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PELVIC FRACTURES – EPIDEMIOLOGY AND TREATMENT

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KAROLINSKA INSTITUTET * ANNO 1810 *

Karolinska Institutet

Stockholm 2023

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Published by Karolinska Institutet.
Printed by Universitetsservice US-AB, 2023

ISBN 978-91-8016-954-7
Illustrations including cover illustration by Pontus Andersson/Pontus Art Production

Pelvic Fractures – Epidemiology and Treatment

Thesis for Doctoral Degree (Ph.D.)

By

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The thesis will be defended in public at the Nanna Svartz auditorium, J3:12, Bioclinicum, Karolinska University Hospital, Solna, May 12th 2023 at 09:00 AM

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Populärvetenskaplig sammanfattning

Bäckenfrakturer är svåra skador som i många fall orsakar stort lidande och funktionsnedsättning för den drabbade individen, och som i vissa fall kan vara del av ett livshotande tillstånd. Acetabularfrakturer är en undergrupp av bäckenfrakturer som engagerar höftens ledpanna och som ofta omnämns separat. Historiskt sett har behandlingen av bäckenfrakturer varit icke-kirurgisk. Behandlingsmetoden utgjordes av långvarig immobilisering följd av långsam igångsättning medan frakturen höll på att läka. I dagsläget är operation vid felställd högenergi-bäckenskada vanligt förekommande. Operationsmetoder har utvecklats, både vad gäller implantat samt förståelse för skadans art och hur felställningar kan åtgärdas. Detta har skett parallellt med förbättrade anestesiologiska tekniker och ett mer standardiserat omhändertagande av traumapatienter. Operation möjliggör tidig mobilisering samt motverkar stora deformiteter och förbättrar på så sätt det kliniska resultatet. Kirurgin anses dock avancerad och är förknippad med ett flertal komplikationer.

Syftet med denna avhandling var först att undersöka förekomst av bäckenfrakturer i Sverige för att bättre förstå skadans utbredning samt eventuella trender. Därefter analyserades patienter opererade för bäcken- och acetabularfrakturer. Målsättningen här var att kartlägga komplikationer samt att utvärdera en specifik röntgenbaserad metod för att följa rörligheten i bäckenet under läkning. Förhoppningen var att med hjälp av kunskap från dessa studier i framtiden kunna förbättra omhändertagandet av patienter med bäckenfrakturer.

I den första av fyra studier, konstaterades en påtaglig ökning av bäcken- och acetabularfrakturer i Sverige från 2001 till 2016. Denna utgjordes primärt av ett ökat antal frakturer bland äldre kvinnor, men ökningen förekom i hela den vuxna populationen. Kirurgisk behandling var överlag ovanlig, men stora skillnader mellan män och kvinnor förelåg, som inte tydligt kunde förklaras. Kvinnor opererades i mindre utsträckning både bland äldre och yngre patienter.

I de nästkommande två studierna bekräftades den höga komplikationsrisken vid kirurgi av bäcken- och acetabularfrakturer. Mellan 21-25% av patienterna behövde reopereras, och de vanligaste anledningarna var djup infektion, utveckling av artros och felplacerade implantat. Reoperationer innebär såväl ett lidande för den drabbade patienten, som ökade vårdresurser. Statistiska analyser visade att operation med primär höftledsplastik minskade risken för reoperation vid acetabularfrakturkirurgi, vilket kan stödja beslutet att operera utvalda, framförallt äldre, patienter med denna metod. Andra komplikationer som dessa patienter drabbades av var nervskada, blodpropp i ben och lunga, liksom lunginflammation och urinvägsinfektion.

Den avslutande studien visade god användbarhet av den datortomografi-baserade metoden CTMA (Computed Tomography Micromotion Analysis) vid uppföljning av patienter med opererade bäckenfrakturer. Här konstaterades störst rörlighet under de första sex veckorna efter operation, samt en stor individuell variation i storleken av rörlighet.

Sammanfattningsvis förelåg en ökning av bäcken- och acetabularfrakturer i Sverige, talande för ett ökat behov av vård av patienter med dessa skador. Den operativa behandlingen är avancerad med hög risk för komplikationer, vilka måste beaktas under hela vårdförloppet samt under uppföljningen. En noggrann selektion av vilka patienter som ska opereras samt med vilken metod bör eftersträvas. CTMA bedöms användbart vid uppföljning av patienter med opererade bäckenfrakturer, och kan komma att användas vid analys av frakturläkning i framtiden.

Abstract

The epidemiology of pelvic and acetabular fractures has been sparsely described and up-to date information on incidence, demographic distributions and treatment are lacking. Surgical treatment of pelvic and acetabular fractures is often considered for patients after high-energy trauma and/or in acetabular fractures with intraarticular incongruency. The surgery is associated with numerous complications, which has not been properly described for unselected cohorts of patients. Further knowledge regarding the healing process after surgical treatment of pelvic fractures is also needed.

Aim: The aim of this thesis was first to determine the epidemiology of pelvic and acetabular fractures in the Swedish adult population, including the rate of surgical treatment. Second, surgical treatment of both pelvic and acetabular fractures was independently explored to establish rates of complications with particular focus on reoperations. Finally, Computed Tomography Micromotion Analysis was used in the follow-up of surgically treated patients with pelvic fracture. The primary aim here was to investigate the practicability of the method, and secondarily to try to quantify movement in the pelvis during the healing process.

Methods: The National Patient Register was used to acquire data for the epidemiological analysis (Study I). In the analysis of complications after pelvic and acetabular fracture surgery, all adult patients treated for a pelvic or an acetabular fracture at the Karolinska University Hospital in Stockholm, Sweden during a ten-year period were included (Study II+III). To investigate the usability of Computed Tomography Micromotion Analysis, a prospective clinical study was conducted including ten patients surgically treated for a pelvic fracture. All patients were followed with computed tomography for one year (Study IV).

Results: The incidence of pelvic and acetabular fractures increased from 64 to 80 per 100,000 person-years in the Swedish adult population from 2001 to 2016. 2% of all pelvic fractures were surgically treated, compared to 15% for acetabular fractures. The rate of surgical treatment was higher for males (Study I).

A total of 194 patients with surgically treated pelvic fractures and 229 patients with surgically treated acetabular fractures with a median follow-up of 4.9 years were analysed. For the pelvic fracture patients, the rate of reoperation was 25% with infection being the most common cause of reoperation. In the acetabular fracture cohort, reoperation rate was 21%, with arthrosis as the most common indication. Surgical treatment with primary Total Hip Arthroplasty was associated with a reduced risk for reoperation, as was male gender, for the acetabular fracture patients (Study II+III).

The follow-up of surgically treated pelvic fracture patients with Computed Tomography Micromotion Analysis demonstrated largest movement between 0-6 weeks postoperatively, with reduced movement thereafter (Study IV).

Conclusions: The incidence of pelvic and acetabular fractures increased markedly during 2001-2016, indicating a potential upsurge of patients in need of treatment. Reasons for this increase remains unclear but cannot solely be attributed to an ageing population. Surgical treatment of pelvic and acetabular fractures was associated with a high risk of reoperation and other subsequent complications, and measures need to be taken to try to reduce this risk. Gender discrepancies seemed to exist, both regarding rate of surgical treatment but also possibly in risk of reoperation after acetabular fracture surgery. These differences need further scrutiny. Computed Tomography Micromotion Analysis was a valid tool for investigating motion in the pelvis after surgical treatment of pelvic fracture patients. This method has potential to aid in the determination of fracture healing.

List of scientific papers

The thesis is based on the following papers, referred to in the text by their Roman numbers.

I. Lundin N, Huttunen TT, Enocson A, Marcano AI, Felländer-Tsai L, Berg HE.
Increasing incidence of pelvic and acetabular fractures. A nationwide study of 87,308 fractures over a 16-year period in Sweden.
Injury. 2021;52(6):1410-1417.

II. Lundin N, Enocson A.
Complications after surgical treatment of pelvic fractures: a five year follow-up of 194 patients.
Eur J Orthop Surg Traumatol. 2022. Published online 10 February 2022.

III. Lundin N, Berg HE, Enocson A.
Complications after surgical treatment of acetabular fractures: a 5-year follow-up of 229 patients.
Eur J Orthop Surg Traumatol. 2022. Published online 20 May 2022.

IV. Lundin N, Olivecrona H, Bakhshayesh P, Gordon Murkes L, Enocson A.
Computed Tomography Micromotion Analysis in the follow-up of patients with surgically treated pelvic fractures – A prospective clinical study.
Eur J Orthop Surg Traumatol. 2023. Published online 14 April 2023.

Contents

List of abbreviations

AE	Angioembolization
APC	Anterior Posterior Compression (pelvic fracture type)
ASA	American Society of Anesthesiologists
CI	Confidence Interval
CR	Conventional Radiography
CT	Computed Tomography
DEG	Degrees
CTMA	Computed Tomography Micromotion Analysis
DVT	Deep Venous Thrombosis
EQ-5D	EuroQol group-5 Dimensions
GCS	Glasgow Coma Scale
ICD-10	International Classification of Diseases, Tenth revision
ICU	Intensive Care Unit
IQR	Interquartile Range
LC	Lateral Compression (pelvic fracture type)
MM	Millimeters
NPR	National Patient Register
OR	Odds Ratio
ORIF	Open Reduction Internal Fixation
PE	Pulmonary Embolism
PJI	Prosthesis Joint Infection
PROM	Patient Reported Outcome Measures
RSA	Radio-Stereometric Analysis
SI	Sacroiliac
SSI	Surgical Site Infection

SD	Standard Deviation
THA	Total Hip Arthroplasty
VS	Vertical Shear (pelvic fracture type)
VTE	Venous Thromboembolic Event

Introduction

Trauma is one of the leading causes of death in the younger adult population globally today (Rossiter, 2022). Traumatic injuries also contribute to millions of people of working-age being permanently injured every year. The burden of trauma varies worldwide, with low- and middle-income countries being especially affected, as well as countries engaged in armed conflict (Rossiter, 2022). In Sweden, trauma is reported to be the fourth and sixth overall cause of death for males and females respectively in 2021 (Socialstyrelsen, 2023).

Pelvic fractures are not the most common among orthopedic injuries, they are said to constitute only approximately 1.5% of all fractures (Court-Brown, 2006). They are however frequently found in multitrauma patients, typically after motor vehicle accidents or fall injuries in a civilian setting, or after blast injuries in a military setting (Abdelrahman et al., 2020, Rankin et al., 2020). Approximately 10% of patients admitted at trauma centers are reported to have a pelvic fracture (Abdelrahman et al., 2020). These patients often present not only with their pelvic injury, but often with other concomitant injuries which contribute to an overall severe and sometimes life-threatening situation (Holtenius et al., 2018). The management and treatment of these patients is a team effort requiring several competencies and a structured trauma organization. This is true both for the initial life-saving phase and primary treatment, but also in the longer term with often extensive rehabilitation processes involving several professions.

Despite the severity of the high-energy pelvic fracture, and maybe since it is not commonly encountered to most orthopaedic surgeons, comparably little is known regarding its epidemiology and treatment regimes. Conducting research in trauma is challenging due to the often acute need for treatment as well as the heterogenicity of the affected patients, but still important. This thesis aims at exploring the epidemiology and treatment of pelvic fractures in Sweden, as well as clarifying possible surgical complications and improvements in radiological follow-up regimes.

1 Background

1.1 Anatomy

The anatomy of the human pelvis has changed considerably during the course of human evolution due to its fundamental importance in our survival. One vital function is the enabling of the bipedal locomotion that optimizes mobility (Gruss et Schmitt, 2015). The two hip bones (os coxae) are linked anteriorly via the symphysis and posteriorly to the sacrum via the sacroiliac (SI)-joints. The acetabulum is the hip joint socket, the articular surface to which the head of the femur articulates. The male and female pelvis differ somewhat in their anatomy where the female pelvis has a wider pubic arch with a round pelvic inlet and the male pelvis presents with an oval/heart shaped inlet, deeper pelvic cavity, and higher iliac crests, potentially designed to support a heavier body build (Figures 1 and 2).

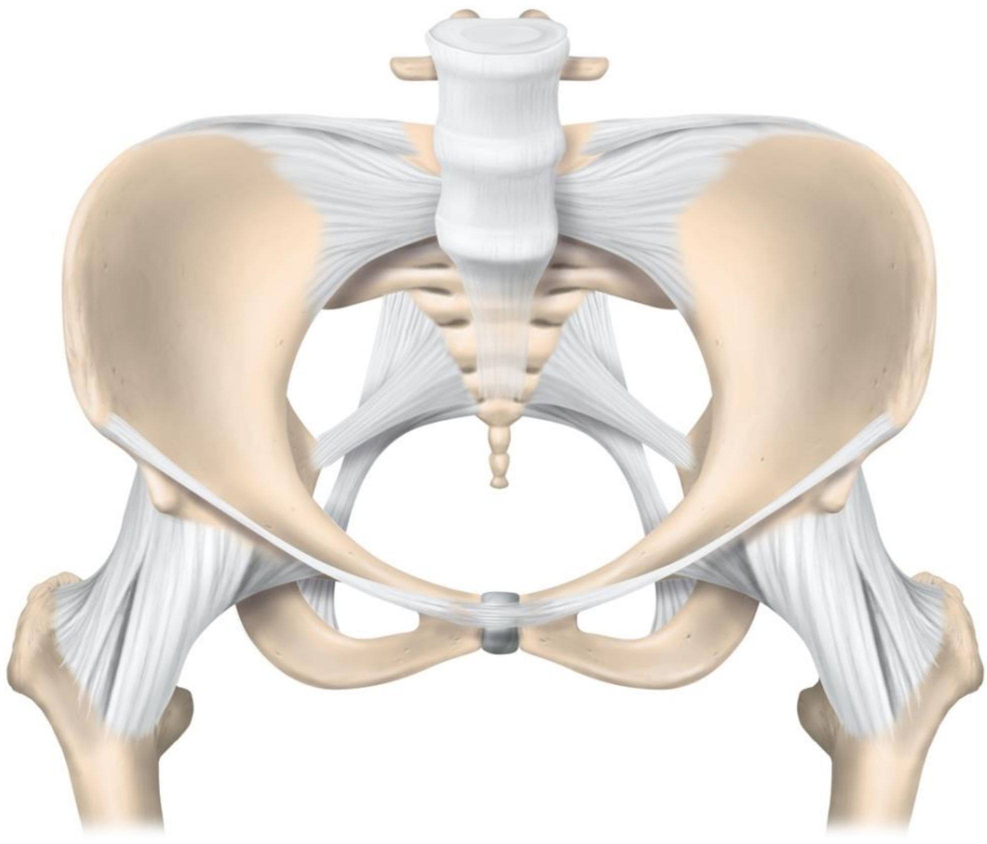

FIGURE 1. The female pelvis, anterior view

The pubic symphysis is a non-synovial amphiarthrodial joint containing a fibrocartilaginous disc between two thin layers of hyaline cartilage. The two ligaments, the superior and inferior pubic ligament, hold the symphysis together, with the inferior one providing the most of the joint's stability (Gamble et al., 1986) (Figure 2).

The hip bones and sacrum are held together posteriorly via the SI-joints by strong ligaments, which create a resilient bony ring structure. The anatomy of the sacrum poses a specific surgical challenge due to different anatomic variances with a so-called dysmorphic sacrum with a narrower corridor in the first sacral vertebrae for potential SI-screw placement. Important anatomical landmarks in relation to the ligament structures are the sciatic spine and sciatic tubercle, insertions for the sacrospinous and sacrotuberous ligaments respectively, as well as the transverse processes of the fifth lumbar vertebrae where the iliolumbar ligaments attach. The anterior and posterior SI-ligaments are important stabilizers of the SI-joints, with the posterior part being the stronger of the two (Figure 2).

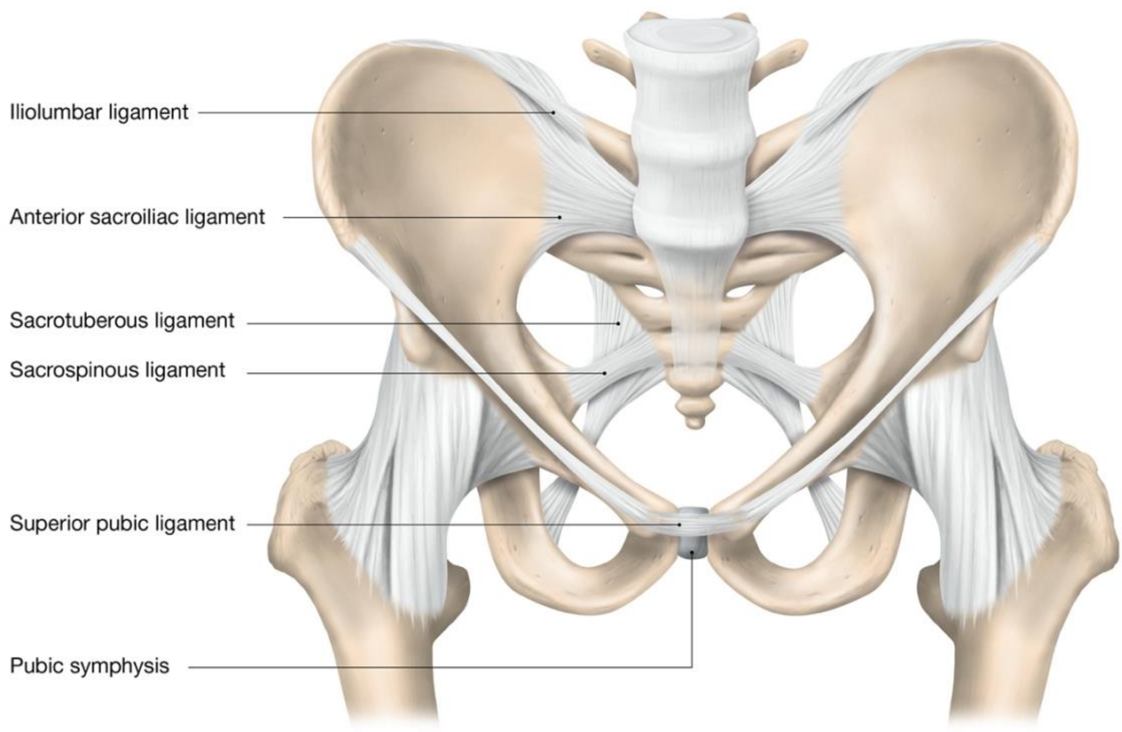

FIGURE 2. The male pelvis, anterior view

Another essential anatomic feature of the pelvic ring is the closeness of major vessels and nerves. The internal iliac artery and its branches are enclosed within the pelvic girdle, and a large venous plexus as a result from anastomoses between the lateral and median sacral veins lie just anterior to the sacrum. Peripheral nerve roots from the sacral and coccygeal nerve plexuses run through the pelvic girdle as well, making them susceptible to damage not only at the time of injury but also during surgical procedures. Especially vulnerable is the fifth lumbar vertebrae nerve root which is at risk during SI-screw placement, as it runs just anterior to the pars lateralis of the first sacral vertebrae.

1.2 Fracture classification

The two main pelvic fracture classification systems used in the literature today are the Young-Burgess and the Tile-AO classification (Burgess et al., 1990, Tile, 1996). The Young-Burgess classification of pelvic fractures is based on the vector of the transmitted force at the time of injury as well as the quantity of displacement of the pelvis because of that force (Burgess et al., 1990). It divides pelvic fractures into three main categories: APC (anterior posterior compression) type 1-3, LC (lateral compression) type 1-3 and VS (vertical shear), (Figure 3). There is also a fourth category; combined mechanical injury, with a combination of the above mentioned categories.

The APC fracture is typically caused by an anteroposterior force to the pelvis which results in disruption of both the symphysis pubis and the SI-joints. This fracture is often referred to as an "open book" pelvic fracture. The first injury to occur through this trauma mechanism is a disruption of the symphysis pubis without, or with only minor disruption of the SI-joints (APC type 1). As the force increases, the ligaments around the SI-joints eventually break as well, first the anterior SI-ligament (APC type 2) and later the posterior SI-ligament (APC type 3). The APC type 3 pelvic fracture results in a completely detached hemipelvis. The LC pelvic fracture pattern starts with an anterior transverse fracture of the os pubis with a concomitant (most often) ipsilateral fracture of the sacrum (LC type 1) and increases in severity through increasing fracture types 1-3. The VS fracture usually occurs due to fall from height, where one hemipelvis displaces vertically with fracture of both the pubic bones and the sacrum. Due to the anatomy and mechanical properties of the pelvis, a fracture at one site of the pelvic ring most likely results in a second disruption, either due to ligament injury or fracture, at a second point of the pelvic girdle.

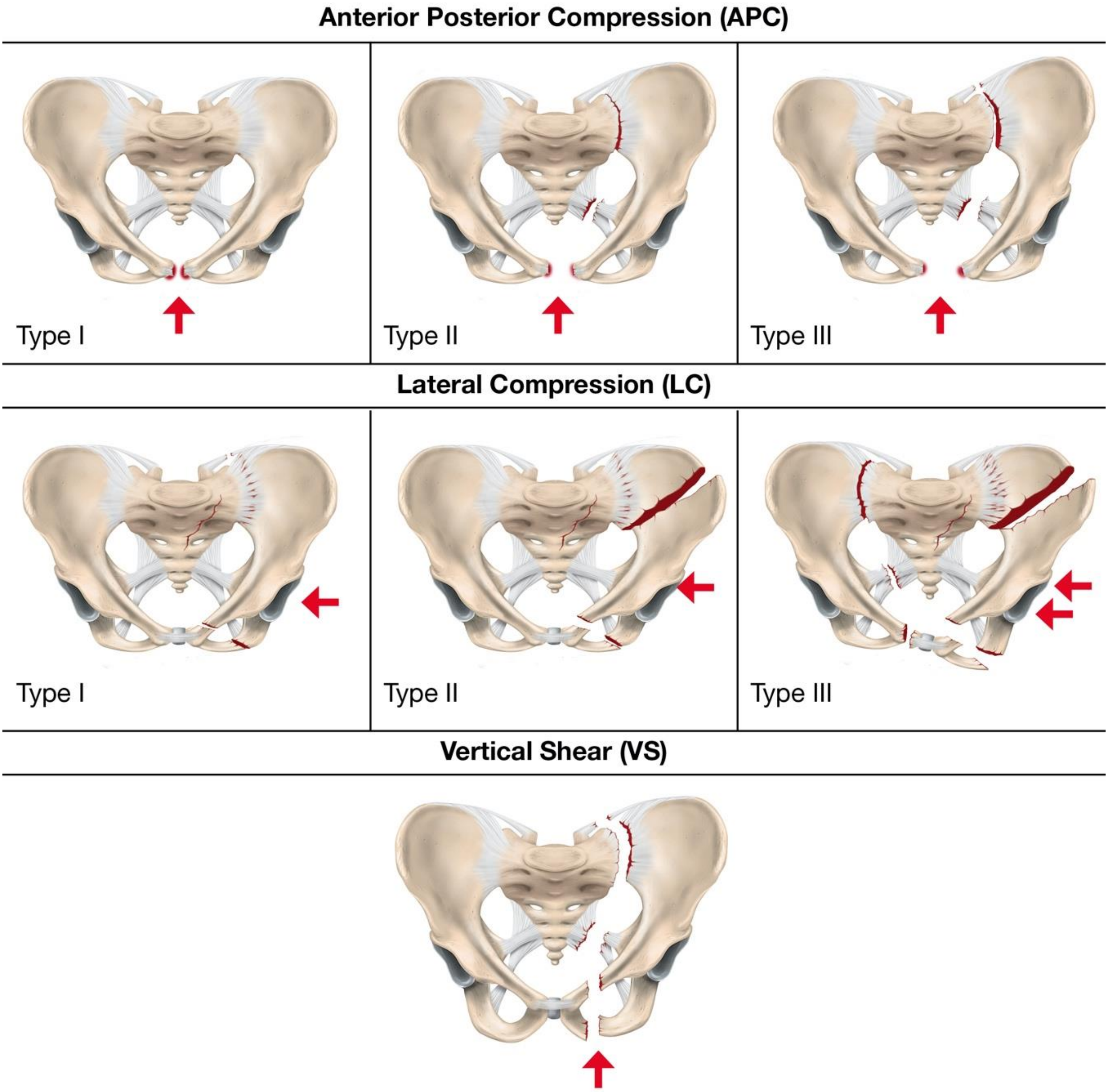

FIGURE 3. The Young-Burgess classification system of pelvic fractures

Fractures of the acetabulum are usually described as a separate entity, and they do not affect the mechanical stability of the pelvic ring to the same extent as the pelvic fracture, although still severe injuries because of their intraarticular nature. The classification system for acetabular fractures was described already in the 1960s, the Judet-Letournel classification, and it is based on the idea of a two-columnar (anterior and posterior) support of the acetabulum. It divides acetabular fractures into five elementary and five associated fracture types (Judet et al., 1964) (Figure 4).

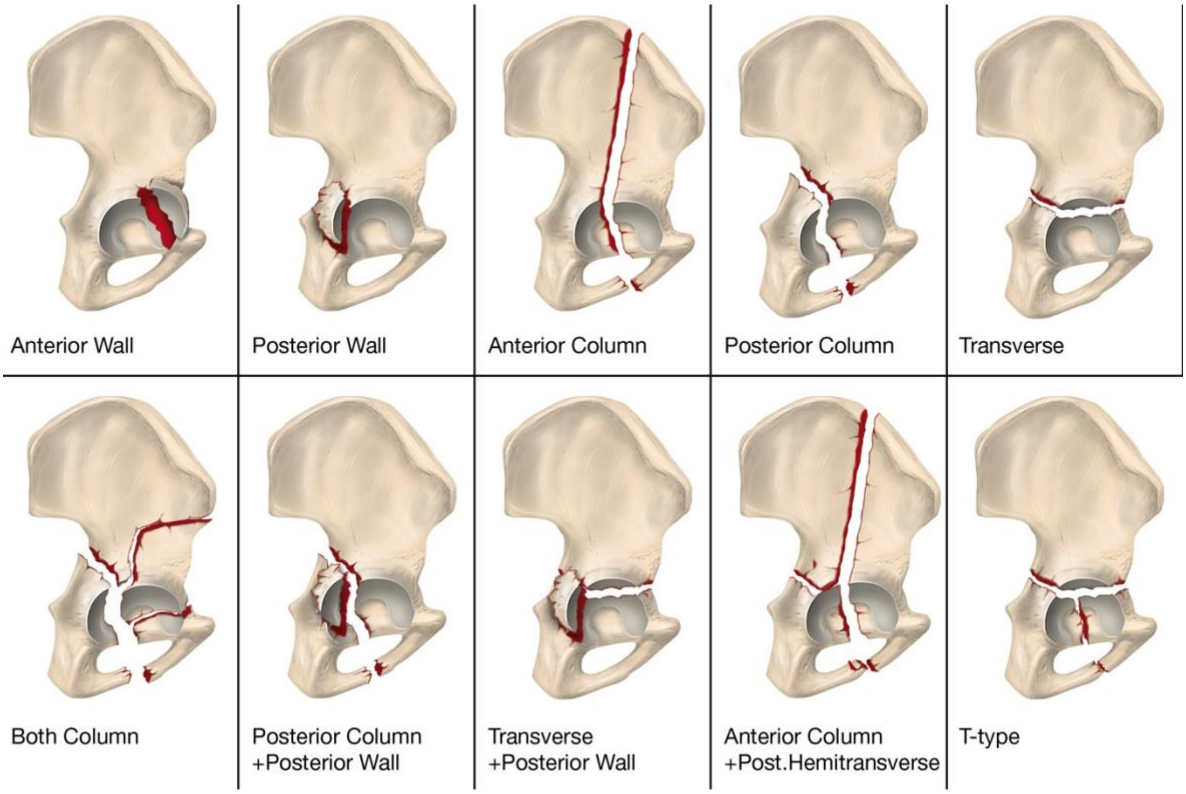

FIGURE 4. The Judet-Letournel classification system of acetabular fractures

1.3 Epidemiology

Incidence

Existing epidemiologic literature on pelvic and acetabular fractures is limited, and the variability in how data is reported and how the cohorts of patients are selected is large. Many studies describe selected cohorts rather than entire populations which make comparisons of incidence between studies difficult.

Numbers on incidence on pelvic fractures vary between 23-34/100,000 person-years (Balogh et al., 2007, Buller et al., 2016, Melhem et al., 2020). There is, however, a lack of up-to date studies on unselected cohorts of pelvic fracture patients properly describing the demography of today. Still now, descriptions of pelvic fracture incidence often rely on two well-cited studies conducted in Finland and Sweden more than 30 years ago which described incidence rates of 24 and 20 per 100,000 person-years respectively (Lüthje et al., 1988, Ragnarsson et al., 1992). Large population-based cohorts from Finland have found increasing incidence rates of pelvic fracture in the Finnish population from 1970 to 2013. However, in their impressively large material only certain age groups of older patients with pelvic fracture were included which limits comparison with other studies (Kannus et al., 2000, Kannus et al., 2015). Still, it highlights the problem of a potentially increasing number of patients with pelvic fracture in the future, and the possible increasing strain on health care related to an ageing population.

There are a few more recent population-based studies exploring the incidence of pelvic fractures. An American study, with data from 2007, found an incidence of 34/100,000 person-years and a French study reported an incidence of 28/100,00 person-years (Buller et al., 2016, Melhem et al., 2020). Both studies found increasing incidence trends just like in the Finnish material earlier described. Another Finnish population-based study on adults showed incidence rates of as high as 56/100,000 person-years in 2014 but for both pelvic and acetabular fractures (Rinne et al., 2020). All mentioned studies report on fractures among in-patients only which is problematic since not all patients with pelvic or acetabular fracture need in-hospital care and hence the true incidence might be higher than what current literature states. Other issues that complicate comparisons between studies are distinguishing between pelvic and acetabular fractures and the selection of studied age groups.

Acetabular fractures are more uncommon than the pelvic fractures and incidences range from 3-10/100,000 person-years (Laird et al., 2005, Rinne et al., 2018, Best et al., 2018, Melham et al., 2020). Just as for pelvic fractures, there seems to be an increasing incidence although numbers are much smaller (Melham et al., 2020).

Gender differences

When looking at gender distribution of pelvic fractures, females dominate both in terms of incidence and absolute number, due to the high number of older females sustaining the fracture (Buller et al., 2016, Kannus et al., 2000, Melhem et al., 2020). On the other hand, high-energy pelvic fractures among patients with normal bone quality is described to be more common among males, and a bimodal distribution pattern has been described (Balogh et al., 2007, Mann et al., 2018), although few studies describe large cohorts of patients with high-energy pelvic fractures. Acetabular fractures seem to be more common among males regardless of age (Melhem et al., 2020), but current literature on the subject is scarce.

Mortality

Mortality rates among younger patients sustaining pelvic fractures after high-energy trauma has been reported at rates of 6-31% (Demetriades et al., 2002, Sharma et al., 2008, Palmcrantz et al., 2012, Fitzgerald et al., 2014). Better outcomes for patients with complex pelvic injuries treated at trauma centers compared with non-trauma centers have been reported (Morshed et al., 2015), but questions remain if survival has improved after implementation of damage control resuscitation (Fitzgerald et al., 2014). Both studies above investigated high-energy injuries where patients often had other serious injuries apart from their pelvic fracture. It is questionable whether the actual pelvic injury is lethal or if in fact it rather represents a severe overall injury situation in the multi-traumatized patient (Holtenius et al., 2018).

1.4 Radiography of pelvic and acetabular fractures

Both conventional radiography (CR) and computed tomography (CT) are valid methods when evaluating injuries to the pelvis, although there are precision benefits of using CT when assessing fracture type and displacement. CT is often used in the setting of diagnosing high-energy pelvic fractures, while CR is common when diagnosing low-energy pelvic injuries, typically among older patients after simple falls. The use of CR when diagnosing pelvic and acetabular fractures is known to have apparent limitations and might even fail to detect fractures at all, especially in the posterior pelvic ring or in the acetabulum (Schicho et al., 2016). It is also associated with problems in accurately deciding upon the exact dislocation of injuries of the SI-joints or articular fragment displacement in acetabular fractures (Borrelli et al., 2002, Nystrom et al., 2013). The failure to detect an existing fracture is obviously a hazard, but also the inability to correctly evaluate and classify a pelvic or acetabular fracture might pose problems in the treatment and care of the affected patient (Vajapey et al., 2021).

Few recent studies report on radiological follow-up of surgically treated pelvic fractures. The surgeon and local traditions of the hospital might influence decisions on how many radiographs and of what modality should take place. Although CR offers a lower radiation dose, it has a disadvantage in that it relies on adequate image projections to accurately evaluate implanted hardware, fracture reduction, and fracture healing during follow-up. The use of CT, also in the follow-up, is presumably increasing with improved technology and reduced effective radiation doses (Eriksson et al., 2019).

Radio-stereometric analysis (RSA) is a gold standard radiographic method to precisely quantify movement of orthopedic joint implants and has during the last decades been valuable in determining implant loosening (Kärrholm et al., 2012). It utilizes plain CR and relies on the implantation of marker beads inserted in the patient during surgery. In the early 21st century, an alternative method to the RSA, using CT instead of CR, was proposed (Olivecrona et al., 2002). The new CT-RSA method used a similar methodology as the standard RSA, but with the three-dimensional properties of CT instead of CR, and without the need for marker bead implantation. Since then, this method has been further developed and implemented into a commercially available software program, Computed Tomography Micromotion Analysis (CTMA, Sectra AB, Linköping, Sweden) used today in both research and clinical patient care (Brodén et al., 2016, Olivecrona et al., 2016, Brodén et al., 2020a). Several studies using CTMA have shown a precision in the same order of magnitude as attained with RSA (Bakhshaeysh et al., 2019, Brodén et al., 2020a, Brodén et al., 2020b, Brodén et al., 2021). Until recently, CTMA has primarily been utilized for detecting implant motion in hip arthroplasty, similar to its predecessor, RSA, and its application in the follow-up of fracture patients is currently limited. CTMA has however been evaluated in vitro in the assessment of pelvic fractures and in investigating the symmetry of hemipelvises (Bakhshaeysh et al., 2019, Bakhshayesh et al., 2020), but still not within a clinical study of pelvic fracture patients.

1.5 Treatment of pelvic and acetabular fractures

Most patients with pelvic fractures after high-energy trauma are treated non-surgically, with approximately one third of the patients undergoing operative treatment (Bhakshayesh et al., 2018, Abdelrahman et al., 2020). Even fewer patients with pelvic fractures after low-energy trauma are treated surgically, in comparison to patients with acetabular fractures where surgical treatment is more common. The typical trauma mechanism for these injuries being a simple fall in the same level (Rinne et al., 2017). Population-based studies report that 2-10% of all patients with pelvic fractures are surgically treated (Buller et al., 2016, Melhem et al., 2020,) while the rate for acetabular fractures including all fractures regardless of trauma energy-level is between 14 and 20% (Best et al., 2018, Melhem et al., 2020).

A variety of methods for definitive surgical treatment of pelvic and acetabular fractures exist, with the standard procedure of today being internal osteosynthesis rather than the use of external fixators (Lindahl et al., 1999). For pelvic fractures, one common surgical approach is to reduce and fixate the pelvis anteriorly with a symphysis plate along with posterior stabilization with one or more SI-screws, but multiple other reduction and fixation strategies are available. The surgery is commonly regarded as a complex procedure, with certain aspects, such as the percutaneous placement of SI-screws, being particularly challenging (Zwingmann et al., 2013). The surgical treatment of acetabular fractures is somewhat different in its aspect and primary aim of obtaining anatomic reduction of the articular surface rather than just achieving a stable internal fixation. In a geriatric patient with severe displacement of the acetabular joint surface, a primary arthroplasty is often used, usually in combination with internal fixation (Manson et al., 2021).

1.6 Complications

Complication rates after pelvic fracture surgery are not thoroughly covered in the literature but has previously been described to be high. Existing studies suggest that 15-22% of patients surgically treated for a pelvic fracture need to undergo further surgery (Sems et al., 2010, Bakhshayesh et al., 2018, Ochenjele et al., 2018). Possible reasons for reoperations could be infection, fixation failure or heterotopic ossification. Other complications after pelvic fracture surgery include iatrogenic nerve injuries, deep venous thrombosis, or other infections such as pneumonia or urinary tract infection (Sems et al., 2010).

The complication rate after acetabular fracture surgery appears to be similar to that of pelvic fracture surgery although only occasional studies on the subject exist (Ding et al., 2018, Küper et al., 2020). Commonly described causes for reoperation were, apart from infection, also revision with conversion to total hip arthroplasty (THA) and implant removal due to joint penetration (Ding et al., 2018).

2 Research aims

To investigate the incidence of pelvic and acetabular fractures in the Swedish adult population over a longer time-period, and to describe the demography of the patients as well as the rate of patients surgically treated (Study I).

To explore and report on complications after surgical treatment of patients with pelvic and acetabular fractures, with focus on reoperations and possible risk factors (Study II+III).

To use CTMA in the follow-up of surgically treated pelvic fracture patients and explore its potential in determining movement in the pelvis during fracture healing (Study IV).

3 Patients and methods

The first study in this thesis was based on data from the National Patient Register (NPR). The study populations for study II-IV were all derived from patients with surgically treated pelvic or acetabular fractures admitted to the Karolinska University Hospital in Stockholm, Sweden. In study IV, a software program called Computed Tomography Micromotion Analysis (CTMA) was used to analyse fracture movement in patients with surgically treated pelvic fractures over time.

All studies included in this thesis were performed in accordance with the Helsinki Declaration (World Medical Association, 2013), and all were approved by the Regional Ethical Review Board of Stockholm (Study I) or the Swedish Ethical Review Authority (Study II, III and IV).

3.1 The National Patient Register (NPR)

The National Patient Register was founded in the 1960's when the National Board of Health and Welfare started to collect data regarding in-patients at public hospitals in Sweden. In 1984, the Ministry of Health and Welfare together with the Federation of County Councils decided it was mandatory to report to the register, and from 1987 it contains all in-patient care in Sweden. Over the years the register has grown and since 2001 it also comprises out-patient doctor visits from both private and public caregivers, although primary care is not yet covered (Socialstyrelsen, 2023). The inclusion of both in- and out-patients makes the NPR quite unique compared to other population-based registers. It is based on the Swedish personal id-number given to every citizen, and includes information on admission and discharge dates, age, gender, primary and secondary diagnoses, and surgical procedures performed.

The register has been validated and has a well-known high level of completeness, especially for in-patients, and for surgical procedures (Ludvigsson et al., 2011). Recent literature also demonstrates a high completeness for patients with fracture diagnoses often treated as out-patients (Bergdahl et al., 2021). The data is automatically retrieved based on diagnostic codes from medical records and several problems related to this exists. One major issue is the lack of information on time of first injury in relation to subsequent follow-up visits. This can lead to the registration of follow-up visits as acute fracture registrations. When using the NPR or similar population-based registers in epidemiologic research, this problem can be overcome by only counting the same patient once. This solution might however be problematic when studying for example fractures over longer time periods, where multiple fractures in the same individual could occur. Other issues with the NPR are the lack of information on mechanism of injury, laterality, fracture severity, other co-morbidities as well as possible misdiagnosis by the responsible doctor. This results in potential problems regarding accuracy of the register, which needs to be considered when using the data for research.

3.2 Computed Tomography Micromotion Analysis (CTMA)

CTMA is an image post-processing software program used to determine movement between two selected bodies with a very high precision. As earlier mentioned, this technique presents an alternative to the Radio-stereometric Analysis (RSA), which is used mainly in determining implant migration, a predictor of clinical implant loosening, where it is decisive in detecting even very small motions (Brodén et al., 2020a). The idea of the CTMA technique is to investigate how two rigid bodies, not deforming over time, move in relation to one another. It calculates movement in translation and rotation in millimeters and degrees respectively between the two selected bodies of two consecutive CT scans. The system requires one body or surface to be selected as stationary, and a second one as moving, and it provides numerical migration values along three orthogonal axes (X, Y and Z) for both translation and rotation. The system will detect whether the chosen surfaces align sufficiently to one another in a color-coded system response before the analysis starts. This lets the user know if the analysis can proceed to yield reliable migration values or if a new registration of surfaces should be considered (Figure 5).

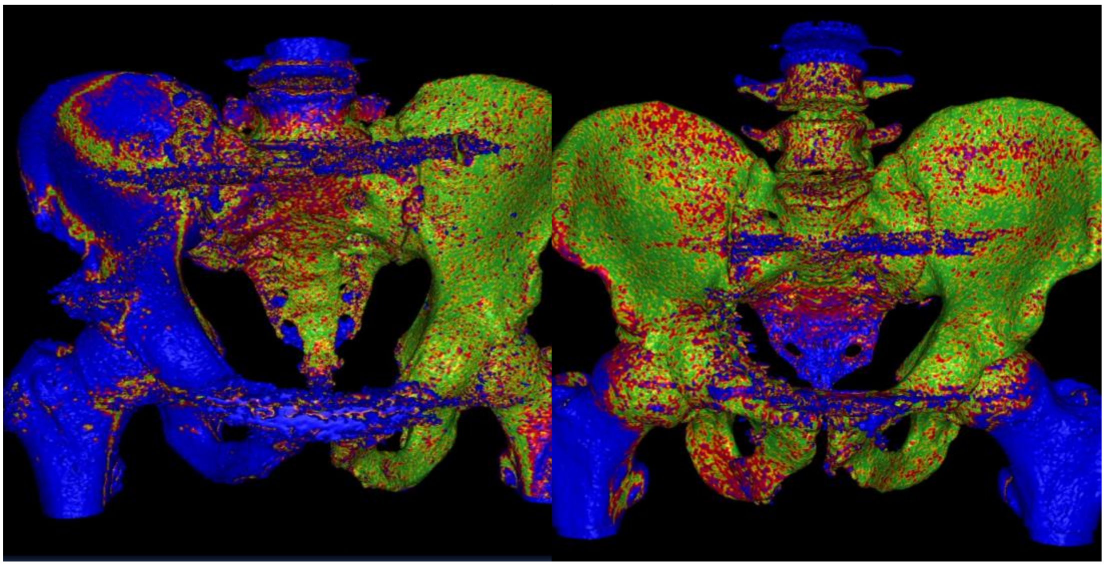

FIGURE 5. Alignment after registration of reference surfaces (left acetabulum) in two CT-stacks for two different patients. The left image displays a movement of >1mm of the right injured area of the pelvis (blue colored), compared to the left side. The right image illustrates a movement of <0.2mm of the right injured hemipelvis

3.3 STUDY I

Study design

Nationwide register study.

Study population and primary outcome

Data on all adult Swedish citizens ≥18 years, with a pelvic fracture diagnosis (ICD-10 S32.1, S32.3, S32.5, S32.7-8) or an acetabular fracture diagnosis (S32.4) between Jan 1st 2001 and Dec 31st 2016, were retrieved from the NPR and included. The primary outcome was the incidence rate of pelvic and acetabular fractures.

Methods and statistical analysis

The variables collected for each patient were age, gender, diagnostic code(s) and surgical code(s). The surgical codes included all NEJxx- and NFBxx-codes and had to be related to one of the fracture codes for pelvic or acetabular fractures mentioned above. The first observation was considered as the incident case, and subsequent visits for the same patient were counted anew only after 365 days from the incident case, or if another of the selected diagnostic codes appeared. Data on the Swedish population was extracted from the open access register of Statistics Sweden (Statistics Sweden, 2020). Statistical testing of the variables was not performed since the study population contained the entire Swedish population.

3.4 STUDY II AND III

Study design

Single center retrospective cohort studies.

Study population and primary outcome

Both studies contained patients ≥18 years surgically treated for a pelvic or an acetabular fracture at the Karolinska University Hospital in Stockholm Sweden during 2010-2019. Patients were identified through the local surgical planning software program. The primary outcome in both studies was the rate of unplanned reoperations.

Methods and statistical analysis

Medical charts were manually reviewed to collect all variables, including radiographic imaging. Demographic variables were age, gender, and American Society of Anesthesiologists (ASA) classification. Injury variables were date of injury, injury mechanism, vital parameters at arrival, Glasgow Coma Scale (GCS), hemoglobin level at arrival, other simultaneous injuries, and fracture type. Fracture classification was performed according to Young-Burgess for pelvic fractures and Judet-Letournel for acetabular fractures (Judet et al., 1964, Burgess et al., 1990). Treatment variables were date of primary surgery and type of surgical treatment including surgical incision type. Follow-up variables were unplanned reoperations, including causes of reoperation, any other adverse event not requiring reoperation and mortality. Additional variables were length of stay at hospital including Intensive Care Unit (ICU).

Logistic regression analysis was performed to investigate potential variables associated with increased risk for either unplanned reoperation or any other adverse event. Certain selected variables were first tested in univariable models to find the crude association for each variable. Secondly, a multivariable model was used to study the adjusted associations. The associations were presented as odds ratios (ORs) with 95% confidence intervals (CIs). The tested variables were age, gender, fracture type and concomitant abdominal injury for pelvic fractures and age, gender, hip dislocation, ICU-care and surgical method (ORIF vs. THA) for acetabular fractures.

3.5 STUDY IV

Study design

Prospective clinical study.

Study population and primary outcome

10 patients surgically treated for a pelvic fracture at the Karolinska University Hospital, Stockholm, Sweden were included after informed personal consent. Patients were included from January 2019 to May 2020. Inclusion criteria were age ≥18 years and a pelvic fracture requiring surgical fixation at two points in the pelvic girdle. Exclusion criteria were non-residents or any condition that made the patient unable to assess the study material or to take informed personal consent. This was a feasibility study, and the primary outcome was whether the CTMA-method was usable in a clinical setting of pelvic fracture patients.

Methods and statistical analysis

Patients underwent standard protocol postoperative CT scan and subsequently low-dose CT scan at 6, 12 and 52 weeks post-operatively. The patient reported outcome measures EuroQol-5D (EQ-5D) index score and Majeed score were collected from the study patients at inclusion (recall value before injury) and at follow-up visits at 6, 12 and 52 weeks (Majeed, 1989, Rabin et al., 2001). The collected CT files were analysed with CTMA to measure movement between two designated areas, one of each hemipelvis, comparing scans between 0-6, 6-12, 12-52 and 0-52 weeks. Collected variables were gender, age, fracture type, surgical fixation method, translation (mm) and rotation (deg) over time and EQ-5D index score and Majeed score. No statistical testing was performed due to the low number of patients and the fact that we conducted a test of practicability of the CTMA method.

4 Results

4.1 STUDY I

A total of 87,308 pelvic and acetabular fractures (71% females) were found during the 16-year long study period. The mean (± SD, min-max) age was 75 (± 18, 18-111) years. For males, the mean age was 68 (± 21, 18-106) years and for females it was 78 (± 16, 18-111) years. Less than 3% of the fractures occurred after 365 days from the first incident visit (fractures counted again for the same patient). Incidence increased from 64 to 80 per 100,000 person-years from 2001 to 2016. The increase was highest in the older population (80 years and older), but still, an increasing incidence trend was found among all age groups. In the younger age groups (18-59 years), incidence rates for males were almost stationary, while females of the same age exhibited an increasing incidence trend during the study period to similar levels as that of the males. From age 70, females dominated in terms of incidence with rates twice or large as that of the males, and with increasing incidence rates for both genders (Table 1).

TABLE 1. Age-specific total incidence rate (number per 100,000 person-years) in patients ≥ 18 years with pelvic and acetabular fractures in Sweden 2001-2016.

	Patient (age) and gender															
	18-29		30-39		40-49		50-59		60-69		70-79		80-		total	
Year	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
2001	18	9	13	10	14	12	24	16	31	45	84	170	267	696	37	90
2002	19	15	12	9	17	11	24	21	33	43	88	171	254	672	37	90
2003	15	13	15	12	18	14	25	20	34	51	79	172	243	589	36	84
2004	17	11	11	9	13	14	23	24	40	43	84	176	264	642	38	88
2005	18	14	14	11	14	14	24	21	37	52	88	175	275	662	39	92
2006	17	16	14	12	16	13	25	25	38	48	86	198	284	770	40	103
2007	20	12	17	12	18	12	27	24	44	49	94	197	312	790	45	103
2008	20	13	13	12	17	11	24	26	35	50	86	196	386	791	45	103
2009	16	16	11	12	18	13	25	26	43	53	97	196	344	808	45	105
2010	16	13	15	12	14	16	29	31	43	62	101	223	340	869	45	115
2011	17	18	14	14	15	18	27	29	47	65	99	194	374	851	48	112
2012	14	15	13	16	15	13	27	28	47	60	85	186	365	883	45	111
2013	16	15	14	13	16	16	27	31	49	64	101	193	383	875	49	112
2014	17	16	12	14	19	17	26	27	49	56	90	198	363	858	47	110
2015	15	17	12	15	21	21	26	31	49	66	110	196	381	909	50	117
2016	17	18	14	13	19	19	27	31	50	60	90	184	383	858	49	110

The pelvic fractures constituted the largest part of the study material with a total of 79,360 fractures. Incidence increased from 58 to 73 fractures per 100,000 person-years. There were 11,999 acetabular fractures and the incidence rate increased from 8.7 to 11 fractures per 100,000 person-years. The incidence of acetabular fractures was higher for males across all age-groups, unlike incidence rates for pelvic fractures were females dominated due to the high number of elderly females (≥70 years).

Surgical treatment was overall uncommon for pelvic fractures (2.0%) but more frequent for acetabular fractures (15%). The highest rate of surgical treatment was seen in the younger population (18-59 years) where 8.2% and 28% of pelvic and acetabular fractures respectively were treated surgically. There was a large gender difference in treatment of both pelvic and acetabular fractures, where treatment of males was surgical to a larger extent. 4.4% of all males and 1.2% of all females with pelvic fractures were surgically treated, and 19% and 10% of males and females with acetabular fractures, respectively. This difference was evident across all age groups, even among younger patients aged 18-59 years. For pelvic fractures, 11% of males vs. 5.9% of females in the age group 18-59 years were treated surgically (Figure 6a). This can be compared to 31 vs. 22% for males and females respectively with acetabular fractures aged 18-59 years (Figure 6b).

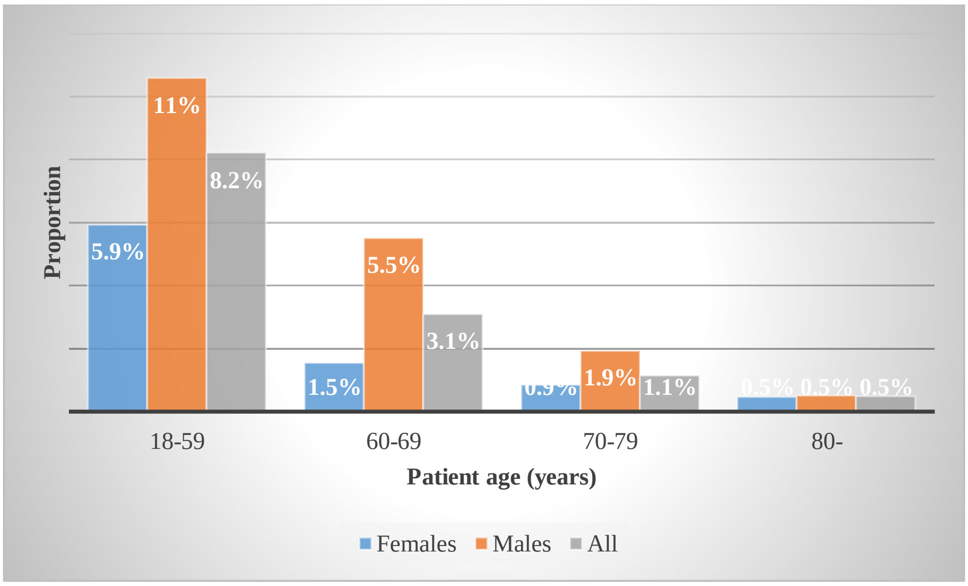

FIGURE 6a. Surgical treatment of pelvic fractures in patients ≥18 years in Sweden 2001-2016, per age group

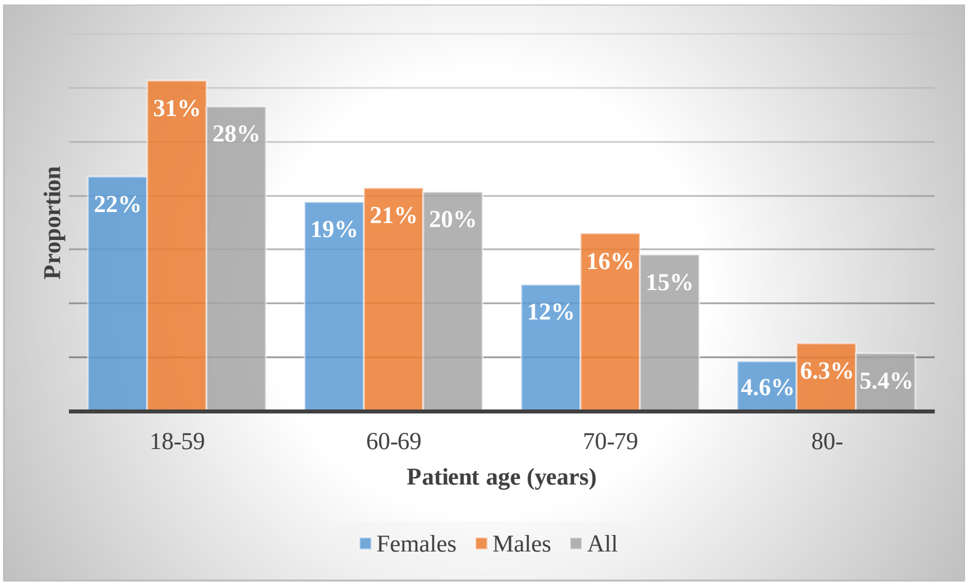

FIGURE 6b. Surgical treatment of acetabular fractures in patients ≥18 years in Sweden 2001-2016, per age group

4.2 STUDY II

Study population

A total of 194 patients surgically treated for a pelvic or a combined pelvic and acetabular fracture were included during the 10-year study period (2010-2019). The mean age (± SD, min-max) was 45 (16, 18-83) years and the majority of the patients were males (n=121, 62%). The median (IQR) follow-up time was 1890 (1791) days (4.9 years). The most common trauma mechanism was fall from height >2 meters (n=70, 36%) followed by car or motorcycle accident (n=54, 28%). 97% of the patients (n=188) had a high-energy trauma mechanism. 16% (n=32) of the patients underwent acute pelvic packing and 13% (n=26) angiography with or without embolization.

Associated injuries were common with chest injury being the most frequent (n=98, 51%) followed by head or neck injury (n=63, 33%) and abdominal injury (n=50, 26%). 61% (n=118) of the patients in this cohort needed intensive care and the median (IQR) total hospital length of stay was 15 (23) days.

Unplanned reoperations

25% (n=48) of the patients underwent an unplanned reoperation, with infection (n=18, 9%) being the most common cause of reoperation. Indications and rates of unplanned reoperations are presented in Table 2.

TABLE 2. Indication for first unplanned reoperation after pelvic fracture surgery

Indication; *n* = (%)	All patients *n* = 194
Infection	18 (9.3)
Malplaced implant	11 (5.7)
Mechanical irritation	11 (5.7)
Failure of osteosynthesis	4 (2.1)
Heterotopic ossification	3 (1.5)
Other	1 (0.5)
All	48 (25)

None of the tested variables (age, gender, fracture type, abdominal injury) were associated with an increased risk for reoperation in the uni- or multivariable logistic regression analyses.

Other adverse events and mortality

40% of the patients (n=78) sustained other adverse events not requiring surgery, with the most common being nerve injury (n=34, 18%). In the regression analysis, presence of abdominal injury was associated with an increased risk for other adverse events in both the univariable (OR 2.4, 95% CI 1.2–4.6, $p < 0.01$) and multivariable (OR 2.5, 95% CI 1.3–4.9, $p < 0.01$) analyses. The 30-day mortality was 1.5% (n = 3) and the 1-year mortality 6.2% (n = 12).

4.3 STUDY III

Study population

A total of 229 patients surgically treated for an acetabular fracture were included during the 10-year study period (2010-2019). The mean age (± SD, min-max) was 60 (19, 19-94) years and the majority of the patients were males (n=180, 79%). The median (IQR) follow-up time was 1779 (1906) days (4.9 years). The most common trauma mechanism was simple same level fall (n=83, 36%), although 57% of the patients (n=130), had sustained their surgically treated acetabular fracture through a high-energy trauma mechanism. 24% (n=55) of the patients had a dislocated hip at the time of hospital arrival. Only 14% (n=33) of the patients needed ICU-care and the median (IQR) hospital length of stay was 8 (7) days.

Treatment

The main surgical treatment method was ORIF with plating and screws (74%, n=169). 54 patients were treated with a primary THA, with or without concomitant plating (n=54, 24%).

Unplanned reoperations

47 patients (21%) underwent an unplanned reoperation, with the most common cause for reoperation being arthrosis (n=17, 7.4%). All indications for reoperation are presented in Table 3. The rate of unplanned reoperation due to infection was 3.9% (n=9), and no patient in this material sustained a prosthetic joint infection (PJI). Six of the patients treated with THA (11%) had a postoperative dislocation of the THA, and all these six patients had been operated with a posterior surgical hip approach. In the regression analysis, male gender was associated with a reduced risk for reoperation compared to female in the multivariable analysis (OR 0.4, 95% CI 0.2–0.9, $p = 0.02$) and THA as surgical method was associated with a lower reoperation rate compared to ORIF in the multivariable analysis (OR 0.3, 95% CI 0.1–0.8, $p = 0.01$).

TABLE 3. Indication for first unplanned reoperation after acetabular fracture surgery

Indication	Patients $n = (\%)$	Time (days) to reoperation Median (range)
Arthrosis	17 (7.4)	342 (114–1103)
Infection	9 (3.9)	23 (11–80)
PJI	0 (0)	0 (0)
Dislocated THA	6 (2.6)	13 (1–314)
Malplaced implant	5 (2.2)	6.0 (3–52)
Osteosynthesis failure	4 (1.7)	36 (16–97)
Loose bone fragments in joint	3 (1.3)	4 (3–5)
Disturbing implant	3 (1.3)	352 (322–564)
All	47 (21)	80 (1–1103)

PJI Prosthesis joint infection

Other adverse events and mortality

31% of the patients (n=72) suffered an adverse event not requiring surgery, with the most common event being nerve injury (n=27, 12%). In the regression analysis, admittance to ICU was associated with an increased risk for adverse events in both the univariable (OR 2.5, 95% CI 1.1–5.0, p = 0.03) and multivariable (OR 2.6, 95% CI 1.2–5.7, p = 0.02) analysis. 30-day mortality was 3.1% (n = 7) and 1-year mortality 5.7% (n = 13).

4.4 STUDY IV

All 10 patients attended every follow-up visit including low-dose CT scans, EQ-5D index score and Majeed score surveys. The mean age (± SD, min-max) of the patients was 52 (16, 31-80) years and the majority of the patients were males (n=7, 70%). The median effective radiation dose was 0.4-0.5 millisievert (mSv) per CT scan for the low-dose CT examinations.

The median (IQR, range) global translation was largest between 0-6 weeks: 4.4 (4.3, 1.6-10.6) mm and median global rotation was 1.7 (1.6, 1.1-4.2) deg. Largest translation values were found along the Z-axis. Median (IQR, min-max) global translation and rotation for the 10 patients for the different time intervals is presented in box plots in Figures 7a-b.

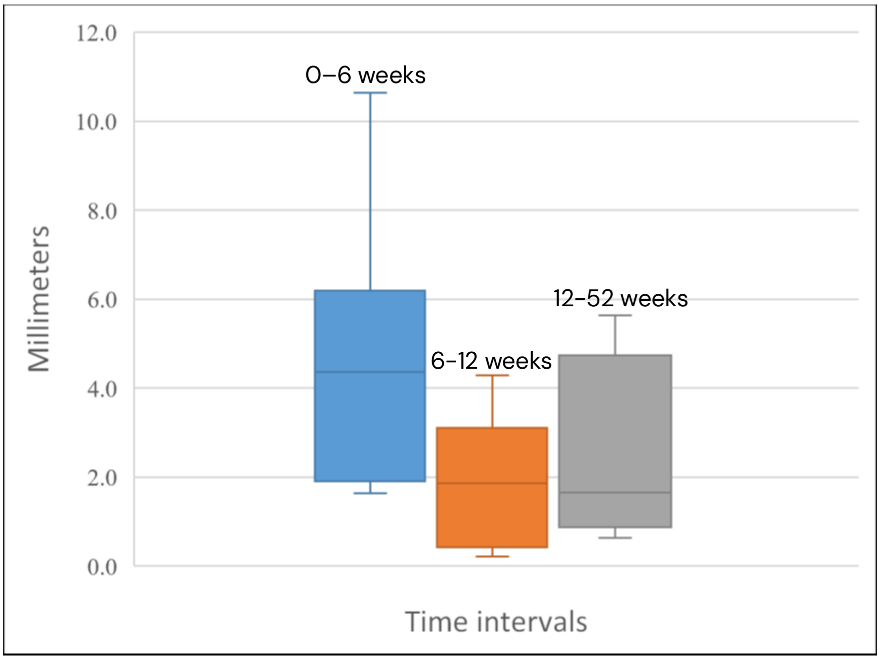

FIGURE. 7a Box plot displaying the median (IQR, min-max) of the global translation in millimeters for all 10 patients for the different time intervals

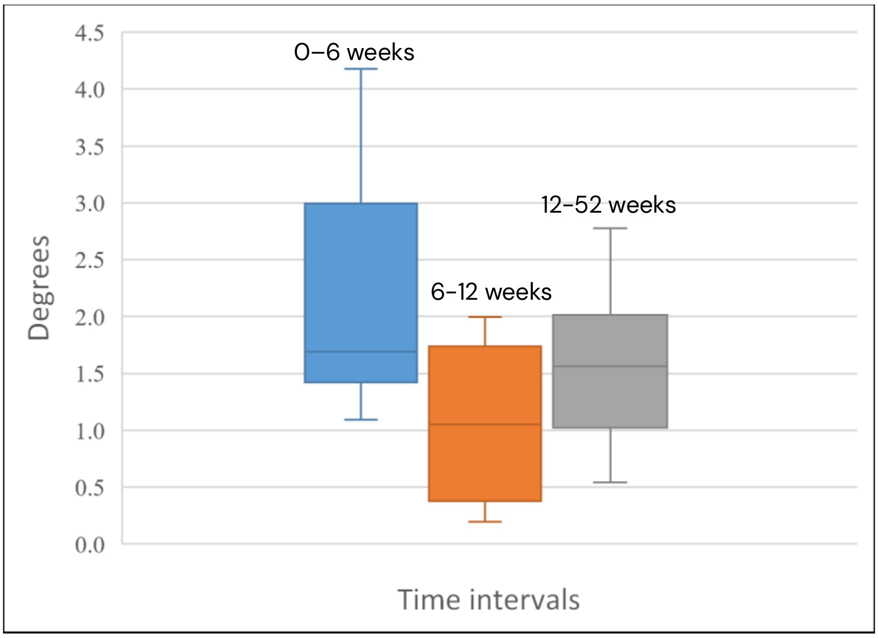

FIGURE. 7a Box plot displaying the median (IQR, min-max) of the global rotation in degrees for all 10 patients for the different time intervals

Individual differences in translation and rotation ranged from 1.4-13 mm and 0.7-4.7 deg respectively during the entire study period of 52 weeks. The detailed translation and rotation for each patient between 0-52 weeks is presented in Table 4.

TABLE 4. Translation and rotation of the injured hemipelvis between the first and the 52-week postoperative CT for all 10 patients

Patient number	Translation X (mm)	Translation Y (mm)	Translation Z (mm)	Translation global	Rotation X (deg)	Rotation Y (deg)	Rotation Z (deg)	Rotation global
1	6.1	5.8	0.9	**8.5**	2.1	-0.6	4.1	**4.7**
2	-0.2	-0.2	3.1	**3.1**	-0.2	2.1	0.8	**2.3**
3	-3.3	-0.4	3.8	**5.1**	-1.3	2.4	-1.5	**3.1**
4	-3.5	-6.7	10.1	**12.6**	-2.2	1.3	-1.2	**2.9**
5	-0.7	-1.3	0.1	**1.4**	-0.1	0.7	0.0	**0.7**
6	5.6	-4.4	2.2	**7.5**	-2.1	-1.3	4.0	**4.7**
7	-2.6	-6.1	3.6	**7.6**	-1.8	1.8	2.3	**3.5**
8	2.3	-1.4	1.9	**3.3**	-1.4	-1.6	-0.8	**2.2**
9	1.1	2.0	3.9	**4.5**	-1.3	0.2	-0.8	**1.5**
10	1.5	-0.9	6.6	**6.8**	-0.8	0.7	0.1	**1.1**
All Median (IQR), Min-Max	**0.4 (5.9), -3.5-6.1**	**-1.1 (5.2), -6.7-5.8**	**3.4 (2.9), 0.1-10.1**	**6.0 (4.6), 1.4-12.6**	**-1.3 (1.7), -2.2-2.1**	**0.7 (2.7), -1.6-2.4**	**0.0 (3.6), -1.5-4.1**	**2.6 (2.4), 0.7-4.7**

The PROMs (EQ-5D index score and Majeed score) illustrated a trend with most patients starting off at high scores (pre-operative) which decreased markedly in the first post-operative follow-up (6 weeks) and recovered to different extent during the study period (Table 5). All patients with EQ-5D index score below median value at 52 weeks (patient 1, 6, 7 and 10, Table 5) displayed translation above median between 0-52 weeks (Table 4). A similar trend was seen for Majeed score, with the patients 1, 7 and 10 reporting values below median at 52 weeks (Table 5). Patient 4 was an exception with the largest global translation during the study period (13 mm) but still scored above median at EQ-5D index and Majeed score (Table 4-5).

TABLE 5. EQ-5D index score and Majeed score for patient number 1-10 preoperatively (0) and at 6, 12 and 52 weeks postoperatively

EQ-5D index score	0 weeks	6 weeks	12 weeks	52 weeks	Majeed score	0 weeks	6 weeks	12 weeks	52 weeks
Patient					**Patient**				
1	0.89	0.74	0.77	0.71	**1**	90	47	78	78
2	1.00	0.81	0.85	1.00	**2**	100	78	93	100
3	1.00	0.88	0.92	0.89	**3**	84	58	89	84
4	1.00	0.81	0.81	1.00	**4**	100	43	58	98
5	1.00	0.81	0.85	0.89	**5**	100	42	64	100
6	1.00	0.66	0.81	0.78	**6**	100	47	67	98
7	1.00	0.67	0.67	0.81	**7**	100	39	52	63
8	1.00	0.85	1.00	1.00	**8**	100	69	98	100
9	1.00	0.83	0.74	0.89	**9**	100	56	60	95
10	1.00	0.70	0.66	0.74	**10**	96	56	49	56
All Median (IQR), Min-Max	**1.00 (0), 0.89-1.00**	**0.81(0.14), 0.22-0.88**	**0.81(0.14), 0.66-1.00**	**0.89(0.23), 0.71-1.00**	**All Median (IQR), Min-Max**	**100 (6), 84-100**	**52 (18), 39-78**	**66 (34), 49-98**	**97 (26), 56-100**

5 Discussion

The aggregated work of this thesis aimed to improve treatment for patients with pelvic and acetabular fractures through a combination of epidemiological and clinical studies. A substantial part of this work explored the range of complications associated with the surgical treatment, and in particular the rate of reoperations. The results, and potential importance of them, are discussed in the following sections, as well as comparisons with previously published literature.

5.1 Incidence and demographics of pelvic and acetabular fractures

Incidence of both pelvic and acetabular fractures increased markedly in Sweden during 2001-2016, particularly among older patients (≥80 years). The findings from Study I confirm data from other countries, but with higher incidence numbers than previously reported (Buller et al., 2016, Melhem et al., 2020, Rinne et al., 2020). This is interesting as it contrasts with data on the anatomical nearby hip fracture, where several reports instead demonstrated decreasing incidence trends (Cooper et al., 2011, Rosengren et al., 2017, Kannus et al., 2018). It is difficult to explain this difference, but one possible explanation is the increased use of CT, and hence the diagnosis of previously occult pelvic fractures not visible on CR (Schicho et al., 2016). Another reason could be ageing of the population, as demographic data demonstrates an increase of adults 60-79 years from 2001-2016 in Sweden (Statistics Sweden, 2020). Still, the increasing incidence emphasizes the clinical importance of pelvic and acetabular fractures and the fact that these injuries might have been previously underdiagnosed. However, the increasing incidence of pelvic fractures found among younger adults, and particularly females 18-49 years, might not solely be explained by a previous missed fracture, as pelvic fractures in this age group would be assumed to be related to high-energy trauma to a higher extent. The NPR does not provide sufficient information on injury mechanism and fracture classification, and hence reasons to the increase remain unclear. Possible explanations could be an overall increase in for example female stress fractures of the pelvis (Shaffer et al., 2006) or an increase in fall-injuries in this age cohort (Court-Brown et al., 2017).

The rate of surgical treatment of pelvic fractures at 2% was in the lower range of previously published material, ranging between 2 and 10% (Buller et al., 2016, Melhem et al., 2020, Rinne et al., 2020). There might be different local surgical criteria that could explain the discrepancies, but it also likely relates to the fact that Study I explored an entire population including both in- and outpatients, compared to previously mentioned literature. Still, the surgical rate of acetabular fractures was 15% in Study I which corresponded well to already published data of 14-20% (Best et al., 2018, Melhem et al., 2020).

One major finding which needs to be addressed regarding treatment was the large gender differences, where males were treated surgically to a larger extent for both their pelvic (4.4 vs. 1.2%) and acetabular (19 vs. 10%) fractures. The differences were visible across all age groups, even in the younger population (18-59 years). This discrepancy is only sporadically described in previous literature. One German study reported on gender differences in surgically treated pelvic fracture patients ≥60 years where older females were surgically treated to a lesser extent (Rollman et al., 2017). Possible reasons to the gender difference were speculated to be a higher grade of osteoporosis in females making surgery more difficult, less pain in female patients or even potential gender bias. There might be differences in trauma mechanisms, i.e., high- vs. low-energy trauma, rendering more displaced fracture patterns for males, but the data from the NPR did unfortunately not provide that type of information. Further studies are required to clarify this difference. Future studies using more detailed data from the national Swedish Fracture Register might be an option when the number of patients in this register is increasing.

A major problem when comparing incidence rates between different countries and different register studies is the great variability in how demographic data is collected and reported. This applies to the handling of age groups and calculation of incidence, as well as the inclusion of patients not admitted for their pelvic or acetabular fractures. In Study I, the crude incidence rate of the entire adult population was conveyed, together with the age-specific incidence rates for different designated age groups. An alternative would have been to calculate age-adjusted or population-adjusted incidence rates, which would eliminate the confounding factor of different age distributions among different populations. However, the method of using crude and age-specific incidence rates allowed more detailed information per age group and was considered of most clinical use when describing the disease-burden, although this could be debated.

The next step when investigating pelvic and acetabular fracture incidence would be to follow incidence trends from 2017 and onwards to see if the increase remains or levels off. It would also be sensible to further investigate surgical treatment among young and middle-aged adults to better understand which patients receive surgical treatment and what factors these decisions are based on.

5.2 Surgical treatment of pelvic and acetabular fractures

Surgical treatment strategies for pelvic and acetabular fractures differ somewhat, as the joint survival must also be taken into consideration for patients with acetabular fractures. For this reason, ORIF might not be suitable for all patients with an acetabular fracture, especially among elderly patients. The cohort of patients with surgically treated pelvic fractures (Study II), were younger compared to the patients with surgically treated acetabular fractures in Study III (mean age 45 vs. 60 years) and more often had sustained their fracture through a high-energy mechanism (97 vs. 57%). The surgically treated pelvic fracture patients often had concomitant injuries and were admitted to the ICU to a higher extent than the surgically treated acetabular fracture patients.

5.3 Pelvic fractures - complications

Reoperations

Reoperation rate after pelvic fracture surgery was 25% in Study II. This is higher than previously reported, although not comprehensively described (Sems et al., 2010, Ochenjele et al., 2018). The extensive follow-up of the patients in Study II, with a median of 4.9 years, was long compared to previously mentioned literature. This long follow-up likely rendered a capture of late complications such as mechanical irritation of implants and heterotopic ossification, complications otherwise often overlooked. Additionally, later implant removal was included in the calculation of reoperations, in opposite to other studies (Sems et al., 2010, Ochenjele et al., 2018).

The main indication for reoperation in Study II was infection, and this rate (9%) was in level with previously reported numbers of 2-9% (Sems et al., 2010, Ochenjele et al., 2018, Kanakaris et al., 2021). Deep surgical site infection (SSI) in other fracture surgeries such as hip fractures vary but are usually reported lower, with rates around 2% (Masters et al., 2020). Sustaining a deep postoperative infection can be devastating for the patient as this might result in multiple reoperations, and in current material from Study II, this cohort of patients had a considerable higher mortality rate. Plausible risk factors of sustaining an SSI could be the presence of an open fracture (Tischler et al., 2022) or undergoing abdominal or pelvic packing upon arrival before the definitive pelvic fracture surgery, although none of these parameters struck out in the regression analysis. Open pelvic fractures are rare in general, and only 4% (8/194) of the surgically treated pelvic fracture patients were reported to have an open fracture (Study II). This rate was however similar to existing literature although some concern could be raised regarding for example vaginal lacerations, which sometimes is considered as one definition of an open pelvic fracture, and which might be underdiagnosed (Tischler et al., 2022). Fracture complexity as a risk for subsequent reoperation has been suggested (Ochenjele et al., 2018) but this could not be confirmed from the data of Study II. Prolonged operative time is another factor, possibly connected to increased fracture complexity, which has been shown to increase the risk of SSI (Cheng et al., 2017), especially for operations with durations >3 hours. This data was not collected when analysing complication rates in this thesis but might be an important variable in the context of SSI in pelvic fracture surgery.

Other adverse events

As well as having a high risk of reoperation, pelvic fracture patients also risk other adverse events. Examples of these are nerve injuries, venous thromboembolic events (VTE) and pulmonary and urinary tract infections. Thromboembolic events affected 13% of the patients in Study II and included both pulmonary embolism (PE) at 9% and deep venous thrombosis (DVT) at 6%.

The high risk of VTE in pelvic fracture patients is well-known but exact rates vary. In studies screening with duplex ultrasound, as many as 29% of surgically treated pelvic or acetabular fracture patients were reported to have DVT either pre- or postoperatively (Wang et al., 2019), and 14% in a preoperative cohort (Zhao et al., 2022). A screening study from the UK reported a considerably lower rate of only 4% for DVT (Elnahal et al., 2020), and this rate was similar to the rate in a French study only recording clinical DVTs during the in-hospital admission time (Ostrowka et al., 2018). Early VTE prophylaxis is routine management in Sweden but might be delayed until hemodynamic stability is achieved (TQIP A., 2015, Parks et al., 2022). Measures to accomplish hemodynamic stability apart from blood transfusions are preperitoneal pelvic packing and angioembolization (AE). Both these interventions have shown to correlate with an increased risk of subsequent VTE (Bokenkamp et al., 2022, Parks et al., 2022), although this could not be confirmed in Study II. Other concomitant bleeding conditions such as hemorrhagic brain injury might also delay initiation of VTE prophylaxis for these patients, and the timing and dosage of starting the treatment can be a delicate balancing.

Concomitant abdominal injury was found to correlate with an increased risk of adverse events not requiring reoperation. It might be a parameter of overall injury severity but could also serve as a marker for extra observation in the postoperative period.

Mortality at 30 days (1.5%) and 1 year (6%) was assessed similar to existing data for patients surgically treated (Mann et al., 2018). Patients that underwent multiple reoperations due to deep SSI exhibited a higher mortality rate at 1 year (17%, n=4/24). Although few in number, this indicates the severity of this condition.

5.4 Acetabular fractures - complications

Reoperations

One major strength of study III of patients with surgically treated acetabular fractures was the unselected cohort of patients regarding surgical method, where patients treated with either ORIF or primary THA were included in the same analysis, which is only sparsely provided in existing literature before. There was a high rate of reoperations (21%), but considerably lower in the primary THA treatment group compared to the ORIF group (11 vs. 23%). The primary indication for reoperation in this material was arthrosis, and the finding supports considering THA as primary treatment for selected patients with acetabular fracture (mainly elderly), and it also emphasizes previous findings that the outcome for these patients is good (Mears et al., 2002, Sermon et al., 2008, Enocson et Blomfeldt, 2014, Makridis et al., 2014, Borg et al., 2019, Manson et al., 2022).

Earlier reports on reoperation rates after acetabular fracture surgery mainly investigate younger and older patients separately and vary between 4.5-15% for cohorts with younger patients than in our material (Giannoudis et al., 2005, Ding et al., 2018, Patterson et al. 2022). Older patients are usually assessed to have a greater risk of subsequent arthrosis development (and thus eventually reoperation) after acetabular fractures (Tannast et al., 2012, Verbeek et al., 2018). This is however somewhat in contrast to the findings of Study III, where no association between age and risk of reoperation could be found. The importance in selecting between ORIF and primary THA for older patients seem to gain interest along with an ageing population and a potential upsurge of patients with acetabular fracture in need of surgical treatment. A recent prospective American study compared ORIF with ORIF+THA for patients older than 60 years. They found, just as in study III, a considerably lower reoperation rate in patients treated with THA, with as much as 46% of the patients treated with only ORIF in need of reoperation (Manson et al., 2022).

There was an association between female gender and an increased risk for reoperation in the logistic regression analysis. Although cautious to draw firm conclusions regarding this finding due to the low number of reoperated females (n=15), it is an interesting finding. There are previous reports on female gender as a risk factor for reoperation after for example arthroscopic knee surgery (Capogna et al., 2020, Lord et al., 2020), but no known reports regarding pelvic fracture surgery. Anatomic differences of the pelvis, bone quality and possibly muscle strength might contribute to this finding but future focused analyses on females with acetabular fracture could add knowledge.

Reoperation due to deep infection was considerably lower in the acetabular fracture cohort compared to the pelvic fracture cohort (3.9 vs. 9%), although not statistically compared. These numbers are equivalent to previously published literature of 3-7% (Suzuki et al., 2010, Ding et al., 2018). The tendency was an overall lower rate of adverse events for patients surgically treated for acetabular fractures, compared to pelvic fracture patients. This might relate to the overall less severely injured patients in this cohort and suggests some adverse events might not relate to the surgical intervention or fracture but rather the patients' overall condition.

The third most common cause for reoperation for acetabular fracture patients was dislocated THA which affected 11% of the patients treated with THA in Study III, and this was the only cause of reoperation in the THA-treated patient cohort. This rate is somewhat higher than the 4% described in the systematic review by Makridis et al.

(2014) exploring complications after surgical treatment of acetabular fractures with THA. In study III all patients with dislocated THA were operated with a posterior surgical approach which is a known risk factor for dislocation in hip fracture patients (Enocson et al., 2009). In the end, only one patient needed further revision surgery with change of implant. Obviously, there is a challenge in the treatment of acetabular fracture patients, further confirmed by the results of our study III, due to the two different surgical methods (ORIF and THA) used, and the need of experience in both regimes to successfully manage these patients.

Other adverse events

The most common adverse event not requiring reoperation was nerve injury, affecting 12% of the patients, which was comparable to other reported numbers of 8-16% (Giannoudis et al., 2005). The coverage of nerve injuries in Study III was broad and included even sensory loss due to an injured lateral femoral cutaneous nerve. Pneumonia was second among the adverse events not requiring reoperation and affected 8 % of the patients. There was an association between ICU-care and increased risk for an adverse event not requiring reoperation, which is previously reported for patients with acetabular fractures (Ding et al., 2018).

5.5 CTMA in the follow-up of pelvic fracture patients

In the prospective clinical study (Study IV), CTMA was successfully used to follow and analyse fracture movement during the healing process in 10 surgically treated pelvic fracture patients during one year. The prerequisite for doing this was the low-dose CT examinations performed with median effective radiation doses of only 0.4-0.5 mSv.

The largest translational and rotational values were found during the first six postoperative weeks, with subsequent decrease between week six and 12 postoperatively. This course of movement was interpreted as an increased mechanical stability after six weeks and can be used as a proxy for fracture healing. While it's important to exercise caution when drawing conclusions based on a sample size of just 10 patients, the findings do suggest that there may be improved stability and healing after a six-week period, potentially lending support to recommendations for limited weight bearing during the early postoperative period. CTMA is highly interesting for the follow-up of pelvic fracture patients, as the healing of a pelvic fracture potentially relies on healing of ligaments as well as bone, and therefore, assessment of callus formation only (bone healing) might not be sufficient to determine healing of the entire pelvic ring injury. Another aspect concerns possible deformation of the pelvic ring over time due to impaired ligament structures that perhaps does not heal at all.

Definitions of fracture healing are still today not firmly defined but relies on different criteria whereof evaluation of the mechanical stability is one important factor. However, when sufficient stability is achieved, and how this is assessed remains under debate (Augat et al., 2014, Fisher et al., 2019). CTMA may be valuable in investigating the healing process of fractures in the future and could potentially be utilized in the follow-up of other fracture types. Examples could be fractures surgically treated, where some callus formation exists but questions regarding healing and stability remains. If sufficient mechanical stability can be concluded through CTMA, restrictions regarding weight bearing could be reduced, and this makes the technique potentially usable for fractures of the lower extremity.

It was not possible to either confirm or decline a clear relationship between an increased movement over time and a worse clinical outcome in the form of PROMs due to the limited number of included patients. Still, the tendency was that patients with lower than median outcome scores exhibited higher than median translation values. Studies with a larger number of patients would be needed to get an answer to this relevant concern, and to establish reference values of movement during the healing process. It would then also be proper, if possible, to include a more unselected cohort of surgically treated pelvic fracture patients. There might be a selection bias in Study IV in favor of less overall injured patients, as we excluded patients not able to take informed personal consent during the first days after admission, and additionally, the study patients reported PROMs at 1 year after injury at levels in the higher range of existing literature (Moon et al., 2014, Brouwers et al., 2018, Hermans et al., 2019).

Along with improved technology and the ability to reduce radiation doses, the use of CT is predicted to increase. The radiation doses in Study IV (0.4-0.5 mSv) corresponded to doses of CR of the pelvis with 3-5 projections (0.3-0.4 mSv) (Eriksson et al., 2019, Chen et al., 2020). Still, it could be debated to what extent increased use of postoperative CT will improve patient outcome, as it is important to balance the risk-benefit of every examination performed. The collected findings from this thesis emphasizes the severity of pelvic and acetabular fractures, and that these patients encounter negative events long after their injury, possibly affecting their quality of life. It is therefore arguable to provide a safe and precise radiological follow-up, in addition to the clinical evaluation, to detect implant related or healing problems as early as possible. CTMA offers a reliable method for this, but future clinical use is essential to gain further experience.

6 Conclusions

The incidence of pelvic and acetabular fractures has increased, particularly among the elderly population, but also among young and middle-aged adults in Sweden. Most of these fractures were managed non-surgically, although males across all age groups underwent surgical treatment more frequently than females. Patients with acetabular fractures were more often treated surgically compared to patients with pelvic fractures. Additionally, the acetabular fracture is one of few affecting males more than females, even in older age groups (Study I).

Surgical treatment of pelvic fractures is complex with a large rate of reoperations (25%) and other complications. These patients are often fragile due to other concomitant injuries and the usually high-energy trauma mechanism that their body has been exposed to. Deep infection requiring one or several reoperations is a severe condition commonly affecting these patients. Concomitant abdominal injury should be considered a risk factor for other adverse events (Study II).

The rate of reoperations was high also after acetabular fracture surgery (21%). Patients treated with primary THA had a reduced risk of reoperation, and the overall primary cause of reoperation was arthrosis. With an ageing population this suggests considering THA as primary treatment for selected patients with acetabular fractures. Females with surgically treated acetabular fractures are rare patients, possibly with increased risk for reoperation (Study III).

CTMA can be used to examine movement in the pelvis during the healing process after pelvic fracture surgery. Patients seemed to exhibit largest movement during the first six weeks after surgical fixation. The individual differences in magnitude of movement were considerable and might relate to patient reported outcomes (Study IV).

7 Points of perspective

Despite the growing global interest in the epidemiology of pelvic and acetabular fractures in recent years, additional research is required to clarify the reasons for the increasing incidence trends. It is important to analyse the ongoing incidence rates from 2017 onwards to determine whether the increase will persist or plateau. Additional analyses on pelvic fractures among younger adults regarding fracture type and treatment is also important, to better evaluate the gender differences.

Reducing rates of reoperations must be considered fundamental foremost due to the negative impact on the affected patient, but also in terms of excessive resources for every unnecessary surgery performed. The high rate of reoperations and other complications after surgical treatment of pelvic and acetabular fractures imply that any surgical treatment that these patients are subject to must be carried out with best possible preparation, performance, and follow-up. It is probably advisable to try to reduce operating time for these patients with a designated team of both surgeons, anesthesiologists, theatre staff and assistant nurses. Improved intraoperative radiology could be considered. It further entails a multiprofessional approach in highly specialized centers, starting already at the admission of the patient in the trauma or emergency room. All personnel involved in treating these patients should preferably be aware of possible complications and how to detect them early. Routines in performing gynecological examinations for females with high-energy pelvic fracture could be discussed, as well as screening for DVT with duplex ultrasound.

Criteria for surgical treatment of high-energy pelvic fractures rely on fracture severity, fracture displacement and pain but vary most likely between surgeons and hospitals both nationally and worldwide. A next step for future research in this area could be to compare surgical or non-surgical treatment for patients with selected fracture types, possibly nation based through national registers, and measuring clinical outcomes.

The use of CTMA among fracture patients is novel and the need of additional clinical studies in this field is obvious, at first just to further confirm its clinical usability. Regarding patients with surgically treated pelvic fractures, a larger series of patients would be needed to confirm or deny the findings of Study IV, and to investigate the potential relationship between movement in the fracture and the clinical outcome. Further use of CTMA in research on other fracture types is appealing as well. The technique could for instance be applied in the studying of general fracture healing, and could aid in determining a level of mechanic stability of a fracture, and hence decide when it is healed.

8 Acknowledgements

Jag vill tacka all de som bidragit i arbetet med denna avhandling, och särskilt följande personer:

Anders Enocson, huvudhandledare, för att du genomfört den här forskningsresan tillsammans med mig. Tack för din utmärkande kunskap, ditt engagemang och din aldrig sinande drivkraft att hela tiden komma vidare. Jag har lärt mig mycket av dig och inspireras av hur du brinner för att behandla och förbättra vården för traumapatienter.

Hans Berg, bihandledare, för ditt arbete som handledare, och för att du varit en viktig diskussionspartner, klinisk kollega och vän. Tack för din alltid så skarpsynta feedback och nya idéer.

Henrik Olivecrona, bihandledare, för att du givit mig inblick och lärt mig CTMA-tekniken, samt varit positiv och bidragit med din erfarenhet samt perspektiv på rollen som doktorand.

Tack till **Försvarsmakten** som anställde mig som civilmilitär ST-läkare 2018 och i och med det har bidragit till den här avhandlingen.

Li Felländer-Tsai, medförfattare. Tack för möjligheten att genomföra studie I, och för att du hela tiden uppmuntrar till forskning och vidareutbildning.

Alejandro Marcano och **Toumas Huttunen**, medförfattare till studie I. Tack för gott samarbete.

Lena Gordon Murkes, medförfattare, radiolog. Utan dig hade vi inte kunnat genomföra studie IV. Tack för att du lyckades åstadkomma så låga stråldoser med bibehållen hög bildkvalitet för våra studiepatienter, och för att du tog dig an detta projekt.

Peyman Bakhshayesh, medförfattare, för ditt stora kunnande inom bäckenfrakturer och för ditt förarbete inom bäckenforskning som ledde fram till färdigställandet av studie IV.

Olof Sandberg på Sectra för hjälp med CTMA och studie IV, och för inspirerande workshops.

Anna Tötterman, kollega, bäckenkirurg. Tack för att du inspirerat och undervisat mig inom ämnet bäckenfrakturer.

Gunnar Sandersjöö, verksamhetschef och bäckenkirurg, för ditt inspirerande, jämställda och stöttande ledarskap. Du har ända sedan jag började på Ortopeden på "gamla Karolinska" hösten 2015 väckt ett traumaintresse hos mig vilket bidragit till den här avhandlingen.

Wilhelmina Ekström, ST-läkarchef. Tack för att du tog dig an mig som adept under min ST-tjänstgöring, och för att du alltid varit så proffsig, lyhörd och stöttande, både till min forskning samt till min kliniska utveckling. Ditt ledarskap är ett föredöme och jag har lärt mig mycket av dig.

Karl-Åke Jansson, tidigare sektionschef, tidigare tillförordnad ST-läkarchef. Tack för ditt stöd och ledarskap både som chef och kollega. Din erfarenhet inom trauma och förmåga att vara närvarande i verksamheten är mycket värdefull. Tack för feedback (både positiv och negativ) på min forskning samt kliniska beslut under dessa år.

Peter Landell, sektionschef. Tack för ditt engagemang och för möjligheten att få genomföra dessa doktorandstudier parallellt med det kliniska arbetet.

Tack till alla mina **kollegor på Ortopeden Solna och Huddinge**, inom akut-trauma, elektiv, tumör och rygg. Ni gör alla ett enormt jobb för våra patienter dagligen, och bidrar samtidigt till en utvecklande och trygg arbetsmiljö med inspiration att bedriva forskning. Tack vare er är min arbetsplats stimulerande och rolig att gå till varje dag.

Tack till min familj och mina vänner som stöttat mig under den här resan. Särskilt tack till min mamma **Gunilla** och pappa **Roland** som alltid funnits där och är öppensinnade och positiva till vad jag än tar mig för, samt som alltid kan sätta saker och ting i perspektiv. Tack till mina bröder **Leonard** och **Patrik** för att jag fick växa upp med just er, och för att ni fortsätter peppa mig, och lyssna på stort som smått genom livet.

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