hip fracture per patient, or the first right- and first left-sided operatively treated fractures when laterality data were available through NCSP coding (Fig. 32). Moreover, identifying nonoperatively treated hip fractures, which we were originally hoping to report, was clearly infeasible. We acknowledge that a small portion of hip fractures are treated nonoperatively, such as certain cases of trochanter tip avulsions or cases where the patient is in terminal care or unwilling to undergo surgery. However, as the portion of these nonoperatively treated hip fractures is small, we consider the trends in operatively treated hip fracture incidence to represent the overall trends in hip fracture incidence with reasonable reliability. This also seems to be the case when comparing our results with previously published data on Finnish hip fracture incidence. (Kannus et al. 2018)

6.4 Future aspects

The increasing numbers of these and other orthopedic traumas pose a rising challenge to our health care system and national economy. It is important to closely monitor trends in incidence when planning and resourcing health care, and to continuously re-evaluate the efficacy of the treatments we provide. We still do not have all the answers to questions of efficacy, but work is ongoing. Finally, it is important to assess whether the knowledge of best practices translates into actual practice, or at the very least whether we as health care providers are on the right path.

RCTs are arguably the gold standard of scientific research, and systematic reviews derived from them form the foundation for treatment recommendations. Still, all this effort may be meaningless if it is not implemented into clinical practice. The findings of this research project show that, in the case of these common orthopedic traumas, Finnish treatment practices have indeed developed in line with evidence-based medicine, with a reasonably good national consensus. The Philos plate and IF of femoral neck fractures have followed the trajectory of Scott's parabola, and only time will tell if fracture RSA is next in line.

7 Conclusions

The following conclusions can be drawn from the studies in this thesis:

1. The incidence of PHFs has risen in Finland, and there has been a clear evidence-based shift toward nonoperative treatment of these fractures.

2. The incidence of ATRs has risen in Finland, especially among the elderly. Nonoperative treatment has become mainstream across all age groups, in accordance with accumulating evidence favoring nonoperative care.

3. Hip fracture incidence has remained relatively stable, although numbers have increased due to the growing elderly population. In Finnish femoral neck fractures, we observed an evidence-based shift in treatment from IF to arthroplasty with cemented stems.

4. In the treatment of trochanteric fractures, the use of DHS was largely replaced with CMNs. In operative treatment of PHFs, reverse shoulder arthroplasty has become more common in relation to IF and hemiarthroplasty. Both trends have also been observed internationally, despite a lower level of evidence in their favor.

5. There has been a rather good national consensus regarding the treatment of PHFs throughout the observed decades in Finland.

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