Pelvic ring injuries

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Recovery of patient-perceived physical functioning and quality of life

Hester Banierink

The iliac bone, the large expanded bone which bounds the greater pelvis laterally, is also referred to as the iliac *wing*. Butterflies are a symbol of life, transformation and hope, but in some believes also death. Although I have seen patients die as a result of their pelvic ring injury, most I have seen transform again into physically and mentally healthy persons. I hereby like to thank all those patients and families who contributed to the research described in this thesis.

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INTRODUCTION

Anatomy and evolution of the human pelvis

The pelvic ring is a fascinating three-dimensional structure that permits bipedal walking in an upright posture. The ring consists of three bones: the right and left iliac wings and the dorsal sacrum, held together by strong ligaments. The iliac bones are formed by the fusion of the embryonic iliac, ischium and pubic bones. The frontal part of the pelvic ring consists of the pubic bones, held together by a strong ligament called the pubic symphysis. Major neural, vascular, and visceral structures reside within the bony pelvis. These include the rectum, bladder, vessels of the iliac, obturator, femoral arterial and venous systems and reproductive organs. The distal branches of the spinal motor, sensory, and autonomic nerves are located within the sacrum and enter the pelvic visceral space via the sacral foramina (1). The pelvic anatomy impacts human performance. Changes in pelvic anatomy during evolution represent, among others, changes in locomotion. The overall shape is different in many ways from the primates we are related to. The size, shape and orientation of the pelvic bones differ between apes and humans in a way that reveals human adaptations to bipedalism. For example, the curvature in de lower back (lumbar lordosis) helps to balance the trunk over the pelvis. The mechanical goals of modern bipedalism are to walk with long strides, with high mechanical efficiency and a minimal risk of injury (2). For this ability to balance the body over the legs during walking, the pelvis must be robust and have a shape that maximizes muscle lever arms and minimizes load (2,3).

Incidence and cause of pelvic ring injuries

Pelvic ring injuries encompass all fractures occurring in the bony structures of the pelvis as well as disruptions of the pubic symphysis ligament. Therefore, in this thesis the terminology of pelvic ring *injuries* is used and not pelvic ring *fractures*. A low-energy trauma (LET) is often caused by a fall from standing position, causing minor pelvic ring injuries such as a fracture of the pubic bones. A high-energy trauma (HET) on the other hand includes traffic accidents and falls from height, which are more likely to cause major pelvic ring injuries like complete fractures through the sacral bone. The incidence of pelvic ring injuries in the Netherlands is reported to be 14.3 per 100,000 inhabitants per year, which accounts for approximately 2500 pelvic ring injuries each year in the Netherlands. The incidence increases with age, presenting more often in elderly patients (≥65 years) compared to younger patients (respectively 57.9 and 6.4 per 100,000 persons). Minor pelvic ring injuries occur in 10.7 per 100,000 persons whereas major injuries are rare with only 3.5 per 100,000 persons (4). Low-energy trauma resulting in pelvic ring injury appear regularly in frail elderly patients and deserve special attention within the aging population. Specific types of pelvic ring injuries may occur in the elderly after a minor trauma or even spontaneously where the patient has no recall of any trauma at all. These are called fragility fractures of the pelvis (FFPs), and are caused by an injury that would normally be insufficient to fracture healthy bone (5). Osteoporosis, a decrease in bone mass and strength, often plays a role in the occurrence of these fragility fractures. Moreover, elderly can be vulnerable due to the presence of sarcopenia, a progressive and generalized skeletal muscle disorder involving the accelerated loss of muscle mass and function, which is associated with falls, functional decline and mortality. Sarcopenia often co-exists with myosteatosis, which is excess deposition of fat into a muscle. Similar to sarcopenia, myosteatosis has been correlated with a decreased function and increased mortality (6–8).

Diagnosis of pelvic ring injuries

Pelvic ring injury types vary widely from simple undisplaced fractures to life-threatening multi-fragmentary severely displaced fractures. The modern history of pelvic ring injury diagnosis

begins with the French surgeon and medical historian Joseph-François Malgaigne (1806–1865) (9). In the nineteenth century, physical examination was the golden standard to accurately diagnose injuries before the discovery of radiographic imaging. By palpation and manipulation, Malgaigne experienced that crepitation at the affected site could indicate a pelvic ring injury. Also, careful estimation of the height of the iliac crest could distinguish pelvic ring injuries from the more common hip fractures, which are more often associated with lower extremity shortening (9). After the discovery of X-ray technology in 1895 by Wilhelm Conrad Rontgen (1845-1923), diagnostic accuracy and classification of pelvic ring injuries dramatically improved. This also allowed monitoring of the healing process. Traditionally, pelvic X-rays have been sufficient to diagnose anterior pubic ring injuries. Today, computed tomography (CT) is mostly considered the golden standard as concomitant posterior pelvic injuries may occur which cannot be visualized accurately on X-ray alone. The rise of CT and 3D imaging modalities has improved our understanding of the complex patterns in pelvic ring injuries and provided new opportunities to assess these injuries. CT and 3D imaging can also guide the surgeon with an operative plan. Besides, a variety of concomitant injuries that may accompany a pelvic injury can be identified on CT.

Types of pelvic ring injuries

Malgaigne identified a distinctive type of pelvic ring injury; a fracture of the inferior and superior rami of the pubis together with a posterior pelvic ring injury of the sacrum, ilium or SI joint. This is considered one of the first historic descriptions of a so-called ”vertical shear” injury with bilateral sacro-iliac joint dislocations and anterior fractures of the pubic rami, and gave rise to the eponymous term ‘Malgaigne’s fracture’ (10,11). Sir Frank Wild Holdsworth (1904-1969) a professor of Orthopedics in Yorkshire, England, dedicated significant work to refining the diagnostic and therapeutic strategies for pelvic injuries (12). He reported on two distinct entities of traumatic pelvic ring injuries in one of his studies conducted between 1937 and 1946. The first entity included a dislocation of the sacro-iliac joint and the second a fracture of the ilium or sacrum adjacent to the sacro-iliac joint. Both types of injury involved separation of the symphysis pubis, or fracture of both pubic rami. Moreover, the hemi pelvis was displaced laterally, or laterally and cranially (13). His descriptions and detailed observations represent patterns that we nowadays still refer to as “open book”, “lateral compression” or “vertical shear” injuries. In a sense, Holdsworth provided the first rough classification of pelvic ring injuries. Holdsworth was succeeded by Pennal and Sutherland in 1961, who provided the first clinically relevant systematic classification of pelvic ring injuries based on the mechanisms of the injury (14). They identified three distinct types of injuries, known as avulsion fractures, ‘stable’ fractures and ‘unstable’ fractures, in an attempt to correlate injury severity with outcomes. Marvin Tile, an orthopedic surgeon and professor at the university of Toronto, introduced and added the concept of ‘fracture stability’ in 1980 to the original classification (15), e.g. vertically stable but rotationally unstable. In 1986, Young & Burgess, both orthopedic surgeons from the United States of America, introduced a classification system that was based on the original Pennal/Sutherland classification (16). They divided injuries into the direction of the force that caused the injury, namely anterior-posterior compression (APC), lateral compression (LC) or vertical shear (VS) injuries. Currently used classification systems are mainly based on these landmark publications by Pennal and Sutherland, Young & Burgess and Tile. Their purpose was to facilitate decision-making in the acute management of patients with pelvic ring injuries (17,18). The most widely used system today is the AO/OTA classification (19), dividing injuries into type A, B or C. Within this classification, type A is considered a stable fracture, including undisplaced fractures of the pubic bones and isolated iliac wing fractures. Type B is an incomplete disruption of the posterior arch and type C a complete disruption of the posterior arch.

Associated injuries and mortality

In case of high-energy trauma, it is not surprising that pelvic ring injuries frequently occur simultaneously with several other traumatic injuries of the human body. Malgaigne already noted an association between pelvic injuries, bleeding, visceral injuries and nerve injuries, as did Lorenz Böhler (1885-1973), a surgeon from Vienna known as the creator of trauma surgery (20). Because the arteries and veins of the internal iliac system and pre-sacral venous plexus are located just anterior to sacroiliac joints, they are prone to injury by the same forces that also disrupt these ligaments (1). The pelvis can contain 4-6 liters of blood before a tamponade effect occurs, causing a risk of death by exsanguination. The bladder and urethra can be damaged due to the proximity of these structures to the pubic bones, (1) which may result in urinary leakage. In rare cases, injuries of the rectum can occur (20). Moreover, nerve injuries are not uncommon as several motor and sensory nerves are situated close to the pelvic bones. The most important are the sciatic, femoral and obturator nerves, which are prone to injuries and when damaged may result in paresthesias, muscle weakness and subsequent mobility problems. Malgaigne noted that vertically displaced pelvic fractures were often accompanied by impairment or complete loss of lower extremity function. He noted: “If life is preserved, lameness is very apt to ensue”, making the general prognosis of a pelvic ring injury poor. He noticed that many patients would not survive a severe pelvic injury. If a patient was fortunate to survive, there still remained a high risk of infection and sepsis, which is likely the result of contaminated open fracture wounds and associated visceral injuries. In the mid-20th century, the number of severe pelvic ring injuries increased rapidly due to an increasing number of high-speed motor vehicle accidents. It became clear that pelvic fractures were involved in a significant number of fatal injuries, mostly related to exsanguination due to retroperitoneal hemorrhage (21). Up to 5% of patients died as a direct result of the pelvic ring injury. Currently, death as a direct result of the pelvic ring injury occurs in only 1% of the patients (1), although overall mortality is estimated 15% in multi-trauma patients with a pelvic ring injury (1).

Treatment of pelvic ring injuries

Treatment of pelvic ring injuries has gone through an impressive evolution, yet it remains one of the most challenging clinical problems (1). The first concept of fracture stabilization dates back 5,000 years ago, when ancient Egyptians splinted fractures with wooden sticks and roller bandages (22). During the era of Malgaigne, resuscitation strategies were still in their infancy, and until today there is an ongoing debate regarding the appropriate sequence and surgical priorities in acute pelvic hemorrhage management (23). In the case of vertical shear injuries, Malgaigne advocated the restoration and maintenance of lower extremity length. A closed reduction maneuver was followed by maintenance in a modified traction bed with the application of a pelvic sling for a minimum of 45 to 50 days. As many patients could not tolerate the prolonged immobilization in traction, most fractures healed with significant limb shortening. Holdsworth and Böhler refined the pelvic sling with skeletal traction and provided technical recommendations for fracture reduction and immobilization. Böhler even described that mistakes in the treatment of anterior as well as posterior pelvic ring injuries included operative treatment (20). In the second half of the 20th century, external fixation of pelvic ring injuries was introduced to decrease ongoing blood loss by eliminating motion at the fracture site. It was also intended to reduce intrapelvic volume in ‘open book’ injuries to limit retroperitoneal blood loss (24). Gradually, treatment protocols moved towards surgical fixation for selected types of pelvic ring injuries. Tile used his own classification system to guide treatment recommendations (24). Into the 1980s operative internal fixation was applied in vertically as well as rotationally unstable injuries (24). Surgical fixation of unstable pelvic ring injuries was performed to allow early mobilization and provide better clinical outcomes (25,26), thereby becoming the international standard of care in

the 21st century. Currently, the choice of treatment is mainly based on the fracture type, degree of displacement and the surgeon's preference. However, other factors like age, comorbidities and the patient's own preferences start to play an increasing role in treatment decisions. Generally speaking, 'stable' injuries are treated non-operatively, which principally consists of non- or partial weight bearing for six weeks in combination with adequate pain medication. In minor injuries, weight-bearing as tolerated is allowed right after the injury. Operative treatment is usually required in severe 'unstable' pelvic ring injuries, which can either be treated with percutaneous fixation by using screws or with open reduction and internal fixation (ORIF). In the latter, lag screws and plates are used for fracture reduction in order to restore pelvic ring symmetry and provide biomechanical stability for early mobilization.

'Positive health' and the shift towards patient-reported outcomes

Pelvic ring injuries may have great consequences on the patients' physical functioning and quality of life. Böhler noticed that most patients recovered within weeks to months, although it could take up to two years in vertical shear injuries without concomitant injuries(20). Holdsworth was probably the first to look at clinical outcomes using return to previous employment as a measure of functional recovery. He noticed that nearly all patients with a fracture of the iliac wing or sacrum returned to heavy labor. This was in contrast to patients with sacro-iliac joint dislocations of whom less than half returned to previous work activities (13). With his work, Holdsworth was the first to predict post-injury outcomes linked to the type of injury. Nonetheless, research concerning outcomes after pelvic ring injuries mainly focused on outcomes like mortality, complications and fracture healing. In 1948, the WHO provided a definition for health: 'health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'. Now, almost 75 years later, this concept remains unchanged. Health and health-related problems are described from biological, personal and societal perspectives: the International Classification of Functioning, Disability and Health (ICF)(27). In the ICF, problems with functioning are categorized in three interconnected areas: 1) Body Function and Structure, 2) Activity Limitation and 3) Participation restriction. Recently, Huber et al. (28) introduced a new concept 'positive health' defined as 'health as the ability to adapt and to self-manage, in the face of social, physical and emotional challenges'. Within this concept, the human being plays the central role instead of the disease. Functioning, resilience and self-control are major subjects (28). It includes six dimensions, namely 1) bodily functions, 2) mental function and perception, 3) spiritual/existential, 4) quality of life, 5) social and societal participation, and 6) daily functioning. This growing focus on patient-centred care has resulted in a shift in terms of outcome assessment and the increasing use of Patient Reported Outcome Measurements (PROMs). These single or multi-item questionnaires seek to assess the influence of the patient's condition on the daily functioning and emotional status and can provide critical information to enhance patient-centred health care (29). Several studies used PROMs to measure the outcomes following pelvic ring injuries in terms of physical functioning and quality of life. Yet, small populations with mostly operatively treated patients and the use of non-validated PROMs make it difficult to interpret the results (30). No actual guidance exists for appropriate PROM-based assessment after these injuries and many different types of generic outcome instruments as well as pelvis-specific measures have been used (31). Due to the wide variety in types of pelvic ring injuries and the variability in treatment, outcomes are challenging to compare, leaving both doctors and patients in doubt about the actual outcomes following these injuries. Besides, research is limited by the mostly unknown level of physical (dis)ability and quality of life before the injury. Despite the limitations of current literature, the available results do indicate that many patients have long-term disabilities and decreased quality of life after pelvic ring injuries (32,33). For example, chronic pelvic pain and mobility problems can result in patients not being able to return to their

previous work, which subsequently can have a major impact on both a personal as well as society level. By clarifying perceived physical disabilities and factors that may negatively influence the patient's quality of life, rehabilitation programs can be adjusted to the patient's specific needs and psychological support can be integrated.

AIMS OF THIS THESIS

The *general aim* of this thesis is to gain more insight into the patient's perception of functional recovery and quality of life after pelvic ring injuries. Hence, it provides the foundation for more personalized care with the intention to optimally treat the patient in order to achieve the best possible perceived functional recovery and quality of life after these devastating injuries. The first aim was to gain insight into the patient-reported physical functioning and quality of life following pelvic ring injuries in patients of all ages. The second aim was to zoom in on a specific entity of pelvic ring injuries in the elderly. At last, the third aim was to provide insight into developments in treatment strategies of pelvic ring injuries.

OUTLINE OF THE THESIS

This thesis is divided in three parts.

Part I: Insight into the patient's health perspective
This part addresses PROMs assessing physical functioning and quality of life after pelvic ring injuries in patients of all ages. A systematic review is presented in **chapter 2,** focusing on current concepts of patient-reported outcomes in terms of physical functioning and quality of life following these injuries. In **chapter 3,** a retrospective study is presented evaluating physical functioning and quality of life in a large group of patients, divided according to their age distribution and injury type at long-term follow-up. A large prospective longitudinal study is presented in **chapter 4**, including important baseline measurements of the patient's perception on his own health before the injury. Within these chapters, the main goal is to clarify the course of rehabilitation in the first two years after the injury. Chapter 4 is directed to physical functioning, while chapter 5 describes the impact on mental health and social participation.

Part II: Zooming in: specific entities of pelvic ring injury in the elderly
The second part of this thesis focuses on patients aged over 65 years with a pelvic ring injury. As elderly patients are fragile and the overall population ages, this subgroup is becoming more important and deserves special attention. **Chapter 5** describes mortality rates as well as physical functioning and quality of life after pelvic ring injuries compared to age-matched peers from the general Dutch population. **Chapter 6** studies the incidence of fragility fractures of the pelvis in relation to generally applied treatment, with the goal to propose a multidisciplinary treatment protocol in order to optimize patient care. At last, **chapter 7** examines muscle quantity and quality in elderly patients with pelvic ring injuries expressed by sarcopenia and myosteatosis and how these may hamper physical functioning and quality of life.

Part III: A glance into the future: treatment improvement
Part three gives insight into the future treatment strategies for patients with pelvic ring injuries, looking at three-dimensional (3D) techniques. In **chapter 8**, a systematic review was performed in which current 3D assisted operative treatment techniques and their influence on intra-operative outcomes (operation time, blood loss, accuracy of screw placement), as well as clinical outcomes in terms of fracture reduction and functional recovery were assessed. This thesis ends with a general discussion including future perspectives in pelvic ring injury rehabilitation and treatment (**chapter 9**).

APPENDICES TO THE GENERAL INTRODUCTION

I: Anatomy of the pelvis (34)

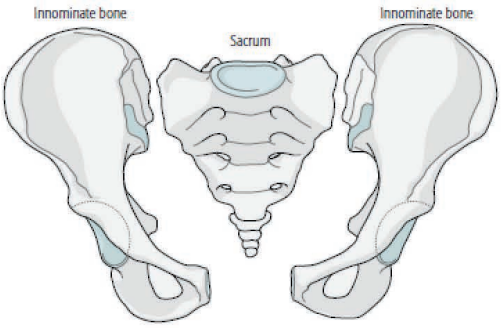

Figure 1: anatomy of the pelvic bones

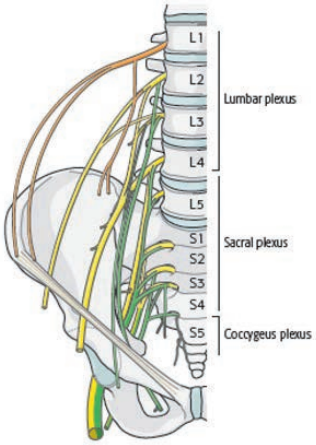

Figure 2: pelvic nervous system: the lumbosacral plexus

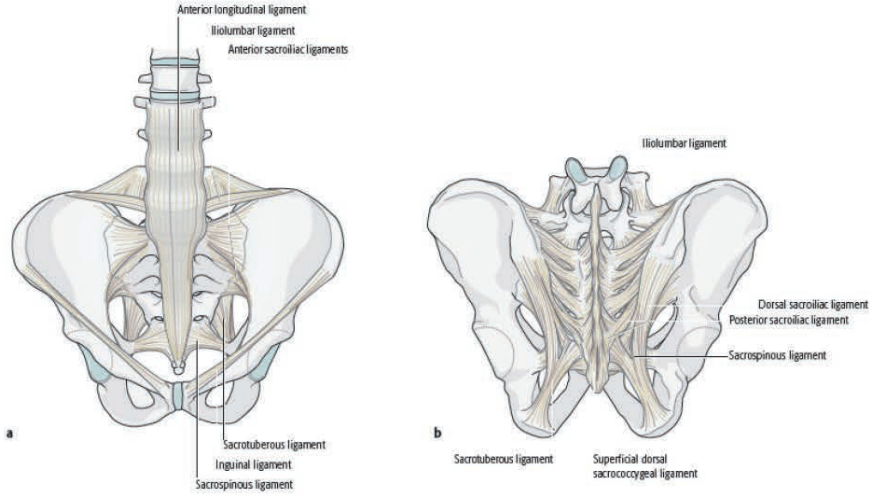

Figure 3: the major posterior stabilizing structures are ligaments. a) ligaments from anterior aspect of pelvis, b) ligaments from posterior aspect of pelvis

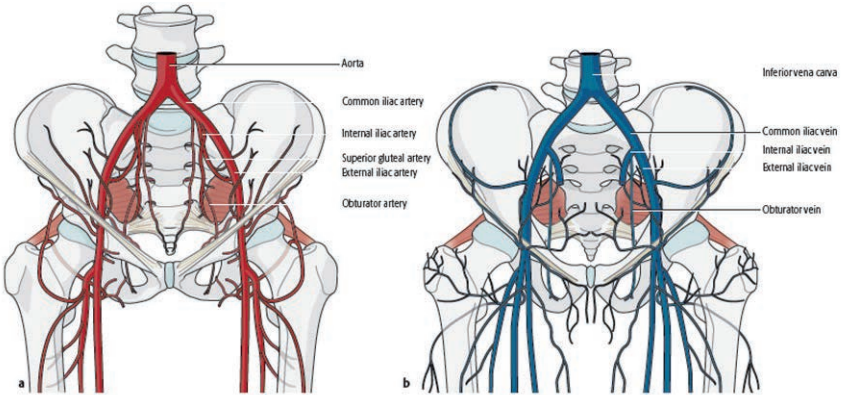

Figure 4:
a) arteries of the pelvis,
b) veins of the pelvis

II: Classification of pelvic ring injury types

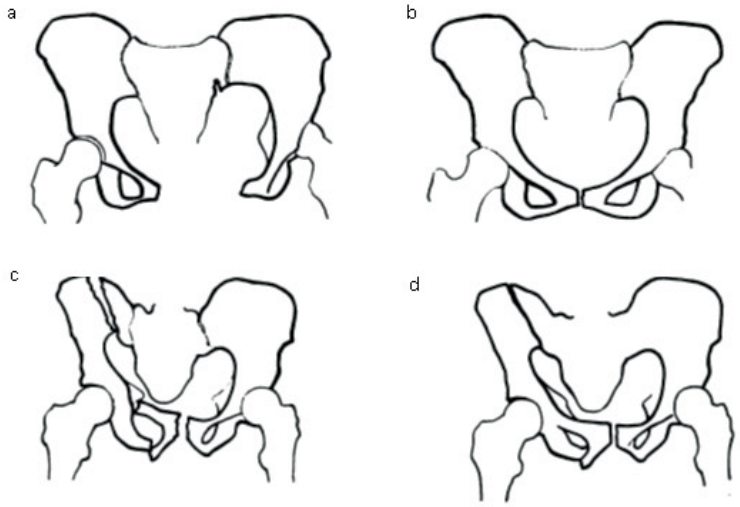

Figure 1. Types of pelvic ring injuries identified by Holdsworth in 1948 (13). Gross separation of one half of the pelvis with wide separation of the symphysis and dislocation of one sacro-iliac joint (a). The same case is shown after reduction by a pelvic sling (b). Fracture dislocation of the pelvis with double pubic fractures and a fracture of the ilium near the sacro-iliac joint (c). The same case is shown after reduction by the pubic sling (d).

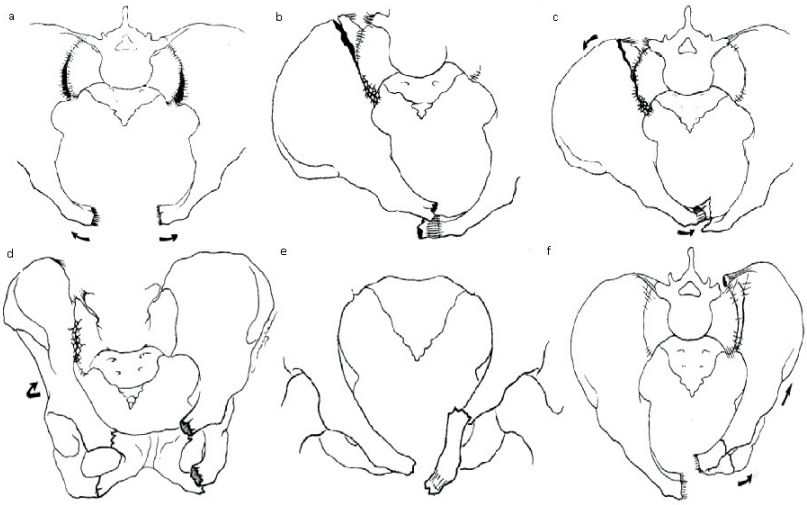

Figure 2. Types of pelvic ring injuries as shown by Pennal & Tile in 1979 (15). A typical anteroposterior compression fracture (open-book type) showing a disruption of the symphysis pubis and the anterior sacroiliac ligaments (a). Lateral compression injury, ipsilateral type, showing a posterior fracture and the anterior disruption of the pubic rami with internal rotation of the hemi pelvis (b). Typical lateral compression injury (contralateral or bucket handle type) showing the right posterior lesion and the left pubic rami lesion (c). Lateral compression injury showing the posterior disruption of the right sacroiliac complex and all four pubic rami fractured anteriorly (d). Unusual type of lateral compression injury characterized by buckling of the superior pubic ramus and disruption of the symphysis. The medial fragment rotates inferiorly and anteriorly (e). Vertical shear type injury with complete disruption of the left hemi pelvis (f).

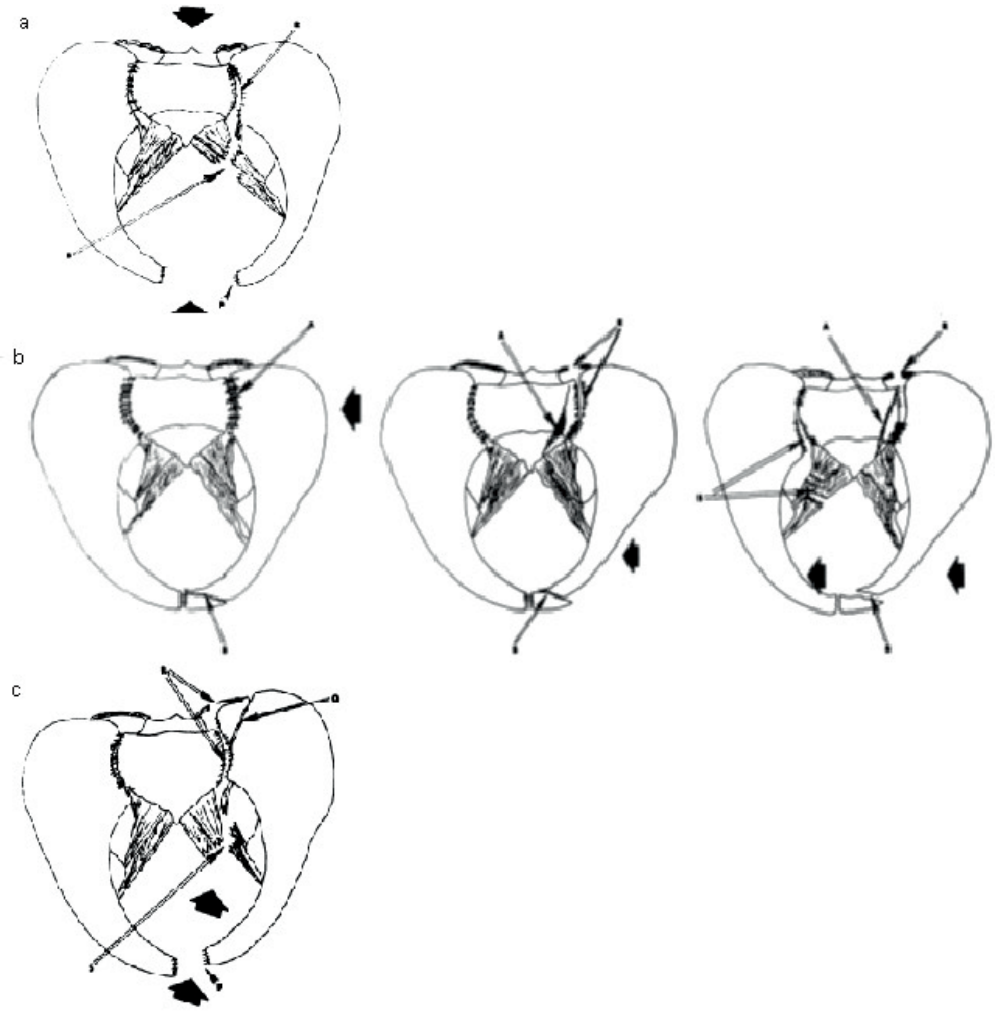

Figure 3. Types of pelvic ring injuries as presented by Young & Burgess in 1986 (16). AP-compression injury (a). The direction of the force is in the AP (or posterioranterior) direction (large arrows). This has caused splaying of the symphysis and rupture of the anterior sacroiliac ligaments, sacrotuberous/sacro-iliac complex and symphysis ligaments, with “opening” of the pelvis. Lateral compression injuries (b). A lateral force is applied posteriorly (left). This causes a crush effect on the SI, which may be visible as a fracture radiographically. The characteristic fracture pattern on the pubic rami will be seen. No ligamentous injury is seen. A force is applied anteriorly (middle), causing the typical anterior fracture. In this case, however, rotation of the pelvis around the anterior sacral margin may occur, causing rupture of the posterior sacroiliac ligaments. A crush fracture of the sacrum may also be seen. A force is applied anteriorly causing internal rotation of the anterior hemipelvis (right). Continuing through to the contralateral hemipelvis, the force causes external rotation. The result is a pattern of lateral compression on the ipsilateral side, with apparent AP compression of the contralateral side with rupture of the posterior sacroiliac ligaments on the left and rupture of the sacrospinous/sacrotuberous complex and anterior ligaments on the right. There may also be a crush fracture of the sacrum. Typical fractures of the pubic rami are to be expected.

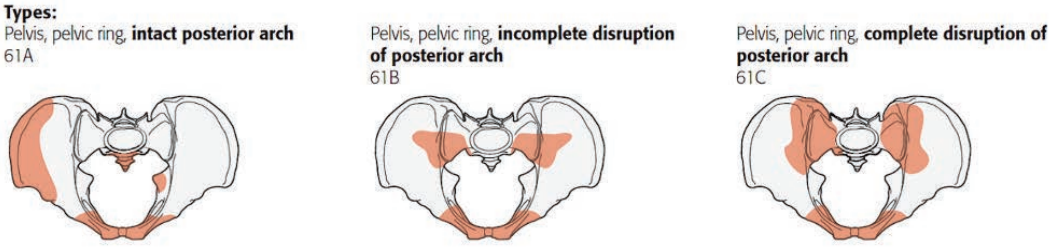

Figure 4. Modern classification of pelvic ring injuries according to Tile and the AO/OTA (34)

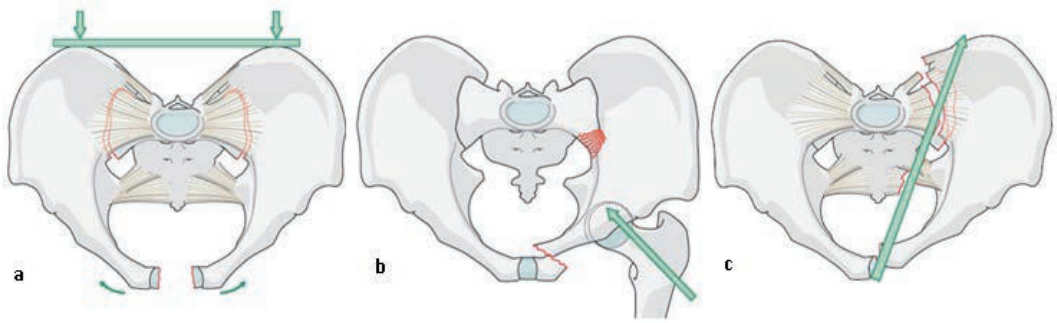

Figure 5. Direction of forces that can lead to disruption and fractures of the pelvis. a) anterior-posterior compression injury that can lead to disruption of the pubic symphysis. b) lateral compression force causing a fracture of the pubic rami and disruption of the sacroiliac complex. c) vertical shear force causing marked displacement of bone and gross disruption of soft tissues resulting in major pelvic instability (34)

III: Skeletal traction

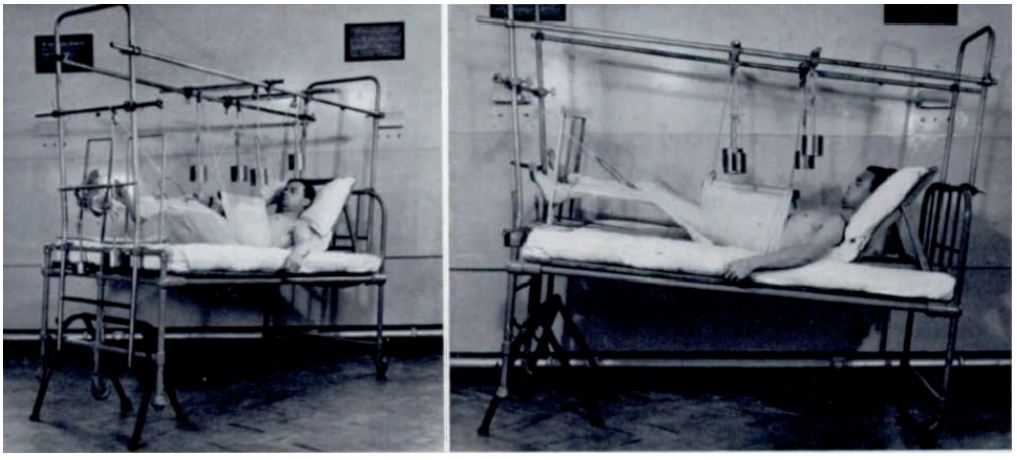

Figure 1. Fracture dislocation of the pelvis immobilized in sling and frames with skeletal traction applied to the left leg. By Holdsworth, 1948 (13).

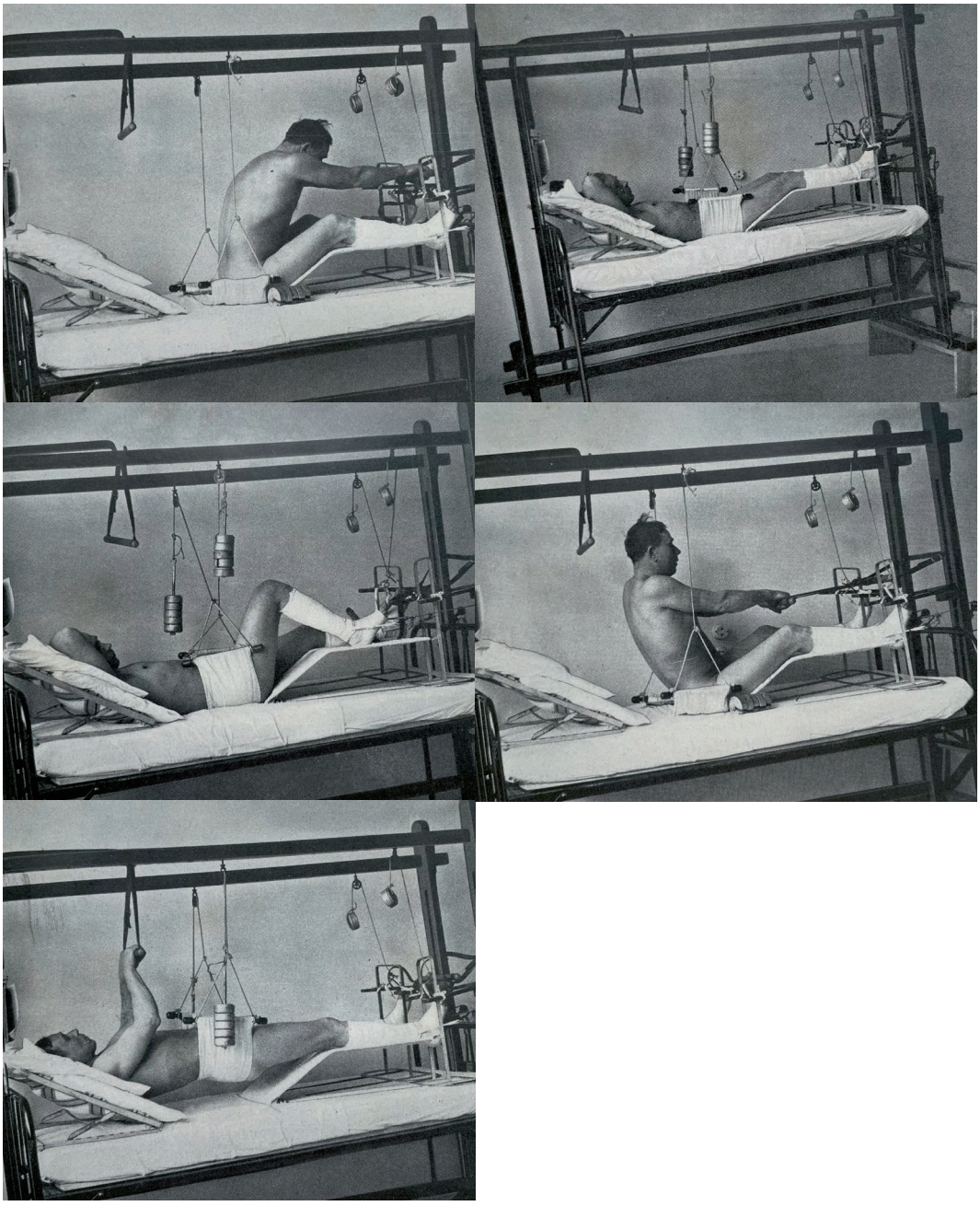

Figure 2. Patient with a pelvic ring injury immobilized in a sling and frames with skeletal traction. Both lower legs are placed on a so called "Braun'schen Schienen", a sort of splint, and wrapped in stretch bandage and a cast with 5kg of weight attached. The feet carry 1 kg of weight. The pelvis is rested in a special hammock with 5 kg weight on each side. The lower part of the bed is placed 30 cm high on a small staircase. Images by Böhler, 1932 (20).

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Part I

INSIGHT INTO THE PATIENT's HEALTH PERSPECTIVE

Chapter 2	**Patient-reported physical functioning and quality of life after pelvic ring injuries – a systematic review of the literature.** *PLoS One. 2020 July 17;15(7):e0233226*
Chapter 3	**Long-term physical functioning and quality of life after pelvic ring injury** *Archives of Orthopedic and Trauma Surgery. 2019 September;139(9):1225-1233*
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Chapter 2

Patient-reported physical functioning and quality of life after pelvic ring injuries – a systematic review of the literature

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ABSTRACT

Background. Pelvic ring injuries are one of the most serious traumatic injuries with large consequences for the patients' daily life. During recent years, the importance of the patients' perception of their functioning and quality of life following injury has increasingly received attention. This systematic review reports on self-reported physical functioning and quality of life after all types of pelvic ring injuries.

Methods. The online databases MEDLINE-PubMed and Ovid-EMBASE were searched for studies published between 2008 and 2019 to identify published evidence of patient-reported physical functioning and quality of life after which they were assessed for their methodological quality.

Results. Of the 2577 articles, 46 were reviewed in full-text, including 3049 patients. Most studies were heterogeneous, with small cohorts of patients, a variety of injury types, treatment methods and use of different, often non-validated, outcome measures. The overall methodological quality was moderate to poor. Nine different PROMs were used, of which the Majeed Pelvic Score (MPS), SF-36 and EQ-5D were the most widely used. Mean scores respectively ranged from 75-95 (MPS), 53-69 (SF-36, physical functioning) and 0.63-0.80 (EQ-5D).

Conclusions. Physical functioning and quality of life following pelvic ring injuries seem fair and tend to improve during follow-up. However, differences in patient numbers, injury definition, treatment strategy, follow-up duration and type of PROMs used between studies hampers to elucidate the actual effects of pelvic ring injuries on a patient's life.

Implications of key findings. Physicians and researchers should use valid and reliable patient-reported outcome instruments on large cohorts of patients with properly defined injuries to truly evaluate physical functioning and quality of life after pelvic ring injuries.

INTRODUCTION

Pelvic ring injuries can be seen as one of the most serious traumatic injuries with large consequences for the patients' daily life. Apart from the substantial mortality rates (1,2), principally in high-energy trauma, these injuries coincide with long periods of impaired mobilization and intense rehabilitation. In addition, pelvic ring injuries are increasingly caused by low-energy trauma in the frail elderly. Injury types vary from stable type A fractures, usually treated non-operatively, to highly unstable type C fractures, often demanding operative fixation and long term recovery. Despite this, adequate prospective follow-up studies, both on short-term and long-term outcome, on pelvic ring injuries are lacking.

Many factors that characterise a patient's health status cannot be observed, measured with a device, or analysed with even the most sophisticated imaging methods. How a patient feels and performs remains largely impenetrable to devices (3). The growing focus on patient-centred care has resulted in a shift in terms of outcome assessment and the increasing use of Patient-Reported Outcome Measurements (PROMs). These questionnaires seek to assess the influence of the patients' condition on their daily functioning and emotional status, and can provide critical information to enhance patient-centred health care (4). Conceptually, PROMs can be viewed either as a 'tool for evaluation' or as a 'mechanism for improvement'.

No actual guidance exists for appropriate PROM-based assessment after pelvic ring injuries. Hence, the problem arises with regard to the long list of different PROMs used, many of which have no proof of being valid or reliable either. Lefaivre et al. (5) showed that many different types of generic outcome instruments as well as pelvis-specific measures are used to assess the outcomes after pelvic ring injuries. Besides, due to the wide variety in types of pelvic ring injuries and the variability in treatment strategy, outcomes are hard to compare, leaving physicians, researchers and patients in doubt about the actual outcomes following these injuries.

In this perspective, the main objective of the present systematic review was to identify and analyse published studies, thereby providing a representative overview of the outcomes in terms of patient-reported physical functioning and quality of life following pelvic ring injuries. Moreover, following the results of this review, our aim was to highlight whether changes can be made for future research in order to properly evaluate the consequences of these severe injuries.

METHODS

For this systematic review the PRISMA method (6) for literature collection and manuscript construction was followed. The review protocol has been registered in PROSPERO International prospective register of systematic reviews under registration number CRD42019129176.

Identification of studies: search strategy

The search strategy sought to retrieve references relating to physical functioning and quality of life after pelvic ring injuries. Therefore, the items "pelvis", "injury" and "outcome" were combined to develop the search strategy. Searches used medical subject headings (MeSH terms) and free text searching to combine terms specific to pelvic ring injuries with terms relevant to PROMs evaluation. The full electronic search strategy was developed in collaboration with an experienced medical librarian and is presented in table 1. Two databases were searched to identify original articles: MEDLINE-PubMed (2008-15-04-2019) and Ovid-EMBASE (2008-15-04-2019).

Table 1: search strings by database

Database	Search string
MEDLINE-PubMed	(((“Pelvis”[Mesh:NoExp] OR “Sacrum”[Mesh] OR “Sacroiliac Joint”[Mesh] OR “Pubic Bone”[Mesh] OR “Pelvic Bones”[Mesh] OR pelvic[tiab] OR pelvis[tiab] OR sacrum[tiab] OR sacral[tiab] OR sacroiliac[tiab] OR pubic[tiab]) AND (“Wounds and Injuries”[Mesh] OR injur*[tiab] OR fractur*[tiab] OR trauma*[tiab]) AND (“Quality of Life”[Mesh] OR quality of life[tiab] OR “Recovery of Function”[Mesh] OR functional status[tiab] OR functional outcome*[tiab] OR physical function*[tiab] OR “Patient Outcome Assessment”[Mesh] OR patient reported outcome*[tiab] OR outcome assessment[tiab] OR SMFA[tiab] OR short musculoskeletal function assessment[tiab] OR EQ-5D[tiab] OR euroqol[tiab] OR SF-36[tiab] OR short form[tiab] OR SF-12[tiab] OR majeed[tiab] OR merle d’aubigne[tiab] OR (IPS[tiab] OR iowa[tiab])) NOT case reports[pt]) AND (“2008/01/01”[PDat] : “3000/12/31”[PDat]))
Ovid-EMBASE	(‘pelvis’/de OR ‘sacrum’/exp OR ‘sacroiliac joint’/exp OR ‘pubic bone’/exp OR ‘pelvis fracture’/exp OR ‘pelvis injury’/exp OR ‘sacral fracture’/exp OR pelvic:ti,ab OR pelvis:ti,ab OR sacrum:ti,ab OR sacral:ti,ab OR sacroiliac:ti,ab OR pubic:ti,ab) AND (‘injury’/exp OR injur*;ti,ab OR fractur*:ti,ab OR trauma*:ti,ab) AND (‘quality of life’/exp OR ‘convalescence’/exp OR ‘patient-reported outcome’/exp OR ‘patient outcome assessment’:ti,ab OR ‘patient reported outcome*’:ti,ab OR ‘quality of life’:ti,ab OR ‘functional status’:ti,ab OR ‘functional outcome*’:ti,ab OR ‘physical function*’:ti,ab OR ‘outcome assessment’:ti,ab OR smfa:ti,ab OR ‘short musculoskeletal function assessment’:ti,ab OR ‘eq 5d’:ti,ab OR euroqol:ti,ab OR ‘sf 36’:ti,ab OR ‘short form’:ti,ab OR ‘sf 12’:ti,ab OR majeed:ti,ab OR (merle:ti,ab AND aubigne:ti,ab) OR (ips:ti,ab AND iowa:ti,ab)) AND [embase]/lim AND [2008-2018]/py NOT ‘case report’/de NOT ‘conference abstract’/it

Inclusion and exclusion criteria and procedure

Eligible studies included patients aged 18 years or older with a pelvic ring injury. Studies that focused on the outcomes after non-operative as well as operative treatment were eligible. The outcome measures used should include patient-reported outcome measures (PROMs). Except for case studies and conference abstracts, all study designs were accepted for inclusion. Concerning language, studies written in English, German, Spanish, French and Dutch were included. There was no limitation on the search by publication status. Studies on geriatric fractures or fragility fractures were excluded. Studies with a sample size of less than 20 patients in follow-up were excluded, because PROMs results based on so few patients seem unreliable. Moreover, studies that included outcomes after both pelvic ring injuries and acetabular fractures and that did not differentiate between these injuries in terms of outcomes, were excluded as well. The study selection was performed in two screening phases: 1) title and abstract screening, and 2) full text screening. Both selection phases were independently performed by the same researchers (HB, IR).

Data extraction

Data extraction was performed in sequence using a standardized data extraction spreadsheet developed prior to data extraction, for evaluating physical functioning and quality of life after pelvic ring injuries. During both selection phases, articles were selected on the basis of language, number of patients, age of patients, population (pelvic ring injury and human/non-human), study type and use of PROMs. Relevant data from the included articles were extracted by the senior author including the 1) names of the authors, 2) year of publication, 3) study design, 4) number of patients in follow-up, 5) type of pelvic injury, 6) details on type of treatment, 7) type of PROMs, and 8) outcome of PROMs. In case of discrepancies during any of the stages, the topic of disagreement was discussed within the entire review team (HB, IR, FIJ, KtD) in order to resolve disagreements.

PROMs
The variables for which data were sought included all PROMs used to assess physical functioning and quality of life after pelvic ring injuries. These included the disease-specific Majeed Pelvis Score, Iowa Pelvic Score, Pelvic Outcome Score and Merle D'Aubigne-Postel score, as well as the generic Musculoskeletal Function Assessment, the Short Musculoskeletal Function Assessment, Short Form-36, Short Form-12 and EuroQuol-5D. A description of each of these PROMs can be found in supporting file 1.

Assessment of methodological quality
Two authors (HB, IR) independently rated the methodological quality and risk of bias for each study by using a quality assessment tool developed by the McMaster University Occupational Therapy Evidence-Based Practice Research Group (7). The Modified McMaster Critical Review form for Quantitative Studies consists of nine categories: citation, study purpose, literature, design, sample, outcomes, intervention, results, and conclusions and implications. This review form is appropriate to assess RCTs, cohort studies, single-case designs, before- and after-designs, case control studies, cross-sectional studies and case studies. The guidelines established by Law et al. (7) were utilized for the quality assessment. Every item was answered with 'yes; 1 point', 'no; 0 points', 'not addressed; 0 points' or 'not applicable (N/A); no points given'. The sum of these outcomes predicted the overall quality of the study assessed, ranging from 0 to 14 for RCTs and 0 to 12 for other study designs. The final score is given as the percentage of the maximum score. Qualitative assessment of intervention was not performed for the reason that this was irrelevant for the purpose of this review. Disagreements between the review authors were resolved through discussion until consensus was reached.

Strategy for data synthesis
Data synthesis involved the comparison, combination, and summary of findings. Efforts were made to retrieve missing data on follow-up duration and missing scores on the questionnaires, by contacting the corresponding authors. Data is presented as part of a narrative synthesis, involving text and tables. The data are grouped according to the time of follow-up and the outcomes of the different types of PROMs that were used.

Statistics
The results of the various questionnaires are shown according to the standards of the specific questionnaire, either as number with percentage or as mean with standard deviation or median with range or interquartile range (IQR). Pooled means and standard deviations were manually calculated for the complete cohort of every study in case the outcomes of the PROMs were provided for two or more groups.

RESULTS
Selection of studies
The initial searches (conducted from January 2008 to April 15th 2019) generated 2577 articles. Following title and abstract assessment, 95 articles were reviewed in full text. A total of 46 articles were included in the review, of which most (N=22) were cross-sectional studies, followed by case-control studies (N=12), cohort studies (N=10), one RCT and one combination of a cohort and cross-sectional study. Figure 1 demonstrates a flowchart of the inclusion procedure.

Patient and injury characteristics
Overall, data of a total of 3049 patients were reported in the studies. The number of patients included in the studies varied widely, from as little as 20 patients (8) up to as much as 263

patients (9). However, most studies were relatively small; only seven studies (9–15) included more than 100 patients and more than half reported on even less than 50 patients. Thirty-eight studies focused on unstable pelvic ring injuries (Type B and/or Type C according to the AO classification system (16)), whereas only six studies included all types of pelvic ring injuries (10,12,15,17–19). Two studies focused on the outcomes after sacral fractures (20,21). Both non-operative treatment as well as several operative techniques were applied to treat the patients, although no study solely focused on the outcomes after non-operative treatment. Operative techniques varied from external fixation to internal fixation with osteosynthesis plates to percutaneous fixation and other minimally invasive techniques. All included studies are described in Table 2.

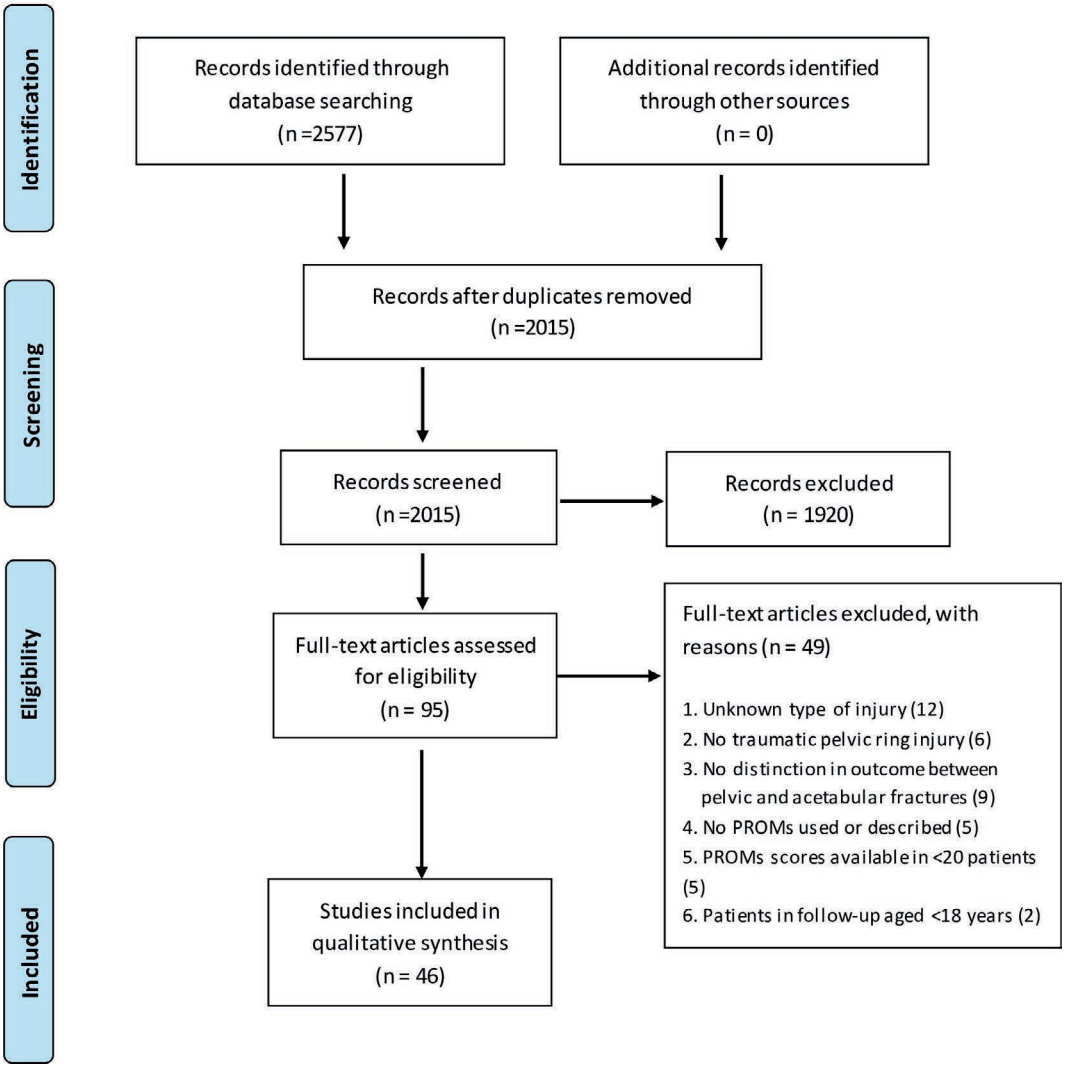

Figure 1. Flow diagram according to the PRISMA method (6)

Table 2. Study characteristics

No.	Study	N	Method	Study period	Injury type (AO/OTA) ‡	Interventions	PROMs	Follow-up in months
1	Abhishek et al. (22)	41	CS	2007 – 2014	B, C	Percutaneous iliosacral screw fixation	MPS	12
2	Adelved et al. (23)	28	CS/CSS	1996 - 2001	C	Surgical treatment with open or closed reduction	SF-36	12 (short FU) and 128 (mean; range 97-161) (long-term FU)
3	Ayvaz et al. (8)	20	CSS	2004 – 2006	B, C	Closed reduction and percutaneous fixation	SF-36, MPS, IPS, POS	33 (mean; range 24-52)
4	Banierink et al. (12)	192	CSS	2007 – 2016	A, B and C	Non-operative and operative treatment	SMFA-NL, EQ-5D	53 (mean; range 12-120)
5	Bastian et al. (24)	63	CSS	2004 – 2013	B, C	Anterior fixation by modified Stoppa approach	MPS	40 (mean; range 12-96)
6	Bi et al. (25)	43	CCS	2012 – 2016	B	S: Modified pedicle screw-rod fixation C: Anterior pelvic external fixation	MPS	12
7	Borozda et al. (26)	28	CS	2009 -2013	C	External fixation with separate anterior and posterior modules	MPS	12
8	Bott et al. (27)	74	CS	1994 – 2005	B, C	Surgical treatment	SF-36, EQ-5D	180 (mean; range 132-264)
9	Brouwers et al. (10)	195	CSS	2011 – 2015	A, B and C	Non-operative or surgical treatment	MPS, EQ-5D	29 (mean; range 6-61)
10	Chen et al. (28)	58	CCS	2002 – 2007	C	S: Internal fixation with percutaneous reconstruction plate via posterior approach C: Internal fixation with percutaneous sacroiliac screws via posterior approach	MPS	21 (mean; range 12-36)
11	Chen et al. (29)	21	CSS	2006 – 2009	B	Endobutton technique for dynamic fixation of traumatic symphysis pubis disruption	MPS	23 (mean; range 18-26)
12	Chen et al. (30)	32	CCS	2002 – 2009	B, C	S: Percutaneous iliosacral screw fixation C: Non-operative treatment	SF-36, MPS	12
13	Dienstknecht et al. (31)	62	CSS	2000 – 2007	C	Minimally invasive stabilizing system	POS	37 (mean; range 36-42)

14	Feng et al. (32)	26	CCS	2009 – 2013	B	S: percutaneous fixation of traumatic pubic symphysis diastasis using a TightRope and external fixator C: percutaneous cannulated screw fixation	MPS	15 (mean; range 12-20)
15	Frietman et al. (19)	37	CSS	2003 – 2013	A, B and C	Symphyseal plating	SF-36, MPS	34 (median; range 12-109)
16	Ghosh et al. (33)	75	CS	2015 – 2016	B, C	Nonoperative or surgical	MPS	6
17	Grubor et al. (18)	47	CSS	1999 – 2009	A, B and C	Nonoperative (sling, side-lying, resting) or Surgically (internal fixation, AO plates and screws) through Emile-Letournel's, suprapubic or sacroiliac approach	Merle d' aubigne - postel	≥18 after trauma
18	Hoch et al. (14)	128	CS	2004 – 2010	B	Nonoperative and operative (minimally invasive posterior pelvic ring procedures).	SF-12, EQ-5D	24
19	Hoffman et al. (13)	119	CS	2000 – 2010	B	Nonoperative and operative (open or closed reduction and internal fixation)	SMFA	6, 12 and 24
20	Holstein et al. (15)	172	CSS	2004 – 2011	A, B and C	Nonoperative and operative	EQ-5D	36 (median; range 12-72)
21	Hua et al. (34)	23	CSS	2012 – 2015	B, C	Minimally invasive interior internal pelvic fixator (INFIX) with or without a posterior pedicle screw-rod fixator	MPS	14 (mean; range 6-27)
22	Kokubo et al. (35)	82	CSS	1991 – 2010	B, C	Nonoperative, external fixator or surgical	MPS	12 (short FU) and 89 (mean; range 26-187) (long-term FU)
23	Li et al. (36)	64	CCS	2004 – 2006	C	S: Surgical treatment with use of 3D printing model of the fracture C: Without 3D printing model	MPS	12 and 144
24	Li et al. (37)	47	CSS	2007 – 2014	C	Iliac screw fixation in the posterior column of the ilium	MPS	21 (mean; range 12-36)
25	Liu et al. (38)	45	CCS	2016 – 2017	B, C	S: Robot-assisted percutaneous screw placement combined with pelvic internal fixator C: Percutaneous screw placement using conventional fluoroscopic imaging	MPS	5 (mean; range 4-12)
26	Lybrand et al. (39)	54	CSS	2000 – 2013	B, C	Symphyseal fixation	EQ-5D, MPS	84 (mean; range 24-168)

27	Ma et al. (9)	263	CCS	2009 – 2015	B, C	S: Internal fixation C: External fixation	MPS	6
28	Muller et al. (40)	36	CS	2004 – 2012	C	Anterior subcutaneous internal fixator (ASIF)	SF-12, POS	18
29	Nie et al. (41)	30	CSS	2015 – 2017	B, C	Minimally invasive surgery assisted by 3D printing technology	MPS	10 (mean; range 4-16)
30	Oh et al. (42)	22	CSS	2008 – 2012	B, C	Anterior plate fixation through Stoppa approach	Merle d' Aubigne - Postel	16 (mean; range 10-51)
31	Park et al. (43)	64	CCS	2009 – 2013	B, C	S: ORIF with plate fixation and additional tension band wiring C: ORIF with plate fixation alone	MPS	34 (mean; range 26-39)
32	Schmitz et al. (17)	55	CSS	2004 -2014	A, B and C	Nonoperative and operative fixation	SF-36, EQ-5D	50 (mean; SD 35)
33	Schweitzer et al. (44)	71	CSS	1998 – 2005	B, C	Closed reduction and iliosacral percutaneous fixation	MPS	31 (mean; range 12-96)
34	Shui et al. (11)	117	CSS	2003 – 2013	B, C	Percutaneous screw fixation	MPS	14 (mean; range 6-24)
35	Vallier et al. (45)	87	CSS	1997 – 2006	B, C	Nonoperative, external or internal fixation	MFA	41 (mean; range 16-137)
36	Van Loon et al. (46)	32	CSS	1996 – 2008	B	Nonoperative, external or internal fixation	SF-36, MPS	84 (median)
37	Wang et al. (47)	29	CSS	2010 – 2016	B, C	Minimally invasive stabilization with pedicle screws connected to a transverse rod	MPS	38 (mean; range 12-84)
38	Wang et al. (48)	29	CS	2010 – 2016	B, C	Modified pedicle screw-rod fixation	MPS	12
39	Wu et al. (49)	23	CS	2013 – 2015	B, C	Anterior fixation using a modified pedicle screw-rod fixator with or without posterior fixation using a transiliac internal fixator (TIFI)	MPS	10 (mean; range 4-12)
40	Wu et al. (50)	44	RCT	2009 – 2012	B, C	S:Internal fixation through minimally invasive adjustable plate (MIAP) C: internal fixation with locking compression plate (LCP)	MPS	S: 27 (mean; range 13-48) C: 22 (mean; range 12-42)
41	Yin et al. (51)	74	CCS	2015 – 2017	B, C	S: Anterior subcutaneous internal fixator (INFIX) C: Plate fixation	MPS	27 (mean; range 21-32)
42	Yu et al. (52)	51	CCS	-	B	S: reconstruction plate screw fixation C: percutaneous cannulated screw fixation	MPS	29 (mean; range 18-54)

43	Zhang et al. (20)	42	CCS	2011 – 2017	Unilateral sacral fractures	S: lumbopelvic fixation C: Novel adjustable plate	MPS	12
44	Zhang et al. (53)	22	CSS	2016 – 2017	B	Nonoperative and operative	MPS	12 (mean; range 8-15)
45	Zhang et al. (21)	70	CCS	2009 – 2016	Unilateral zone II sacral fractures	S: Sacroiliac screw C: Minimally invasive adjustable plate	MPS	25 (mean; SD 5)
46	Zhu et al. (54)	37	CS	2008 – 2012	B, C	Ilioinguinal approach combined with a minimally invasive posterior approach	MPS	12

* CSS, Cross-sectional study; RCT, randomized controlled trial; CS, cohort study; CCS, case-control study; S, study group; C, control group; IPS, Iowa Pelvic Score; VAS, visual Analog scale; SF-36, MOS 36-item Short Form Health Survey; SF-12, Short Form-12; EQ-5D, EuroQuol-5D. ‡ The Young-Burgess classification was translated to the AO/OTA classification.

Methodological quality assessment

The results of the quality assessment of the included articles are presented in table 3. Total scores in percentages ranged between 50% and 92%. The average score was 72%. No studies were excluded based on this assessment. Most studies scored fairly positive on the first four areas, regarding citation (1), study purpose (2), relevant background literature (3), and description of the sample (4). None of the studies justified sample size (5), which is the reason that no studies scored the maximum amount of points on the assessment. In the RCT (50) randomization of groups was performed (6), but it was not clearly described by which method (7). The first eight studies used valid (8) and reliable (9) PROMs, though some used both valid PROMs and PROMs of which the validity was not established (+/-). The ten studies in the list with the lowest quality scores did often not report results in terms of statistical significance (10) and did not use appropriate analysis methods (11). The last three areas regarding clinical importance (12), dropouts (13) and appropriate conclusions (14) were mostly sufficiently described.

Table 3: Scores of the quality assessment list ranged from best to worst score

	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%
Adelved et al. (23)	1	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Banierink et al. (12)	2	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Bott et al. (27)	3	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Hoch et al. (14)	4	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Hoffman et al. (13)	5	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Holstein et al. (15)	6	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Schmitz et al. (17)	7	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Vallier et al. (45)	8	+	+	+	+	-			+	+	+	+	+	+	+	11/12	92
Brouwers et al. (10)	9	+	+	+	+	-			+/-	+/-	+	+	+	+	+	10/12	83
Chen et al. (30)	10	+	+	+	+	-			+/-	+/-	+	+	+	+	+	10/12	83
Frietman et al. (19)	11	+	+	+	+	-			+/-	+/-	+	+	+	+	+	10/12	83
Lybrand et al. (39)	12	+	+	+	+	-			+/-	+/-	+	+	+	+	+	10/12	83
Ma et al. (9)	13	+	+	+	+	-			-	-	+	+	+	+	+	10/12	83
Muller et al. (40)	14	+	+	+	+	-			+/-	+/-	+	+	+	+	+	10/12	83
Bastian et al. (24)	15	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75

Feng et al. (32)	16	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Kokubo et al. (35)	17	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Liu et al. (38)	18	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Park et al. (43)	19	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Shui et al. (11)	20	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Van Loon et al. (46)	21	+	+	+	+	-			+/-	+/-	-	+	+	+	+	9/12	75
Wang et al. (48)	22	+	+	+	+	-			-	-	-	-	+	+	+	9/12	75
Wang et al. (47)	23	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Yin et al. (51)	24	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Zhang et al. (20)	25	+	+	+	+	-			-	-	+	+	+	+	+	9/12	75
Wu et al. (50)	26	+	+	+	+	-	+	-	-	-	+	+	+	+	+	10/14	71
Bi et al. (25)	27	+	+	+	+	-			-	-	+	-	+	+	+	8/12	67
Borozda et al. (26)	28	+	+	+	+	-			-	-	+	+	+	-	+	8/12	67
Chen et al. (28)	29	+	+	+	+	-			-	-	+	+	+	-	+	8/12	67
Chen et al. (29)	30	+	+	+	+	-			-	-	+	-	+	+	+	8/12	67
Li et al. (36)	31	+	+	+	+	-			-	-	+	+	+	-	+	8/12	67
Li et al. (37)	32	+	+	+	-	-			-	-	+	+	+	+	+	8/12	67
Yu et al. (52)	33	+	+	+	-	-			-	-	+	+	+	+	+	8/12	67
Zhang et al. (20)	34	+	+	+	+	-			-	-	+	+	+	-	+	8/12	67
Dienstknecht et al. (31)	35	+	+	+	+	-			-	-	-	-	+	+	+	7/12	58
Grubor et al. (18)	36	+	+	-	+	-			-	-	+	+	+	-	+	7/12	58
Hua et al. (34)	37	+	+	+	+	-			-	-	-	-	+	+	+	7/12	58
Schweitzer et al. (44)	38	+	+	+	+	-			-	-	-	-	+	+	+	7/12	58
Wu et al. (55)	39	+	+	+	+	-			-	-	-	-	+	+	+	7/12	58
Zhang et al. (21)	40	+	+	+	+	-			-	-	+	-	+	-	+	7/12	58
Zhu et al. (54)	41	+	+	+	+	-			-	-	-	-	+	+	+	7/12	58
Abishek et al. (22)	42	+	-	+	+	-			-	-	-	-	+	+	+	6/12	50
Ayvaz et al. (8)	43	+	+	-	+	-			+/-	+/-	-	-	-	+	+	6/12	50
Ghosh et al. (33)	44	+	-	+	+	-			-	-	+	-	+	+	-	6/12	50
Nie et al. (41)	45	+	-	+	+	-			-	-	-	-	+	+	+	6/12	50
Oh et al. (42)	46	+	+	+	+	-			-	-	-	-	+	+	+	6/12	50

Every plus sign means that the question was answered with 'yes'. Every minus sign means that a question was answered with 'no' or 'not adressed'. +/- was given in case both a valid as well as non-validated PROM was used and represents a score of 0.5. Questions 6 and 7 are only applicable for RCTs. The final two columns represent the total scores and percentages of maximal attainable scores (%).

Patient-reported Outcome Measures

Thirty-eight studies (8–11,18–22,24–26,28–30,32–44,46–54,56) used a pelvic-specific PROM, either as a single instrument or in combination with a generic PROM. Generic PROMs for physical functioning and quality of life were used in 15 studies (8,10,12,13,15,17,19,23,27,30,39,40,46,57, 58). The follow-up moment when these questionnaires were assessed ranged from six months to 15 years after the injury. Scores on the PROMs per study are given in Table 4.

Table 4. Outcome of PROMs

				Outcome of PROM at mean time of follow-up			
PROMs	**Study**	**Year**	**N**	**<12 months**	**12-23 months**	**24 months-5 years**	**>5 years**
MPS, N (%)							
	Abhishek et al. (22)	2015	41		Excellent: 21 (51), Good : 13 (32) Fair : 4 (10), Poor : 3 (7)		
	Ayvaz et al. (8)	2011	20			Mean 93.3 (range 72-100) Excellent: 19 (95), Good : 1 (5) Fair : -, Poor : -	
	Bastian et al. (24)	2016	63			Excellent: 37 (59), Good : 12 (19) Fair : 9 (14), Poor : 5 (8)	
	Bi et al. (25)	2017	43		Mean 81.97 (range 64-94) Excellent: 19 (44), Good : 17 (40) Fair : 7 (16), Poor : -		
	Borozda et al. (26)	2015	28		Mean 81 (range 58-97) Excellent: 12 (43), Good : 11 (39) Fair : 4 (14), Poor : 1 (4)		
	Brouwers et al. (10)	2018	195			Mean 76 (SD 14.8) Excellent: 119 (61), Good 52 (27) Fair: 17 (9), Poor: 7 (3)	
	Chen et al. (28)	2012	58		Mean: 80.7 Excellent: 19 (33), Good : 32 (55) Fair : 7 (12), Poor : -		
	Chen et al. (29)	2013	21		Excellent: 15 (71), Good : 5 (24) Fair : 1 (5), Poor : -		
	Chen et al. (30)	2012	32		Excellent: 10 (31), Good : 8 (25) Fair : 8 (25), Poor : 6 (19)		
	Feng et al. (32)	2016	26		Excellent: 18 (69), Good: 7 (27) Fair: 1 (4), Poor: -		
	Frietman et al. (19)†	2016	37			Mean 75.3 (SD 19.5)	
	Ghosh et al. (33)	2018	75	Excellent: 27 (36), Good: 29 (39) Fair: 12 (16), Poor: 7 (9)			

Hua et al. (34)	2019	23		Excellent: 13 (57), Good: 6 (26) Fair: 4 (17), Poor: -		
Kokubo et al. (35)	2017	82		Excellent + Good (satisfactory): 52 (63) Fair + Poor (Unsatisfactory): 30 (37)		Excellent + Good (satisfactory): 70 (85) Fair + Poor (unsatisfactory): 12 (15)
Li et al. (36)	2017	64		Excellent: 38 (60), Good : 13 (20) Fair : 13 (20), Poor : -		Excellent: 36 (56) , Good : 12 (19) Fair : 16 (25), Poor : -
Li et al. (37)	2018	47		Mean 80.2 (range 48-100) Excellent: 13 (28), Good: 30 (64) Fair: 4 (8), Poor: -		
Liu et al. (38)	2018	45	Mean 85.4 (SD 8.9)			
Lybrand et al. (39)	2017	54				Mean 76 (SD 17)
Ma et al. (9)	2017	263	Excellent: 125 (48), Good : 67 (25) Fair : 53 (20), Poor : 18 (7)			
Nie et al. (41)	2018	30	Excellent: 21 (70), Good : 9 (30) Fair : - , Poor : -			
Park et al. (43)	2017	64			Excellent: 31 (49), Good : 18 (28) Fair : 11 (17), Poor : 4 (6)	
Schweitzer et al. (44)	2008	68			Excellent + good: 62 (91) Fair : 4 (6), Poor : 2 (3)	
Shui et al. (11)	2015	117		Excellent: 48 (41), Good : 39 (33) Fair : 24 (21), Poor : 6 (5)		
Van Loon et al. (46)	2011	32				Mean 95.7
Wang et al. (47)	2017	29			Excellent: 10 (35), Good : 16 (55) Fair : 3 (10), Poor : -	
Wang et al. (48)	2018	29		Excellent: 15 (52), Good : 12 (41) Fair : 2 (7), Poor : -		

	Wu et al. (49)	2018	23	Excellent: 14 (61), Good : 7 (30) Fair : 2 (8), Poor : -		
	Wu et al. (50)	2015	44			Mean 81.7 (SD 8.4)
	Yin et al. (51)	2019	74			Mean 86.2 (SD 7)
	Yu et al. (52)	2015	51			Excellent: 36 (71), Good : 12 (24) Fair : 3 (5), Poor : -
	Zhang et al. (20)	2019	42		Excellent + Good (satisfactory): 33 (79) Fair + Poor (Unsatisfactory): 9 (21)	
	Zhang et al. (53)	2019	22		Mean 81 (SD 11)	
	Zhang et al. (21)	2019	70			Excellent + Good (satisfactory): 56 (80) Fair + Poor (Unsatisfactory): 14 (20)
	Zhu et al. (54)	2015	37		Excellent: 29 (78), Good : 8 (22) Fair : -, Poor : -	
Iowa Pelvic Score (IPS)						
	Ayvaz et al. (8) †	2011	20			Mean 86 (range 82-90) Excellent: 11 (55) Good: 9 (45)
Pelvic Outcome Score						
	Dienstknecht et al. (31) #	2011	62			Excellent: 19 (31), Good : 16 (26) Fair : 25 (40), Poor : 2 (3)
	Muller et al. (40) #	2013	36		Excellent: 9 (29), Good : 11 (35) Fair : 8 (26), Poor : 3 (10)	
Merle d'Aubigne-Postel						
	Grubor et al. (33) #	2011	47		Excellent : 22 (47), Good : 15 (32) Fair : 4 (9), Poor : 6 (12)	
	Oh et al. (42) #	2015	22		Excellent : 7 (32), Good : 12 (55) Fair : 3 (13), Poor : -	
MFA						
	Vallier et al. (45) †	2012	87			Mean : 33 (22)
SMFA						

	Banierink et al. (12)	2019	192			Function index: 22 Bother index: 26 Lower extremity: 21	
	Hoffman et al. (13)	2012	119	Function index: 28 Bother index: 31 Lower extremity: 33	Function index: 26 Bother index: 30 Lower extremity: 32	Function index: 22 Bother index: 24 Lower extremity: 26	
SF-36							
	Adelved et al. (23) †	2014	28		PF 62 (28), RP 42 (45), BP 51 (32), GH 65 (23), VT 47 (20), SF 69 (27), RE 62 (43), MH 67 (25)		PF 66 (26), RP 46 (45), BP 49 (29), GH 59 (26), VT 53 (23), SF 78 (22), RE 49 (44), MH 72 (21)
	Ayvaz et al. (8)	2011	18			BP: 3.3, GH: 4.4, SF: 7.9	
	Bott et al. (27) †	2019	74		PF 69 (30), RP 68 (32), BP 62 (28), GH 59 (28), VT 53 (23), SF 75 (29), RE 78 (31), MH 70 (23)		
	Chen et al. (30) †	2012	32		PF 53 (27), RP 24 (30), BP 50 (20), GH 42 (19), VT 46 (16), SF 52 (23), RE 50 (47), MH 52 (12)		
	Frietman et al. (19) †	2016	37			PF 63 (26), RP 56 (41), BP 64 (27), GH 64 (25), VT 62 (30), SF 81 (24), RE 80 (32), MH 78 (18)	
	Schmitz et al. (17) †	2018	55			PCS: 34 (8) MCS: 45 (8)	
	Van Loon et al. (46)	2011	32				GH: 62, VT: 58, MH: 72, BP: 68, SF: 80, RE: 85, RP: 71, PF: 74
SF-12							
	Hoch et al. (14) *	2016	128			PCS 37 (11-56) MCS 43 (21-66)	
	Muller et al. (40) †	2013	36		PCS 43 (2) MCS 46 (2)		
EQ-5D							
	Banierink et al. (12) *	2019	192			Mean 0.76 (-.134-1)	
	Bott et al. (27) †	2019	74		Mean 0.71 (SD 0.3)		

Brouwers et al. (10) †	2019	195	Mean 0.78 (0.26)			
Hoch et al. (14) †	2016	128	Mean 0.75 (0.14)			
Holstein et al. (15)‡	2013	172	Median: 0.78 (0.63-1.00)			
Lybrand et al. (39) †	2017	54		Mean (0.20)		0.80
Schmitz et al. (17) †	2019	55	Mean 0.63 (0.28)			

* Data are given as N (%). Abbreviations:* Data given as mean (range). † Data given as mean (SD). ‡ Data given as median (IQR). # Data given as N (%). S, study group; C, control group; IPS, Iowa Pelvic Score; VAS, visual Analog scale; SF-36, MOS 36-item Short Form Health Survey; PF, physical functioning; RP, role physical; BP, bodily pain; GH, general health; VT, vitality; SF, social functioning; RE, role emotional; MH, mental health; SF-12, Short Form-12; EQ-5D, EuroQuol-5D; MFA, Musculoskeletal function assessment; SMFA, Short Musculoskeletal Function Assessment

Patient-reported physical functioning

PROMs results

Of the 34 studies (8–11,19–22,24–26,28–30,32–37,39,41,43,44,46–54) that used the Majeed Pelvic Score (MPS), in 28 of them (9,11,20–22,24–26,28,29,32–38,41,43,44,47–54) it was the only outcome instrument used. Most studies described the results in terms of the clinical grade. These were 'excellent' in 28-95% of the patients, 'good' in 5-64%, 'fair' in 0-25% and 'poor' in 0-19% of patients. Seven studies (19,38,39,46,50,51,53) only described the mean, ranging from 75 up to 95. Three studies (20,21,35) combined 'excellent' and 'good' results to 'satisfactory' (range 56-85%) and 'poor' and 'fair' to 'unsatisfactory' (range 15-37%). The Iowa Pelvic Score (IPS) was used by one study (8). The mean score was 86 (range 82-90). The Pelvic Outcome Score (POS) was used by two authors (31,40). The rates for 'excellent' in both studies were 29% and 31%, for 'good' 26% and 35%, for 'fair' 26% and 40% and for 'poor' 3% and 10%. Two studies (18,42) used the Merle D' Aubigne-Postel score for evaluation of function after pelvic ring injuries and graded it into 'excellent' (32% and 47%), 'good' (32% and 55%), 'fair' (9% and 13%), and 'poor' (0% and 12%). The Musculoskeletal Function Assessment (MFA) was used by only one study (45) evaluating female patients treated for pelvic ring injury. The mean score was 33 (SD 22). The Short Musculoskeletal Function Assessment (SMFA) was used in two studies (12,13). One study (12) reported a score of 22 on the function index, 26 on the bother index and 21 on the lower extremity subscale. The other study (13) evaluated the scores of the SMFA on three time points (6, 12 and 24 months). Subsequently, scores on the function index were 28, 26 and 22, on the bother index 31, 30 and 24, and 33, 32 and 26 on the lower extremity subscale.

Changes in physical functioning

Three studies described physical functioning at different time points, and almost all of them showed improved scores at a later stage. Kokubo et al. (35) applied the MPS at one year and once again after a mean of 7.4 years, while Li et al. (36) also applied the MPS at one year and 10 years after the injury. Kokubo et al. found satisfactory (excellent + good) results of 63% after 1 year and 85% after 7.4 years. Unsatisfactory (fair + poor) results were found in 37% at one year and 15% after 7.4 years. Li et al. found excellent results in 60% after one year and 56% after 10 years, good results in 20 and 19%, fair in 20 and 25%, and no poor results. Hoffman et al. (13) used the SMFA at 6, 12 and 24 months revealing consecutive scores of 28, 26 and 22 on the function index, 31, 30 and 24 on the bother index and 33, 32 and 26 on the lower extremity subscale.

Patient-reported quality of life

PROMs results

The SF-36 was used in seven studies (8,17,19,23,27,30,46). Five studies (19,23,27,30,46) described all eight components of the SF-36 and one study (8) only described three of them. Scores ranged from 53 up to 69 (physical functioning), 24 to 71 (role physical), 49 to 68 (bodily pain), 42 to 65 (general health), 46 to 62 (vitality), 52 to 81 (social functioning), 49 to 85 (role emotional) and 52 to 78 (mental health). One study (17) only described the PCS and MCS score, which was 34 and 45 respectively. The SF-12 was used by two authors (14,40). The scores on the PCS were 37 and 43, and the scores on the MCS 43 and 46. The EQ-5D for the evaluation of quality of life was used in seven studies (10,12,14,15,17,27,39). Mean scores ranged from 0.63 to 0.80.

Changes in quality of life

Only one study (23) assessed the SF-36 twice, at one year and once again after a mean of 10.7 years. Most of the scores improved after an interval of 10 years, although some decreased. Consecutive scores were as follows: physical functioning: 62 and 66, 42 and 46 (role physical), 51 and 49 (bodily pain), 65 and 59 (general health), 47 and 53 (vitality), 69 and 78 (social functioning), 62 and 49 (role emotional), 67 and 72 (mental health).

DISCUSSION

The management of and recovery of pelvic ring injuries has had gained attention over the years by clinicians and researchers. Although the focus primary laid on radiographic outcomes over the past decades, more recently this focus shifted towards the use of patient-reported outcome measures (PROMs). This is the first systematic review to evaluate outcomes in terms of physical functioning and quality of life after pelvic ring injuries. The extensive literature search resulted in the inclusion of 46 studies regarding patients with a broad range of injury types and treatment methods. Physical functioning and quality of life was mainly assessed between one and five years after pelvic ring injury. Most studies had small sample sizes, with more than half including even less than 50 patients. Besides, the quality of the studies was moderate to poor. Nine different outcome measures were used; 38 studies used disease-specific PROMs and 15 studies used generic PROMs. None of the disease-specific PROMs have been proven valid for use in patients with pelvic ring injuries. Overall, the recovery of physical functioning and quality of life following pelvic ring injuries seemed fair, although the reported results varied widely between studies and the different PROMs. Taking all of the above into account, it is challenging to conclude an overall result in terms of physical functioning and quality of life after pelvic ring injuries. Hence, some critical remarks can be made on the included studies based on the results of this systematic review.

Most studies reported on a wide variety of pelvic ring injury types. According to the AO/OTA classification system (16), pelvic ring injuries can be divided into type A, B or C injuries. However, sometimes the Young-Burgess classification (59) was used, which divides these injuries into ‘anterior posterior compression (APC)’, ‘lateral compression (LC)’ or ‘vertical shear injuries (VS)’. In the studies that were included in this systematic review, it was not always clear what type of injury the patients had and most studies did not differentiate in the outcomes between for example B and C type injuries. Although type B as well as type C injuries are considered to be unstable fractures, type B injuries are simply rotationally unstable and therefore more likely to result in good outcomes, compared to the rotationally as well as vertically unstable type C injuries. Also, type A injuries were only assessed in six studies (10,12,15,17–19) even though this

type consists most of all types of pelvic ring injuries (12). Moreover, there was no differentiation in outcomes of patients with solely a pelvic ring injury, and of patients with multiple injuries, which is seen in polytrauma patients. This may clearly affect results of generic PROMs.

None of the studies focused solely on the outcomes after nonoperative treatment of pelvic ring injuries. Only a few of the included studies (10,12–15,17,18,33,35,46,53,57,60) evaluated outcomes of patients that were treated either operatively or nonoperatively, while most studies only assessed operatively treated patients. Moreover, among the operatively treated patients, a wide variety of surgical techniques was used. The used techniques varied from external fixation, to purely anterior or posterior fixation, to a combination of both and even experimental techniques for specific pelvic ring injury types. Due to this variety in applied surgical techniques, which were often also poorly described, it was not possible to perform subgroup analyses. After all, the aim of this systematic review was to provide a general assessment of outcomes after pelvic ring injuries, but not of any specific operative approach.

Follow-up was mainly assessed between one and five years, missing the important short-term (<12 months) as well as long-term (>5 years) consequences of these injuries on the patients' daily life. Especially in the studies evaluating surgical techniques, the short-term follow-up is highly important, as this is a critical period in which the most improvement in physical functioning can be achieved. On the other hand, long-term follow-up might be just as important, revealing the late complications like gait impairment, chronic pelvic and back pain as well as delayed consequences of lumbosacral plexus injury (61). Also, the unknown pre-injury condition for physical functioning and quality of life leaves us guessing about the actual effect of the injury on the patients daily life.

Another problem in the evaluation of the studies was that the sample sizes of most studies were small, often including even less than 50 patients (N=24). The methodological quality assessment revealed that no sample size calculation was performed in each of the studies, which makes it arguable whether enough patients were included to draw conclusions from in terms of physical functioning and quality of life. The quality assessment also revealed that, overall, the methodological quality was moderate and did not reach perfection in any of the studies, as all missed the justification for sample size. Moreover, many studies failed to achieve higher scores due to the use of nonvalidated outcome measures like the MPS.

The use of nine different PROMs was another issue. Of the four different disease-specific PROMs, the MPS was by far the most frequently used PROM in 34 studies, even though it has never been validated in patients with pelvic ring injuries. The reason for its frequent use could be explained by the compact length of the questionnaire and the possibility to compare outcomes to those of other studies. Similar to the results of this review, Lefaivre et al. showed that the MPS is the most commonly used pelvic outcome score (5). Results were most often graded as 'excellent', although there was a wide variation in the proportion of patients that had an excellent score between the various studies. Only three studies (12,13,57) used two different generic PROMs (MFA and SMFA) to assess physical functioning, while quality of life was assessed in 13 different studies using the SF-12, SF-36 and EQ-5D, showing acceptable quality of life following pelvic ring injuries. The asset of these generic questionnaires is the availability of normative data to compare results with. A complicating factor was that the scores on identical questionnaires were often reported in different ways, making them hardly comparable. For example, the results on the MPS of the SF-36 were frequently reported by the categories (excellent, good etcetera), whereas other studies only presented mean scores with standard deviation, range, or a combination of these. In addition, scores varied widely, even between studies that used the same PROMs.

None of the disease-specific questionnaires that were used have been proven to be valid to assess physical functioning of patients with pelvic ring injuries, while all generic outcome instruments have. The ability of the outcomes of PROMs to improve decision-making in clinical research relies on the psychometric strength of the instrument to capture the burden of disease or treatment. Reliability and validity are separate psychometric properties, both essential for any measure (62). Measures can be highly reliable but not measure what they are supposed to measure (63). Some studies compared pelvic-specific PROMs with generic PROMs to investigate the validity of disease-specific instruments in examining pelvic-specific areas, but failed to do so (5,64–66). Hence, until there is a disease-specific questionnaire for pelvic ring injuries that is proven to be valid and reliable, it seems preferable to use a reliable and valid generic PROM to assess physical functioning and quality of life following these injuries. Another advantage of the latter is that, for these generic PROMs normative data often available is.

PROMs enable important clinical questions to be answered in clinical research (3). Its use should be integrated in the clinical evaluation of a patient with pelvic ring injuries, next to the more objective measures like radiographic outcomes, because PROMs directly reflect the patients' perspective on the impact of their injury on daily life. Some types of pelvic injuries may look highly unfavourable on radiographic imaging, but the patient may grade his physical functioning and quality of life fairly well, or the other way around. Despite the fact that there has been discussion on the actual contribution of PROMs to the improvement of patient care, these instruments have the potential to facilitate patient involvement in treatment decision-making and provide guidance for health-care decisions (63). Patients may monitor their health status over time and eventually will be more actively engaged in striving for health outcomes like full rehabilitation. Also, PROMs may help clinicians quickly identify which of their patients experience improved or deteriorated health outcomes. This may help to identify any structural patient complaints, which would suggest that refinements to care pathways might be needed. However, at this moment, PROMs function more as a tool for the use in clinical research, than they do in substantially changing medical practice.

Strengths and limitations

Some strengths and limitations of this systematic review and its conclusions need to be addressed. To start with, this is the first systematic review to evaluate patient-reported physical functioning and quality of life after pelvic ring injuries. Also, search criteria were not limited by the type of study (e.g. cohort study, RCT), which provided a complete overview of all study results published during the past decade. Moreover, this systematic review underlines that some changes are needed in the future in order to examine the true consequences of pelvic ring injuries on the patients' daily life, for example to only use reliable and valid patient-reported outcome instruments. In this systematic review, a highly sensitive comprehensive search was conducted following the recommendations of an experienced medical librarian in order to identify articles of interest. For practical reasons though, only studies published in English, German, Spanish, French or Dutch were included in the final review, which might have led to selection bias. Additionally, studies published before 2008 were excluded after consultation with two experienced pelvic trauma surgeons. The argument for this was that, before 2008, treatment methods differed such an extent that including studies published before that time might lead to bias in the results of this systematic review. In this review, we included all types of pelvic ring injuries, treatment methods and types of PROMs. Due to this heterogeneity, individual outcomes of the included studies were not suitable for reliable comparisons. At last, sample sizes were not justified in any of the included studies.

CONCLUSION

Even though the above-mentioned critical remarks make it ambitious to draw conclusions in terms of physical functioning and quality of life after pelvic ring injuries, the results imply that patients' physical functioning and quality of life seem reasonably fair and improve over time. However, a heterogeneous group of studies was presented, including small cohorts of patients with a wide range of injury types, treatment methods and diverse, often nonvalidated, outcome measures. Hence, there is a high need to use a valid and reliable outcome measure to evaluate and compare the recovery in terms of physical functioning and quality of life after pelvic ring injuries on large groups of patients. The following section provides some guidance for future research.

Practical implications and recommendations for future research regarding use of PROMs after pelvic ring injuries:

- Authors should clearly define the injury type according to the AO/OTA classification and distinguish between outcomes of different types of injuries. They should also distinguish between a pelvic ring injury as the only injury or as part of multiple injuries.
- Prospective longitudinal studies are needed with sufficient number of patients and multiple time intervals at short-term as well as long-term (>5 years) follow-up.
- (Recalled) pre-injury status of physical functioning and quality of life should be recorded.
- Only valid and reliable PROMs should be used, for example the SMFA for physical functioning and the EQ-5D or SF-36 for quality of life. These PROMs can be compared with age-specific norm data of the general population. The use of non-validated pelvic-specific PROMs should be avoided.
- There is still a challenging and a necessary task to validate existing pelvic-specific PROMs and develop an uniform PROM for pelvic injuries worldwide.

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SUPPLEMENTARY FILE 1. Description of the included PROMs

Majeed Pelvic Score (MPS)
The MPS is a physician-rated score to assess function after major pelvic ring injuries (66). The score consists of seven items divided into five subscales, pain, work, sitting, standing, (walking aids, gait unaided, walking distance), and sexual intercourse. The total amount of points that can be achieved is 100, or 80 in case patients were not working before the injury. Majeed suggested cut-off values for excellent, good, fair, and poor results in those working before the injury (respectively: >85, 70-84, 55-69, and<55 points) and those not working before the injury (respectively >70, 55-69, 45-54, and <45 points). Although the MPS demonstrated acceptable psychometric properties for outcome assessment in chronic sacroiliac joint pain (65), its validity for outcome assessment after pelvic ring injuries has not been established.

Iowa Pelvic Score (IPS)
The IPS was developed by Templeman et al. (67). It consists of 25 items within six subscales: activities of daily living, work history, pain, limp, visual pain line, and cosmesis. The total amount of points that can be achieved is 100, with higher scores indicating better function. The validity of the IPS in patients with pelvic ring injuries has not been studied.

Pelvic Outcome Score (POS)
The so called 'Becken outcome score' or Pelvic Outcome Score was developed by Pohlemann et al. (68). It is a categorical scoring instrument, divided into three sections:1) radiological result,2) clinical result with rating of function, neurological, urological and sexual deficits, and 3) status of reintegration. The first and second sections are summarized as "pelvic outcome". The validity for outcome assessment after pelvic ring injuries has not been established.

Merle d'Aubigne-Postel Score
The Merle d'Aubigne-Postel Score was developed by d'Aubigne and Postel (69) for the evaluation of functional results after hip arthroplasty with acrylic prosthesis, and is therefore not a pelvic outcome score, although regularly used as such. The score is divided into three sections; pain, mobility, and ability to walk, each of which can score up to six points in case of the best possible situation. Clinical grades (very good, good, medium, fair, poor) are given by the scores of pain and walking ability and adjusted down one to two grades, depending on the mobility score. The score was found to be reliable (70) but not valid, for the use in patients with total hip arthroplasty. Also, its validity for the assessment of function of patients with pelvic ring injuries has not been established.

Musculoskeletal Function Assessment (MFA)
The MFA questionnaire is a 100-item self-reported health status instrument designed by Martin et al. (71) for use in a broad range of patients with musculoskeletal disorders of the extremities. Scores can range from 0 to 100, with a higher score indicating poorer function. It has been found both valid and reliable in five musculoskeletal disorders of the upper and lower extremities (fractures, soft-tissue injuries, repetitive motion disorders, osteoarthritis, and rheumatoid arthritis).

Short Musculoskeletal Function Assessment (SMFA)
The SMFA questionnaire is a shorter version of the MFA and was developed by Swiontkowski et al. (REF) and consists of 46 items. It was designed to assess the functional status of patients with various musculoskeletal disorders and injuries. The SMFA items are divided over two

indices: “function index” and “bother index” (72). In the Dutch version the items are additionally structured into four subscales (lower extremity dysfunction, upper extremity dysfunction, problems with daily activities and mental and emotional problems). The scoring system is similar to that of the MFA. The SMFA has been proven to be a valid and reliable questionnaire and the Dutch version has also been shown to be valid and reliable for patients sustaining injuries (73).

Short-Form-36 (SF-36)
The SF-36 (74) and is a widely used valid and reliable instrument to measure health-related quality of life. It is subdivided into eight scales: physical functioning (PF), role physical (RP), bodily pain (BP), general health (GH), vitality (VT), social functioning (SF), role emotional (RE), and mental health (MH). Score on each subscale is transformed into a 0-100 point scale, with a higher score indicating less disability. Additionally, scores from the subscales can be aggregated in two distinct, higher-order summary scores:: the Physical Component Summary (PCS) representing the physical dimension and the Mental Component Summary (MCS) representing the mental dimension.

Short-Form-12 (SF-12)
The SF-12 (75) is derived from the SF-36 and is a multipurpose generic measure of health status. This 12-item questionnaire was designed to reduce respondent burden while achieving minimum standards of precision monitoring health in general and in specific populations. Similar to the SF-36, it measures eight health aspects and the same two summary scales (PCS and MCS) can be calculated. It has been found valid and reliable for multiple health conditions.

EuroQuol-5D (EQ-5D)
The EQ-5D is a 5-item questionnaire that measures health-related quality of life based on five dimensions of health: mobility, self-care, daily activities, pain/discomfort and anxiety/depression (76). Patients can use the dimensions to delineate to what extent they experience problems, scoring from 1 (no problems) up to 5 (extreme problems). The combination of scores on the 5 dimensions are converted to a utility value that ranges from ≤0 to 1, in which a higher score indicates a better quality of life. The EQ-5D is widely used and found to be both valid and reliable in a wide range of conditions and populations.

Chapter 3

Long-term physical functioning and quality of life after pelvic ring injury

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ABSTRACT

Background. Pelvic ring injuries are serious injuries, often associated with substantial morbidity and mortality rates. The long-term consequences of these injuries might affect the patients personal life. Our aim was to assess the long-term effects of pelvic ring injuries on physical functioning and quality of life (QoL) by using validated patient-reported outcome measures (PROMs) and comparing these results to normative data from the general population.

Patients and Methods. A retrospective cohort study was conducted on adults treated for pelvic ring injuries between 2007 and 2016. Demographics, fracture type, injury mechanism, treatment and complications were recorded. PROMs questionnaires concerning physical functioning (SMFA) and quality of life (EQ-5D) were used. Patients were divided according to their age (18-30, 31-64, 65 and older) and fracture type (Tile/AO type A, B or C). Differences in SMFA and EQ-5D scores of the operatively and non-operatively treated patients and between the study population and general population were analysed.

Results. A total of 413 patients were identified of which 279 were eligible for follow-up. One-hundred and ninety-two (69%) patients responded, with a mean follow-up of 4.4 years. Patients reported a median score of 13.9 on the SMFA function index, 16.7 on the bother index, 12.5 on the lower extremity, 18.8 on the activities of daily living and 23.4 on the emotion subscale. A median EQ-5D score of 0.8 was reported. There was no difference in physical functioning and QoL between operatively and non-operatively treated patients. Comparison of these results to normative data of the general population revealed a significant ($P<0.05$) decrease in physical functioning and QoL in patients with all types of pelvic ring injuries.

Conclusion. Long-term physical functioning and QoL in patients who had sustained a pelvic ring injury seems fair, although significantly decreased in comparison with their peers from the general population.

INTRODUCTION

Pelvic ring injuries have a prevalence of 20-37/100,000 in the general population and are often caused by severe accidents (1). Most pelvic ring injuries are caused by (blunt force) high-energy trauma (2), with the majority of the causes being motor vehicle collisions (3,4). However, pelvic ring injuries in the elderly are often caused by low-energy accidents, such as a fall on a slippery surface.

Life-threatening situations can occur due to traumatic disruption of the pelvic ring (5). The reported overall mortality varies from 5% in isolated pelvic ring injuries, up to 46% in poly-trauma patients (6,7). Patients who get through the initial hospital course following these injuries often have to endure a long period of impaired mobilization and intense rehabilitation.

Pelvic injuries do not only have a major impact in the short-term, but also long-term permanent limitations which can affect daily functioning. The latter includes gait impairment, chronic pelvic and back pain as well as delayed consequences of lumbosacral plexus injury (8), all of which may influence the patient's quality of life (9).

Pelvic ring injuries occur in patients of all ages, with different comorbidities and physical conditions. The seminal work entitled 'Fractures of the pelvis and acetabulum' written by Tile et al. (page 361), clearly states that "adequate follow-up studies on pelvic ring fractures are lacking" (10). This was our incentive to perform a large cohort study about the long-term personal and societal impact of these injuries by using validated questionnaires (Short Musculoskeletal Function Assessment and EuroQol 5D).

Hence, the aim of this study was to provide an overview of the physical functioning and quality of life (QoL) of patients with pelvic ring injuries attending a level 1 trauma center over a period of 9 years. Additionally, the level of physical functioning and QoL of these patients were compared to normative data from the general Dutch population.

PATIENTS AND METHODS

Patients

All the adult patients (≥ 18 years of age) who had been treated for a pelvic ring injury at the Department of Trauma Surgery of the University Medical Center Groningen (UMCG) between January 2007 and January 2016 were approached for this study. The UMCG is a Level 1 trauma center and a secondary referral center for the treatment of pelvic injuries in the northern part of the Netherlands. Data about the patient's characteristics were collected by reviewing each patient's medical and operation records. Additional data were retrieved from the Dutch Trauma Registry, concerning injury severity in terms of the Abbreviated Injury Scale (AIS) (11) and Injury Severity Score (ISS) (12). Subsequently, two trauma surgeons with ample experience in pelvic fracture surgery reassessed the radiographic images (plain anteroposterior, inlet and outlet radiographs and computerized tomography scans) of all the patients and classified the pelvic ring injuries into type A, B and C injuries (appendix 1) according to the AO/OTA Trauma pelvis and acetabulum manual (9). Patients were divided according to their age (18-30, 31-64, 65 and older) and fracture type (Tile type A, B or C). The local Medical Ethical Review Board reviewed the methods employed and waived further need for approval (METc 2016.385).

Long-term physical functioning and quality of life

Patients who had no cognitive disorders and were still alive in the follow-up period received

a series of questionnaires by mail to assess long-term physical functioning and quality of life. Physical functioning was measured with the Dutch version of the Short Musculoskeletal Function Assessment (SMFA-NL). The SMFA questionnaire consists of 46 items and was designed to assess the functional status of patients with various musculoskeletal disorders and injuries. The SMFA includes two indices: "function index" and "bother index" (13). The Dutch version of the SMFA (SMFA-NL) has an additional four subscales that cover the physical functioning of all extremities, problems with daily activities and psychological aspects of functioning (14). The scores vary from 0-100, with a higher score indicating a worse function. The SMFA scores of this study were compared to the normative data of the SMFA-NL in the general Dutch population (15). Quality of life was assessed with the EuroQol 5D (EQ-5D). The EQ-5D is a brief questionnaire that measures health-related quality of life based on five dimensions of health: mobility, self-care, usual activities, pain/discomfort and anxiety/depression (16). Patients can use the dimensions to delineate whether they have (1) no problems, (2) moderate or (3) severe problems. The EQ-5D scores of this study's population were compared to the normative data from the EQ-5D of the general Dutch population (17). Moreover, physical functioning and quality of life between operatively and non-operatively treated patients were compared.

Statistical Analysis

Descriptive statistics were performed to present demographics, injury mechanism, fracture patterns and treatment methods. Means and standard deviations were calculated from the normally distributed data and the median and range from not-normally distributed data. To attain the SMFA-NL and EQ-5D data, the patients were divided according to their type of injury: type A, type B and type C. To analyze the association between fracture type and outcome with regard to physical functioning and quality of life, univariate analyses of variance (ANOVA) were performed. To compare the SMFA-NL and EQ-5D scores between operatively and non-operatively treated patients, Mann-Whitney U tests were performed. Additionally, the SMFA-NL and EQ-5D scores were compared to the age-matched normative data of the Dutch population by using a manual T-test with pooled means and pooled SD's. The data were analysed using the IBM SPSS software, version 23.0 for Windows (IBM Corporation, Armonk, NY). Statistical significance was accepted at $P \leq 0.05$.

RESULTS

Patients

A total of 413 adults (≥ 18 years of age) with pelvic ring injuries were identified over a study period of 9 years (January 2007 until January 2016) of which 279 (68%) patients were eligible for follow-up by means of patient reported outcomes. The main reason for exclusion was that 110 (26%) of the patients had died at long-term follow-up. A total of 192 patients (69%) at a mean follow-up of 4.4 ± 2.6 years after the pelvic ring injury responded. The other 84 patients (31%) declined to participate or did not respond (figure 1). A non-response analysis was performed which showed no significant differences between the responders and non-responders, except for a difference in age (57 vs. 47). Table 1 demonstrates the demographic and injury characteristics of the 192 responders, divided into the different fracture types (A, B and C).

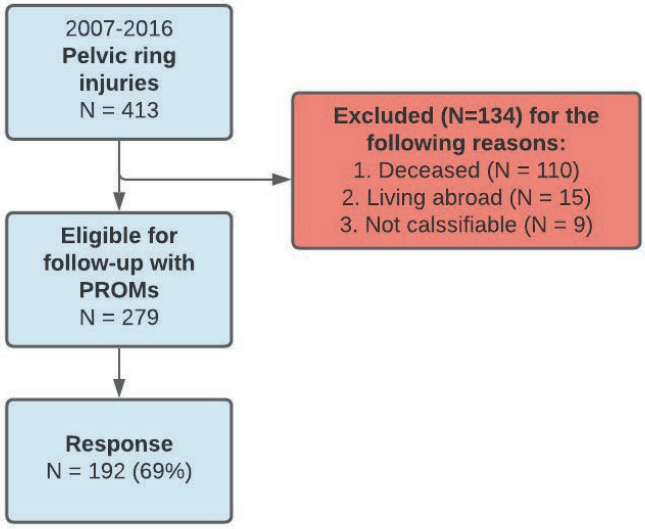

Figure 1. Flow-chart of patient inclusion for assessment of long-term physical functioning and quality of life after pelvic ring injuries

Table 1. Individual and injury characteristics of the responders

	Type A (n=75)	**Type B** (n=99)	**Type C** (n=18)	**All patients** (n=192)
Follow-up in years				
Mean ± Std.	4 ± 2.6	4.4 ± 2.6	5.2 ± 2.8	4.3 ± 2.7
Age (yrs) at injury				
Median (range)	60 (20, 93)	51 (18, 89)	38 (19, 62)	54 (18, 93)
Male, n (%)	32 (43)	60 (61)	16 (89)	108 (56)
Injury mechanism				
LET	38 (51)	22 (22)	0 (0)	60 (31)
HET	37 (49)	77 (78)	18 (100)	132 (69)
Treatment				
Conservative	71 (95)	74 (75)	5 (28)	150 (78)
Operative	4 (5)	25 (25)	13 (72)	42 (22)
ISS				
Median (range)	9 (4, 43)	13 (4, 75)	21 (11, 43)	13 (4, 75)
ISS≥16, n (%)	29 (39)	44 (44)	14 (78)	87 (45)
Highest pelvis AIS				
Median (range)	2 (2, 5)	3 (2, 5)	3 (2, 4)	2 (2, 5)
AIS 2, n (%)	58 (78)	43 (43)	4 (22)	105 (55)
AIS 3, n (%)	16 (21)	47 (48)	13 (72)	76 (39)
AIS 4, n (%)	0 (0)	4 (4)	1 (6)	5 (3)
AIS 5, n (%)	1 (1)	5 (5)	0 (0)	6 (3)

LET low-energy trauma, *HET* high-energy trauma, *ISS* injury severity score, *AIS* abbreviated injury score

Physical functioning and quality of life

The results of the patient-reported outcomes are presented in table 2. Overall, patients with pelvic injuries, regardless of the type of injury, gave fair scores for all the SMFA parts (table 2). They reported moderate limitations with, respectively, a median of 13.9 on the function index, 12.5 on the lower extremity and 18.8 on the activities of daily living (ADL) subscale. Patients

with type A pelvic injuries reported slightly higher scores on most SMFA indices and subscales in comparison with type B and C injuries. However, no significant differences were found in the function and bother indices and lower extremity, ADL and emotion subscales of the SMFA between patients with type A, B and C injuries. The only significant difference was between type A and type C injuries regarding the SMFA upper extremity subscale (P=0.047). The three SMFA questions with the highest scores (mean of more than 2.5 on a scale from 1-5), in relation to decreased physical functioning, were regarding feeling disabled, feeling tired and the effect of doing too much in one day which could affect what the patient is able to do the next day. Concerning the lower extremity subscale of the SMFA, the three questions with the highest scores (mean of more than 2 on a scale from 1-5) concerned difficulties with bending and kneeling down, moving after sitting or lying and walking with a limp.
Overall, all patients who had sustained a pelvic ring injury, irrespective of the type, reported a reasonable QoL (table 2) with a mean EQ-5D score around 0.8 (on a scale from -0.329 to 1, with a higher score indicating a better QoL). Furthermore, there were no significant differences in EQ-5D scores between the various types of pelvic ring injuries. Also, no differences in physical functioning and QoL were found between the conservatively and operatively treated patients.

Table 2. SMFA-NL and EQ-5D outcomes

	Type A	Type B	Type C	All patients
SMFA				
Function Index (n=165)				
Median (range)	15.4 (0, 92)	13.6 (0, 83)	9.0 (0, 51)	13.9 (0, 92)
Mean ± Std.	25.2 ± 27.4	20.7 ± 20.7	17.5 ± 17.2	21.9 ± 22.9
Bother Index (n=192)				
Median (range)	19.8 (0, 88)	14.6 (0, 81)	16.7 (0, 65)	16.7 (0, 88)
Mean ± Std.	28.8 ± 27.2	24.6 ± 23.3	22.9 ± 21.6	26.1 ± 24.7
Lower extremity (n=171)				
Median (range)	13.5 (0, 96)	10.4 (0, 94)	11.5 (0, 58)	12.5 (0, 96)
Mean ± Std.	24.3 ± 27.9	18.8 ± 22.1	17.2 ± 18.4	20.5 ± 23.9
Upper extremity (n=192)				
Median (range)	0 (0, 96)	0 (0, 79)	0 (0, 33)	0 (0, 96)
Mean ± Std.	16.4 ± 26.9	9.6 ± 19.6	2.3 ± 7.9	11.5 ± 22.4
ADL* (n=178)				
Median (range)	21.3 (0, 96)	18.6 (0, 90)	13.1 (0, 65)	18.8 (0, 96)
Mean ± Std.	30.8 ± 31.5	26.3 ± 25.1	22.2 ± 22.5	27.5 ± 27.4
Emotion (n=192)				
Median (range)	25 (0, 84)	21.9 (0, 84)	18.8 (0, 68.6)	23.4 (0, 84)
Mean ± Std.	29.5 ± 22.3	25.9 ± 20.6	27.1 ± 21.5	27.4 ± 21.3
EQ-5D (n=191)				
Median (range)	0.807 (-0.109, 1)	0.805 (-0.134, 1)	0.843 (0.298, 1)	0.805 (-0.134, 1)
Mean ± Std.	0.742 ± 0.275	0.764 ± 0.264	0.792 ± 0.214	0.758 ± 0.264

SMFA and EQ5D scores compared to normative data from the Dutch population
SMFA and EQ5D scores were compared to normative data from the general Dutch population. Regarding the SMFA, middle- and older-aged patients who had sustained either a type A, type B or type C pelvic ring injury, reported significantly more physical impairment on the function index in comparison to their peers in the general population (table 3). The results of the SMFA bother index were similar for patients with type A and B injuries. Patients who had sustained a

pelvic injury and were aged >30 reported significantly worse physical functioning on most subscales compared to the normative data of the general Dutch population (table 4). These results apply to all the types of pelvic ring injuries, especially regarding the lower extremity and daily activity subscale. All the patients in this study cohort generally reported worse mean function (22 vs. 12), bother (26 vs. 13), lower extremity (21 vs. 11), daily activity (28 vs. 12) and emotional (27 vs. 21) outcome scores on the SMFA after 4 years of follow-up in comparison to the normative data. With respect to the EQ-5D, significant differences were found between type A and type B fractures in the 31-64 and ≥65 age groups compared to their peers in the general Dutch population, whereby the patients who had sustained a severe pelvic ring injury reported a relatively lower quality of life (table 5).

Table 3: SMFA indices scores compared to normative data of the Dutch population

Patients (N)	**Fracture type***	**Dutch population***	**P-value**	**Difference on a scale from 0-100 (%)****
Function				
Age	**Type A**			
18-30 (n=8)	16.1 ± 20.1	10.1 **±** 12.4	>0.05	6.0
31-64 (n=28)	20.7 ± 21.3	12.2 ± 13.4	**<0.05**	8.5
≥65 (n=19)	35.6 ± 35.2	12.9 **±** 13.5	**<0.05**	22.7
	Type B			
18-30 (n=14)	17.0 ± 21.0	10.1 **±** 12.4	**<0.05**	6.9
31-64 (n=56)	20.4 ± 19.6	12.2 ± 13.4	**<0.05**	8.2
≥65 (n=24)	23.7 ± 23.3	12.9 **±** 13.5	**<0.05**	10.8
	Type C			
18-30 (n=4)	11.0 ± 11.8	10.1 **±** 12.4	>0.05	0.9
31-64 (n=11)	21.4 ± 18.5	12.2 ± 13.4	**<0.05**	9.2
Bother				
Age	**Type A**			
18-30 (n=9)	17.6 ± 21.6	9.0 ± 14.5	>0.05	8.6
31-64 (n=30)	25.1 ± 24.7	15.1 ± 18.6	**<0.05**	10.0
≥65 (n=37)	34.5 ± 29.4	15.3 ± 18.7	**<0.05**	19.2
	Type B			
18-30 (n=15)	21.0 ± 25.7	9.0 ± 14.5	**<0.05**	12.0
31-64 (n=59)	23.8 ± 22.6	15.1 ± 18.6	**<0.05**	8.7
≥65 (n=27)	28.3 ± 23.8	15.3 ± 18.7	**<0.05**	13.0
	Type C			
18-30 (n=5)	23.8 ± 22.0	9.0 ± 14.5	**<0.05**	14.8
31-64 (n=12)	24.5 ± 22.3	15.1 ± 18.6	>0.05	9.4

* Mean SMFA scores and standard deviation

** Decrease in Physical functioning compared to normative data of the Dutch population

Table 4: SMFA subscale scores compared to the Dutch population normative data

Patients (N)	**Fracture type***	**Dutch population***	**P-value**	**Difference on a scale from 0-100 (%)****
Lower extremity				
Age	**Type A**			
18-30 (n=8)	11.7 ± 17.7	7.6 ± 12.9	>0.05	4.1
31-64 (n=29)	18.8 ± 21.3	10.8 ± 14.4	**<0.05**	8.0
≥65 (n=21)	36.7 ± 35.0	13.6 ± 14.8	**<0.05**	23.1
	Type B			
18-30 (n=15)	15.7 ± 21.6	7.6 ± 12.9	**<0.05**	8.1
31-64 (n=56)	17.5 ± 20.4	10.8 ± 14.4	**<0.05**	6.7
≥65 (n=24)	23.8 ± 26.1	13.6 ± 14.8	**<0.05**	10.2
	Type C			
18-30 (n=5)	13.8 ± 16.2	7.6 ± 12.9	>0.05	6.2
31-64 (n=12)	20.1 ± 19.6	10.8 ± 14.4	**<0.05**	9.3

Upper extremity				
Age	**Type A**			
18-30 (n=8)	9.4 ± 16.5	5.5 ± 10.0	>0.05	3.9
31-64 (n=56)	10.1 ± 16.3	5.7 ± 11.4	**<0.05**	4.4
≥65 (n=37)	23.0 ± 33.5	7.2 ± 13.8	**<0.05**	15.8
	Type B			
18-30 (n=15)	1.9 ± 5.6	5.5 ± 10.0	>0.05	▲3.6
31-64 (n=59)	9.7 ± 20.8	5.7 ± 11.4	**<0.05**	4.0
≥65 (n=27)	13.6 ± 21.1	7.2 ± 13.8	**<0.05**	6.4
	Type C			
18-30 (n=5)	0 ± 0	5.5 ± 10.0	>0.05	▲5.5
31-64 (n=12)	3.5 ± 9.7	5.7 ± 11.4	>0.05	▲2.2
Daily activities				
Age	**Type A**			
18-30 (n=8)	18.6 ± 26.9	9.0 ± 14.9	>0.05	9.6
31-64 (n=28)	25.4 ± 27.1	14.0 ± 18.1	**<0.05**	11.4
≥65 (n=27)	40.0 ± 35.3	14.0 ± 17.3	**<0.05**	26.0
	Type B			
18-30 (n=14)	21.3 ± 28.4	9.0 ± 14.9	**<0.05**	12.3
31-64 (n=28)	25.5 ± 23.1	14.0 ± 18.1	**<0.05**	11.5
≥65 (n=26)	30.8 ± 27.9	14.0 ± 17.3	**<0.05**	16.8
	Type C			
18-30 (n=4)	15.0 ± 18.0	9.0 ± 14.9	>0.05	6.0
31-64 (n=11)	26.9 ± 23.8	14.0 ± 18.1	**<0.05**	12.9
Emotion				
Age	**Type A**			
18-30 (n=9)	24.3 ± 16.7	21.0 ± 16.6	>0.05	3.3
31-64 (n=30)	25.3 ± 20.9	22.0 ± 17.7	>0.05	3.3
≥65 (n=37)	34.1 ± 24.0	19.8 ± 17.1	**<0.05**	14.3
	Type B			
18-30 (n=15)	24.2 ± 25.5	21.0 ± 16.6	>0.05	3.2
31-64 (n=59)	26.2 ± 20.8	22.0 ± 17.7	>0.05	4.2
≥65 (n=26)	26.4 ± 17.9	19.8 ± 17.1	>0.05	6.6
	Type C			
18-30 (n=5)	26.9 ± 20.0	21.0 ± 16.6	>0.05	5.9
31-64 (n=12)	29.2 ± 22.7	22.0 ± 17.7	>0.05	7.2

* Mean SMFA scores and standard deviation

** Decrease in Physical functioning compared to normative data of the Dutch population, except for scores indicated with ▲, which indicates the score is higher compared to that of the Dutch population

Table 5: EQ-5D scores compared to the Dutch population normative data

Patients (N)	**Fracture type***	**Dutch population***	**P-value**	**Difference on a scale from -0.329 – 1 (%)****
EQ-5D				
Age	**Type A**			
18-30 (n=9)	0.817 ± 0.133	0.894 ± 0.154	>0.05	5.8
31-64 (n=30)	0.767 ± 0.241	0.853 ± 0.178	**<0.05**	6.5
≥65 (n=38)	0.712 ± 0.317	0.865 ± 0.170	**<0.05**	11.5
	Type B			
18-30 (n=15)	0.781 ± 0.285	0.894 ± 0.154	**<0.05**	8.5
31-64 (n=59)	0.779 ± 0.255	0.853 ± 0.178	**<0.05**	5.6
≥65 (n=29)	0.733 ± 0.284	0.865 ± 0.170	**<0.05**	9.9
	Type C			
18-30 (n=5)	0.766 ± 0.291	0.894 ± 0.154	>0.05	9.6
31-64 (n=12)	0.803 ± 0.189	0.853 ± 0.178	>0.05	3.8

* Mean EQ-5D scores and standard deviation

** Decrease in Quality of Life compared to the Dutch population

DISCUSSION

The aim of this study was to provide an overview of the long-term physical functioning and quality of life (QoL) of patients following pelvic ring injuries. Additionally, their level of physical functioning and quality of life were compared to the normative data of the general Dutch population. The results of this study show fair long-term physical functioning and QoL after all types of pelvic ring injuries (table 2). No clinically relevant differences in long-term physical functioning and quality of life were found between patients who had sustained A, B or C type pelvic ring injuries. However, comparisons with the normative data of the Dutch population showed a significant decrease in physical functioning and QoL in all types of pelvic ring injuries and in all age groups (table 3, 4 and 5). Moreover, the fact that research has shown that injured patients initially report better pre-injury health status compared to the general population (18) even more suggests that the impact of pelvic ring injuries on physical functioning and quality of life may even be larger than the results of this study indicate. A few small cohort studies have reported the results of physical functioning after pelvic ring injuries. Lefaivre et al. found poorer physical functioning after type B and type C pelvic ring injuries on applying the SMFA (19), with a mean of 52.12 points for type B injuries and 62.57 points for type C injuries, compared to 20.7 and 17.5 respectively in our study population. The SMFA bother index scores were 51.51 for type B and 64.18 for type C injuries compared to 24.6 and 22.9 in our study population. However, it is hard to compare these results because only 38 patients participated in their study, none of whom had type A injuries and all the patients were treated operatively. Our large cohort of both conservatively and operatively treated patients, on the other hand, reflects daily clinical practice.

In our study, the pelvic ring injury patients demonstrated substantially lower physical functioning (mean SMFA function score 22 vs. 12; bother 26 vs. 13; lower extremity 21 vs. 11; daily activity 28 vs. 12; emotion 27 vs. 21) and quality of life (mean EQ-5D 0.76 vs. 0.87) after 4 years of follow up in comparison to their peers from the general population. The decrease in physical functioning at follow up, as measured by the SMFA, mainly strikes patients aged >30 years and especially patients aged ≥ 65 (table 3 and 4). This could probably be explained by the fact that, even though more young people sustain the relatively severe type B and C injuries, they tend to have better recovery capacity and coping mechanisms compared to older patients. Older patients often sustain the more stable type A injuries, but are more likely to have pre-existing comorbidities. Together with the age-related vulnerability and limited rehabilitation capacity, this may explain the fact that elderly patients had significantly decreased physical functioning after a pelvic ring injury compared to the younger patients.

To the best of our knowledge, only a few papers compared validated PROMs regarding physical functioning and QoL following pelvic ring injuries with normative data (18,19). In one of these studies, by Hoffmann et al., patients with LC pelvic injuries reported worse daily activity (23.9 vs. 11.9), emotional (32.7 vs. 20.5), lower extremity (25.7 vs. 13.6), function (21.8 vs. 12.7) and bother (24.2 vs. 13.8) outcome scores on the SMFA after two years of follow-up in comparison to the normative data (20).

The patients in our study still had a decreased QoL (median EQ-5D of 0.8) due to their pelvic ring injuries several years after the accident. The decrease in QoL, as found in our study, seems to be in line with previous literature. A study by Harvey-Kelly et al. showed a significant decrease in all five domains of the EQ-5D score (median 0.67) at 1 year follow up after traumatic pelvic injury, compared to the pre-injury status (21). Dienstknecht et al. divided their patients into three groups namely, isolated anterior pelvic ring injuries, isolated posterior pelvic ring injuries and combined anterior and posterior pelvic ring injuries. They found poorer quality of life after a minimum of

10 years of follow-up in patients with posterior pelvic ring injuries and combined anterior and posterior pelvic ring injuries, as measured by the SF-12 (22). Moreover, Holstein et al. found that older patients had a higher likelihood of reduced quality of life following complex trauma and surgery (9).

There has been an increase in the use of generic outcome instruments. The overall validity, reliability and responsiveness of pelvic outcome instruments have not been established and the information in the existing literature is inadequate for surgeons or patients about the functional outcomes after these injuries (23). The EQ-5D and SMFA-NL are valid and reliable questionnaires that provide a generalized (functional) personal outcome score. They were used here because of these characteristics and the ability to compare our data with the normative data from the Dutch population. Moreover, these questionnaires were considered to complement each other in specific aspects following pelvic injuries. Historically, outcome reports after pelvic injuries mainly focused on radiographic measures. However, the patients' own perception with regard to social, physical and emotional challenges is of greater importance.

Some strong points and some limitations of this study should be addressed. The strengths of this study include the size of the patient cohort, the relatively long follow-up period and the high response rate (69%). Moreover, whereas other studies mostly used non-validated measures to evaluate outcomes after pelvic ring injuries, this is one of the few studies that used several validated questionnaires to assess long-term physical functioning and quality of life in a large cohort of patients who had sustained a pelvic ring injury. The use of validated questionnaires enabled comparison of the results with normative data from the general population. Most studies which evaluated functional outcomes after pelvic ring injuries excluded pelvic type A injuries caused by low-energy traumas; these type of injuries were included in our study because they form the largest part of the entire population with pelvic ring injuries. A possible limitation is the fact that the study suffers from heterogeneity in terms of fracture patterns and presence of associated injuries, although this is a clinical reality in patients suffering from pelvic ring injuries. Secondly, the retrospective cross-sectional study design has inherent restrictions. Despite this, we believe that several critical important issues were addressed.

CONCLUSION

In conclusion, it seems correct to address long-term patient-reported physical functioning and quality of life of patients who have sustained a pelvic ring injury, especially as it can be substantially lower in comparison with their age-matched peers from the general population. This indicates that pelvic ring injuries have a significant personal as well as societal impact, even years after the injury occurred. Further prospective research with validated PROMs is necessary to assess the course of physical functioning and quality of life at regular time intervals, from the pre-injury status to a number of years post-injury.

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Chapter 4

The impact of pelvic ring injuries on quality of life, physical, and mental health - a prospective cohort study

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ABSTRACT

Purpose. Pelvic ring injuries are known to affect the patients' daily life in terms of physical functioning and quality of life (QoL). Still, prospective studies on the patient's perception over the first two years of rehabilitation are lacking. Therefore, patients cannot be properly informed about whether or when they will return to their pre-existing level of physical functioning and QoL.

Methods. A prospective longitudinal cohort study was performed over a four-year period including all consecutive patients above 18 years who sustained a pelvic ring injury in a level 1 trauma center. Validated patient reported outcome measures (PROMs) were used to assess physical functioning (SMFA) and QoL (EQ-5D) at baseline (recalled pre-injury score), six weeks, three months, six months, one year and two years after the injury. It was assessed whether patients had fully recovered by comparing follow-up scores to baseline PROMs. Binary logistic regression analysis was used to identify independent predictors for patients who did not fully recover. Most experienced difficulties at three months and one year were identified by analyzing the highest reported scores on individual items of the SMFA.

Results. A total of 297 patients with a pelvic ring injury were identified of which 189 were eligible for follow-up and 154 (82%) responded. Median SMFA function score at three months, one and two years was 70, 78 and 88 respectively compared to 96 out of 100 before the injury. Median SMFA bother score was 67, 79 and 88, respectively. Median EQ-5D score at three months, one and two years was 0.61, 0.81 and 0.85 respectively compared to 1 (maximum achievable) before the injury. After one and two years of follow-up, 61% and 75% of the patients fully "recovered" in physical functioning and 52% and 71% fully recovered in terms of QoL. Female gender and high-energy trauma were independent predictors for not fully recovering after one year. After three months of follow-up, 54% of patients reported severe difficulties with recreational activities, whereas after one year, most experienced difficulties (31% of patients) concerned heavy house or yard work. Moreover, after three months and one year, 44% and 27% of patients reported feeling physically disabled.

Conclusion. Pelvic ring injuries have a large impact on the patients' daily life in the first two years of rehabilitation. Directly after the injury, physical functioning and QoL decrease strongly but then gradually improve over a two-year period with about 75% of patients fully recovering. Female gender and high-energy trauma are shown to be independent predictors for not fully recovering. After three months, patients experience difficulties with both the physical and mental effects of the injury which continue to be present after one year.

INTRODUCTION

Pelvic ring injuries have an estimated annual incidence of 14-37 per 100,000 inhabitants (1,2). In the younger population, high-energy trauma like traffic accidents are often the cause of injury (3), whereas in the fragile elderly low-energy trauma like a fall from standing is more likely to occur. Pelvic ring injuries can have serious impact on the patient's physical functioning and quality of life (QoL) (4), especially during the first months of rehabilitation. They often coincide with a long period of impaired mobilization and pain (5).

Although there has been a shift in terms of outcome assessment with increasing emphasis on patient-reported outcome, prospective follow-up studies on pelvic ring injuries are scarce (6). A systematic review revealed that some retrospective studies reported that patient-reported physical functioning and QoL seem fair and tend to improve after the injury (7). However, most studies had several methodological limitations (7). First, patient numbers were often small and groups were heterogeneous in terms of age, type of injury and treatment. Secondly, a large number of different generic and pelvic-specific Patient-Reported Outcome Measures (PROMs) were used, while most of these were not validated. At last, most studies used a retrospective design, thus lacking information on the pre-injury health status and rehabilitation period (7). Still, it is unknown whether or when patients return to their pre-existing level of physical functioning and QoL. As a result, patients cannot be informed properly about prognosis because clinicians lack knowledge about the early recovery of physical functioning and QoL after a pelvic ring injury.

A prospective cohort study was performed concerning the short-term effects of pelvic ring injuries on patient-reported physical functioning and QoL. Based on this information, patients can be informed properly about what to expect from the rehabilitation period in terms of when or whether they will regain their normal life again. Hence, the research questions of this study include: 1) what is the course of recovery in terms of physical functioning and QoL within the first two years after a pelvic ring injury?; 2) which patient characteristics are predictive for a decrease in physical functioning and QoL one year after the injury?; and 3) from a patient perspective, what are the most experienced difficulties in life at three months and one year of follow-up after a pelvic ring injury?

PATIENTS AND METHODS

Patients

A prospective longitudinal cohort study was performed, including all consecutive adult patients (above 18 years of age) who had been treated for a pelvic ring injury at a level-1 trauma center between January 2017 and June 2021. Data on the patients' characteristics were prospectively collected and directly entered in the database upon clinical presentation. These included information about the injury, treatment, complications and mortality. Additional data were retrieved from the Dutch Trauma Registry (8), concerning injury severity in terms of the Injury Severity Score (ISS) (9). Subsequently, two trauma surgeons with ample experience in pelvic ring injury surgery assessed the radiographic images (plain anteroposterior, inlet and outlet radiographs and CT scans) of all the patients and classified the pelvic ring injuries into type A, B and C injuries according to the AO/OTA classification (10). The local Medical Ethical Review Board reviewed the methods employed and waived further need for approval (METc 2017/543).

Patient-reported physical functioning and quality of life

All patients who survived the initial injury, without cognitive disorders and who were able to speak and understand the Dutch language were informed about the study and asked to

participate. Physical functioning was measured with the Short Musculoskeletal Function Assessment (SMFA). The SMFA questionnaire consists of 46 items which are scored on a 5-item Likert scale. It was designed to assess the functional status of patients with various musculoskeletal disorders and injuries. Two indices (function and bother index) (11) and, additionally, four subscales (upper extremity dysfunction, lower extremity dysfunction, problems with daily activities, and mental and emotional problems) can be calculated (12). Scores are calculated by summing up the scores on the individual items and transforming scores on a range from zero to 100, with higher scores indicating better function. The SMFA-NL has been shown to be a valid and reliable questionnaire for assessment of physical functioning in injured patients (12,13). Quality of life was assessed with the EuroQol-5D (EQ-5D (14)). The EQ-5D is a brief questionnaire that measures health-related quality of life based on five dimensions of health: mobility, self-care, usual activities, pain/discomfort and anxiety/depression (15). Items are scored on a 5-item Likert scale through which patients can delineate whether they have (1) no problems, (2) slight problems, (3) moderate problems, (4) severe problems or (5) extreme problems. Based on these values, a utility score ranging from 0 to 1 was formed, with higher scores indicating better function. The EQ-5D has been shown to be a valid and reliable questionnaire in injured patients (16). The SMFA-NL and EQ-5D were administered at the following time points: During hospital admission (assessment of recalled pre-injury status), three months, six months, one year and two years after the injury. Additionally, the EQ-5D was also administered at six weeks of follow-up (FU). The PROMs were digitally distributed through a secured system, RoQua, and linked to the electronic patient files. This system provides a personal code which is linked to a secure website and allowed patients to complete the digital PROMs at home or during their follow-up visits at the pelvic outpatient clinic.

Statistical Analysis

Descriptive statistics were performed to present patient and injury characteristics such as injury mechanism, fracture patterns and treatment methods. Means and standard deviations were calculated from the normally distributed data and the median and interquartile range (IQR) from not-normally distributed data. Either Chi-Square test, independent samples t-tests or Mann-Whitney U tests were performed accordingly to assess differences in characteristics between included patients and patients that were not eligible or declined to participate. To gain insight into the decrease in physical functioning (SMFA) and QoL (EQ-5D) at every time point of FU relative to their pre-injury status, the scores on the SMFA and EQ-5D were expressed as a percentage of the pre-injury score. Additionally, each patient was classified as “recovered” in terms of physical functioning when his/her score on the SMFA Indices and subscales was 15 points or less below the recalled pre-injury SMFA scores. Similar, for the EQ-5D, patients were classified as “recovered” in terms of quality of life when his/her score on the EQ-5D was 0.15 or less below the re-called pre-injury score. Independent predictors for patients that were classified as not being recovered as measured by the SMFA function and bother index and the EQ-5D after one year of follow-up, were analyzed by using a binary logistic regression analysis (backward selection procedure, p-out =0.20). Gender (female/male), age (<65/≥65), injury mechanism (LET/HET), ISS (<16/≥16), injury type (AO type A/B/C) and complications (yes/no) were evaluated for being possible predictors. The results of the final model are presented as odds ratios (ORs) with their corresponding 95%CI, and P-values. To be able to identify in which domains or activities people felt most limited and whether the (level of) limitations on these domains/activities change over time, the five individual items of the SMFA at which most patients experienced severe problems at three months and one year of follow-up were reported. Data were analysed using the IBM SPSS software, version 23.0 for Windows (IBM Corporation, Armonk, NY). Statistical significance was set at $P \leq 0.05$.

RESULTS

Study population

A total of 297 patients with a pelvic ring injury were treated during the study period of four years. One-hundred and eight patients (36%) were excluded due to reasons mentioned in Figure 1. One-hundred and eighty-nine patients were eligible for follow-up of which 35 refused (18%) to participate. Eventually, 154 patients (82%) filled out one or more follow-up questionnaires. A non-response analysis between the responders and the patients that refused to participate revealed several differences. Patients that were included in the follow-up had a lower median ISS of 13 (IQR 8-20) compared to 17 (IQR 8-37) of patients that were not included (p=0.01). Furthermore, included patients differed from non-included patients in injury types (28% *vs.* 51% type A, 57% *vs.* 40% type B and 15% *vs.* 9% type C); p<0.001, associated lower extremity injuries (13% *vs.* 27%; p=0.004), operative treatment (28% *vs.* 8%; p<0.001) and emergency laparotomy (1% *vs.* 8%; p=0.002). Patient characteristics are shown in Table 1.

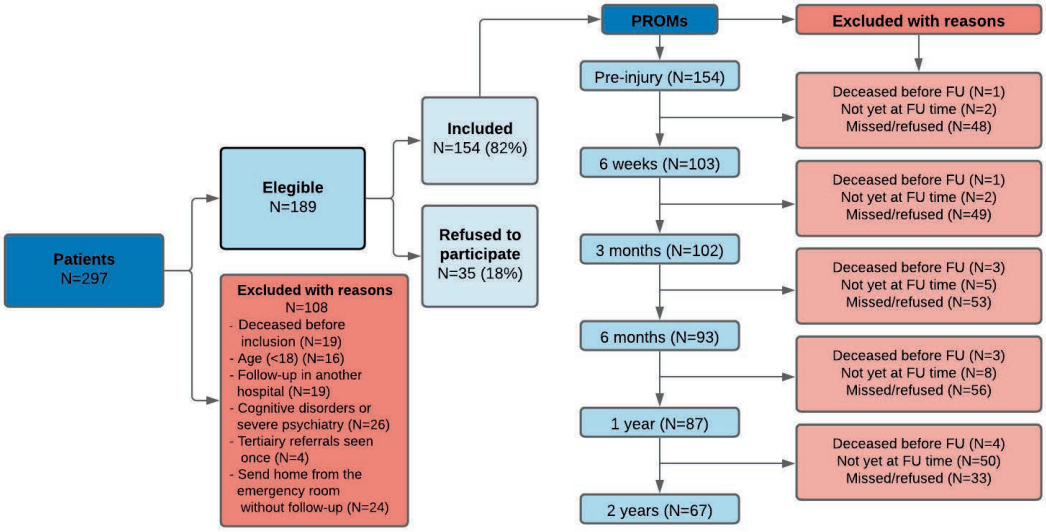

Figure 1: Flowchart of patient inclusion

Table 1: Patient characteristics

	All patients (N=297)
Female, n (%)	157 (53)
Age at the time of injury (mean ± SD)	57 ± 22
HET, n (%)	115 (39)
Injury Severity Score (ISS) median (IQR)	14 (8-26)
Injury type, n (%)	
Type A	117 (39)
Type B	144 (49)
Type C	36 (12)
Isolated pelvic ring injury, n (%)	123 (41)
Associated lower extremity injuries, n (%)	59 (20)
Operative treatment, n (%)	53 (18)
Emergency laparotomy, n (%)	12 (4)
External fixator, n (%)	14 (5)
Embolization, n (%)	7 (2)

Complications <30 days, n (%)	37 (13)
Late onset complications, n (%)	8 (3)
Deceased, n (%)	53 (18)
<30 days	19 (6)
<1 year	38 (13)

Patient-reported physical functioning and QoL

Figure 2 graphically shows the development of physical functioning and QoL during the first two years of the rehabilitation phase. All PROMs results are presented in Table 2 together with the median percentage of recovery at every time point of follow-up. For the function index of the SMFA, 61% of patients regained a full recovery at one year, and 75% at two years of follow-up (table 2, last column). For the bother index of the SMFA, 57% (1 year) and 68% (2 years) regained full recovery. After one year and two years of follow-up, respectively 52% and 71% had regained full recovery in QoL as measured by the EQ-5D. Additional PROMs analysis of subgroups can be found in supplementary file 1 (operatively and non-operatively treated patients) and in supplementary file 2 (Type A, B and C injuries).

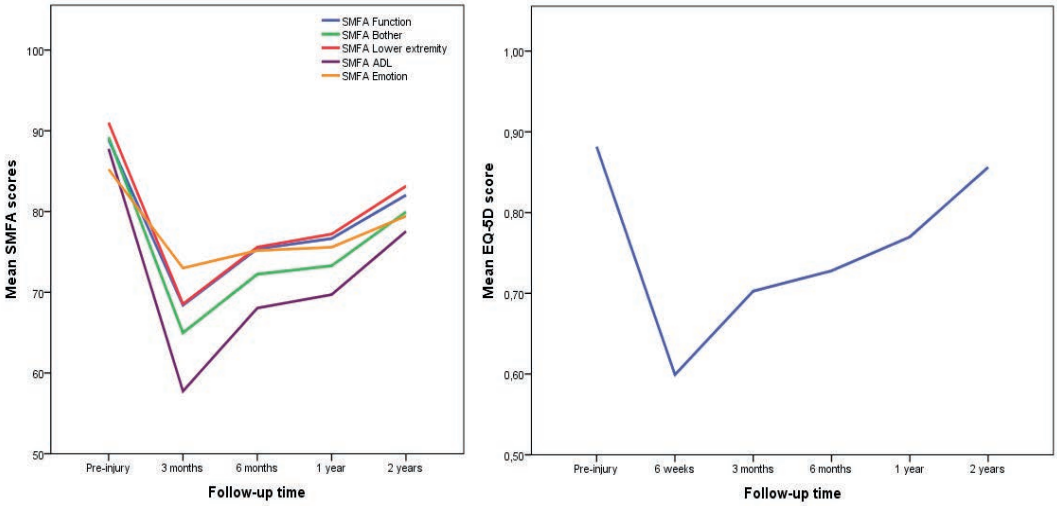

Figure 2: Outcome of PROMs for the SMFA and EQ-5D at different time points

Table 2: PROMs scores (first column) with level of recovery at every time point of follow-up compared to pre-injury scores expressed in median (IQR) percentage (second column) and the actual number of patients that has fully recovered (last column)

		PROMs scores* median (IQR)	**Level of recovery **** (median, IQR)	**Number of patients fully recovered** N (%)
SMFA				
Function index	Pre-injury	95.6 (82.9-98.6)	-	-
	3 months	69.5 (52.6-85.8)	75 (62-92)	42 (45)
	6 months	76.5 (63.6-90.9)	87 (70-99)	49 (59)
	1 year	78.3 (62.5-92.8)	89 (76-99)	48 (61)
	2 years	87.5 (74.3-96.3)	94 (82-99)	33 (75)
Bother index	Pre-injury	95.8 (84.9-100)	-	-
	3 months	66.7 (45.8-85.4)	71 (56-92)	36 (38)
	6 months	75.0 (55.7-91.7)	87 (65-98)	47 (57)
	1 year	79.2 (57.3-92.2)	87 (69-100)	45 (57)

	2 years	87.5 (75.0-97.9)	92 (78-98)	30 (68)
Lower extremity	Pre-injury	98.9 (89.1-100)	-	-
	3 months	70.8 (50.5-91.7)	75 (58-96)	97 (100)
	6 months	79.2 (63.0-93.8)	88 (71-100)	64 (97)
	1 year	81.3 (64.6-95.8)	91 (73-100)	57 (97)
	2 years	87.5 (72.9-97.9)	96 (83-100)	31 (94)
Activities of	Pre-injury	97.5 (80.9-100)	-	-
Daily Living	3 months	57.5 (37.5-79.7)	65 (47-88)	28 (30)
(ADL)	6 months	70.0 (51.6-90.6)	81 (59-97)	37 (45)
	1 year	73.1 (52.8-90.6)	84 (66-99)	39 (49)
	2 years	85.0 (76.5-97.5)	101 (100-106)	39 (89)
Emotion	Pre-injury	90.6 (78.1-96.9)	-	-
	3 months	75.0 (59.4-87.5)	88 (74-97)	54 (57)
	6 months	78.1 (62.5-90.6)	91 (76-100)	56 (68)
	1 year	78.1 (64.8-90.6)	93 (78-100)	51 (65)
	2 years	84.4 (68.8-93.8)	93 (83-100)	30 (68)
EQ-5D	Pre-injury	1.00 (0.85-1.00)	-	-
	6 weeks	0.61 (0.42-0.79)	71 (47-88)	29 (29)
	3 months	0.74 (0.56-0.84)	81 (64-93)	38 (40)
	6 months	0.78 (0.65-0.87)	85 (72-99)	38 (45)
	1 year	0.81 (0.72-0.89)	85 (76-100)	42 (52)
	2 years	0.85 (0.76-1.00)	92 (85-100)	32 (71)

* Median (IQR) scores of the SMFA and EQ-5D
** Individual PROMs scores at every time point of follow-up were expressed as percentage of the pre-injury score. Median percentages (IQR) are presented here.

Factors associated with no full recovery one year after the injury

Binary logistic regression analyses revealed that the female gender and a high-energy trauma were independent predictors for not being fully recovered in terms of physical functioning after one year of follow-up (Table 3 and 4). The odds of not recovering on the function index were about three times higher in women compared to men and at least four times higher in patients sustaining a high-energy trauma. The odds of not recovering on the bother index was almost four times higher in females. Female gender and high-energy trauma were also significant predictors for decreased QoL after one year (Table 5). The odds of not recovering was about four times higher in female patients and patients with a high-energy trauma. Polytrauma as measured by the ISS (<16/≥16) and injury type (AO type A/B/C) did not turn out to be independent predictors for decreased physical functioning and QoL one year after the injury.

Table 3: Independent predictors for no full recovery of the SMFA function Index at 1 year

	B	OR	95% CI		P-value*
Female gender	1.14	3.13	1.12	8.79	**0.03**
High-energy trauma	1.42	4.15	1.29	13.39	**0.017**

B regression coefficient; *OR* Odds ratio; *95% CI* 95% confidence interval
* Results on the final model with the P-value set at 0.20.

Table 4: Independent predictors for no full recovery of the SMFA bother Index at 1 year

	B	OR	95% CI		P-value*
Age <65 years	-0.95	0.39	0.14	1.07	0.06
Female gender	1.27	3.56	1.31	9.70	**0.013**
Complications <30 days	0.86	2.36	0.78	7.12	0.13

B regression coefficient; *OR* Odds ratio; *95% CI* 95% confidence interval
* Results on the final model with the P-value set at 0.20.

Table 5: Independent predictors for no full recovery of the EQ-5D at 1 year

	B	OR	95% CI		P-value*
Female gender	1.29	3.64	1.28	10.33	**0.015**
High-energy trauma	1.28	3.60	1.19	10.84	**0.02**
Complications <30 days	0.73	2.07	0.70	6.09	0.18

B regression coefficient; *OR* Odds ratio; *95% CI* 95% confidence interval
* Results on the final model with the P-value set at 0.20.

Patients' perception of most experienced difficulties during rehabilitation

The individual items of the SMFA to which the patients responded with experiencing severe difficulties (SMFA item score of four or five) were assessed in detail. Subsequently, a top five of encountered difficulties from a patient perspective was composed. A substantial number of patients still experienced limitations in physical activities as well as effects of the injury on their mental wellbeing after respectively three months and one year of follow-up (Table 6). More than half of patients reported severe problems with recreational activities as well as heavy house work or yard work. The latter was still present after one year in 31% of patients. Forty-four percent of patients felt physically disabled after three months, which gradually decreased to 27% of patients after one year.

Table 6: Patients' perception of most experienced difficulties at respectively three months, one year, and two years of follow-up after a pelvic ring injury

	SMFA					
	Three months	**%***	**One year**	**%***	**Two years**	**%***
1	Recreational activities	54	Heavy house or yard work	31	The effect of doing too much on one day	25
2	Heavy house work or yard work	53	Bothered by problems with activities around the house	28	Problems performing daily work	21
3	Problems performing daily work	44	Problems with bending or kneeling down	28	Heavy house or yard work	18
4	Feeling physically disabled	44	Feeling physically disabled	27	Feeling physically disabled	18
5	Bothered by problems with recreational activities	41	The effect of doing too much on one day	27	Bothered by problems with recreational activities	18

* Percentage of patients that experience severe difficulties (SMFA item score of 4 or 5)

Table 7 shows the percentages of patients with their reported difficulties regarding sexual activities from pre-injury up to two years after the injury. Most problems were reported at three months after the injury and these gradually improved over time.

Table 7. Levels of sexual dysfunction at consecutive time points after sustaining a pelvic ring injury

	Pre-injury (N=150)	**Three months (N=97)**	**Six months (N=86)**	**One year (N=81)**	**Two years (N=44)**
No problems (%)	85	40	61	58	68
Some problems (%)	6	20	17	19	14
Moderate problems (%)	2	16	6	7	7
Severe problems (%)	1	7	5	9	9
Unable (%)	5	18	12	7	2

DISCUSSION

In this prospective longitudinal study we evaluated patient-reported physical functioning and quality of life up to two years after a pelvic ring injury and investigated which patient characteristics were predictive of a decreased physical functioning and QoL at one year after the injury. Directly after the injury, physical functioning and QoL decrease strongly but then gradually improve up to two years after the injury. However, after two years, physical functioning as well as QoL are still decreased with a recovery percentage of 75% for physical functioning and 71% for QoL compared to the pre-injury level. Female gender and high-energy trauma are shown to be independent predictors for not fully recovering at one year after the pelvic injury. After three months, patients experience difficulties with both the physical and mental effects such as difficulties with heavy house or yard work, as well as with feeling physically disabled, which continue to be present after one year.

Patients report an evident decrease in physical functioning three months after the injury compared to the recalled pre-injury health status. From that moment on, physical functioning keeps on improving up to two years after the injury. Between six months and one year, the recovery curves flatten slightly, while they rise again between one and two years, a finding that is in line with previous literature (17). Median scores on the SMFA function and bother index were respectively 76 and 75 out of 100 at six months, 78 and 79 at 1 year and both 88 at two years of FU. Hoffman et al. (18) reported slightly lower scores using the SMFA in a retrospective cohort study evaluating outcomes after surgically treated lateral compression pelvic ring injuries in 280 patients at six, 12 and 24 months. Scores on the function, and bother index were respectively 72 and 69 at six months and improved slightly to 74 and 70 at 1 year and 78 and 76 at two years of FU. After one and two years of follow-up, respectively 61% and 75% of the patients in our study fully “recovered” in physical functioning (SMFA function index). There are no other prospective studies on recovery of physical function after pelvic ring injuries that use validated PROMs to compare our results with. Next to the reported physical disabilities following a pelvic ring injury, our study showed that patients are also highly affected by the mental consequences as 68% of patients “recovered” on the SMFA bother index and mental & emotional subscale after two years.

The high number of patients still being bothered and experiencing mental and emotional problems at two years after the injury, highlights the fact that psychological and social effects should also be taken into account to gain an overall picture of the patient’s health perspective. Until recently, subjective emotional disturbances, pain, social and professional consequences have hardly been considered in patients with pelvic ring injuries, even though these injuries can seriously affect QoL (4,19,20). After the pelvic ring injury, an obvious decrease in QoL develops in the first six weeks compared to the recalled pre-injury health status. From that moment on, QoL keeps on improving up to two years after the injury. Similar to curves on physical functioning, QoL reached a plateau phase between six months and one year, but rises quite sharply again between one and two years. Median EQ-5D scores in our study after six months, one year and two years were respectively 0.78, 0.81 and 0.85. Brouwers et al. (17) support these findings, similarly using the EQ-5D to evaluate QoL. They reported a mean EQ-5D scores of 0.77 at one year and 0.80 at two years and a flattened curve between six months and one year. Moreover, we showed that after one and two years following the injury, “only” 52% and 71% of the patients reported full “recovery” in QoL. Brouwers et al. underline these findings, as they reported that most patients did not achieve their pre-injury state of QoL after one year.

Female gender showed to be an independent predictor for achieving no full recovery of physical functioning and QoL one year after the injury. However, it is difficult to provide a clear explanation

for this finding. Taking a closer look at the demographic characteristics, females were older (mean age 62, SD 23) compared to males (mean age 52, SD 21). They also sustained more type C injuries (15% vs. 9%) and reported higher degrees of sexual dysfunction one year after the injury (24% vs. 8%). These findings could be a possible explanation. In other studies, some contradictive results were found regarding the relationship between gender and outcome. One study also reported female gender to be a predictor for decreased QoL (17), whereas another study did not (4). Polinder et al. and Holbrook et al. (21,22) found that female gender was a prognostic factor of decreased QoL after general trauma. Independently of injury severity and mechanism, women are reported to show a substantially higher risk of psychological morbidity after major trauma than men with higher rates of post-injury depression, symptoms of acute stress reaction and posttraumatic stress disorder (PTSD) (22). Female gender was also shown to be a predictor for decreased physical functioning, but only at long-term follow-up (mean of 7 years after the injury) (23). However, other studies reported no differences between physical functioning in males and females (18) or even improved physical functioning in females (24). Next to female gender, we also found a high-energy trauma to be a predictive factor for decreased physical functioning and QoL. Brouwers et al. (17) found that ISS was an independent predictor for QoL, a factor closely related to a high-energy trauma as patients often sustain concomitant injuries when sustaining a high-energy trauma. On the other hand, Holstein et al. (4) did not find ISS to be an independent predictor for decreased QoL.

Based on the SMFA questionnaire for physical functioning, we analyzed the factors to which patients experience the most severe difficulties at three months and one year after the injury. After three months, over 40% of patients reported to experience severe difficulties with recreational activities, heavy house work or yard work and daily work. However, the mental impact of the injury such as feeling physically disabled were even so key disabilities. Although the percentage of patients that experienced severe difficulties decreased after one year, 30% of patients still report severe physical, as well as mental disabilities. Results of a previous study from our research group evaluating long-term physical functioning and QoL in a large group of patients sustaining a pelvic ring injury, support these findings (19). At a mean follow-up of 4.4 ± 2.6 years, feeling physically disabled, feeling tired and the effect of doing too much on one day affecting the next day were the top three most experienced problems. Difficulties with sexual activities were mostly present at three months after the injury and these gradually improved over time.

Some strengths and limitations of this study need to be addressed. The prospective longitudinal design, including recalled pre-injury physical functioning and QoL, is undoubtedly a strength of the present study. With comparable data collected at six different time points, change over time in individual patients could be observed and recall bias avoided. We also reported a high response rate on the PROMs of 82% of the eligible patients. To the best of our knowledge, this is one of the largest prospective longitudinal follow-up studies evaluating physical functioning and QoL after pelvic ring injuries by using validated questionnaires. By comparing PROMs scores at different time points to the pre-injury scores, insight was given in the course of recovery. As a result, both the clinician and subsequently the patient could be provided with valuable information about whether and when to expect complete recovery. A limitation of this study might be the heterogeneity of the group in terms of age, fracture types, injury severity and presence of associated injuries. However, our study population is an actual reflection of patients with pelvic ring injuries presenting to a large level 1 trauma center. Future research with an even larger sample size, enabling further subgroup analyses, would be preferable. Moreover, 18% of patients passed away within the study period and could therefore not be included in (some of the) follow-up analysis with PROMs. The reported scores could therefore even be an overestimation of the actual perceived physical functioning and QoL since patients with deteriorated health passed away.

CONCLUSION

Pelvic ring injuries have a large impact on patient-perceived physical functioning and quality of life. Although both improve over the two-year period following the injury, only 75% of patients reported to be fully recovered in terms of physical functioning, 68% in terms of being bothered by the injury and 71% in QoL. Female gender and high-energy trauma are independent predictors for patients not fully recovering after one year. Most patients experience some mental effects of the injury after both three months and one year in addition to physical disabilities. The results of this study can be used as a valuable tool by the clinician in order to inform patients about their expected recovery in terms of physical functioning and QoL in the rehabilitation phase of two years after the injury. A multidisciplinary approach covering both the physical and mental aspects of pelvic ring injuries seems appropriate and deserves further attention in prospective research.

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SUPPLEMENTARY FILE 1. SMFA and EQ-5D scores of respectively non-operatively and operatively treated patients.

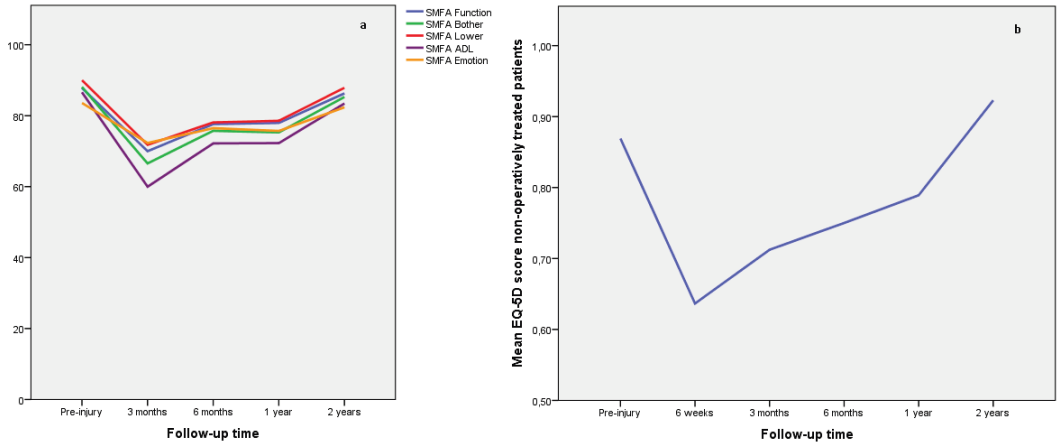

Figure 1. Scores representing recovery of physical functioning (SMFA) and quality of life (EQ-5D) over time after non-operative treatment of pelvic ring injuries (N=244); a) SMFA scores and b) EQ-5D scores. Both the scores are lowest shortly after the injury has occurred at six weeks (EQ-5D) and three months (SMFA) and these gradually improved up to almost the pre-injury level of physical functioning or quality of life at two years after the injury.

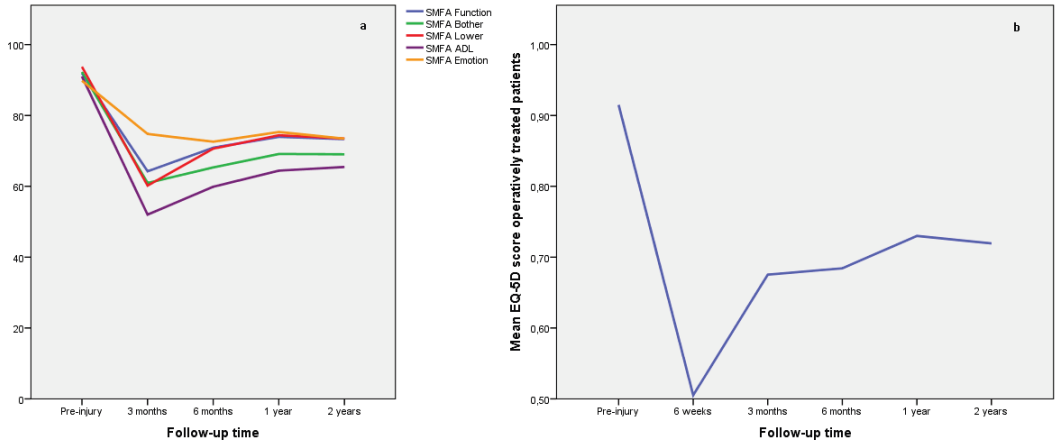

Figure 2. Scores over time after operative treatment of pelvic ring injuries; a) SMFA scores and b) EQ-5D scores. Compared to the non-operatively treated patients (N=244) (figure 1), operatively treated patients report a faster decline in score shortly after the injury at six weeks (EQ-5D) and three months (SMFA). Moreover, the recovery of physical functioning (SMFA) and quality of life (EQ-5D) after operative treatment progresses more gradually compared to the non-operative group, which is probably inherent to the severity of the injury.

SUPPLEMENTARY FILE 2. Outcome of PROMs after respectively type A, type B or type C pelvic ring injuries

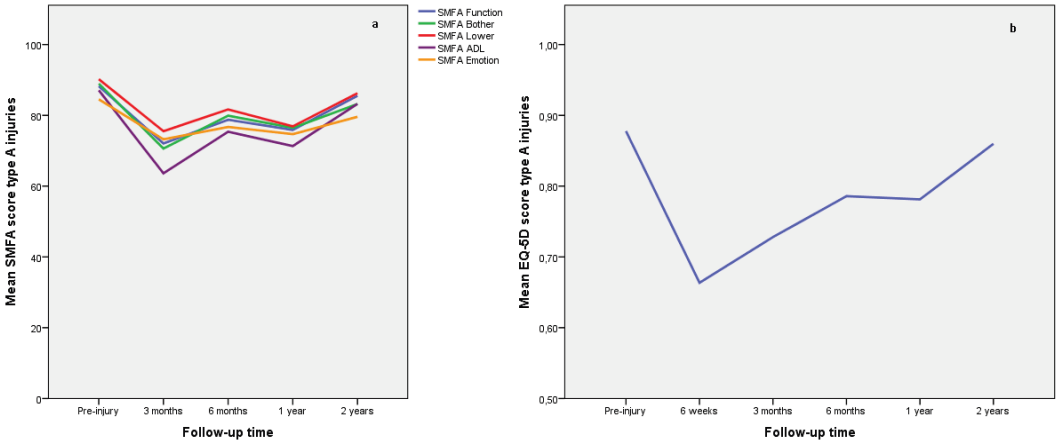

Figure 1. Scores representing recovery of physical functioning (SMFA) and quality of life (EQ-5D) over time of patients with type A pelvic ring injuries (N=117); a) SMFA scores and b) EQ-5D scores. A decrease is seen shortly after the injury at six weeks (EQ-5D) and three months (SMFA and these gradually increased up to two years after the injury.

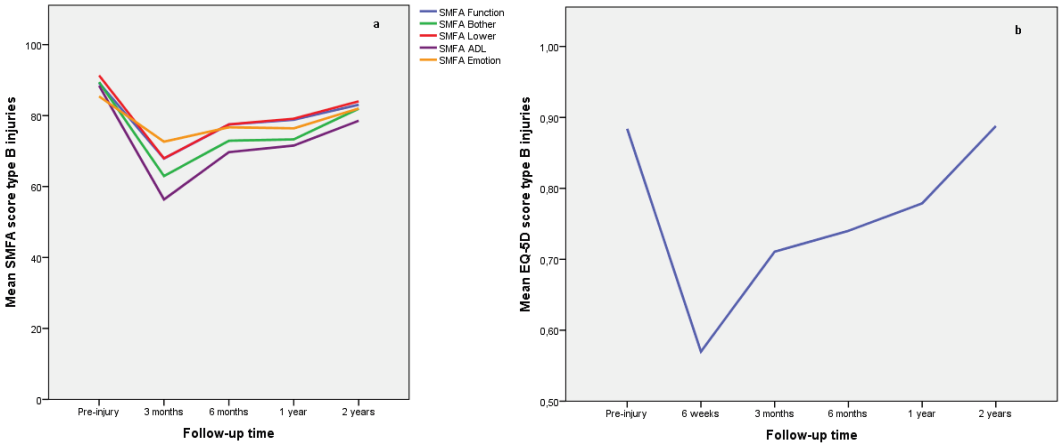

Figure 2. Scores over time of patients with type B pelvic ring injuries (N=144); a) SMFA scores and b) EQ-5D scores. After a decrease shortly after the injury, both scores continued to increase up to two years after the injury.

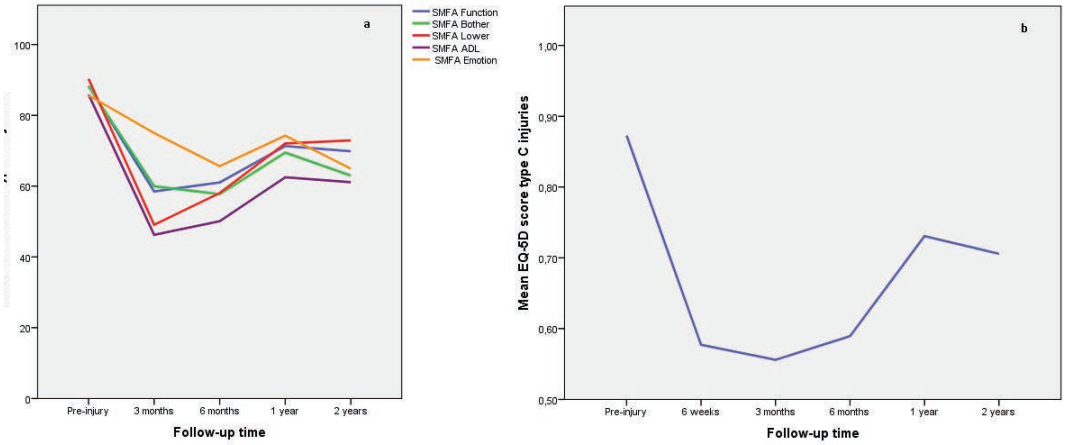

Figure 3. Scores over time of patients with type C pelvic ring injuries (N=36); a) SMFA scores and b) EQ-5D scores. The SMFA scores, indicating physical function (function index, lower extremity and ADL), dropped rapidly shortly after the injury and gradually increased after three months and reach a plateau phase after one year.

Part II

ZOOMING IN: SPECIFIC ENTITIES OF PELVIC RING INJURY IN THE ELDERLY

Chapter 5 **Pelvic ring injury in the elderly: Fragile patients with substantial mortality rates and long-term physical impairment**
PLoS One. 2019 May 28;14(5):e0216809

Chapter 6 **What is the long-term clinical outcome after fragility fractures of the pelvis? - a CT based cross sectional study**
Injury. 2021 Oct 1;S0020-1383(21)00837-8.

Chapter 7 **Are sarcopenia and myosteatosis related to decreased physical functioning and QoL in elderly patients with a pelvic ring injury?**
Journal of Clinical Medicine. 2021 October 22; 4874 (10)

Chapter 5

Pelvic ring injury in the elderly: Fragile patients with substantial mortality rates and long-term physical impairment

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PLoS One. 2019 May 28;14(5):e0216809

ABSTRACT

Background. Pelvic ring injuries in the elderly often occur after low-energy accidents. They may result in prolonged immobilization, complications and an intense rehabilitation process. The aim of this study was to assess mortality, physical functioning and quality of life (QoL) in elderly patients with pelvic ring injuries.

Methods. A cross-sectional study was performed including all elderly patients (≥ 65 years) admitted for a pelvic ring injury between 2007-2016.Mortality and survival were evaluated and patient reported outcome measures (PROMs) were used to assess physical functioning (SMFA) and QoL (EQ-5D). These were compared to age-matched normative data from the general Dutch population.

Results. A total of 153 patients, with a mean age of 79 years (SD 8) at the time of injury, were included in this study. The mortality rate was 20% at 30 days, 27% at 1 year and 41% at 3 years of follow-up. All six patients with a type C fracture died within 30 days. Analyses of the 153 patients showed that increasing age, fracture type C and Injury Severity Score (ISS) were all independent risk factors for mortality. Eventually, after excluding patients that died (N=78) or were unable to contact (N=2), 73 patients were eligible for follow-up, of which 53 patients (73%) responded. Mean Short Musculoskeletal Function Assessment (SMFA) scores were respectively 67.4 (function index), 65.2 (bother index), 66.5 (lower extremity), 60.4 (activities of daily living) and 68.2 (emotion). Mean EuroQuol-5D (EQ-5D) score was 0.72. Overall, physical functioning and quality of life were significantly decreased in comparison with normative data from the general population.

Conclusion. Elderly people who sustain a pelvic ring injury should be considered as a fragile population with substantial mortality rates. The patients who survived demonstrated a substantially lower level of physical functioning and quality of life in comparison with their age-matched peers from the general population.

INTRODUCTION

The elderly population (≥ 65 years of age) has rapidly increased over the last few decades and it is predicted that this growth will continue in the future. In the Netherlands, the elderly population will grow from 2.7 million in 2012 to 4.7 million in 2041 (1). One-third of all fractures and 73% of all pelvic injuries occur in the elderly (2). Although the overall incidence of a pelvic ring injury is estimated at 20-37/100,000 per year (3), the incidence rises to 92/100,000 per year for the population aged over 65 years (4).

The elderly population is vulnerable as a result of age-related reduced physical condition, pre-existing comorbidities, limited rehabilitation capacity and decreased coping mechanisms. Although most fractures are isolated and stable, the ability of the elderly to mount a physiologic response is limited and hence high morbidity and mortality rates are reported (5). The majority of pelvic ring injuries in this population is caused by low-energy mechanisms like a fall from standing position, often resulting in AO type A fractures (6–8), that are considered stable fractures with an intact posterior arch involving innominate bone avulsion, iliac wing, pubic rami, transverse sacral or coccyx fractures (9).

The rehabilitation to independent mobilization for this group is of utmost importance. This determines whether someone could regain its autonomy and will be able to participate in social activities. Yet, it frequently occurs that elderly patients with a pelvic ring injury end up in nursing homes and are not able to return to their own household (10). They are prone to complications like decubitus, pneumonia and urinary tract infections (11). Moreover, long-term permanent disabilities can affect their daily physical functioning and quality of life (12). Hence, optimal treatment of pelvic ring injuries remains challenging, requiring a timely multidisciplinary approach.

In the elderly patients with pelvic ring injuries, mortality has often been studied intensively, while physical functioning and quality of life have hardly been assessed by means of patient reported outcome measurements (PROMs). We hypothesized that factors like comorbidity, fracture type, injury severity and age might influence mortality following pelvic ring injuries in the elderly. Moreover, physical functioning of these patients may be decreased compared to that of the general population. Hence, the aim of this study was to assess risk factors for mortality, as well as to provide an overview of physical functioning and quality of life of elderly patients after pelvic ring injuries.

PATIENTS AND METHODS

Patients

A cross-sectional study was performed. Elderly patients (≥ 65 years of age) who were treated for a pelvic ring injury at the Department of Trauma Surgery of the University Medical Center Groningen (UMCG) between January 2007 and January 2016 were included. For all patients, the life status (alive or date of death) and the current contact details were verified in the Dutch population registry. All patients alive at the time of the study were contacted and asked to complete questionnaires in order to assess long-term physical functioning and quality of life. Patients with cognitive disorders were excluded from follow-up with the questionnaires. The local Medical Ethical Review Board reviewed the methods employed and waived further need for approval (METc 2016.385).

Methods

The patients' demographics and clinical characteristics concerning injury mechanism and fracture type were collected by reviewing their medical and operation records. Injury mechanisms were divided into low- or high-energy trauma. Low-energy trauma mainly consists of a low-energy fall, which is defined by the Dutch Trauma Registry (DTR) (13) as a fall below two-to-three times the body length. Injury characteristics in terms of the Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS) (14,15) were retrieved from the DTR. The AIS is an anatomically based global injury severity scoring system that helps to classify the injury on the level of severity, based upon different body regions. The scores vary from 1 (minor) to 6 (currently not treatable). The AIS can be used to calculate the ISS, which is sum of squares of the three highest AIS scores of three different body regions and can range from 1 to 75, in which 75 means that the chance of survival is extremely low. The Charlson comorbidity index score (CCI) (16) was calculated to evaluate the pre-injury condition. The CCI provides a simple and valid method of estimating risk of death from comorbid disease by scoring the severity of the comorbid conditions and adding up the scores on a scale from 1-6, with 1 extra point for each decade above 40 years of age. Two senior trauma surgeons with ample experience in pelvic fracture surgery assessed the radiographic images (plain anteroposterior, inlet and outlet radiographs and computerized tomography scans) of all the patients and classified the pelvic ring injuries into type A, B and C injuries, according to the Tile/ AO classification (Fig 1) (9,17).

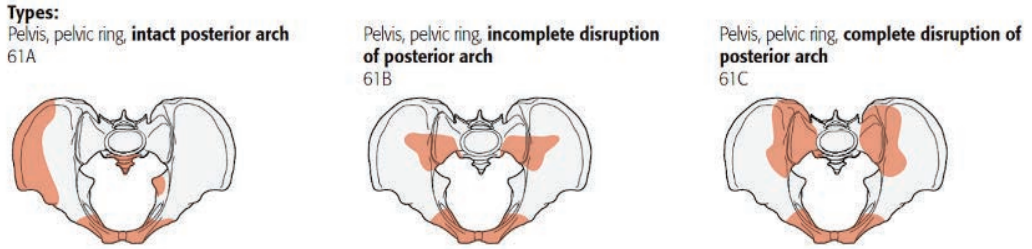

Figure 1: types of pelvic ring injuries (9)

Complications, mortality and survival

Demographics and injury characteristics of patients still alive at follow-up were compared with those of patients that had died. It was evaluated whether age, sex, injury mechanism (low- vs. high-energy trauma), fracture type, complications, CCI and ISS were independent mortality risk factors and whether effect modification existed. Moreover, survival was analysed in three age groups (age 65-75, 76-85, and >85). Mortality rates were compared to those of the general Dutch population, based on the numbers provided by the national Central Agency for Statistics (18).

Functional outcome instruments

Physical functioning was measured with the Dutch version of the Short Musculoskeletal Function Assessment (SMFA-NL), consisting of the two original indices (function and bother) (19) and four additional subscales (lower extremities, upper extremities, daily activities and emotion) (20). The 46 items are scored on a 5-item Likert scale, ranging from 1 (poor function) to 5 (good function). Scores are calculated by summing up the individual items and transforming scores on a range from zero to 100, with higher scores indicating better function. Missing items in the SMFA were handled according to the instruction manual of this questionnaire. In case less than 50% of the answers were missing in any category of the function index, the mean value of that category was substituted for the missing items. If answers were missing in the bothersome index, patients were omitted from the analysis of this index. Quality of life was assessed with the EuroQol 5D (EQ-5D) (21), which screens five health levels (mobility, self-care, daily activities, pain/inconvenience and

fear/depression) and is expressed as a score from -0.329 (worst condition) to 1 (best QoL). Both the SMFA and EQ-5D scores of the patients in this study were compared to the normative data of the age-matched general Dutch population (22,23). The EQ-5D instruction manual does not provide information on how to handle missing items. Therefore, in case one or more items were missing, data of these patients were omitted from further analysis.

Statistical Analysis

Demographic and clinical data are presented as means and standard deviations (SD) for the continuous variables and as percentages for categorical variables. Median and interquartile range (IQR) are presented for non-Gaussian distributions. Either independent samples t-test or Mann-Whitney U Test were performed accordingly to detect mean differences between the groups that had deceased or not. Categorical variables were evaluated using the chi-squared test. Survival was analysed using a Kaplan-Meier curve. Additionally, independent predictors for mortality were analysed by using a multivariate backward cox regression analysis with the removal p-value set at 0.157. The variables age at time of injury, low- vs. high-energy trauma and ISS were checked for possible effect modification. A non-response analysis was performed to evaluate differences between responders and non-responders. Difference in functional outcome and QoL (SMFA-NL and EQ-5D) between the study population and the age-matched general Dutch population was assessed by using the independent samples T-test. The level of significance was defined at $p < 0.05$. The data were analysed using the IBM SPSS software, version 23.0 for Windows (IBM Corporation, Armonk, NY).

RESULTS

Patient and injury characteristics

The data concerning patient and injury characteristics are presented in table 1. A total of 153 elderly patients with pelvic ring injuries were identified over a study period of 9 years (January 2007 until January 2016). Age ranged from 65 to 100 years at the time of injury (mean (SD) 79 (8)) and mean follow-up was five years after injury. Forty-five patients were men (29%). The majority of the pelvic ring injuries were classified as AO type A (66%) injuries. Most patients (63%) sustained low-energy traumas and median ISS was 9 (range 4-59). Four patients needed a trauma laparotomy and five patients underwent angio-embolization. In the whole study cohort, 35 complications occurred within 30 days in 25 patients (16%), the majority being delirium (N=12) and pneumonia (N=8). The majority of the study population was treated conservatively (N=141, 92%), whereas only 12 patients (8%) were treated operatively with respectively plate fixation (N=6), an external fixator (N=2), SI screws (N=1), a combination with plate fixation and SI screws (N=2), or a combination with plate fixation and an external fixator (N=1). Conservative treatment of pelvic ring injuries consisted of early mobilization with weight bearing as tolerated in combination with appropriate pain medication. Eventually, 31 patients were discharged to a nursing home.Fifteen patients (10%) died at the day of the injury and a total of thirty-one patients (20%) died within the first 30 days after the injury. All six patients with type C injuries had died within 30 days after the injury. Comparison of the group that had died within the first 30 days after the injury to the group that survived this critical period revealed significant differences in injury mechanism (low- or high-energy trauma), fracture type (A, B or C), complications, AIS and ISS (table 1).

Table 1: Baseline characteristics of patients alive and deceased 30 days after injury

	All patients (N=153)	**Patients deceased within 30 days after injury** (N=31)	**Patients alive after 30 days** (N=122)	**P-value***
Age at time of injury median (IQR)	79 (71-84)	79 (79-84)	80 (71-84)	0.57
Male	45 (29)	13 (42)	32 (26)	0.12
Low-energy trauma	97(63)	4 (13)	93 (76)	**<0.001**
High-energy trauma	56 (37)	27 (87)	29 (24)	**<0.001**
Fall from height	7 (13)	1 (3)	6 (5)	-
Crush injury	1 (2)	-	1 (1)	-
One-sided motor vehicle/ motorcycle injury	4 (7)	2 (7)	2 (1)	-
Pedestrian/cyclist vs. motor vehicle/motorcycle	27 (48)	15 (48)	12 (10)	-
Motor vehicle/motorcycle vs. motor vehicle/motorcycle	16 (29)	8 (26)	8 (7)	-
Shot injuries	1 (2)	1 (3)	-	-
Fracture classification				**0.001**
Type A	101 (66)	12 (39)	89 (73)	-
Type B	42 (28)	11 (36)	31 (25)	-
Type C	6 (4)	6 (19)	-	-
No Classification**	4 (2)	2 (6)	2 (2)	-
Complications <30 days	35 (23)	2 (7)	23 (19)	**0.02**
Delirium	12 (34)	1 (3)	11 (9)	-
Pneumonia	8 (24)	1 (3)	7 (6)	-
Urinary infection	6 (17)	-	6 (5)	-
Urinary system	3 (9)	-	3 (2)	-
Wound infection	1 (3)	-	1 (1)	-
Infection (other)	2 (5)	1 (3)	1 (1)	-
Lung embolism/DVT	2 (5)	-	2 (1)	-
Bleeding	1 (3)	-	1 (1)	-
Nerve injury	-	-	-	-
Unknown (e.g. patient was transferred to another hospital/institution)	6 (4)	-	6 (5)	-
Highest AIS pelvis median (IQR)	2 (2-3)	3 (3-3)	2 (2-2)	**<0.001**
ISS median (IQR)	9 (4-25)	34 (34-45)	5 (5-13)	**<0.001**
ISS >15	55 (36)	29 (93)	26 (21)	**<0.001**
CCI median (IQR)	5 (4-6)	5 (5-6)	5 (5-7)	0.41

Numbers are expressed in N with the percentage in parentheses unless otherwise specified

* Statistically significant results are in bold

** Classification could not be performed due to lack of imaging

Survival analysis

A total of 41 patients (27%) died within a year and 63 patients (41%) within 3 years after the injury. Figure 2 demonstrates the survival of the elderly patients divided into three age-groups with survival rates decreasing for patients aged 75-85 years, and even more for those aged >85 years, compared to patients aged 65-75 years at the time of injury. There was a significant difference in one-year mortality (P=0.007) between the three age groups. Table 2 demonstrates the mortality rates of the three age groups from year one up to year five after the injury (rows 2, 4 and 6) and the mortality rates from the general Dutch population (rows 3, 5 and 7). This table demonstrates excessive differences in mortality after sustaining a pelvic ring injury compared to the general population.

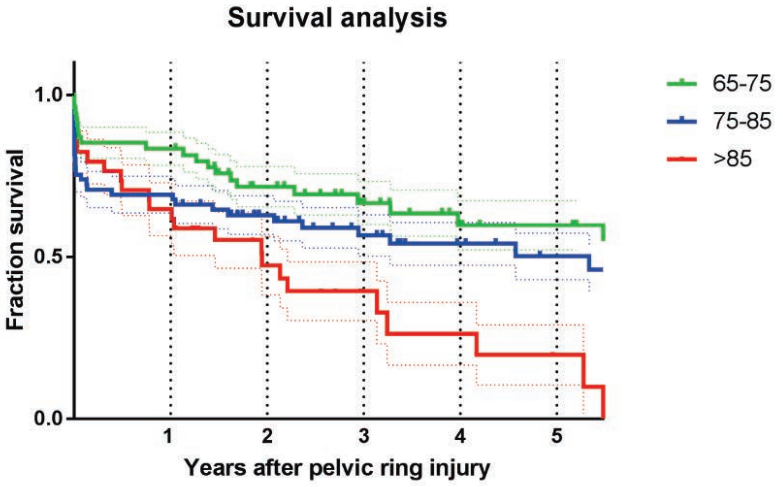

Figure 2: Kaplan-Meier survival curve indicating survival in years according to age at the time of injury

Table 2: Cumulative percentages of deceased patients from the study population and the Dutch population according to age at time of injury

	N	Year 1	Year 2	Year 3	Year 4	Year 5
65-75	54	17%	39%	56%	70%	74%
65-75 (NL)*		2%	3%	5%	7%	8%
76-85	65	31%	49%	63%	75%	82%
76-85 (NL)*		5%	11%	16%	21%	27%
>85	34	35%	65%	82%	88%	94%
>85 (NL)*		15%	29%	42%	53%	62%

* Mortality rates of the general Dutch population (Central Agency for Statistics) (18).

Mortality risk factors

Cox regression analysis was performed to assess independent risk factors for mortality. No effect modification existed. The analysis showed that higher age at time of injury, pelvic fracture type C and higher ISS were shown to be independent risk factors for mortality (table 3). There was a 7% increase in the odds of dying with every year of increasing age. Moreover, patients with type C fractures were almost five times more likely to die than patients with type A fractures. Finally, the odds of the patients dying increased by 6% with every point increase in ISS. Higher Charlson Comorbidity Index tended to have an effect on mortality as well, although not statistically significant (P=0.07).

Table 3: multivariate Cox regression analysis on mortality

	N	HR	95% CI		p-value*
Final multivariate model					
Age at time of injury (years)	153	1.07	1.03	1.10	**<0.001**
Fracture type**	153				
Type B		0.75	0.39	1.45	0.39
Type C		4.70	1.54	14.40	**0.007**
ISS	153	1.06	1.04	1.09	**<0.001**
CCI	153	1.13	0.99	1.28	0.07

* Statistically significant results are in bold.; HR: hazard ratio; ISS: Injury Severity Score; CCI: Charlson comorbidity index

** Reference category: fracture type A

Follow-up by means of PROMs

Of the 153 patients, 51% (N=78) of the patients had died at long-term follow-up and two patients were living abroad and could therefore not be contacted, leaving 73 patients eligible for follow-up by means of patient-reported outcome measures. A total of 53 patients (73%) responded at a mean follow-up of 3.4 ± 2.7 years after the pelvic ring injury. The other 20 patients (27%) declined to participate or did not respond. A non-response analysis showed differences in the proportion of pelvic fracture types; a higher proportion of patients with a type B injury responded (P=0.01). Moreover, patients with higher ISS were more likely to respond (P=0.002). No other differences were found between the responders and non-responders.

Physical functioning and quality of life

Overall, patients with pelvic injuries reported moderate limitations with respectively a mean of 67.4 on the function index, 65.2 on the bother index, 66.5 on the lower extremity, 60.4 on the ADL (activities of daily living) and 68.2 on the emotion subscale of the SMFA (table 4). Concerning the lower extremity subscale of the SMFA, patients indicated having the most problems with climbing stairs and with bending and kneeling down. Patients who had sustained any type of pelvic ring injury reported a reasonable QoL (table 4) with a mean EQ-5D score of 0.72. The comparison of SMFA and EQ-5D scores with the age-matched normative data from the general Dutch population revealed significant differences regarding all parts of the SMFA as well as the EQ-5D, meaning that physical functioning and quality of life in an elderly patient with a pelvic ring injury was significantly decreased (table 4).

Table 4: Outcomes on the SMFA-NL and EQ-5D

	Study population	General Dutch population	P-value*
SMFA**			
Function Index	67.4 ± 29.4	87.1 **±** 13.5	**0.001**
Bother Index	65.2 ± 26.7	84.7 ± 18.7	**<0.001**
Lower extremity	66.5 ± 31.2	86.4 ± 14.8	**0.001**
ADL	60.4 ± 32.0	86.0 ± 17.3	**<0.001**
Emotion	68.2 ± 20.1	80.2 ± 17.1	**<0.001**
EQ5D**	0.72 **±** 0.277	0.87 ± 0.170	**<0.001**

* Statistically significant results are in bold.; ADL: activities of daily living

** Expressed as mean ± std

DISCUSSION

Elderly patients who sustain a pelvic ring injury are fragile and prone to complications, high rates of mortality as well as physical impairment and decreased quality of life (QoL). This study revealed high mortality rates (up to 41% after 3 years) among the elderly patient with a pelvic ring injury and demonstrated that survival rate decreased as the patient's age and ISS increased and when pelvic fracture type is more severe. Moreover, elderly patients demonstrated a substantially lower level of physical functioning and quality of life 3 years after pelvic ring injury, in comparison to their peers from the general Dutch population.

The mortality rates of elderly people who had sustained a pelvic ring injury were high, namely 10% at the day of the injury, 20% within 30 days, 27% within a year and 41% at 3 years of follow up. Morris et al. reported a comparable one-year mortality rate (8). Although Balogh et al. found a slightly lower one-year mortality rate, it was comparable at 23% (24). With 12.9%, Bible et al. (25) found a lower one-year mortality rate. However, they only included isolated pelvic fractures with posterior ring involvement, whereas our study included all types of pelvic ring injuries. Moreover, the 1-year mortality rates in elderly who sustained a pelvic ring injury (27% in this study) seem comparable with elderly with intertrochanteric or femoral neck fractures (21-23% according to a review of RCTs by Mundi et al.) (26).
The present study demonstrated a significant difference in one-year mortality between the different age groups (65-75, 76-85 and >85 years of age), showing that the patients aged >85 had an increased risk of dying. Moreover, this study showed that the mortality rates of patients with pelvic ring injuries is substantially higher compared to the mortality rates of their age-matched peers from the general Dutch population. This emphasises the fragility of this patient population, although it is interesting to speculate on whether the increased mortality is because of the injury or whether the injury itself is a sign of physical and general systems decline. De Vries et al. showed that elderly patients sustaining a polytrauma have an increased risk of dying compared to younger patients, even though the severity of the injury is comparable (27). Given these numbers, the high impact of a pelvic ring injury in the elderly, with often pre-existing comorbidity, limited rehabilitation capacity and coping mechanisms, should not be underestimated.

In this study, high age at time of injury, type C fractures and ISS were shown to be independent mortality risk factors. A recent study by Verbeek et al. revealed age as the most important independent predictor for in-hospital mortality after any type of pelvic injury (28). Not surprisingly, Forni et al., who evaluated predictive factors for 30-day mortality in geriatric patients with hip fractures, corroborated that advancing age is an independent risk factor for mortality (29). In addition, several studies found older age, increased comorbidity, lower pre-fracture function, and cognitive impairment to be associated with higher three to six month mortality following surgically treated hip fractures as described in an extensive systematic review of the literature over the past decades (30).

Most studies of pelvic ring injuries in the elderly focused on mortality rates, but data about (the recovery of) physical functioning and quality of life of the survivors is hardly available. Schmitz et al. evaluated quality of life in patients aged 60 years and older after pelvic ring injuries and found a significant decrease compared to a reference population (12). However, no data on physical functioning was published. In studies that focused on geriatric hip fractures, outcomes in terms of quality of life and physical functioning were sparsely assessed and consequently no real conclusions could be drawn (30). Our study showed that both the long-term physical functioning as well as quality of life at a mean follow-up of 3.4 years after pelvic ring injury were significantly decreased when compared to the age-matched normative data from the general

Dutch population. This indicates that not only the elderly show signs of fragility in terms of high mortality rates shortly after the injury, long-term effects of the injury may also reduce the patients physical functioning and quality of life. In order to improve the latter, physicians could for instance focus on a multidisciplinary approach, consulting a geriatrician, keeping a close eye on nutritional status and encourage early mobilisation under the direct control of a physiotherapist.

Thirty-one percent of the patients in this study was discharged to a nursing home. This is in concordance with previous research evaluating patients sustaining a pubic rami fracture (7), who were less likely to return to their original place of domicile. Another study by Studer et al. found that 43.4% of the elderly patients with a pubic rami fracture were institutionalized after one year (31). Van Dijk et al. evaluated 99 patients with pelvic ring injuries and concluded that 33% of the patients needed temporary or permanent admission to a nursing home (32). This underlines that decreased physical functioning as a result of the pelvic ring injury has a significant personal as well as societal impact.

This study has a retrospective character and is therefore susceptible to the inherent limitations such as the absence of baseline PROMs concerning the patients' physical health prior to the injury. Moreover, although 73% of the patients in follow-up with questionnaires responded, this is only 35% of the total elderly population in our study due to high mortality rates. Another subject of discussion could be the generalization of the results because of the single centre study design. Yet, to the best of our knowledge, this is one of the few studies that evaluated both mortality and long-term functional outcome of elderly patients with a pelvic ring injury. Most studies on pelvic ring injuries in the elderly focused solely on complication and mortality rates. However, in our study, the patients' own perception with regard to physical functioning and quality of life had a central role. The used patient-reported outcomes measures EQ-5D and SMFA-NL complement each other and are both valid and reliable questionnaires that provide a generalized physical functioning and quality of life outcome score. Moreover, using these PROMs enabled us to compare the results with age-matched normative data from the general Dutch population. Other strengths of this study are the long follow-up period and the comparison of mortality data to that of the general Dutch population.

CONCLUSION

In conclusion, elderly patients with pelvic ring injuries are fragile patients with high risks of mortality and decreased functional outcome compared to their peers from the general population. High age at the time of an accident, severity of the pelvic ring injury (type C) and ISS are all independent mortality risk factors. By highlighting the absolute numbers regarding mortality, physical functioning and quality of life among a large cohort of elderly who sustained a pelvic ring injury, we hope that physicians will be aware of the vulnerability of these patients and pay attention to interventions, like a multidisciplinary approach, optimal nutrition and early mobilization, which may benefit the injured elderly person.

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Chapter 6

What is the long-term clinical outcome after fragility fractures of the pelvis? - a CT based cross sectional study

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ABSTRACT

Background. Recently, Rommens and Hoffman introduced a CT-based classification system for fragility fractures of the pelvis (FFP). Although fracture characteristics have been described, the relationship with clinical outcome is lacking. The purpose of this study was to get insight into the type of treatment and subsequent clinical outcome after all types of FFP.

Methods. A cross-sectional cohort study was performed including all elderly patients (≥65 years) with a CT-diagnosed FFP, between 2007-2019 in two level 1 trauma centers. Data regarding treatment, mortality and clinical outcome was gathered from the electronic patient files. Patients were asked to complete patient-reported outcome measures (PROMs) regarding physical functioning (SMFA) and quality of life (EQ-5D). Additionally, a standardized multidisciplinary treatment algorithm was constructed.

Results. A total of 187 patients were diagnosed with an FFP of whom 117 patients were available for follow-up analysis and 58 patients responded. FFP type I was most common (60%), followed by type II (27%), type III (8%) and type IV (5%). Almost all injuries were treated non-operatively (98%). Mobility at six weeks ranged from 50% (type III) to 80% (type II). Mortality at 1 year was respectively 16% (type I and II), 47% (type III) and 13% (type IV). Physical functioning (SMFA function index) ranged from 62 (type III and IV) to 69 (type II) and was significantly decreased (P = < 0.001) compared to the age-matched general population. Quality of life was also significantly decreased, ranging from 0.26 (type III) to 0.69 (type IV).

Conclusion. FFP type I and II are most common. Treatment is mainly non-operative, resulting in good mobility after six weeks, especially for patients with FFP type I and II. Mortality rates at one year were substantial in all patients. Physical functioning and quality of life was about 20-30% decreased compared to the general population.

INTRODUCTION

Fragility fractures of the pelvis (FFPs) are fractures "caused by an injury that would be insufficient to fracture normal bone" (1), i.e. low-energy traumas. During recent years these low-energy fractures are gaining more attention due to its increased incidence within the growing elderly population. Seventy-three percent of all pelvic ring fractures occur in the elderly (2). Rommens et al. recently introduced a classification system for FFP based on CT imaging of the pelvis (3). It distinguishes different subtypes with increasing degrees of instability ranging from simple type I injuries, defined as isolated anterior pelvic ring fractures, to more complex type IV injuries consisting of bilateral displaced posterior pelvic fractures.

Additional CT imaging for distinction between different fracture subtypes was rarely performed. In line with the extensive work by Rommens et al. (4), more CT scans have been performed and radiological subtypes have been described. Traditionally, FFPs were treated non-operatively. Management goals of FFP may include pain control, early mobilization and bone health assessment, fracture union and personal independence. However, high morbidity and mortality rates may occur after FFPs. Unlike after high-energy traumas, with resultant damage to intrapelvic organs, soft tissues and substantial bleeding, the limited physical condition and coping mechanisms of the elderly influence outcomes. Besides, FFPs are thought to have a major impact on physical functioning and quality of life, as they may lead to pain, immobility and loss of independence (3).

Literature about CT based diagnosis of FFP subtypes, treatment strategies and their clinical and functional outcome is lacking. Moreover, a comprehensive treatment algorithm for these injuries is currently not available. Before subsequent clinical studies will be conducted in this frail patient population, insight is needed on the management of these injuries and the recovery of these patients following these injuries over the last decade. Therefore, the purpose of this study was to evaluate the treatment strategy and clinical outcome in terms of mobility, mortality, physical functioning and quality of life for all types of FFP over the last decade. The study was approved by the local Medical Ethical Review Boards (METc 2016.385 and 2018.181108).

PATIENTS AND METHODS

Participants

A cross-sectional cohort study was performed including all consecutive patients treated for an FFP at two level 1 trauma centers between 2007 and 2019. Included were elderly patients (age ≥ 65 years) after a low-energy trauma who sustained a FFP as diagnosed on a CT-scan. A low-energy trauma is defined as 'a fall below two-to-three times the body length, with an impact less than 20 km/h' (5). Electronic medical records were reviewed in order to collect baseline characteristics. Two senior trauma surgeons reassessed all CT-scans and classified the FFPs according to the Rommens and Hoffman classification (figure 1) (3).

Treatment and outcome

Electronic medical and surgical records were reviewed. For each type of FFP it was recorded whether the patient had non-operative or operative treatment. Non-operative treatment consisted of early mobilization with weight bearing as tolerated or, in a few cases, bed-chair mobilization during the first six weeks in combination with appropriate pain medication. In case operative treatment was performed, surgical techniques were described. The Charlson Comorbidity Index score (CCI) (6) was determined to evaluate the patient's pre-injury physical condition. If a Dual energy X-ray Absorptiometry (DXA) scan was performed to evaluate the bone quality and presence of osteoporosis, the result of this scan was recorded. Medical records from

the time the patient was admitted, as well as records from the outpatient clinic were reviewed to assess time to mobilization, either with or without walking aid. The national population registry was contacted to verify whether patients were still alive at follow-up. For this study, the Short Musculoskeletal Function Assessment (SMFA) was used. The SMFA contains 46 items which are scored on a 5-item Likert scale. Two indices (function and bother) (7) and, additionally, four subscales (upper extremity dysfunction, lower extremity dysfunction, problems with daily activities, and mental and emotional problems) can be calculated (8). Scores are calculated by summing up the individual items and transforming scores on a range from zero to 100, with higher scores indicating better function. Quality of life (QoL) was assessed with the EuroQol-5D (EQ-5D-5L) (9), which screens five health levels (mobility, self-care, daily activities, pain/inconvenience and fear/depression). The five-level version uses 5-item Likert scales per health level, from 1 (no problems) up to 5 (extreme problems, or 'unable to'). Based on the score given for each health level, utility scores can be calculated which range from -0.329 (worst condition) to 1 (best QoL). Both the scores on SMFA and EQ-5D were compared to normative data from the general Dutch population (10,11). Because of the use of reliable and valid outcome measures, no risk of assessment bias was expected. However, due to inevitable loss to follow-up, some transfer bias might have been present. A multidisciplinary treatment algorithm for FFPs will be presented based on our experiences of the last decade and the available literature.

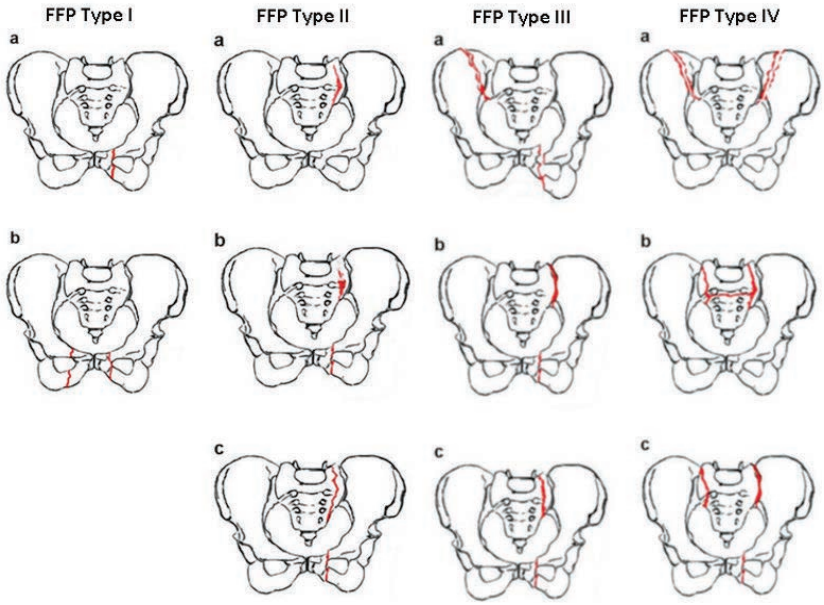

Figure 1. Types I-IV with subtypes (a, b, c) of fragility fractures of the pelvic ring according to Rommens and Hofmann

Statistical Analysis

Descriptive statistics were used to describe the study population, using mean and standard deviation (SD) for normally distributed data and median and interquartile range (IQR) if data were not normally distributed. A pie chart was made to show the distribution of the different types of FFPs. A non-response analysis was performed by using a chi-square test for categorical variables and an independent samples t-test for numeric variables to identify possible differences between the responders and non-responders. Scores on physical functioning and QoL (SMFA and EQ-5D) were compared to the age-matched normative data of the general population using a one-sample T-test with pooled means and SDs. The level of significance was defined at $p < 0.05$. The data were analyzed using IBM SPSS software, version 23.0 for Windows (IBM Corporation, Armonk, NY).

RESULTS

Between March 2007 and 2019, 1009 elderly patients with an FFP were treated. Of these, 781 were excluded because no CT-scan was available, another 38 were excluded because of concomitant acetabular fractures, and three more because of pathological fractures, leaving 187 patients with an FFP as diagnosed on a CT-scan available for follow-up analysis. Figure 2 shows the distribution of the different types of FFPs in our study population. Median follow-up of the 187 patients was four (IQR 2-7) years, of which 70 patients had deceased at a median of four years (IQR 2-6) after the injury. As a result, 117 patients with a median of three years (IQR 2-6) after the injury were available for follow-up with patient-reported outcome measures (PROMs). These patients were contacted and asked to complete two questionnaires, of which 58 patients (response rate 50%) responded after a median follow-up of two (IQR 1-4) years. The non-response analysis showed no differences between responders and non-responders in age, sex, fracture type and follow-up duration.

FFP type I

All patients with FFP type I (N=112) were treated non-operatively. In 32 of these patients (29%) a DXA scan was performed, all showing osteoporosis (66%) or osteopenia (34%). Seventy-seven patients (70%) were able to walk within six weeks, three patients between six weeks and three months after being restricted to only mobilize bed-chair in the first six weeks, one patient was not able to walk within six weeks, one other patient had died within six weeks. In 30 patients, the mobility status was unknown because these patients were not admitted or no further follow-up in the outpatient clinic was performed. Forty out of 112 patients (36%) had died at a median follow-up of 9 (IQR 6-10) years after the injury. No patients died during hospital admission as a direct result of the pelvic ring injury. One 100-year-old patient died in-hospital 6 days after the injury as result of a thorax trauma. Two patients died after respectively six months and two years as a result of cardiac failure and three patients after respectively two, seven and ten months because of cancer. In the other cases, causes of death were unknown. Thirty-two patients with FFP type I filled in the PROMs (median follow-up of 2 (IQR 1-3) years). Scores on the SMFA and EQ-5D-5L are given in table 2. Patients reported a mean decrease of 20% on the SMFA compared to normative data from the general population. Also, EQ-5D score was significantly decreased with an average of 27%. The distribution of the different types of FFPs are shown in figure 2 and baseline characteristics are presented in table 1.

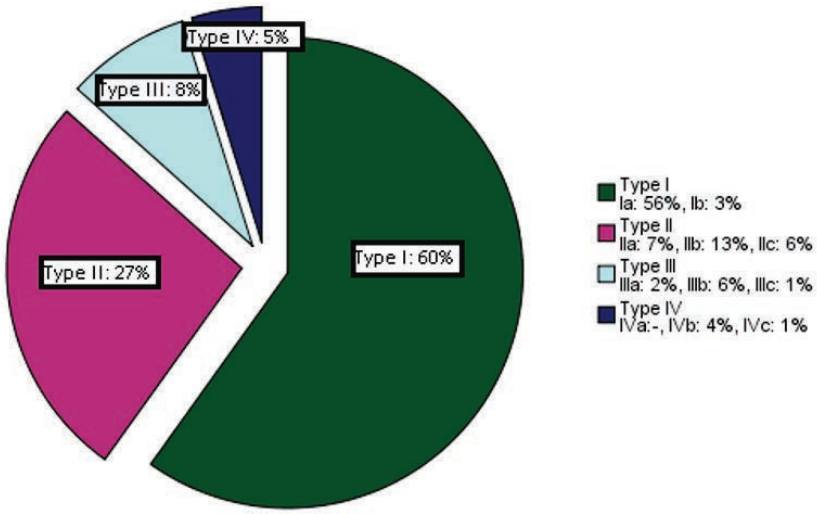

Figure 2. FFPs divided by Rommens and Hofmann subclassification (18)

Table 1: Baseline characteristics

	FFP I (N=112)	FFP II (N=50)	FFP III (N=16)	FFP IV (N=9)	All patients (N=187)
Male	76 (68)	38 (76)	13 (81)	6 (67)	128 (68)
Age at the time of injury median (IQR)	81 (74-86)	78 (69-84)	81 (77-87)	76 (71-89)	79 (73-86)
CCI* median (IQR)	5 (4-7)	5 (4-7)	5 (4-7)	5 (4-5)	5 (4-7)
Time to presentation in days median (IQR)	0 (0-0)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)
ISS median (IQR)	5 (4-9)	9 (4-13)	4 (4-7)	9 (6-9)	5 (4-9)
DXA performed	32 (29)	13 (26)	4 (25)	1 (11)	50 (27)
Osteoporosis or osteopenia	32 (100)	11 (85)	4 (100)	1 (100)	48 (96)
Treatment					
Non-operative	112 (100)	46 (92)	16 (100)	9 (100)	183 (98)
Operative	-	4 (8)	-	-	4 (2)
Walking <6 weeks	77 (70)	40 (80)	8 (50)	5 (56)	130 (70)
FU in years median (IQR)	2 (1-3)	2 (1-4)	4 (1-4)	4 (1-4)	2 (1-4)
Deceased	40 (36)	13 (26)	11 (69)	3 (33)	70 (37)
<30 days	3 (3)	2 (4)	2 (13)	-	7 (4)
Deceased < 3 months	5 (5)	5 (10)	4 (25)	-	14 (8)
Deceased <1 year	18 (16)	8 (16)	7 (44)	1 (11)	34 (18)
Deceased <5 years	34 (30)	10 (20)	8 (50)	3 (33)	55 (30)

Numbers are expressed in N with the percentage in parentheses unless otherwise specified.
* CCI; Charlson Comorbidity Index Score, total scores ranging from 0-37 with higher scores indication a cumulative increased likelihood of one-year mortality

Table 2: scores on SMFA and EQ-5D per FFP type

	Type I (N=32)	Type II (N=19)	Tye III (N=3)	Tye IV (N=4)	Total study population	General population	Type I vs. general population	Type II vs. General population
SMFA								
Function index	68 (21)	69 (21)	62 (11)	62 (21)	68 (20)	87 (14)	**<0.001**	**0.001**
Bother index	70 (22)	67 (22)	53 (6)	60 (22)	68 (21)	85 (19)	**0.001**	**0.003**
Lower extremity dysfunction	69 (22)	71 (22)	60 (18)	61 (23)	69 (22)	86 (15)	**<0.001**	**0.006**
Problems with daily activities	62 (24)	63 (24)	48 (11)	56 (26)	61 (23)	86 (17)	**<0.001**	**0.001**
Mental and emotional problems	74 (19)	70 (19)	66 (5)	62 (15)	71 (19)	80 (17)	0.09	**0.03**
EQ-5D-5L	0.60 (0.32)	0.65 (0.29)	0.26 (0.36)	0.69 (0.29	0.61 (0.31)	0.87 (0.17)	**<0.001**	**0.004**

Data are given as mean (SD).

FFP type II

Four out of 50 (8%) patients with FFP type II were treated operatively. Three patients (FFP type IIc) underwent examination under anesthesia (EUA) to test instability of the pelvis. All three showed rotational instability. The first was treated with an external fixator and an SI screw. The

second was treated with an SI screw and pubic symphysis plate. The third patient got two SI screws. The last patient (FFP type IIb) presented at the day of the injury and was initially treated non-operatively. She dealt with persisting pain sixteen months after the injury. Because imaging showed non-union of the pubic bones, the patient was eventually treated with a pubic symphysis plate. All operatively treated patients recovered uneventfully. A DXA scan was performed in 13 out of 50 patients (26%) showing osteoporosis in six patients (47%), osteopenia in five patients (38%) and normal bone in two patients (15%), respectively. Forty out of 50 patients (80%) were able to walk within six weeks, four between six weeks and three months after being restricted to only mobilize bed-chair in the first six weeks, one patient had died within six weeks and of five patients no information on mobility was available. Thirteen patients (26%) had died at a median follow-up of nine (IQR 6-10) years. No patients died during hospital admission as a direct result of the injury. One patient died after 12 days because of cancer and one after three months because of a septic shock possibly due to intestinal ischemia. In the other cases, causes of death were unknown. Nineteen patients with FFP type I responded to the PROMs (median follow-up of two (IQR 1-3) years). They reported a mean decrease of 20% on the SMFA and EQ-5D scores compared to normative data from the general population (Table 2).

FFP type III

All 16 patients with FFP type III were treated non-operatively. A DXA scan was performed in four of them (25%) all showing osteoporosis. Eight out of 16 patients (50%%) were able to walk within six weeks, one between six weeks and three months after being restricted to only mobilize bed-chair in the first six weeks, one patient was not able to walk at the last follow-up visit seven weeks after the injury, two patients had died within six weeks and of four patients no information on mobility was available. Eleven patients (69%) had died at a median follow-up of nine (IQR 6-10) years. No patients died during hospital admission as a direct result of the pelvic ring injury. Causes of death after years were unknown in all of the cases. Only five patients were available for follow-up analysis of which three responded. This number was considered too low for comparison with normative data in terms of physical functioning and quality of life.

FFP type IV

All nine patients with FFP type IV had been treated non-operatively. One DXA scan was performed showing osteopenia. Five out of nine patients (56%) were able to walk within six weeks, one within three months after being restricted to only mobilize bed-chair in the first six weeks and of three patients no information on mobility was available. Three out of nine patients had died at a median follow-up of nine (IQR 6-10) years. None of these patients died during hospital admission as a direct result of the pelvic ring injury. One patient died after five months because of cancer, in the other cases, causes of death were unknown. Six patients were available for follow-up of which four responded. Similar to FFP type III, the total number of FFP type IV was considered too low for comparison with normative data in terms of physical functioning and quality of life. More details of the patients with FFP type III and IV are presented in supplementary file 1 and 2.

Treatment algorithm

Based on our experiences in the treatment of FFPs during the last decade and the work presented by Rommens et al. among others (4,12), a treatment algorithm for the management of FFPs was constructed (figure 3).

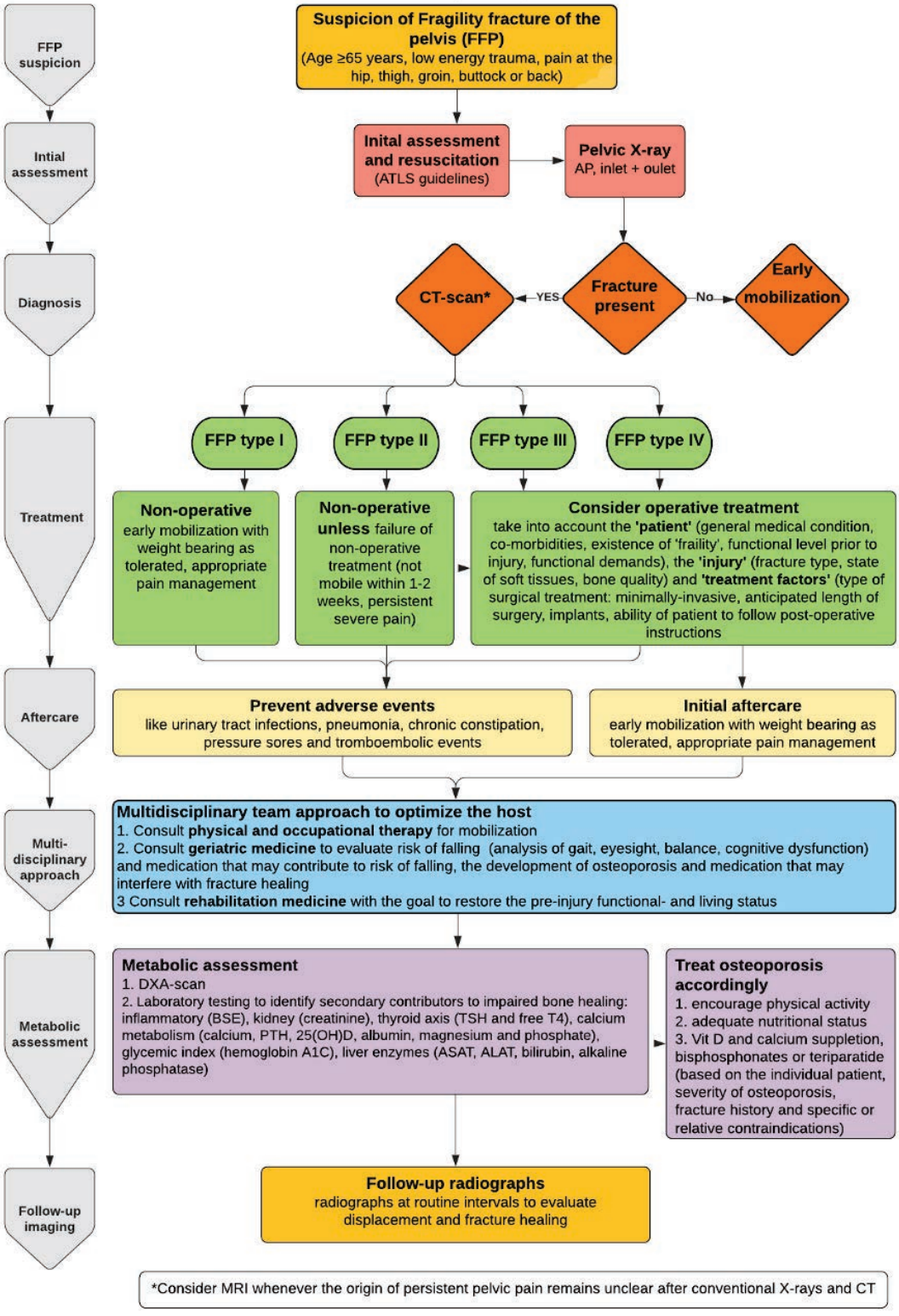

Figure 3. Proposed treatment algorithm of FFP diagnosis and treatment

DISCUSSION

This study evaluated the clinical outcomes in a large cohort of elderly patients who sustained an FFP in the last decade. Insights were gained on CT-based subtypes I-IV with regards to the choice of treatment, mobility, mortality, as well as long-term physical functioning and quality of life. In our cohort FFP type I was most common (60%), followed by type II (27%). Type III (8%) and IV (5%) were rare. Almost all FFPs in this cohort were treated non-operatively. After non-operative treatment, 70-80% of patients with FFP type I and II were able to walk within six weeks compared to only about 50% of patients with FFP type III of IV. Mortality rates were high with 18% at one year increasing up to 30% at five years after the injury. At a median follow-up of two years, patients with FFP type I and II dealt with a decrease of at least 20% in physical functioning and QoL when compared to the age-matched peers from the general population. A treatment algorithm is presented for the management of FFPs. It is based on our experiences and the recent literature.

A limitation of this study was that all patients without a CT scan were excluded from our study population. A CT scan is mandatory for an accurate (sub)classification of FFPs, especially regarding the detection of concomitant posterior ring fractures (4). No valid classification of FFPs can be performed based on only conventional radiographs. Research has shown that in patients presenting with only a pubic fracture on the pelvic radiograph, 54-98% also had an additional fracture of the posterior pelvic ring after obtaining a CT scan of the pelvis (13–16). Traditionally, standard CT evaluation for elderly with low-energy pelvic ring injuries was not common practice. Out of 1007 elderly patients treated for an FFP in our practice over the last decade, 14% of patients had a CT between 2007-2011, 18% between 2012-2016 and 33% between 2017 and 2020. This is in line with the new insights about FFP injury based on the extensive work of Rommens et al. in which CT analysis is recommended for elderly with low energy pelvic ring fractures (3,4,13,17). However, it should be noted that the FFP classification has displayed moderate and substantial intra-rater and inter-rater reliabilities (18), which could have its influence on the distribution and subsequent interpretation of the different types of FFP in our study. Additionally, the absence of baseline measurements of physical functioning and quality of life might be another limitation inherent to the retrospective study design, which leaves us guessing to what extent the decreased physical functioning and quality of life was pre-existent or should be attributed to the injury itself. To the best of our knowledge, this is the only study in which CT-based classification of FFPs subtypes has been related to clinical outcome. However, due to low incidence of FFP type III and IV, substantial mortality rates and low response rate, which is inherent to a fragile elderly population, no comparison to normative data could be made for these injuries, even though this study included FFPs of two level-1 trauma centers over a period of 13 years.

All patients with isolated anterior pelvic ring fractures (FFP type I) were treated non-operatively, which reflects current recommendations (4) and is in line with a recent study by Rommens et al. who evaluated 138 patients with FFP type I of which 98.6% was treated non-operatively (19). Most patients (70%) in our study were able to walk within six weeks post injury, but some required a walking aid either temporarily or permanently. This is similar to the study by Rommens with 75% of patients being mobile at discharge (19), but in contrast to a study by Yoshida et al. who found that only 34% maintained gait ability at one year as measured by the Majeed score (20). All patients from whom a DXA was available had osteoporosis or osteopenia. Therefore, accurate diagnosis and subsequent treatment for (secondary causes of) osteoporosis is important in the follow-up of these patients. The mortality rate at one year was 16%, which is in line with previous studies that reported

1-year rates between 13 and 19% (19,21,22). Five-year mortality was as high as 30%, similar to the 30% found by Rommens (19), but lower than the 54% reported by Hill et al. (21). For the patients that did survive, (long-term) effects on physical functioning and quality of life are expected as these injuries may lead to muscle atrophy due to immobility and loss of independence. However, it is relatively unknown to what extent (3,23,24). Quality of life as measured by the EQ-5D was 0.60, comparable to the 0.62 found by Rommens et al. (19). This translates into a 27% decrease compared to normative data. Besides, physical functioning was decreased with 20%.

Of the patients with FFP type II, four out of 50 (8%) were treated operatively. The indication for operative treatment included instability during EUA in three cases and persisting pain in one case. Since EUA was initially intended for assessment of stability in high-energy injuries, its role in assessment of stability of low-energy FFPs is still unknown (25). Similar to our study, Studer et al. who evaluated a cohort of 132 elderly patients >65 years with low-energy pelvic fractures of which 53% received a CT-scan, found that only 4% of patients initially being treated non-operatively needed operative treatment due to persisting pain (22). However, there is still an ongoing debate whether operative treatment might be indicated for pain relief and early mobilization in some FFP II cases. Similar to FFP type I, most patients (80%) were able to walk within six weeks after the injury. Yoshida et al. found that only 42% of patients maintained gait ability one year after FFP type II (20). Mortality at one year was 16% in our study, similar to the 14-17% reported previously (26–28). Physical functioning and QoL were decreased by an average of 20%. No other studies assessed physical functioning and quality of life after CT-diagnosed FFP type II. Studer et al. reported a 30% loss of independence, and only 56% of patients were living in their own home at one year after the injury (22). Moreover, they did not distinguish between different subtypes of FFP.

The occurrence of FFP type III and IV was rare (respectively 16 and 9 out of 187 patients). All patients were treated non-operatively over the past decade (supplementary file 1 and 2). This is not completely in line with the recently proposed guideline of Rommens et al. which suggests to consider operative treatment of patients with FFP type III and IV (13). Advocates of operative treatment pose pain relief, early mobilization (29,30) and better long-term survival as arguments to proceed to surgery (30). However, there is a high risk of implant loosening due to osteoporosis, wound healing problems, as well as high rates of perioperative complications and morbidity (31) that should be considered before proceeding to operative treatment in a fragile elderly population. Wagner et al. described the lack of clinical evidence for operative treatment (32). Hence, treatment should be individually adapted to fracture morphology, pain level, comorbidities, pre-traumatic level of functioning and, more importantly, the patient's preference. In our study, half of patients with FFP type III and IV were able to walk within six weeks. This rate is higher than the results found by Yoshida et al. with a mobility rate of 41% (type III) and 24% (type IV) one year after the injury (20). Mortality rates <30 days of patients with FFP type III was 13%, and 25% of patients had died within three months. Rapp et al. suggested that, due to complications, pain and immobilization, the majority of deaths occur during hospitalization and within the first three months (33). The mortality rate at one year was respectively 44% (FFP III) and 11% (FFP IV) in our cohort. Physical functioning and quality of life seemed decreased but results could not be compared to normative data due to the low numbers of these types of FFP. No other CT-based studies reported on mortality, physical functioning and quality of life after non-operatively treated FFP type III and IV.
Overall, our cross-sectional study showed that patient care of FFPs was partially lacking from regular CT evaluation, standardized clinical decision-making and a multidisciplinary approach over the past decade (supplementary file 1), even though literature on patients with hip fractures, a comparable injury, has conclusively shown that systematized care with medical co-management and an organized care pathway seems to improve outcome (4). From that perspective, we proposed a

treatment algorithm for the management of FFPs. This algorithm is based on our own experiences and the new insights provided by Rommens and Hofmann (4) and may guide clinicians to structure the care of these fragile patients.

CONCLUSION

Most patients with a fragility fracture present with FFP type I or II injuries. Management of FFPs over the last decade was mainly non-operative. After non-operative treatment, the mobility at six weeks was good in patients with FFP type I and II, but less so in patients with FFP type III and IV. Mortality rates at one and five years were high for all FFP subtypes. Physical functioning and quality of life was about 20-30% decreased in patients with FFP type I and II compared to the general population. By increasing the awareness of FFP subtypes and by highlighting the importance of a standardized multidisciplinary approach, as proposed in our treatment algorithm, we hope this condition will be diagnosed and treated optimally. In line with our study, future prospective studies with validated baseline as well as follow-up patient-reported outcome measurements are mandatory. Recently initiated prospective studies may elucidate which patients may benefit from early operative treatment in terms of clinical outcome and long-term survival and which patients are better off treated non-operatively.

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SUPPLEMENTARY FILE 1. Clinical course of patients with FFP type III and IV treated non-operatively

Case*	Age at time of injury	Trauma mecha-nism	Time to presen-tation (days)	Comor-bidities	DXA	Clinical presen-tation at six weeks	Time to union	Multi-disciplin-ary treat-ment	Days ad-mitted (dis-charge location)	Time to death**
FFP type III										
1	89	Domestic fall	<1	-	Yes, osteoporosis	Moderate pain. Mobilizing with walker similar to pre-injury	No follow-up	Physiotherapy	12 (nursing home)	1 year
2	83	Domestic fall	< 1	Cardiovascular disease, Alzheimer	-	Deceased < 6 weeks	Deceased < 6 weeks	Physiotherapy	16 (back to nursing home)	23 days
3	77	Domestic fall	<1	End stage cardiovascular disease, chronic renal failure	-	Deceased <6 weeks	Deceased <6 weeks	Physiotherapy	4 (nursing home)	16 days
4	79	Domestic fall	<1	RA, COPD, hypertension	-	No pain. Mobilizing with walker	Last X-ray after 18 months: fracture healing	-	1 (home)	8 years
5	82	Domestic fall	<1	Hypertension		Moderate pain. Mobilizing similar to pre-injury condition	Last X-ray after 15 months: complete union	Physiotherapy, risk of falling evaluation	9 (nursing home)	Alive after 3 years
6	67	Fall after epileptic insult	4	Hypertension, DM	Yes, osteoporosis	Moderate pain. Mobilizing without aid.	Last X-ray after 18 months: fracture healing	-	1 (back to nursing home)	Alive after 9 years

7	90	Domestic fall	<1	Hypertension, Alzheimer	-	No follow-up	No follow-up	-	1 (back to nursing home)	6 months
8	95	Domestic fall	<1	Dementia, cardiac failure, PMR	-	No follow-up	No follow-up	Physiotherapy	14 (nursing home)	4 months
9	80	Domestic fall	<1	Hypertension	-	Deceased <6 weeks	No follow-up	-	1 (back to nursing home)	39 days
10	86	Fall from bicycle	<1	Hypertension	Yes, osteoporosis	Moderate pain, walking with aid	Last X-ray after 3 months: fracture healing	-	1 (home)	2 years
11	87	Domestic fall	<1	Cardiovascular disease	-	Six weeks bed-chair, no follow-up after	Last X-ray after 3 months: fracture healing	Physiotherapy	6 (home)	2 years
12	74	Domestic fall	<1	DM, cardiovascular disease, COPD	-	In hospital transfer bed-chair. No follow-up.	No follow-up	Physiotherapy	21 (nursing home)	2 months
13	78	Domestic fall	<1	Cardiovascular disease, DM, COPD, CVA	-	No pain. Walking inside with aid, outside mobility scooter	Last X-ray after 1 month: no fracture healing	Geriatric medicine	14 (nursing home)	Alive after 1 year

14	78	Fall on ice	<1	Hypertension	Yes, osteopenia	Presenting with non-union 8 months after the injury. Immobile. Severe pain.	Last CT after 22 months: non-union pubic fractures, sacral fracture healed	lab, neurology, internal medicine, osteoporotic screening	1 (home)	Alive after 3 years
15	83	Domestic fall	28	-	-	Moderate pain. Mobilizing without aid.	Last X-ray after two months: fracture healing	-	1 (back to nursing home)	2 years
16	72	Domestic fall	<1	Rheumatoid arthritis	Yes, osteoporosis	Persisting pain. Mobilizing with aid.	Last X-ray after two years: increased callus formation	Rheumatolo-gist, endocriniolo-gist	1 (home)	Alive after 2 years
FFP type IV										
17	76	Fall from small ladder	<1	Hypertension, cardiovascular disease	-	No pain. Mobilizing now and then with walker	No follow-up X-ray	Geriatric medicine	unknown	Alive after 8 years
18	70	Fall from small ladder	<1	None	-	No pain. Mobilizing without walking aids	Last X-ray after 2 months: fracture healing	Physiotherapy	unknown	Alive after 9 years
19	89	Domestic fall	<1	None	-	No follow-up	No follow-up X-ray	Internal medicine, physiotherapy, geriatric medicine, occupational therapy	10 (back to nursing home)	1 year

20	71	Domestic fall	<1	RA, osteoporotic fracture Th10	-	No follow-up	No follow-up X-ray	Physiotherapy	10 (nursing home)	Alive after 2 years
21	88	Domestic fall	1	-	-	Moderate pain. Mobilizing with aid similar to pre-injury	Last X-ray after 3 months, no complete union	-	1 (nursing home)	3 years
22	76	Domestic fall	<1	Cardiovascular disease	-	In-hospital bed-chair. No follow-up	No follow-up X-ray	Physiotherapy	13 (nursing home)	Alive after 5 years
23	78	Domestic fall	34	DM, PMR	-	No follow-up	No follow-up X-ray	Neurology, neurosurgery (immobile, incontinent), rehabilitation medicine, geriatric medicine, orthopedics	43 (rehabilita- tion center)	Alive after 5 years
24	89	Domestic fall	<1	-	-	No follow-up	No follow-up X-ray	Unknown, no documenta- tion	Unknown	Alive after 3 years
25	65	Domestic fall	180	Parkinsons disease	Yes, osteopenia	-	Last X-ray after 20 months, increased callus formation	Labs, neurology	Not admitted	Alive after 2 years

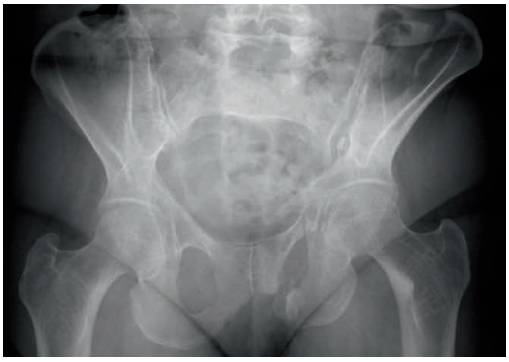
* All patients were treated non-operatively
** Death was not related to the trauma in any of the cases

SUPPLEMENTARY FILE 2. case examples

Case 1: 72-years-old women with an FFP type IIIa, using methotrexate (MTx) for rheumatoid arthritis

• 72-year old patient
• History of osteoporosis and rheumatoid arthritis for which she uses methotrexate
• Injury mechanism: domestic fall
• Presentation: same day in a regional hospital
• Imaging: X-ray: no pelvic ring injury
• Pre-injury PROMs: EQ-5D 1,00. SMFA 91 (function), 94 (bother), 94 (lower-extremity), 84 (emotion), 94 (ADL)

• + 2 months
• Clinically: persisting pain in left hip
• Imaging: X-ray: left pubic rami fractures. Multidisciplinary: consultation oncologist, malignancy ruled out based on MRI
• Treatment: non-operative



• + 3-7 months
• Increased displacement of an occult fracture in the left hemipelvis

• + 11 months: first presentation at our outpatient clinic
• Clinically: still painful in the left hip, but able to walk 30 minutes with a cane.
• Medication: paracetamol, NSAID and MTx.
• Physical examination: painful palpation of the left pubic bones, no sacral pain.
• Imaging: X-ray and CT-scan: non-union of the FFP (type IIIa).
• Multidisciplinary approach: consultation rheumatologist and stop using MTx. Geriatric medicine: start teriparatide, Physical therapist: early mobilization

• Treatment: the initial plan was an operative treatment plan. However, the pain decreased and she was able to mobilize without a cane after she stopped using MTx and started using teriparatide. Therefore, she eventually decided for non-operative treatment.
• PROMs 1 year: EQ-5D: 0,656. SMFA: 51 (function), 50 (bother), 42 (lower-extremity), 69 (emotion), 38 (ADL).

• + 14 months
• Clinically: able to walk two times a day for 30 min without a cane and no pain.
• Physical examination: slight pain with palpation of the left pubic bones and left sacral area.

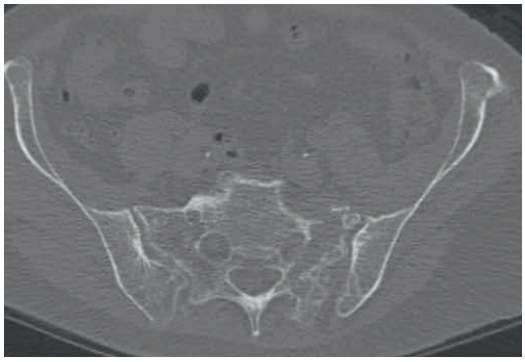
• + 2 years
• Clinically: is able to walk a whole day without a cane and no pain (NRS 0). She is using a sole in the left shoe.
• Imaging: X-rays: no further displacement and some callus formation at the fracture site
• PROMs 2 years: EQ-5D: 1,00. SMFA: 81 (function) 83 (bother), 85 (lower-extremity), 75 (emotion), 77 (ADL).

• + 1,5 years
• Clinically: able to walk 30 min to 1 hour
• Medication: re-started MTx due to pain in the upper extremity related to rheumatoid arthritis.
• Physical examination: no pelvic pain
• Imaging: X-ray and CT-scan: some callus formation at the fracture site

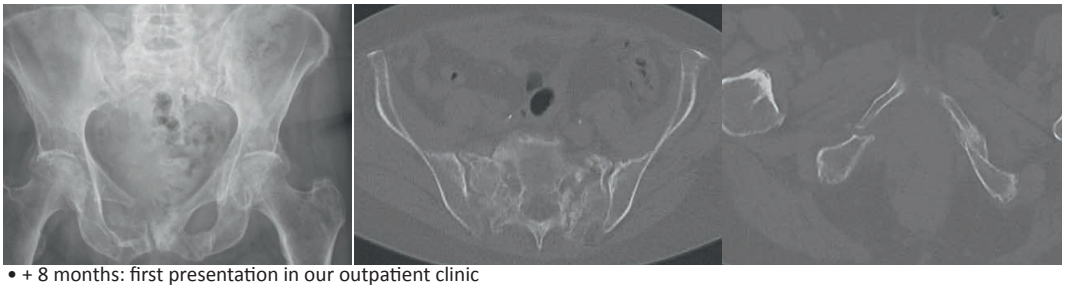
Key points
• An FFP might be hardly detectable on the initial x-ray and then secondarily displace
• A multidisciplinary approach is mandatory
• Optimize the host
• Stop medication that may interfere with fracture healing (e.g. MTx)
• Treat osteoporosis (e.g. teriparatide)

Case 2. 78-years-old women with an FFP type IVc, treated non-operatively

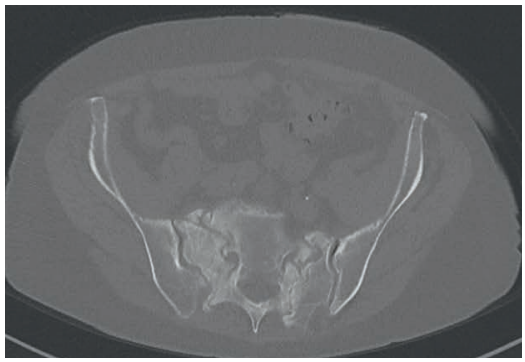
• 78-years-old patient
• Past medical history: hypertension, osteoporosis
• Injury mechanism: fall on ice
• Presentation: regional hospital the same day
• Imaging: X-ray and CT left hip, no hip fracture, bilateral non-displaced pubic rami fractures
• Treatment: non-operative treatment
• PROMs pre-injury: EQ-5D: 1,00. SMFA 95 (function), 96 (bother), 100 (lower-extremity), 81 (emotion), 96 (ADL)



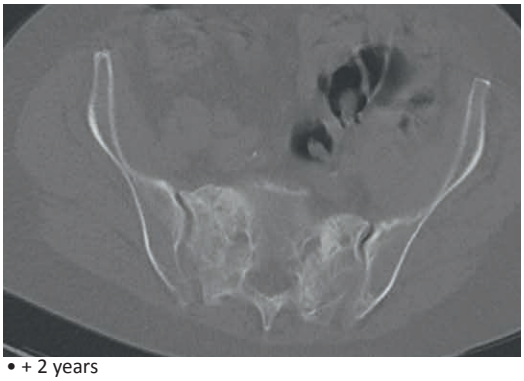
• + 3 months: persisting pain at the lower back and buttocks.
• CT-imaging: non-union of bilateral pubic rami and sacral fractures (FFP IIIc)

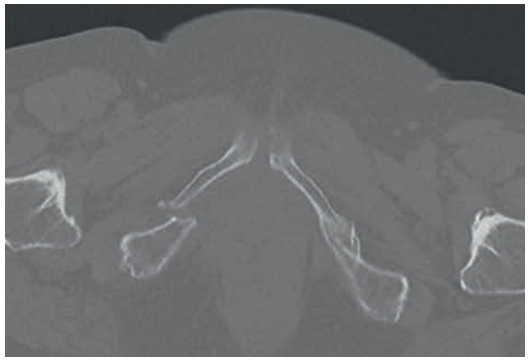


• + 8 months: first presentation in our outpatient clinic
• Clinically: most of the time sitting in a wheelchair, able to walk short distances with a walker at home, pain in the lower back (NRS 8).
• Physical examination: pain in the right groin and lower back
• X-ray and CT-imaging: bilateral non-union of the sacrum and pubic rami (FFP IVc).
• Multidisciplinary approach: consultation geriatric medicine: lab screening, treat osteoporosis (DXA) with alendronate, fall prevention. Consultation neurologist and physical therapist.
• Treatment: our initial plan was to perform operative treatment for the FFP. However, while she was on the waiting list, she was admitted to a regional hospital with perforated diverticulitis. The FFP was treated non-operative.
• PROMs at 1 year: EQ-5D: 0,787. SMFA: 58 (function), 54 (bother), 60 (lower extremity), 50 (emotion), 45 (ADL)



• + 14 months
• Clinically: after bedrest and an abdominal operation, the patient recovered from the diverticulitis. She visited our outpatient clinic and was able to walk 1 km with a walker and without any pain.
• Treatment: continue non-operative treatment





• + 2 years
• Clinically: only slight lower back pain, able to walk short distances without walking aids.
• Physical examination: walks carefully, small steps, a bit unbalanced.
• Imaging: CT: healing of sacral and right pubic rami fractures, persisting non-union of the right pubic bones. MRI: no nerve root compression or other abnormalities.
• Treatment: multidisciplinary approach with consultation of rehabilitation medicine and physical therapist.

• + 3 years
• Clinically: successful rehabilitation course, no pain, able to walk 45 min with a walker, climbing stairs, doing the complete household.
• X-ray: increased callus formation
• Treatment: continue non-operative treatment.

Key points
• Clinical presentation may vary (e.g. pain hip, groin, back, buttocks)
• Delay in treatment occurs regularly
• Consider early CT imaging for FFP fracture classification and making treatment decisions
• Multidisciplinary approach is mandatory
• Non-operative treatment of FFP IV injuries is possible (depending on patient, injury and treatment factors)

Chapter 7

Are sarcopenia and myosteatosis related to decreased physical functioning and QoL in elderly patients with a pelvic ring injury?

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ABSTRACT

Background. The purpose of this study was to evaluate the prevalence of sarcopenia and/or myosteatosis in elderly patients with pelvic ring injuries and their influence on mortality, patient-perceived physical functioning and quality of life (QoL).

Methods. A multicenter retrospective cohort study was conducted including elderly patients aged ≥65 treated for a pelvic ring injury. Cross-sectional computed tomography (CT) muscle measurements were obtained to determine the presence of sarcopenia and/or myosteatosis. Kaplan-Meier analysis was used for survival analysis, and Cox proportional hazards regression analysis to determine risk factors for mortality. Patient-reported outcome measures for physical functioning (SMFA) and QoL (EQ-5D) were used. Multivariable linear regression analyses were used to determine the effect of sarcopenia and myosteatosis on patient-perceived physical functioning and QoL.

Results. Data to determine sarcopenia and myosteatosis was available for 199 patients with a mean follow-up of 2.4±2.2 years. Sixty-six patients (33%) were diagnosed with sarcopenia and 65 (32%) with myosteatosis; 30 of them (15%) had both. Mortality rates in patients at 1 and 3 years without sarcopenia and myosteatosis were 13% and 21% compared to 11% and 36% in patients with sarcopenia, 17% and 31% in patients with myosteatosis, and 27 and 43% in patients with both. Higher age at the time of injury and a higher Charlson Comorbidity Index (CCI) were independent risk factors for mortality. Mental and emotional problems were increased in patients with sarcopenia.

Conclusion. About half of elderly patients with a pelvic ring injury has sarcopenia and/or myosteatosis. Mortality rates at 3 years of follow-up were increased in patients with sarcopenia. Patient-reported mental and emotional problems were significantly increased in patients with sarcopenia.

INTRODUCTION

Pelvic ring injuries in frail elderly patients are a growing health concern as the population ages. One third of all injuries and 73% of all pelvic ring injuries occur in the elderly (1). Changes in body composition take place with age. Frailty, known as aging-related physiological decline, is characterized by vulnerability to adverse health outcomes. A surrogate measure of frailty is the gradual decline in skeletal muscle mass and strength (sarcopenia), which can act synergistically with an increase in intermuscular and intramuscular fat (myosteatosis). The exact mechanisms of sarcopenia and myosteatosis are still unknown, but both have been associated with aging and inactivity. It is estimated that up to 25% of persons under age 70 and over 50% of those 80 or older have sarcopenia (2). Due to the rapidly expanding aging population, it is roughly estimated that sarcopenia will affect over 200 million people worldwide in the next 30 years (3).

Numerous studies have described the harmful health effects of sarcopenia and myosteatosis. Sarcopenia increases the likelihood of falls and injuries (4,5) and could therefore be considered a potential complementary predictive value for fracture risk (6). Sarcopenia is also associated with increased rates of osteoporosis, morbidity and mortality (6–8). Pelvic ring injuries are likewise known for their high mortality rates, which are estimated at 15% (9). In the elderly, mortality can even rise up to 27% at 1 year (10). It has been shown that patients suffering from pelvic ring injuries deal with decreased patient-reported physical functioning and quality of life (QoL) (10,11). Sarcopenia and myosteatosis are seen as important determinants of physical functioning and QoL. The loss of skeletal muscle mass directly contributes to exercise intolerance, impaired ability to perform activities of daily living and loss of independence (3,5,12). Still, the use of sarcopenia and myosteatosis as measures for frailty in musculoskeletal-related literature is sparse and little is known about the prevalence, mortality and effect on patient-perceived physical functioning and QoL in patients with pelvic ring injuries.

The aim of this study was to assess the prevalence of sarcopenia and myosteatosis in patients with pelvic ring injuries. We subsequently evaluated the association between the presence of sarcopenia and/or myosteatosis in patients with pelvic ring injuries and mortality, physical functioning and QoL.

MATERIALS AND METHODS

Patients

A retrospective cohort study was conducted including all patients aged 65 or older and treated for a pelvic ring injury at the trauma surgery departments of two level-1 trauma centers in the Netherlands between 2007 and 2020 (UMCG Groningen and Isala Hospital Zwolle). Inclusion criteria were patients aged ≥ 65, a CT scan at the time of injury including the fourth lumbar vertebra (L4) and available data on patients' height. Exclusion criteria were patients unable to read Dutch, severe mental disabilities and traumatic brain injury with neurological symptoms. The UMCG Medical Ethics Review Board assessed the methods employed and waived further need for approval (METc 2016.385 and METc 2017.543).

Data acquisition

Data of patients treated for a pelvic ring injury between 2007 and 2016 were gathered retrospectively, while from 2017 onwards, data were collected prospectively. Demographic data and information related to the injury and treatment were extracted from patients' medical and surgical records. Body mass index (BMI) classification was based on the World Health Organization (WHO) definitions (13): for adults, overweight is defined as BMI ≥ 25 and obesity as BMI ≥ 30. Injury mechanisms were divided into low-energy trauma or high-energy trauma. Low-energy

trauma is defined as a fall below two to three times the body height. High-energy trauma can be a fall above two to three times the body height, compression injuries, crush injuries or injuries from traffic accidents (14). The Injury Severity Score (ISS) (15) was retrieved from the Dutch Trauma Registry. The ISS provides information about mortality, morbidity and other measures of severity, and can range from 1 to 75. An ISS score ≥ 16 indicates that a patient is severely injured. Subsequently, two trauma surgeons with ample experience in pelvic injury surgery reassessed the radiographic images (plain anteroposterior, inlet and outlet radiographs and CT scans) of all the patients and classified the pelvic ring injuries into type A, B and C injuries according to the AO/OTA trauma pelvis manual (16). Operative treatment consisted of anatomical reduction and fixation of the pelvis. Non-operative treatment of pelvic ring injuries consisted of early mobilization with weight-bearing as tolerated in combination with appropriate pain medication. The patient's comorbid conditions were classified according to the Charlson Comorbidity Index (CCI) (17). Complications that occurred within 30 days were extracted from the medical charts and reviewed.

Muscle imaging

CT imaging was performed on all patients shortly after arrival at the hospital on a Siemens SOMATOM Definition (AS, Edge, Flash), Force or Sensation (Siemens Medical, Erlangen, Germany) scanner. Slice thickness varied between 0.5 and 5 mm. CT slices were acquired with a 512 × 512 matrix and, after anonymization, stored in DICOM format for further processing. All CT scans were reassessed, and the CT slice, at the level of L4 where both transverse processes were best shown, was selected for each patient. Cross-sectional muscle measurements were obtained at this level. Image analysis was performed blinded by a radiologist with ample experience. The muscles assessed for measurements of sarcopenia and myosteatosis consisted of the psoas major and abdominal wall, including the erector spinae, quadratus lumborum, transversus abdominis, obliquus internus, obliquus externus and rectus abdominis (Figures 1 and 2). In-house developed software (SarcoMeas 0.34; UMCG, Groningen, The Netherlands) was used to assess skeletal muscle mass, in order to determine the presence of sarcopenia and myosteatosis (Figures 1 and 2). This software allows for manual delineation of the area of interest with semiautomatic assessment of skeletal muscle area based on tissue attenuation. According to the standard of Mitsiopoulos et al., muscle voxels were defined within the drawn contours by selecting all voxels with a radiodensity between −29 and +150 Hounsfield units (HU) (18). The obtained cross-sectional skeletal muscle area was subsequently normalized with respect to squared body height to form the skeletal muscle index (SMI), calculated as (muscle area)/(patient height)^2. The SMI is used as an index for sarcopenia. Mean radiodensity of all muscle voxels was calculated to assess myosteatosis.

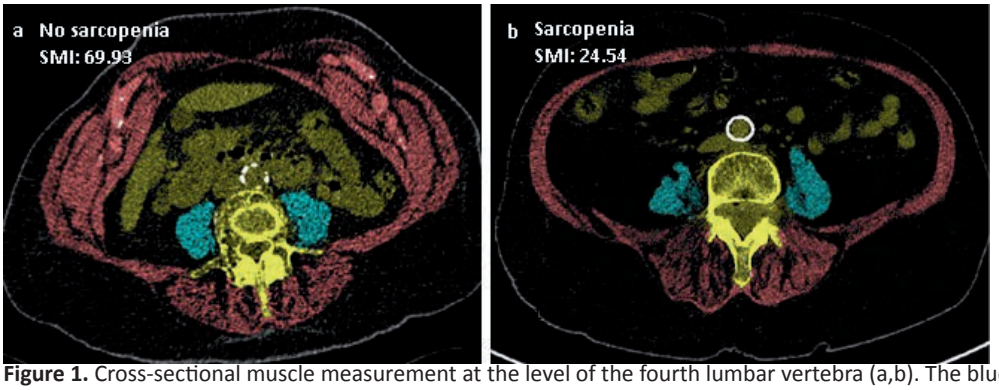

Figure 1. Cross-sectional muscle measurement at the level of the fourth lumbar vertebra (a,b). The blue area identifies the psoas major muscle. The red area represents the abdominal wall and the erector spinae muscles. Together they are used to form the skeletal muscle index (SMI), calculated as (muscle area)/(patient height)^2.

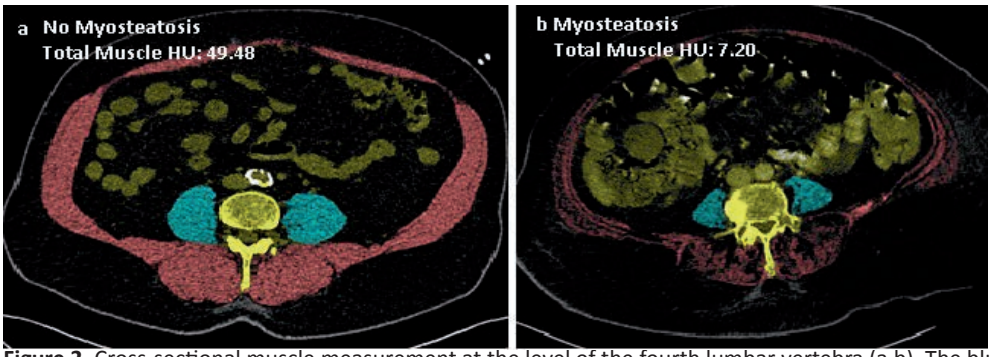

Figure 2. Cross-sectional muscle measurement at the level of the fourth lumbar vertebra (a,b). The blue area identifies the psoas major muscle. The red area represents the abdominal wall and the erector spinae muscles. Total muscle Hounsfield units were calculated to define myosteatosis.

Evaluating Physical Functioning and Quality of Life

Patients alive at follow-up were approached and asked to complete a series of patient-reported outcome measures to assess long-term physical functioning and QoL. Patients from the retrospective cohort received these questionnaires at a single moment in 2017 after at least a one-year follow-up. Patients from the prospective cohort received these questionnaires one year after the injury. Physical functioning was measured with the Dutch version of the Short Musculoskeletal Function Assessment (SMFA-NL) (19). The SMFA contains 46 items that are scored on a 5-item Likert scale. Two indices (function and bother) (20) and four subscales (upper extremity dysfunction, lower extremity dysfunction, problems with daily activities, mental and emotional problems) can be calculated (19). Scores are calculated by summing up the individual items and transforming scores in a range from 0 to 100, with higher scores indicating better function. The SMFA-NL has been shown to be a valid and reliable questionnaire in injured patients (19,21). QoL was measured with the EuroQol-5D (EQ-5D). The EQ-5D is a questionnaire that measures health-related QoL and consists of five items: mobility, self-care, daily activities, pain/discomfort and anxiety/depression (22), scored on a 5-item Likert scale. Based on these values, a utility score ranging from 0 to 1 was formed, with higher scores indicating better function. The EQ-5D has been shown to be a valid and reliable questionnaire in injured patients (23).

Statistical analysis

Descriptive statistics were performed to present demographics, injury patterns and treatment. Means and standard deviations were calculated from normally distributed data and the median and interquartile range from non-parametric data. Based on the SMI and radiodensity of the total musculature, patients were divided as having no sarcopenia/no myosteatosis, sarcopenia/no myosteatosis, myosteatosis/no sarcopenia and both sarcopenia and myosteatosis. Sex-specific SMI were determined, with the lower tertile splits defining sarcopenia (low SMI). BMI-specific (<25 and ≥25) cut-off values were used for HU, with the lower tertile splits defining myosteatosis (low HU). Either independent samples *t*-test or Mann–Whitney U-test were performed to assess differences between groups. Categorical variables were evaluated by using the Chi-squared test. Kaplan–Meier survival analysis was used to assess long-term survival, and Cox proportional hazards regression analysis was used to evaluate whether sex, age (65–75, 76–85, >85), sarcopenia and/or myosteatosis, as categorized above, CCI (2–3 vs. ≥4) and ISS (<16 or ≥16) were predictive factors for mortality. Non-response analyses were performed to evaluate differences between (1) patients with and without sarcopenia and myosteatosis measurements, and (2) patients who responded to the questionnaires and those who did not. Multivariable linear regression analyses were performed to evaluate the association between physical functioning,

QoL and sarcopenia and myosteatosis, corrected for CCI, BMI and age as possible confounders. A subset of the data was analyzed separately that only included scans without an intravenous contrast agent, as this may influence HU and thus myosteatosis measurements (24). A *p*-value < 0.05 was considered to indicate statistical significance. All statistical analyses were performed using IBM SPSS software, v. 23.

RESULTS

Demographics

A total of 363 patients (aged ≥65) with a pelvic ring injury were identified over a study period of 14 years (January 2007 to January 2021) (Figure 3.). For 199 (55%) of these patients the necessary data was available to determine the presence of sarcopenia and myosteatosis. Patients for whom height data or a (suitable) CT scan were not available were excluded from further analysis. Analysis of included and excluded patients revealed significantly more type-B injuries in the excluded group (P=0.03). There were no differences in patient characteristics between the groups. For sarcopenia, the calculated sex-specific cutoff values were 47.7 cm2/m2 for men and 34.1 cm2/m2 for women. For myosteatosis, the calculated BMI-specific cutoff values were 26.2 HU for BMI <25 kg/m2 and 25.9 mean HU for BMI ≥25 kg/m2. Patient characteristics are presented in Table 1. The reference group consisted of patients without sarcopenia and myosteatosis.

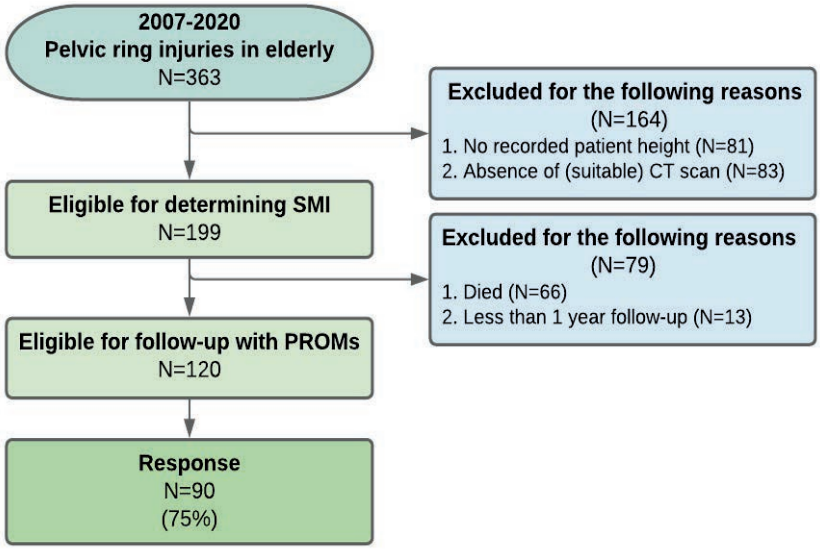

Figure 3. Flowchart of patient inclusion for assessment of skeletal muscle index, long-term physical functioning and quality of life after pelvic ring injuries at follow-up. The thirteen patients with less than one year follow-up were included in the survival analysis but excluded from PROMs assessment.

Eventually, 66 patients (33%) were diagnosed with sarcopenia and 65 (32%) with myosteatosis. When dividing the groups, there were 98 patients (49%) without sarcopenia and myosteatosis (reference group), 36 patients (18%) with sarcopenia but without myosteatosis, 35 (18%) with myosteatosis but without sarcopenia, and 30 (15%) with both (Figure 4). Compared to the reference group, sarcopenic patients had a higher age at the time of injury and more often had suffered a high-energy trauma. Patients with myosteatosis differed from the reference group in terms of more females and higher age at the time of injury. Patients with both sarcopenia and myosteatosis differed from the reference group in all characteristics except for treatment method and complication rates (Table 1).

Table 1. Baseline characteristics of patients with a pelvic ring injury

	All patients (N = 199)	**Reference group**† (N = 98)	**Sarco-penia** (N=36)	P-value ‡	**Myostea-tosis** (N=35)	P-value ‡	**Sarco-penia + myostea-tosis** (N=30)	P-value ‡
Gender*				0.44		**0.04**		**0.05**
Male	70 (35)	39 (40)	17 (47)		8 (23)		6 (20)	
Female	129 (65)	59 (60)	19 (53)		27 (77)		24 (80)	
Age at injury (mean ± SD)	78 ± 8	75 ± 7	79 ± 8	**0.03**	79 ± 8	**0.05**	83 ± 7	**<0.001**
BMI (kg/m2)	25 ± 5	25 ± 4	24 ± 4	0.08	27 ± 6	0.09	24 ± 4	**0.05**
(mean ± SD)	22 (11)	50 (51)	21 (59)		13 (37)		22 (73)	
BMI <25	177 (89)	48 (49)	15 (42)		22 (63)		8 (27)	
BMI ≥30								
SMI (cm2/m2)	41.6 ± 9.3	46.1 ± 8.5	36.7 ± 6.9	**<0.001**	42.5 ± 8.2	0.46	32.0 ± 4.9	**<0.001**
(mean ± SD)								
Male	49.9 ± 7.2	53.8 ± 4.7	43.2 ± 2.9		53.3 ± 6.4		38.5 ± 5.6	
Female	37.2 ± 7.0	41.0 ± 6.3	30.8 ± 2.7		39.3 ± 5.4		30.5 ± 3.2	
Mean muscle	31.1 ±	37.3 ± 7.5	34.7 ±	**0.06**	21.2 ± 3.7	**<0.001**	18.2 ± 5.3	**<0.001**
HU (mean ± SD)	10.3		6.7					
Sarcopenia	-	-	36 (100)		-	-	30 (100)	
Myosteatosis	76 (38)	-	-	-	35 (100)		30 (100)	
CCI (mean ± SD)	6 ± 2	5 ± 2	5 ± 2	0.41	5 ± 2	0.13	6 ± 2	**<0.001**
Injury mechanism				**0.04**		0.38		**<0.001**
Low-energy trauma	122 (61)	48 (49)	25 (69)		22 (63)		27 (90)	
High-energy trauma	77 (39)	50 (51)	11 (31)		13 (37)		3 (10)	
ISS (mean ± SD)	14 ± 11	15 ± 12	11 ± 9	0.06	16 ± 12	0.65	10 ± 9	**0.03**
Injury classification				0.21		0.41		**0.007**
Type A	68 (34)	25 (26)	13 (36)		14 (40)		16 (53)	
Type B	113 (57)	61 (62)	20 (56)		20 (57)		12 (40)	
Type C	18 (9)	12 (12)	3 (8)		1 (3)		2 (7)	
Treatment				0.46		0.77		0.24
Non-operative	165 (83)	79 (81)	31 (86)		28 (80)		27 (90)	
Operative	34 (17)	19 (19)	5 (14)		7 (20)		3 (10)	
Complications ≤30 days	58 (30)	28 (29)	9 (25)	0.58	13 (37)	0.33	8 (27)	0.74

* Numbers are expressed as N (%) unless otherwise specified.
† Reference group: all patients without sarcopenia and/or myosteatosis.
‡ Patients with or without sarcopenia and/or myosteatosis were compared with the reference group.
Statistically significant results are presented in bold.
BMI: body mass index, SMI: skeletal muscle index, HU: Hounsfield units, CCI: Charlson Comorbidity Index, ISS: injury severity score.

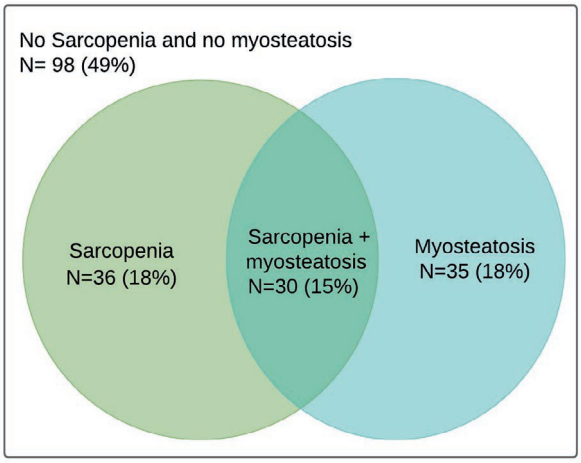

Figure 4. Venn diagram showing patients with sarcopenia, myosteatosis, both, or neither

Mortality and survival

Analysis of mortality rates at different timepoints revealed that patients with sarcopenia had an increased mortality risk three years after the injury (Table 2). Patients with sarcopenia and myosteatosis had an increased mortality risk overall. Five out of 13 patients (38%) who died within 30 days had myosteatosis or both sarcopenia and myosteatosis. One-, three- and five-year mortality rates were respectively 18 out of 31 (58%), 37 out of 58 (64%) and 42 out of 73 (58%) patients. Survival analysis revealed that patients who suffered from both sarcopenia and myosteatosis had the lowest survival rates, with over 50% mortality within the first five years post-injury (Figure 5). This was almost equally followed by patients with sarcopenia but not myosteatosis and patients with myosteatosis but not sarcopenia. Patients from the reference group showed the best long-term survival. In the univariable Cox proportional hazard analysis, sarcopenia and myosteatosis were not associated with overall survival (Table 3). Factors associated with survival in the multivariable analysis were age at the time of injury and CCI. An additional cox regression analysis including only patients without intravenous contrast CT yielded similar results, with only age ≥ 86 years being associated with survival (HR 1.69, 95% CI 2.21-13.49, p=<0.001).

Table 2. Mortality analysis of patients with and without sarcopenia and/or myosteatosis

	All patients (N = 199)	**Reference group*** (N=98)	**Sarcopenia** (N=36)	P-value	**Myosteatosis** (N=35)	P-value	**Sarcopenia + myosteatosis** (N=30)	P-value
Deceased, N (%)	59 (30)	26 (27)	12 (33)	0.44	12 (34)	0.49	16 (53)	**0.006**
< 30 days	13 (7)	8 (8)	0 (0)	0.55	2 (6)	0.55	3 (10)	0.81
< 1 year	31 (16)	13 (13)	4 (11)	0.82	6 (17)	0.39	8 (27)	0.46
< 3 years	58 (29)	21 (21)	13 (36)	**0.003**	11 (31)	0.21	13 (43)	0.23
< 5 years	73 (37)	31 (32)	13 (36)	0.09	12 (34)	0.56	17 (57)	0.20

* Mortality rates of patients with only sarcopenia, only myosteatosis, and both sarcopenia and myosteatosis were compared to the reference group of patients without sarcopenia or myosteatosis. Statistically significant results are in bold.

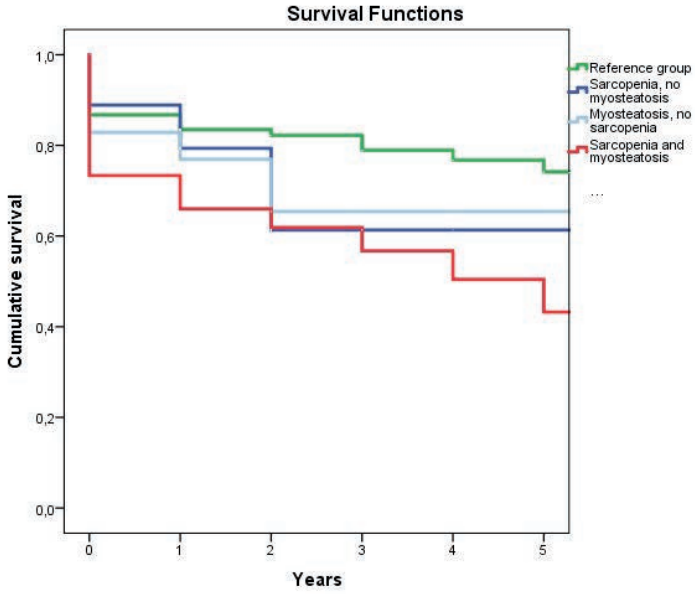

Figure 5. Kaplan-Meier survival curve of patients with or without sarcopenia and/or myosteatosis within the first five years post-injury. The green line represents the reference group (patients without sarcopenia or myosteatosis).

Table 3. Univariable and multivariable Cox proportional hazards model for overall survival

	Univariable analysis			Multivariable analysis		
	HR	95% CI	P-value	HR	95% CI	P-value
Sex						
Male	Ref					
Female	0.33	0.78-2.47	0.27			
Age						
65-75	Ref					
76-85	1.02	1.41-5.42	**0.003**	1.09	1.54-5.74	**0.001**
≥86	1.51	2.18-9.47	**<0.001**	1.65	2.55-10.56	**<0.001**
Sarcopenia/myosteatosis						
No sarcopenia, no myosteatosis	Ref					
Sarcopenia, no myosteatosis	0.36	0.70-2.91	0.33			
Myosteatosis, no sarcopenia	-0.05	0.46-1.95	0.89			
Sarcopenia and myosteatosis	0.35	0.73-2.76	0.31			
Charlson Comorbidity Index						
2-3	Ref					
≥4	0.56	1.01-3.07	**0.05**	0.60	1.07-3.12	**0.03**
Injury Severity Score						
0-16	Ref					
≥16	0.30	0.77-2.39	0.29			

HR: hazard ratio, Ref: reference category, CI: confidence interval

Physical functioning and quality of life in patients with sarcopenia and myosteatosis

The results of the SMFA and EQ-5D are presented in Table 4. Out of 120 eligible patients for follow-up by means of PROMs, 90 patients (75%) responded (Fig 2) at a mean follow-up of 2.4±2.2 years. The other 30 patients did not want to participate or were unable due to cognitive dysfunction. A non-response analysis revealed no differences between respondents and non-respondents. Out of the 90 respondents, 16 (18%) had sarcopenia or myosteatosis and 7 (8%) had both. Multivariable linear regression analyses were conducted to investigate whether the presence of sarcopenia and/or myosteatosis was associated with level of physical functioning or QoL (Table 5). A significant decrease was found on the mental and emotional problems subscale of the SMFA in patients with sarcopenia. No other significant relation between sarcopenia or myosteatosis and patient-reported outcomes could be established for patients who were still alive and responded at a mean follow-up of 2.4±2.2 years. An additional multivariable linear regression analysis including only patients without intravenous contrast CT yielded no relation between sarcopenia or myosteatosis and patient-reported outcomes as well (supplementary file 1).

Table 4. Patient-reported physical functioning and QoL in patients with sarcopenia and myosteatosis

	Reference group (N=51)	**Sarcopenia** (N=16)	**Myosteatosis** (N=16)	**Sarcopenia + myosteatosis** (N=7)
SMFA*				
Function	77 (61-92)	88 (75-96)	75 (60-89)	74 (48-79)
Bother	79 (60-92)	90 (77-98)	79 (57-90)	71 (33-79)
LE	79 (52-94)	88 (76-97)	72 (61-87)	71 (48-79)
ADL	75 (50-89)	83 (67-98)	75 (51-87)	65 (34-71)
Emotion	78 (63-88)	91 (80-94)	78 (67-90)	75 (72-88)
EQ-5D*	0.69 (0.31-1.00)	0.78 (0.23-1.00)	0.75 (0.39-0.88)	0.66 (0.37-0.78)

* Expressed as median (IQR)
IQR: interquartile range; ADL; activities of daily living; LE: lower extremity

Table 5. Multivariable linear regression analysis

	Group*	**B**	**95% CI**	**P-value**
SMFA				
Function	Sarcopenia†	10.25	-1.68, 22.18	0.09
	Myosteatosis‡	1.53	-9.49, 12.55	0.78
	Sarcopenia + myosteatosis§	-3.73	-21.97, 14.52	0.68
Bother	Sarcopenia	11.15	-1.61, 23.91	0.09
	Myosteatosis	0.97	-10.99, 12.93	0.87
	Sarcopenia + myosteatosis	-10.87	-30.66, 8.91	0.28
LE	Sarcopenia	10.67	-2.49, 23.84	0.11
	Myosteatosis	1.48	-10.69, 13.65	0.81
	Sarcopenia + myosteatosis	-2.78	-23.62, 16.06	0.70
ADL	Sarcopenia	12.30	-1.69, 26.25	0.08
	Myosteatosis	2.13	-10.83, 15.09	0.74
	Sarcopenia + myosteatosis	-8.74	-30.21, 12.73	0.42
Emotion	Sarcopenia	10.61	-0.04, 21.26	**0.05**
	Myosteatosis	1.72	-8.19, 11.62	0.73
	Sarcopenia + myosteatosis	0.82	-15.39, 17.04	0.92
EQ-5D	Sarcopenia	-0.03	-0.23, 0.18	0.81

Myosteatosis	0.008	-0.18, 0.19	0.93
Sarcopenia + myosteatosis	-0.07	-0.35, 0.21	0.61

* Group without sarcopenia or myosteatosis is the reference group.
† corrected for CCI and BMI.
‡ corrected for CCI and age.
§ corrected for CCI, BMI and age.
ADL: activities of daily living; LE: lower extremity.

DISCUSSION

The present study assessed the prevalence of sarcopenia and myosteatosis in elderly patients with a pelvic ring injury and their influence on mortality as well as patient-reported physical functioning and QoL. In our study cohort, 33% of patients suffered from sarcopenia, 32% from myosteatosis and 15% of them had both. Patients with sarcopenia showed higher mortality rates after three years compared to non-sarcopenic patients. Survival in the first five years post-injury was lowest in patients with both sarcopenia and myosteatosis. Higher age and more comorbidities were independent risk factors for mortality, while sarcopenia and/or myosteatosis were not. In the patients still alive and responding after the two-year follow-up, no other relation with patient-reported physical functioning and QoL was established besides increased mental and emotional problems in patients with sarcopenia. This might be explained by fact that most survivors did not have sarcopenia or myosteatosis.

Analysis revealed that 33% of our population dealt with sarcopenia. To the best of our knowledge, no other studies have evaluated rates of sarcopenia and myosteatosis and their relation to mortality in patients with pelvic ring injuries. General prevalence of sarcopenia was shown to be 1–33% across different populations (25). When comparing the presence of sarcopenia in our population to populations with fractures in other body parts, some similar numbers were found. Iolascon et al. found that 23% of female patients aged > 55 with a single vertebral fracture had sarcopenia (26). In contrast, Hida et al. found that 47% of female patients aged > 55 with a hip fracture dealt with sarcopenia, as compared to 81% of male patients (27). Their estimation of muscle mass could be affected by surgical intervention and disuse atrophy, with the possibility to overestimate the prevalence. In our study, 32% of patients suffered from myosteatosis, similarly to the rates found by Vedder et al. (28) in patients with peripheral arterial occlusive disease (38%) and O'brien et al. (29) in patients with inflammatory bowel disease (34%).

Analysis of mortality rates at different timepoints revealed that patients with sarcopenia had an increased mortality risk three years post-injury. More than half of patients that passed away after one, three and five years suffered from sarcopenia and/or myosteatosis. Survival was the worst in patients suffering from both conditions. However, neither sarcopenia nor myosteatosis were shown to be independent risk factors for mortality. In a study by Mitchell et al. on acetabular fractures, sarcopenia in patients over age 60 was considered an independent risk factor for one-year mortality (30). They measured sarcopenia with the psoas:lumbar vertebral index (PLVI) and considered patients in the lowest quartile as being sarcopenic. These factors could explain the differences.

Numerous studies reveal a significant decrease in physical functioning and quality of life after pelvic ring injuries compared to population standards, regardless of the presence of sarcopenia or myosteatosis (11,31,32). We found that sarcopenia was negatively correlated with the

mental and emotional status of the patient. No other statistically significant negative effects on patient-reported outcomes and QoL were found in patients with sarcopenia, myosteatosis or both. A possible explanation could be the relatively small number of patients per group, or that patients with a severely declined physical condition had already passed away by the time this cross-sectional study was conducted. Patients alive at least one-year post-injury were invited to participate, with a mean follow-up of 2.4 ± 2.2 years, so patients with a worse physical condition would likely have died before they could have been invited to participate in this study (survivorship bias). Several other studies found that sarcopenia was related to decreased physical functioning. Baumgartner et al. found that sarcopenia was significantly associated with self-reported physical disability in a large general population of community-dwelling men and women, independently of ethnicity, age, morbidity, obesity or income (2). Patel et al. (33) found lower self-reported general health and physical functioning as measured by the SF-36 questionnaire in a general elderly population with sarcopenia, compared to non-sarcopenic age peers. The systematic review of Beaudart et al. (34) on QoL in various diseased and healthy sarcopenic populations revealed heterogeneous outcomes. Some studies found no difference in QoL between sarcopenic and non-sarcopenic participants, while others showed poorer QoL for sarcopenic patients or only poorer results in specific QoL domains. No studies were found evaluating patient-reported physical functioning and/or QoL in patients with myosteatosis.

With sarcopenia and myosteatosis being common clinical problems in the frail elderly together with the high mortality rates shown in this study, some general recommendations for clinical practice can be made. Physicians should be aware that routine CT scans—initially performed for pelvic ring injury assessment—also contain valuable information about the presence of sarcopenia and/or myosteatosis. As these patients are prone to high mortality rates, multidisciplinary treatment should be considered, that includes consultation with a physiotherapist and dietician. The combination of various types of exercises, particularly resistance training, may improve muscle strength and physical performance if performed for at least three months (25). No consistent effect of protein supplementation has been established (25), but essential amino acids (with leucine) and β-hydroxyβ-methylbutyric acid (HMB) proved to have some positive effects on muscle mass and muscle function.

We believe to have addressed several clinically important issues. This is the first study to provide insight into the prevalence of sarcopenia and myosteatosis in elderly patients with a pelvic ring injury. It is also the first to establish a possible relation between sarcopenia, myosteatosis and mortality, as well as between sarcopenia, myosteatosis and patient-reported physical functioning and QoL. We had a high response rate of 75% on the PROMs, despite this being a fragile population.

When interpreting the results of our study, some limitations should also be taken into account. Suboptimal positioning of the patient in the CT scan in the acute setting could have caused some imaging artefacts, possibly influencing sarcopenia and myosteatosis measurements. In some cases, intravenous contrast was used, which can increase radiodensity (24) and thus lower the reliability of myosteatosis measurements. We therefore performed additional Cox regression and multivariable analyses of the 61 CT scans with intravenous contrast that yielded similar results. Muscle measurements are typically taken at the level of the third lumbar vertebra (L3), as the cross-sectional skeletal muscle area at this level is highly correlated with total body skeletal

muscle mass (35). However, several studies revealed that L4 is a good alternative (35,36). In the present study, many patients were excluded from further analysis, as L4 was not always included in routine CT scans of the pelvis. Still, analysis of included and excluded patients based on the availability of usable CT scans yielded no differences in patient characteristics. Although interest in sarcopenia and myosteatosis is growing considerably, widely accepted definitions and adequate cut-off values suitable for use in research are still lacking. So far, no fixed criteria exist for identifying the level at which relative muscle mass becomes deficient. The European Working Group on Sarcopenia in Older People (EWGSOP) recommends cut-off values set at two standard deviations below the mean of a healthy, young adult population (37). In addition to gait speed for performance and handgrip testing for strength, gold standards for measurement of sarcopenia include computed tomography (CT) for muscle mass. In the absence of functional testing data, which was the case in our study due to its retrospective nature, sarcopenia assessment could be completed from CT alone. However, measurement techniques for sarcopenia vary widely and also include thresholds based on measurements derived from DXA scans and cut-off points based on optimal stratification methods. No cut-off values are available in the literature for this population, as no previous studies exist that assessed rates of sarcopenia and myosteatosis in a population with pelvic ring injuries and measured at the level of L4. Hence, we used the lowest tertiles as cut-off points, which is common in the assessment of sarcopenia and myosteatosis (38,39). They provide reliable values based on a specific population. Third and most importantly, the retrospective nature of this study makes it prone to survivorship bias or survival bias. This is a form of selection bias that results from the focus on survivors instead of a broader context that includes those that did not survive. This may lead to a distorted and possibly overly optimistic image of the results. In our cohort, thirty-one (16%) of the patients died within one year after the pelvic ring injury and could therefore not be included for follow-up analysis with PROMs, and 18 (58%) of them had sarcopenia, myosteatosis or both. This could be a feasible explanation for the fact that, besides the relation with mental and emotional problems, no other statistically significant association could be established between sarcopenia and/or myosteatosis and physical functioning and QoL.

CONCLUSIONS

About half of patients over 65 years of age with a pelvic ring injury had sarcopenia, myosteatosis or both. Mortality in the first few years after the injury was high among patients with sarcopenia and/or myosteatosis compared to patients without these conditions. There was a negative correlation between sarcopenia and patients' mental and emotional status. No other statistically significant differences could be highlighted between the presence of sarcopenia and/or myosteatosis and patient-reported physical functioning and QoL at long-term follow-up. Further prospective studies on larger groups of patients are necessary to evaluate whether sarcopenia and/or myosteatosis are potential predictive factors for decreased physical functioning and QoL in elderly patients with a pelvic ring injury, as well as intervention studies for the effects of muscle training and dietary adaptations.

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SUPPLEMENTARY FILE 1: multivariable linear regression analysis of patients without intravenous contrast CT

	Group*	B	95% CI	P-value
SMFA				
Function	Sarcopenia*	5.79	-9.32, 20.89	0.44
	Myosteatosis†	4.52	-8.20, 17.23	0.48
	Sarcopenia + myosteatosis§	-10.99	-31.54, 9.55	0.28
Bother	Sarcopenia	5.13	-9.73, 19.98	0.49
	Myosteatosis	0.70	-12.24, 13,65	0.91
	Sarcopenia + myosteatosis	-19.51	-40.09, 1.08	0.06
LE	Sarcopenia	4.60	-11.93, 21.13	0.58
	Myosteatosis	5.36	-8.54, 19,26	0.44
	Sarcopenia + myosteatosis	-13.25	-35.09, 8.59	0.23
ADL	Sarcopenia	6.78	-10.26, 23.82	0.43
	Myosteatosis	3.95	-10.49, 18.39	0.59
	Sarcopenia + myosteatosis	-16.96	-40.39, 6.38	0.15
Emotion	Sarcopenia	7.03	-4.83, 18.89	0.24
	Myosteatosis	-0.22	-10.93, 10.49	0.97
	Sarcopenia + myosteatosis	-5.14	-21.41, 11.14	0.53
EQ-5D	Sarcopenia	-0.06	-0.33, 0.21	0.64
	Myosteatosis	0.05	-0.19, 0.29	0.68
	Sarcopenia + myosteatosis	-0.15	-0.49, 0.20	0.39

Group without sarcopenia or myosteatosis is the reference group

* corrected for CCI and BMI

† corrected for CCI and age

§ corrected for CCI, BMI and age

ADL activities of daily living; LE lower extremity

Part III

A GLANCE INTO THE FUTURE: TREATMENT IMPROVEMENT

Chapter 8 **Does 3D-assisted operative treatment of pelvic ring injuries improve patient outcome? - a systematic review of the literature**
Journal of Personalized Medicine. 2021 September 18;11(9):930.

Chapter 8

Does 3D-assisted operative treatment of pelvic ring injuries improve patient outcome? - a systematic review of the literature

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ABSTRACT

Background. There has been an exponential growth in the use of advanced technologies for three-dimensional (3D) virtual pre- and intraoperative planning of pelvic ring injury surgery but potential benefits remain unclear. The purpose of this study was to evaluate differences in intra- and post-operative results between 3D and conventional (2D) surgery.

Methods. A systematic review was performed including published studies between January 1st 2010 and May 22nd 2020 on all available 3D techniques in pelvic ring injury surgery. Studies were assessed for their methodological quality according to the Modified McMaster Critical Review form. Differences in operation time, blood loss, fluoroscopy time, screw malposition rate, fracture reduction and functional outcome between 3D-assisted and conventional (2D) pelvic injury treatment were evaluated and a best-evidence synthesis was performed.

Results. Eighteen studies fulfilled the inclusion criteria, evaluating a total of 988 patients. Overall quality was moderate. Regarding intra-operative results of 3D-assisted *versus* conventional surgery: The weighted mean operation time per screw was 43 minutes *versus* 52 minutes; for overall operation time 126 minutes *versus* 141 minutes; blood loss 275 ± 197 ml *versus* 549 ± 404 ml; fluoroscopy time 74 seconds *versus* 125 seconds and fluoroscopy frequency 29 ± 4 *versus* 63 ± 3. In terms of post-operative outcomes of 3D-assisted *versus* conventional surgery: weighted mean screw malposition rate was 8% *versus* 18%; quality of fracture reduction measured by the total excellent/good rate by Matta was 86% *versus* 82% and Majeed excellent/good rate 88% *versus* 83%.

Conclusion. 3D-assisted surgery technologies seem to have a positive effect on operation time, blood loss, fluoroscopy dose, time and frequency as well as accuracy of screw placement. No improvement in clinical outcome in terms of fracture reduction and functional outcome has been established so far. Due to a wide range of methodological quality and heterogeneity between the included studies, results should be interpreted with caution.

INTRODUCTION

Pelvic ring injuries have an estimated annual incidence of 14-37 per 100,000 inhabitants each year (1,2). Treatment can be either non-operative or operative, depending on the injury as well as patient characteristics. The operative treatment of pelvic ring injuries remains a challenging tasks for surgeons due to the complex three-dimensional (3D) shape of the pelvis, morphological variations, limited access to fracture sites, and narrow bone corridors for screw placement (3). The goal of operative treatment is to restore pelvic symmetry and achieve stable fracture fixation, which allows for early mobilization and good functional outcome at the long-term (4,5). Progress in 3D imaging technologies has resulted in an exponential increase in the usage of these techniques -that is both industry- as well as surgeon-driven- for preoperative planning and for translation of the plan to the operative procedure (6). 3D-assisted surgery encompasses a wide spectrum of modalities including 3D virtual preoperative planning, 3D-printed models for pre-contouring of osteosynthesis plates and 3D navigational tools. Some coin these 3D (printing) techniques the "second industrial revolution" in Orthopaedic Trauma Surgery. Nevertheless, the additional clinical value of 3D techniques in pelvic surgery has yet to be elucidated, both practically as well as scientifically.

Conventional X-rays and two-dimensional (2D) computed tomography (CT) images are to date widely used to assess fracture characteristics, reduction quality and positions of osteosynthesis materials in pelvic ring injury treatment (3). However, 3D virtual models may allow the surgeon to gain more insight in the fracture pattern, surgical approach, and positions of osteosynthesis materials. It has been reported that pre-operative virtual simulation and 3D printing-assisted pre-contoured plate fixation of pelvic ring injuries resulted in precise pre-operative planning and accurate execution of the operative procedures (3). Moreover, 3D-assisted surgery for percutaneous screw placement may lower the risk of complications and decrease the need for revision surgery due to a lower rate of screw malposition (7). However, there is a lack of studies with sufficient statistical power to provide evidence on superiority of the available 3D technologies compared to conventional (2D) techniques in different types of pelvic ring injuries.

Hence, the main objective of the present systematic review was to analyse differences in outcomes between currently available 3D-assisted and conventional (2D) pelvic ring injury treatment. Therefore, we asked 1) What is the difference in intra-operative results in terms of operation time, blood loss, screw malposition and fluoroscopy time between 3D-assisted and conventional (2D) surgery?; and 2) What is the difference in post-operative results in terms of fracture reduction and functional outcome between 3D assisted and conventional (2D) surgery?

METHODS

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews (PRISMA) (8). The review protocol has been registered in PROSPERO International prospective register of systematic reviews under registration number CRD42021224915.

Identification of studies: search strategy

The MEDLINE-Pubmed and Ovid-EMBASE libraries were searched on May 22nd of 2020 for articles published between January 1st 2010 until May 22nd 2020. The search string was developed in collaboration with an experienced medical librarian (Table 1). It was developed to identify references related to 3D-imaging and 3D-operative techniques of pelvic ring injuries. Therefore, the items "pelvis", "injury" and "3D/threedimension" were combined to develop the search strategy.

Table 1: search strings by database

Database	Search string
MEDLINE-PubMed	(((“Pelvis”[Mesh] OR pelvic ring[tiab]) AND (“Wounds and Injuries”[Mesh] OR “injuries” [Subheading] OR injur*[tiab] OR fractur*[tiab]))) AND ((3D[tiab] OR three dimension*[tiab] OR 3 dimension*[tiab] OR “Printing, Three-Dimensional”[Mesh] OR “Imaging, Three-Dimensional”[Mesh] OR navigation[tiab])) AND 2010:2020[dp]
Ovid-EMBASE	(‘pelvis’/exp OR ‘pelvis surgery’/exp OR ‘pelvic ring’:ti,ab) AND (‘bone injury’/exp OR injur*:ti,ab OR fractur*:ti,ab) AND (‘three dimensional printing’/exp OR ‘three-dimensional imaging’/exp OR 3d:ti,ab OR ‘three dimension*’:ti,ab OR ‘3 dimension*’:ti,ab OR navigation:ti,ab) AND [embase]/lim AND [2010-2020]/py

Inclusion and exclusion criteria

Eligible studies for inclusion reported either on 1) the use of 3D techniques in the virtual planning of operative treatment of pelvic ring injuries; 2) 3D printed templates with fracture visualization; 3) 3D printed templates with pre-operative plate contouring; 4) 3D virtual planning of screw trajectories; 5) 3D custom-made implants with guides; and 6) 3D navigation for screw placement. Patients should be 18 years or older and patients with fragility fractures of the pelvis (FFP) were included as well. Outcomes directly related to the operative treatment should be reported. These included operation time, blood loss, screw malposition rate and fluoroscopy time or fluoroscopy frequency, fracture reduction and functional outcome. These outcome measures represent the efficiency and accuracy of the surgical procedure itself. We hypothesized that 3D assisted surgery could have an effect on these measures, which is the rationale to choose these outcome measures. Moreover, these are widely used for assessing pelvic ring surgery related to patient outcomes (9–11). Except for case studies with N <10 and conference abstracts, all study designs were accepted for inclusion. Concerning language, studies written in English, German, Spanish, French and Dutch were included. Biomechanical and animal studies were excluded, as well as studies about classification of injuries by means of 3D techniques. Moreover, studies that included outcomes after both pelvic ring injuries and acetabular fractures and that did not differentiate between these injuries in terms of outcomes were excluded.

Study selection

All articles were imported into Rayyan QCRI, a web-based sorting tool for systematic literature reviews (12). The study selection was performed in two screening phases: 1) title and abstract screening, and 2) full text screening. Both selection phases were independently performed by the same researchers. Disagreement was resolved by discussion. The initial searches (conducted from January 1st 2010 to May 22nd 2020) generated 819 articles and after removal of duplicates, 709 potential eligible studies were screened. Following title and abstract assessment, 34 articles were reviewed in full text. A total of 18 articles were included in the review of which most were case-control studies (N=9), followed by cross-sectional cohort studies (N=8) and one prospective cohort study. No randomized controlled trials (RCT’s) were found in this search. Figure 1 demonstrates a flowchart of the inclusion procedure.

Data extraction

The data extraction was independently conducted (HB, FIJ) using a precompiled extraction file (Microsoft Excel version 14.0; Microsoft Inc., Redmond, WA, USA). Study characteristics, fracture classification, 3D technologies and outcome measures were extracted from all the included studies by the senior author.

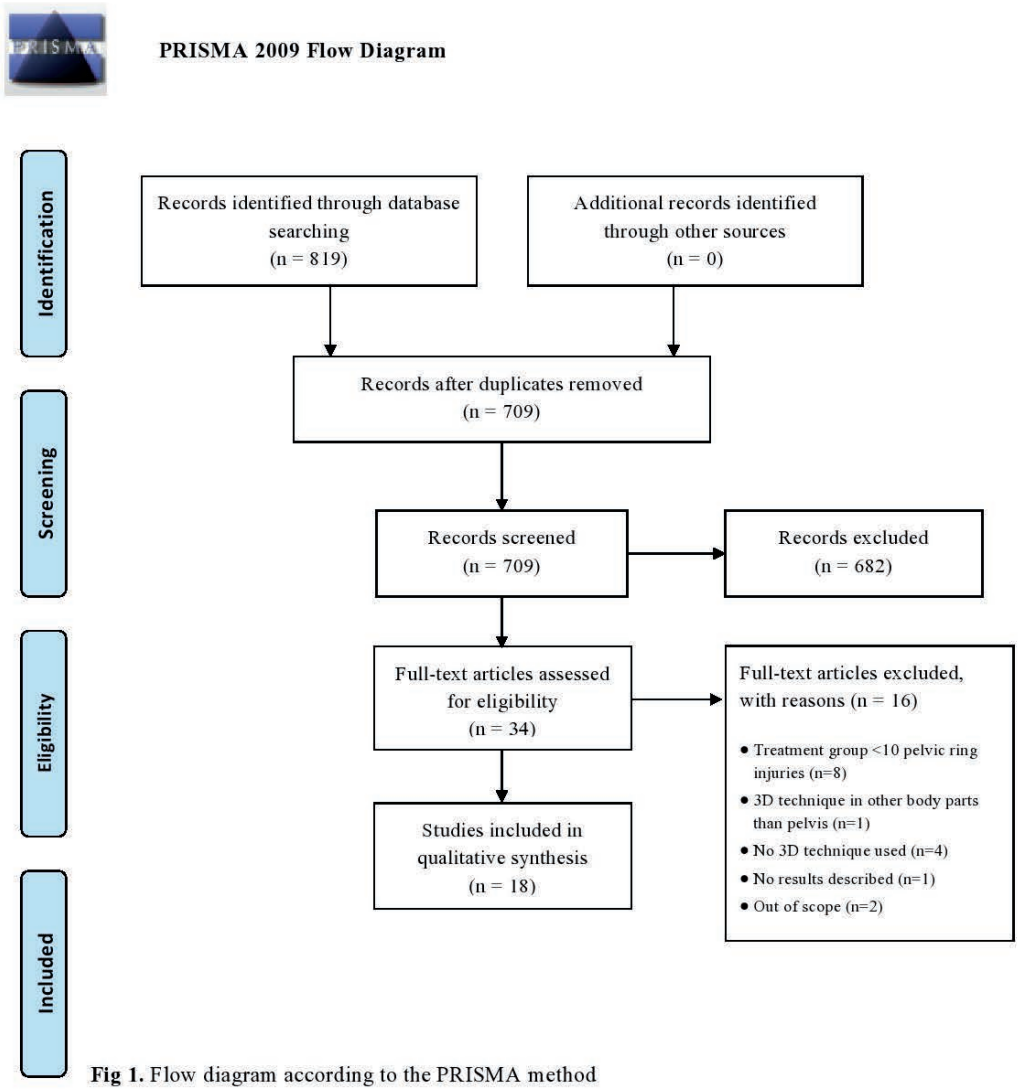

Fig 1. Flow diagram according to the PRISMA method

Assessment of methodological quality

Methodological quality and risk of bias of the included studies was independently assessed according to the guidelines of the McMaster University Occupational Therapy Evidence-Based Practice Research Group (13). The Modified McMaster Critical Review form consists of nine categories: citation, study purpose, literature, design, sample, outcomes, intervention, results, and conclusions and implications. This review form is appropriate to assess RCTs, cohort studies, single-case designs, before- and after-designs, case control studies, cross-sectional studies and case studies. The guidelines established by Law et al. (13) were utilized for the quality assessment. Every item was answered with 'yes; 1 point', 'no; 0 points', 'not addressed; 0 points' or 'not applicable (N/A); no points given'. Any continued disagreements were solved during a consensus meeting (HB and FIJ). The total score reflects the methodological quality with a maximum score of 17 for RCTs and 13 for other designs. The definitive score is calculated in a percentage and may vary from 0–100%, with a higher score indicating a higher methodological quality. Scores below <60% were considered as poor quality, scores between 60-74% were

considered as moderate quality, scores between 75%–89% indicated good-quality and scores between 90%–100% indicated excellent-quality studies. The results of the quality assessment of the included articles are presented in table 2. A maximum score of 13 could be obtained as four items concerning RCTs were left out. Total scores in percentages ranged between 46% and 92% with a mean score of 63% (SD 16). Only one study was considered as excellent quality, five were good-quality, four moderate quality and eight poor quality studies.

Table 2: Scores of the quality assessment list ranged from best to worst score

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total	%
	Citation	Study purpose	Literature review	Sample		Outcomes		Intervention		Results			Conclusion and clinical implications		
Berger-Groch et al. (14)	+	+	+	+	-	+	+	+	+	+	+	+	+	12/13	92
Takao et al. (15)	+	+	+	+	-	+	+	+	+	+	+	-	+	11/13	85
Yang et al. (16)	+	+	+	+	-	+	+	+	+	+	+	-	+	11/13	85
Hung et al. (3)	+	+	+	+	-	+	-	+	+	+	+	-	+	10/13	76
Li. et al. (17)	+	+	+	+	-	+	-	+	+	+	+	-	+	10/13	76
Teo et al. (18)	+	+	+	+	-	+	+	+	+	-	+	-	+	10/13	76
Cai et al.(4)	+	+	+	+	-	-	-	+	+	+	+	-	+	9/13	69
Li et al. (19)	+	+	+	+	-	-	-	+	+	+	+	-	+	9/13	69
Balling (6)	+	+	+	+	-	+	+	+	-	-	+	-	-	8/13	62
Takeba et al. (20)	+	+	+	+	-	+	+	+	-	-	+	-	-	8/13	62
Pieske et al. (21)	+	+	+	+	-	-	-	+	+	-	+	-	-	7/13	54
Beck et al. (22)	+	+	+	+	-	-	-	+	-	-	+	-	-	6/13	46
Chen et al.(23)	+	+	+	+	-	-	-	+	-	-	+	-	-	6/13	46
Gao et al. (24)	+	+	+	+	-	-	-	+	-	-	+	-	-	6/13	46
Ghisla et al. (25)	+	+	+	+	-	-	-	+	-	-	+	-	-	6/13	46
Kim et al. (26)	+	+	+	+	-	-	-	+	-	-	+	-	-	6/13	46
Nie et al. (27)	+	-	+	+	-	-	-	+	+	-	+	-	-	6/13	46
Privalov et al. (28)	+	+	+	-	-	-	-	+	+	-	+	-	-	6/13	46

Every plus (+) sign means that the question was answered with 'yes'. Every minus (-) sign means that a question was answered with 'no' or 'not addressed'. The final two columns represent the total scores and percentages of maximal attainable scores (%).

Outcomes

Outcomes relevant to the operation were recorded. These parameters included operation time, blood loss, screw malposition (varying from contacting cortical bone to actual perforation of the cortical bone), fluoroscopy dose, amount and frequency, fracture reduction according to the guidelines established by Tornetta and Matta (29) and patient- or physician-reported functional outcome.

Patient and injury characteristics

Overall, data of a total of 988 patients were reported in the studies (Table 3). Most studies (N=12) focused on unstable pelvic ring injuries (Type B and Type C according to the AO classification system) (30). Of all included patients, 694 received 3D-assisted pelvic ring injury surgery and 294 had conventional surgery. The study characteristics are shown in table 3.

Table 3. Study characteristics

No.	Study	Year	N	Method*	Study period	Injury type	Intervention
1	Balling (6)	2019	52	CSS	2011-2016	Sacral FFPs®	3D image guided sacral screw fixation via single-sided minimally invasive transgluteal approach
2	Beck et al. (22)	2010	26	CCS	2008-2009	AO/Tile B, C	S: Intra-operative 3D fluoroscopy of iliosacral screws and lumbopelvic implants (N=14) C: Iliosacral screws and lumbopelvic implants without intra-operative 3D (N=12)
3	Berger-Groch et al. (14)	2018	136	CCS	2004-2014	AO/Tile B, C	S: 3D navigated iliosacral screw placement (N=100) C: Conventional iliosacral screw placement (N=36)
4	Cai et al.(4)	2018	137	CCS	2014-2016	AO/Tile B, C	S: 3D printing-based minimally invasive cannulated screw treatment (N=65) C: Conventional surgery without 3D printing (N=72)
5	Chen et al.(23)	2019	28	PCS	2016-2018	AO/Tile B, C	Minimally invasive screw fixation using the “Blunt End” kirschner wire technique assisted by 3D printed external template
6	Gao et al. (24)	2011	22	CSS	2006-2008	AO/Tile B, C	Minimally invasive fluoro-navigation screw fixation
7	Ghisla et al. (25)	2018	21	CSS	2008-2017	Posterior pelvic ring	Intra-operative 3D-CT guided navigation for iliosacral screws
8	Hung et al. (3)	2018	30	CCS	2012-2017	AO/Tile A, B, C	S: ORIF with pre-operative virtual simulation and 3D- printing-assisted contoured plate (N=16) C: ORIF with conventional plate fixation (N=14)
9	Kim et al. (26)	2013	29	CSS	2010	AO/Tile A, B	Percutaneous iliosacral screwing using 3D-fluoroscopy
10	Li et al. (19)	2015	157	CCS	2009-2014	AO/Tile C	S: computer-aided angiography and rapid prototyping technology (N=81) C: conventional imaging (N=76)
11	Li. et al. (17)	2015	81	CCS	2005-2011	AO/Tile B, C	S: 3D C-arm fluoroscopy navigation (N=43) C: C-arm fluoroscopy (N=38)
12	Nie et al. (27)	2018	30	CSS	2015-2017	AO/Tile B, C	3D printing assisted by minimally invasive surgery for pubic rami fractures
13	Pieske et al. (21)	2015	71	CSS	Unknown	AO/Tile B, C	CT-guided sacroiliac percutaneous screw placement

14	Privalov et al. (28)	2020	53	CCS	2017-2018	Posterior pelvic ring	S: intra-operative CT in navigated sacroiliac instrumentation (N=25) C^1: navigated surgery with intra-operative 3D-C-Arm (N=15) C^2: Conventional surgery with intra-operative control by 3D-C-Arm (N=9) C^3: Conventional surgery with intra-operative control by 2D fluoroscopy (N=4)
15	Takao et al. (15)	2019	27	CSS	2011-2016	AO/Tile B, C	3D fluoroscopic navigation of iliosacral screw insertion
16	Takeba et al. (20)	2018	10	CSS	2013-2017	AO/Tile B, C	O-arm and stealthstation navigation for screw fixation
17	Teo et al. (18)	2018	36	CCS	2011-2016	AO/Tile B, C	S: Sacroiliac screw placement with intra-operative navigation C: Sacroiliac screw placement without intr-aoperative navigation
18	Yang et al. (16)	2018	40	CCS	2016-2017	AO/Tile B, C	S: 3D printed external template to guide iliosacral screw insertion (N=22) C: Conventional without external template (N=18)

*CSS, cross-sectional study; PCS, prospective cohort study; CCS, case-control study; S, study group; C, control group

® FFP, Fragility Fracture of the Pelvis

Strategy for data synthesis and statistical analysis

Data synthesis involved the comparison, combination, and summary of findings. Data is presented as part of a narrative synthesis, involving text and tables. Continuous variables are presented as means with standard deviation (SD) (parametric data) or as median with interquartile range (IQR) in case of non-parametric data. Dichotomous variables are given as frequency and percentages. Due to the retrospective nature of the included studies and the heterogeneity of their design, results could not be pooled for statistical analysis. Instead, weighted means of the various outcome variables of the studies were calculated for comparison. Besides, a best-evidence synthesis was performed, taking into account the methodological quality and outcome of the original studies (table 4) (31). Excellent and good quality studies were labeled as high-quality studies whereas moderate and low-quality studies were labeled as low-quality.

Table 4. Best-evidence synthesis

Strong evidence	Consistent findings among multiple high-quality studies
Moderate evidence	Consistent findings in multiple low-quality studies and/or one high-quality study
Limited evidence	Consistent findings in at least one low-quality study
Conflicting evidence	Inconsistent findings among multiple studies (high- and/or low-quality studies)
No evidence	Findings of eligible studies do not meet the criteria for one of the levels of evidence stated above, or there are no eligible studies available

RESULTS

Intra-operative results

Our first question asks about the difference in intra-operative results in terms of operation time, blood loss and fluoroscopy time between 3D-assisted and conventional (2D) surgery. All identified 3D-assisted surgery techniques are shown in figure 2 and described in supplemental digital content 1.

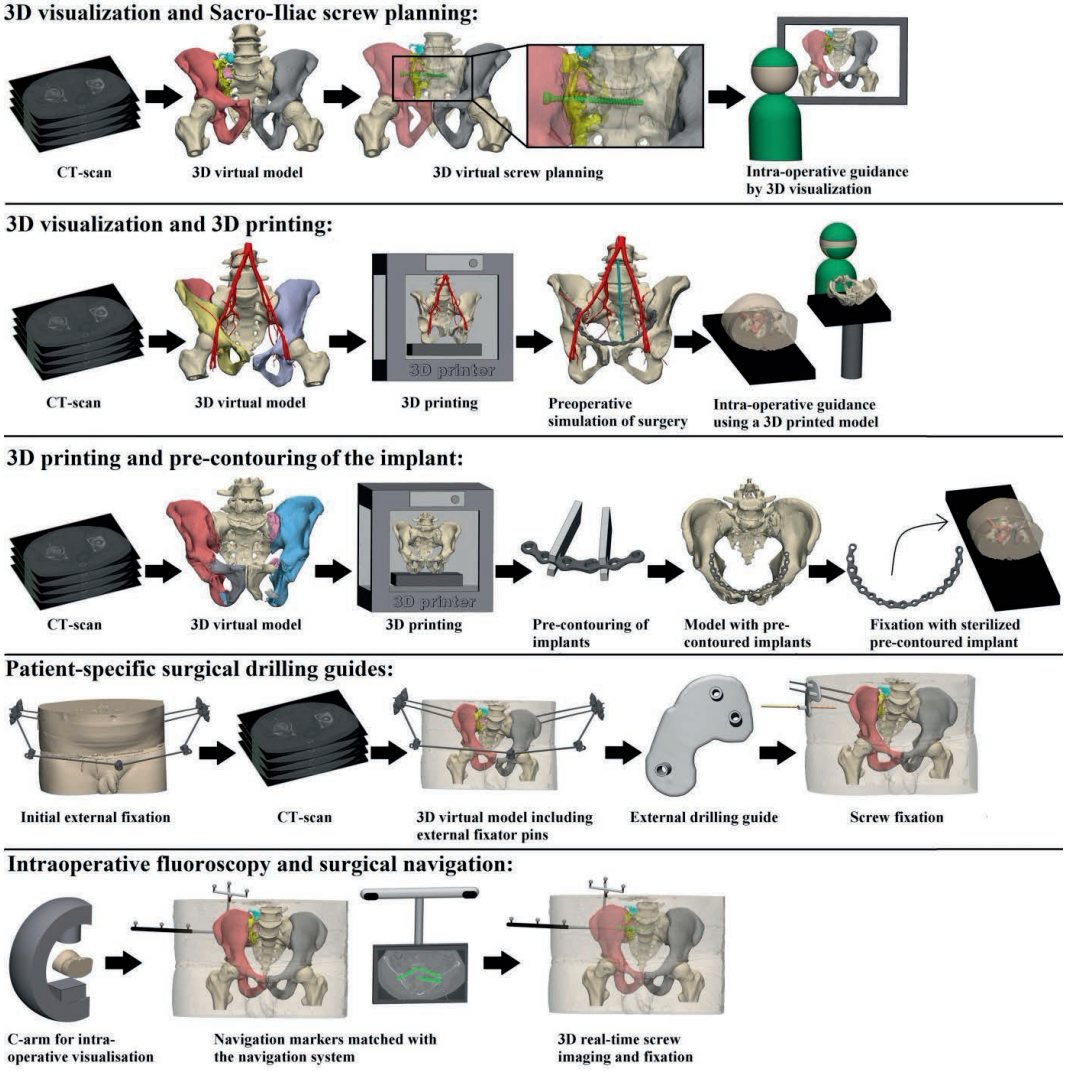

Figure 2. Presentation of the five identified 3D-assisted surgery techniques

Operation time per screw and overall operation time

Two out of three case-control studies reported that 3D-assisted surgery led to a significant decrease in operation time per screw using 3D printed drilling guides (16) and intra-operative 3D imaging (17) (table 5). Berger-Groch et al. (14) found no difference using intra-operative 3D imaging. Weighted mean operation time per screw was 15 min (range 14 – 18) for 3D-assisted and 26 min (range 19-40) for the conventional group. Three case-control studies reported on a significant decrease in overall operation time using a 3D printed model (4,19) and a 3D

printed model combined with pre-contouring of the osteosynthesis plate (3) compared to the conventional technique. The other case-control study found no difference using intra-operative 3D imaging for screw placement (28). Weighted mean overall operation time was 97 min (range 59-206) for 3D-assisted and 113 min (range 72-276) for the conventional group.

Blood loss
The only case-control study by Hung et al. (3) reported a significant decrease in blood loss (275 ± 197 ml *versus* 549 ± 404 ml; p=0.023) using pre-operative virtual simulation and 3D printing-assisted plate contouring. No weighted mean blood loss of all studies was calculated as both open and percutaneous surgery was applied.

Fluoroscopy dose, time and frequency
One case-control study by Yang et al. (16) reported a significantly decreased fluoroscopy dose by using 3D printed drilling guides in comparison to conventional surgery. The other case-control study by Beck et al. (22) did not express the difference in fluoroscopy dose in a P-value. No weighted mean could be calculated because different units were used to report dose. Three of the four case-control studies reported that intra-operative 3D-assisted surgery significantly reduced fluoroscopy time (14,17,28). The remaining case-control study by Beck et al.(22) did not express the difference in fluoroscopy time with a P-value. Weighted mean fluoroscopy time was 74 sec. (range 22-29) for the 3D-assisted and 125 sec. (range 58-248) in the conventional group. One case-control study by Cai et al (4), combining 3D visualization with a 3D printed model for screw placement, reported a significant decrease in fluoroscopy frequency (29 ± 4 *versus* 63 ± 3; p< 0.001) compared to the conventional technique.

Post-operative results
Our second question asks about the difference in post-operative results in terms of fracture reduction and functional outcome.

Screw malposition
Two out of five case-control studies reported significantly less screw malposition rates by using a 3D printed drilling (16) and intra-operative 3D image guided surgery (17). Two other studies found no difference using intra-operative 3D image guided surgery (14,18). Beck et al.(22) did not report on the difference expressed by a P-value. Weighted mean screw malposition rate for 3D-assisted surgeries was 8% (range 0-22.6) compared to 18 % (range 5-24) in the conventional group (varying from contacting cortical bone to actual perforation of the cortical bone).

Post-operative reduction score
Two case-control studies did not report an improved quality of the reduction of the fracture by using a 3D printed model (4) or a 3D printed drilling guide (16). Weighted mean reduction score was 86% (range 79-100) for 3D-assisted surgery and 82% (range 81-89) in the conventional group according to the Tornetta and Matta criteria (29).

Functional outcome
The two case control-studies did not report an increase in functional outcome using a 3D printed model (4) or intra-operative 3D imaging (17). Weighted mean rate of the Majeed score “excellent” and “good” for 3D-assisted surgery was 88% (range 82-100) and 83% (range 81-89) in the conventional group.

Best-evidence synthesis

Intra-operative results

Compared to conventional pelvic ring injury surgery, moderate evidence was found for a decrease in operation time per screw, operation time overall, blood loss, fluoroscopy dose and fluoroscopy time. The evidence for a decrease in fluoroscopy frequency was limited. Conflicting evidence was found for a decrease in screw malposition rate.

Post-operative results

Moderate evidence was found that fracture reduction as well as functional outcome did not improve using 3D assisted pelvic ring injury surgery.'

Table 5: Study outcomes

Measure	Study	3D technology	Groups (N)		Outcomes		
			3D	Conventional	3D	Conventional	P-value
Intra-operative results							
Operation time per screw (min) *Mean ± std or Mean ± (range)*	Berger-Groch et al. (14)	3D navigated iliosacral screw placement	100	36	48 ± 25	50 ± 29	0.74
	Chen et al.(23)	Minimally invasive screw fixation using the "Blunt End" kirschner wire technique assisted by 3D printed external template	28	-	21 ± 3	-	-
	Gao et al. (24)	Minimally invasive fluoro-navigation screw fixation	22	-	24 (16-45)	-	-
	Kim et al. (26)	Percutaneous iliosacral screwing using 3D-fluoroscopy	29	-	36 (18–83)	-	-
	Li. et al. (17)	Percutaneous screw fixation using three-dimensional (ISO-C3D) navigation	43	38	14 ± 1	19 ± 1	**<0.001**
	Pieske et al. (21)	CT-guided sacroiliac percutaneous screw placement	71	-	63 ± 39	-	-
	Takeba et al. (20)	O-arm and stealthstation navigation for screw fixation	10	-	39 (25–68)	-	-
	Yang et al. (16)	3D printed external template to guide iliosacral screw insertion	22	18	18 ± 5	40 ± 11	**< 0.001**
Operation time overall (min) *Mean ± std*	Cai et al.(4)	3D printing-based minimally invasive cannulated screw treatment	65	72	59 ± 13	72 ± 13	**< 0.001**
	Chen et al.(23)	Minimally invasive screw fixation using the "Blunt End" kirschner wire technique assisted by 3D printed external template	28	-	85 (60–150)	-	-
	Hung et al. (3)	Pre-operative virtual simulation and 3D printing-assisted contoured plate	16	14	206 ± 70	276 ± 90	**0.023**

	Li et al. (19)	Computer-aided angiography and rapid prototyping technology	81	76	105 ± 19	122 ± 23	**0.035**
	Privalov et al. (28)	Intra-operative CT in navigated sacroiliac instrumentation	25	28	189 ± 89	C^1: 153 ± 68 C^2: 201 ± 100 C^3: 127 ± 70	0.31 0.70 0.14
Blood loss (mL) *Mean ± std or Mean (range)*	Hung et al. (3)	pre-operative virtual simulation and 3D printing-assisted contoured plate	16	14	275 ± 197	549 ± 404	**0.023**
	Nie et al. (27)	3D printing assisted by minimally invasive surgery	30	-	31 ± 11	-	-
	Takeba et al. (20)	O-arm and stealthstation navigation for screw fixation	10	-	12 (0-120)	-	-
Fluoroscopy Dose *mean ± SD or mean (range) presented in the given unit*	Balling (6)	3D image guided sacral screw fixation via single-sided minimally invasive transgluteal approach	52	-	788 ± 632mGy/cm	-	-
	Beck et al. (22)	Intra-operative 3D fluoroscopy of iliosacral screws and lumbopelvic implants	14	12	181 cGy/cm^2 (90–424)	1376 cGy/cm^2 (485–2)	NA
	Ghisla et al. (25)	Intra-operative 3D-CT guided navigation for sacro-iliac screws	21	-	1918 mGy/cm	-	-
	Pieske et al. (21)	CT-guided sacroiliac percutaneous screw placement	71	-	Male: 6 ± 3 msV, range: 2-17; Female: 9 ± 3 msV, range: 1-28	-	-
	Yang et al. (16)	3D printed external template to guide iliosacral screw insertion	22	18	743 ± 231 cGy/cm^2	1904 ± 845 cGy/cm^2	**< 0.001**
Fluoroscopy time *(sec) mean ± SD or mean (range)*	Beck et al. (22)	Intra-operative 3D fluoroscopy of iliosacral screws and lumbopelvic implants	14	12	64 (60-71)	181 (54-340)	NA
	Berger-Groch et al. (14)	3D navigated iliosacral screw placement	100	36	99 ± 812	164 ± 166	**0.02**
	Gao et al. (24)	Minimally invasive fluoro-navigation screw fixation	22	-	22 (10 - 46)	-	-
	Kim et al. (26)	Percutaneous iliosacral screwing using 3D-fluoroscopy	29	-	84 (22–160)		
	Li. et al. (17)	Percutaneous screw fixation using three-dimensional (ISO-C3D) navigation	43	38	34 ± 2	58 ± 5	**<0.001**

	Privalov et al. (28)	Intra-operative CT in navigated sacroiliac instrumentation	25	28	82 ± 97	C1: 299 ± 374 C2: 243 ± 92 C3: 248 ± 191	**0.03** **0.00** **0.02**
Fluoroscopy frequency *number of times in mean ± SD or mean (range)*	Cai et al.(4)	3D printing-based minimally invasive cannulated screw treatment	65	72	29 ± 4	37 ± 3	**< 0.001**
	Chen et al.(23)	Minimally invasive screw fixation using the "Blunt End" kirschner wire technique assisted by 3D printed external template	28	-	35 (28–60)	-	-
Post-operative results							
Screw malposition rate *(%)*	Beck et al. (22)	Intra-operative 3D fluoroscopy of iliosacral screws and lumbopelvic implants	14	12	7	6	NA
	Gao et al. (24)	Minimally invasive fluoro-navigation screw fixation	22	-	2	-	-
	Ghisla et al. (25)	Intra-operative 3D-CT guided navigation for sacro-iliac screws	21	-	3	-	-
	Kim et al. (26)	Percutaneous iliosacral screwing using 3D-fluoroscopy	29	-	23	-	-
	Li. et al. (17)	Percutaneous screw fixation using three-dimensional (ISO-C3D) navigation	43	38	5	24	**0.015**
	Pieske et al. (21)	CT-guided sacroiliac percutaneous screw placement	71	-	1	-	-
	Takao et al. (15)	3D fluoroscopic navigation of iliosacra screw insertion	27	-	7	-	-
	Takeba et al. (20)	O-arm and stealthstation navigation for screw fixation	10	-	0	-	-
	Teo et al. (18)	Sacroiliac screw placement with and without intra-operative navigation	17	19	12	5	0.48
	Yang et al. (16)	3D printed external template to guide iliosacral screw insertion	22	18	3	14	**< 0.001**
	Berger-Groch et al. (14)	3D navigated iliosacral screw placement	100	36	14	21	0.09

Reduction according to Matta *(excellent + good in %)*	Cai et al.(4)	3D printing-based minimally invasive cannulated screw treatment	65	72	79	81	0.762
	Chen et al.(23)	Minimally invasive screw fixation using the "Blunt End" kirschner wire technique assisted by 3D printed external template	28	-	89	-	-
	Nie et al. (27)	3D printing assisted by minimally invasive surgery for pubic rami fractures	30	-	100	-	-
	Yang et al. (16)	3D printed external template to guide iliosacral screw insertion	22	18	86	89	1.000
Functional outcome *(Majeed excellent + good rate in %)*	Cai et al.(4)	3D printing-based minimally invasive cannulated screw treatment	65	72	82	81	0.884
	Chen et al.(23)	Minimally invasive screw fixation using the "Blunt End" kirschner wire technique assisted by 3D printed external template	28	-	82	-	-
	Li. et al. (17)	Percutaneous screw fixation using three-dimensional (ISO-C3D) navigation	43	38	92	89	0.637
	Nie et al. (27)	3D printing assisted by minimally invasive surgery for pubic rami fractures	30	-	100	-	-

NA, not addressed

DISCUSSION

No overview exists on the currently available 3D technologies and to what extent they contribute to the operative treatment of pelvic ring injuries. In this systematic review we evaluated outcomes of the complete spectrum of innovative 3D technologies applied for pelvic ring injury surgery over the past decade. Thereby, it provides a clinically question-driven overview about the ongoing debate whether these advanced 3D technologies contribute to the results of operations and patient recovery. It encompasses 18 articles, showing that previously applied 3D-assisted pelvic ring injury surgery can be divided in five main groups. These include '3D virtual fracture visualization and preoperative planning', '3D printed model assisted surgery', 'Pre-contouring of osteosynthesis material', '3D printed surgical guides', and 'Intra-operative 3D imaging'. The results reveal that the application of these technologies seem to have a positive effect on the operative treatment of pelvic ring injuries by shortening the duration of surgery, decreasing blood loss as well as fluoroscopy frequency, dose and time and minimizing risks on screw malposition. No difference in fracture reduction and functional outcome between 3D-assisted and conventional surgery was established.

Limitations of this systematic review are considered small patient groups and a wide range of methodological quality including a substantial number of moderate and poor-quality studies.

Hence, a best-evidence synthesis was performed which is a transparent and commonly applied method attempting to answer the key questions (31,32). Moreover, high heterogeneity between the studies was observed in terms of different outcome variables used. As a result, a limited number of comparative studies addressed all outcome variables of interest.

Our first question concerned the effects of 3D-assisted surgery on intra-operative outcomes including operation time, blood loss, fluoroscopy time, dose and frequency as well as screw malposition. The results of this systematic review reveal some potential intra-operative advantages by using 3D-assisted surgery. Overall, operative time can be reduced by using 3D printed models. This is in line with a meta-analysis performed by Zhang et al. (33). Additionally, operation time per screw is shown to be decreased using 3D navigation in percutaneous sacroiliac screw placement. One case-control study showed that blood loss might be reduced by using 3D printing assisted contoured template compared to conventional surgery (3). Fluoroscopy time can be effectively reduced by using 3D techniques as shown by three case-control studies (14,17,28). Moreover, fluoroscopy dose and frequency might be reduced, although more studies are needed to actually draw conclusions with regard to these outcome measures. The majority of the articles (13 out of 18) in our systematic review reported on use of 3D navigation for percutaneous screw placement. Based on these results, we may cautiously conclude that 3D navigation tends towards a decrease in screw malposition, although larger comparative studies are needed. This is in line with the systematic review and meta-analysis by Zwingmann et al. (10).

Our second research question concerned the effects of 3D-assisted surgery on post-operative outcomes including fracture reduction and functional outcome. According to the reduction score by Tornetta and Matta, no difference could be found by using 3D-assisted surgery in comparison with conventional surgery. However, to date reduction measurements in pelvic radiographs have not been validated and interobserver reliability has shown to be poor (34). Moreover, no evidence for improved functional outcome was found using 3D-assisted surgery for pelvic ring injuries. Nonetheless, only a limited number of studies with different methodological quality reported on these outcome measures after iliosacral screw fixation. Hence, future high-quality comparative studies on all five 3D techniques are needed to clarify whether post-operative reduction and functional outcome may benefit from 3D-assisted surgery.

CONCLUSION

Overall, five different techniques of 3D-assisted surgery were identified and are currently in use for pelvic ring injury treatment. These included '3D virtual fracture visualization and preoperative planning', '3D printed model assisted surgery', 'Pre-contouring of osteosynthesis material', '3D printed surgical guides', and 'Intra-operative 3D imaging'. These 3D-based techniques offer additional tools to improve intra-operative efficiency in terms of operation time, blood loss, fluoroscopy dose, time and frequency as well as accuracy of screw placement. However, improved anatomical reduction or functional outcome following 3D-assisted surgery has not been established so far. Due to the heterogeneity of the included studies in terms of methodological quality and number of studies that evaluated each of the outcomes of interest, results should be interpreted with caution. Future high-quality comparative studies are necessary to further establish possible advantages of 3D-assisted surgery in the treatment of pelvic ring injuries.

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SUPPLEMENTARY FILE 1. Overview of 3D assisted surgery techniques

Overview of 3D assisted pelvic ring injury surgery

Five applications of 3D technology in pelvic ring injury surgery were identified: '3D virtual fracture visualization', '3D printed model', 'Pre-contouring of osteosynthesis material on a 3D printed model', '3D printed surgical guides', and 'Intra-operative 3D imaging'. Some studies combined these techniques.

1) Pre-operative 3D virtual fracture visualization

Five studies [16,22,26,9,21] reported on the use of a virtual 3D model for visualization of the fracture(s). This is the basic method utilizing 3D in which the first step is 'segmentation', representing the process whereby CT data is processed. The pelvis is then identified and converted into a digital 3D model. Examples of software that allow for the production of these 3D models are Mimics Medical software (Materialise, Leuven, Belgium) or OrthoMap 3D (Stryker, Kalamazoo, MI, USA). A virtual 3D fracture model allows for detailed evaluation of the fracture pattern, implant selection and basic virtual surgical planning. Virtual screws can be superimposed on the 3D virtual model for pre-operative planning of screw positions, lengths and directions. Takao et al. [21] used the navigation unit of OrthoMap to plan screw positions, which can be adjusted before the actual surgery to keep a safety margin from the nerve root tunnels in S1 and S2. The virtual screws were subsequently superimposed on the 3D virtual model. Besides, Nie et al. [16] used Mimics software to determine the position of the osteosynthesis plate.

2) Pre-operative 3D printed model

Four studies [13,4,16,9] described the usage of a 3D printed model based on the CT scan of the injured pelvis. While 3D virtual models usually provide the surgeon with more information compared to regular CT imaging, 3D printed real-sized models provide surgeons with a tactile feedback of the volume, size and orientation of bone fragments. By understanding the fracture pattern, the optimal surgical approach, reduction technique, and screw trajectories can be planned. Depending on the used materials, some models can also be sterilized and brought to the surgical field. The models were used pre-operatively as a reference for surgeons to assess fracture characteristics and the degree of displacement. Besides, Li et al. [13] designed a 3D printed model including the arteries and veins. These 3D printed models were used to predetermine the optimal operative approach, fracture reduction strategy as well as shape and length of the plate. Besides, the 3D printed models in these studies were also used to predetermine the entry point, angle, amount and length of screws. This was done by simulating the surgery using actual screws. By using the contralateral healthy hemi-pelvis as a reference, Cai et al. [4] simulated the reduction procedure with Kirschner wires (K-wires). The K-wire was used to simulate implantation of the cannulated screw.

3) Pre-contouring of osteosynthesis material

Two studies [16,9] reported on the use of a 3D printed model for pre-contouring of osteosynthesis plates in order to improve implant positioning. To allow for this technique, a 3D printed mirrored image of the opposite intact hemi-pelvis is generated. The printed model is then used to determine the optimal implant sizes and length. Subsequently, the plate is contoured in order to optimally fit the patient-specific pelvic model. Nie et al. [16] also performed a simulated operation on the 3D model. Finally, the pre-contoured osteosynthesis plate is sterilized according to predefined protocols and applied during surgery.

4) 3D printed drilling guides

Two studies [26,5] designed and applied 3D printed surgical guides for sacroiliac screw placement. At the damage control phase an external fixator was applied and after initial stabilization a CT-scan was obtained for preoperative planning of definitive surgery. The external fixator pins were used as a reference to design a drilling guide for sacroiliac screw placement. A virtual 3D screw trajectory was simulated after which a drilling guide was designed in order to translate the virtual surgical plan to the actual surgery. Subsequently, the external templates were 3D printed using photosensitive resin material and sterilized for intra-operative use. After satisfactory fracture reduction during surgery, the drilling guide was firmly assembled to the external fixator pins. Subsequently, a K-wire was inserted through the drilling guide according to the preoperative plan. Standard fluoroscopic control was performed to verify the direction of the K-wire. Subsequently, the drilling guide was removed and a cannulated screw was inserted along the K-wire.

5) Intra-operative 3D imaging

The vast majority of the studies [2,6,3,20,10,14,18,7,22,23,1,21] used a 3D technique for intra-operative imaging. This was largely done during the placement of screws with a 3D fluoroscope or O-arm to verify the correct direction and depth of the guide wire pins or screws [10,7,22,23,1,3,20]. Other studies used the 3D fluoroscope or O-arm to verify the correct position after screw placement [2,18,1]. Using this technology, the surgeon will be able to make per-operative decisions based on 3D instead of 2D fluoroscopy images. In case of dissatisfaction with the fracture reduction or the position of the screw, the surgeon can decide immediately during the operation to perform a revision of the implant positions. Three studies [6,14,21] used 3D computer-assisted navigation of screws by using reference markers fixed near the surgical site, often the iliac crest, to relate anatomical locations and instrumentation. By matching these trackers with the navigation system, 3D real-time position of guides and screws could be visualized.

Chapter 9

General discussion

SCOPE AND AIM

Pelvic ring injuries vary from simple undisplaced ring fractures to severe and life-threatening comminuted fractures. They can strike people of all ages and are challenging to treat due to their complex fracture morphology. The goal of pelvic ring injury treatment and rehabilitation is that patients will return to their original level of physical functioning and quality of life. Although X-rays and CT scans are important supporting imaging modalities to follow up on the recovery in terms of fracture healing, the patients' own perception on health should play the central role in treatment. The general aim of this thesis was to gain more insight into the patient's perception of functional recovery and quality of life(QoL) following pelvic ring injuries. Therefore, this thesis used patient-reported outcome measures (PROMs) to provide an overview of short- as well as long-term outcomes after pelvic ring injuries.

This thesis was divided into three parts. The first part (**chapters 2-4**) aimed to evaluate physical functioning and quality of life after pelvic ring injuries in adult patients. A systematic review of the literature was performed that provided information about current knowledge on patient-reported physical functioning and QoL following pelvic ring injuries (**chapter 2**). This review showed that current studies have too many important limitations to actually draw valid conclusions. Small sample sizes, inclusion of heterogeneous types of injuries and treatment strategies, varying follow-up durations and the use of not validated PROMs hampered to elucidate the true effects of the injury and following treatment on the patients' life. **Chapter 3** evaluated long-term perceived physical functioning and QoL after pelvic ring injuries by performing a retrospective cohort study. The result of this study showed fair physical functioning and QoL and no differences between patients with type A, B or C pelvic ring injuries at a mean follow-up of 4.4 (SD 2.6) years following the injury. However, comparison of the results to normative data of the general Dutch population revealed a significant decrease in physical functioning and QoL in all injury types. A prospective study was performed and presented in **chapter 4** to clarify on the patient's short-term rehabilitation phase up to two years after the pelvic injury. This study showed that a large group of patients had not yet returned to their pre-injury level of physical functioning and QoL at two years after the injury. Female gender, a high-energy trauma and operative treatment were identified as independent predictors for patients not reaching their pre-injury level of physical functioning and QoL. Besides the effect on physical functioning, a pelvic ring injury showed to have a substantial effect on the mental health of these patients. After three months and one year, a substantial part of the patients reported feeling severely bothered by their physical disabilities.

The second part of this thesis (**chapters 5-7**) aimed to specifically investigate the impact of pelvic ring injury on the elderly patient over 65 years of age. A large retrospective cohort study was performed (**chapter 5**). Elderly patients showed to be a fragile population with substantial mortality rates of 20% at 30 days, 27% at 1 year and 41% at 3 years of follow-up and a significant decrease in physical functioning and QoL compared to their age-matched peers from the general Dutch population. **Chapter 6** focused on fragility fractures of the pelvis (FFPs), defined as pelvic ring injuries occurring in elderly patients after a low-energy trauma. Our retrospective multicenter cohort study showed that FFP type I and II are most common and their treatment has been mainly non-operative over the past decade. Although mobility after six weeks was shown to be good, mortality rates at one year were substantial reaching up to 47%. Moreover, physical functioning and QoL was about 20-30% decreased compared to that of the general Dutch population. Based on this study, multidisciplinary treatment protocols are proposed including involvement of a geriatrician, physiotherapist and dietician in order to optimize the health of these frail patients. In **chapter 7** muscle quantity and quality were evaluated in the elderly patient with a pelvic ring injury by means of a multicenter retrospective cohort study. About half of

patients suffer from sarcopenia or myosteatosis which is associated with high mortality rates. However, it could not be proven that sarcopenia and myosteatosis are independent risk factors for decreased physical functioning and QoL.

The aim of the last part of this thesis (**chapter 8**) was to give insight into future treatment strategies for patients with pelvic ring injuries, with the ongoing development of three-dimensional (3D) operative techniques. A systematic review on current scientific literature was performed to assess differences in patient outcomes between 2D and 3D treatment techniques. 3D techniques proved to decrease operation time, blood loss and increase accuracy of screw placement. However, no superiority of 3D treatment techniques in terms of patient-reported physical functioning and QoL could be established.

The present chapter provides an overview and discussion of the main findings of this thesis. The results are examined in a broader perspective and practical implications and future perspectives are discussed.

PART I: INSIGHT INTO THE PATIENT'S HEALTH PERSPECTIVE

Over the past decade, there has been a **shift towards the use of patient-reported outcome measures (PROMs).** Evaluation of healthcare interventions in pelvic ring injury treatment has traditionally focused on objective measures such as radiographic imaging, joint range of motion and mortality. However, many factors that characterize a patient's health status cannot be observed or analyzed with a device. These traditional objective outcome measures have shown to correlate poorly with the patient's own perception on physical functioning and QoL (1). How a patient performs and feels remains largely impenetrable to devices (2). Some types of pelvic ring injuries may look highly unfavorable on radiographic imaging, but the patient may grade his physical functioning and quality of life fairly well, or the other way around. Over the past decade, physicians have become increasingly aware of the importance of the patient's own perception of health. Patient-reported outcome measures (PROMs) can be useful tools to assess complex matters like recovery of physical functioning and QoL. These measures, directly reported by the patient, are increasingly being considered and used as part of health (intervention) evaluations. PROMs directly reflect the impact of the injury and its treatment from the patient's perspective and can measure the tradeoff between efficacy of the treatment and what the patient is willing to tolerate. They include symptoms and other aspects of health such as physical or social function, QoL and satisfaction with treatment (2). PROMs are especially valuable when physical functioning and QoL are important outcomes of concern. By reflecting the patient's perspective, PROMs have the potential to facilitate patient involvement in treatment decision-making and to provide guidance for healthcare decisions. Although imaging modalities such as X-ray or CT will remain relevant for a proper understanding of the injury and its healing process, they should not serve as the gold standard in terms of measuring effectiveness of treatment.

Recommendation:

PROMs and not imaging modalities like X-rays and CT should serve as the gold standard to determine patient recovery after pelvic ring injuries

Before the introduction of PROMs, the focus was more on production of healthcare (e.g. the number of surgeries performed) instead of capturing the patient experience – ideally, the patient benefit (3). Optimally, PROMs outcomes of each patient would need to be available in real time. By comparing the results to those of their healthy peers, patients might be more actively engaged in striving for health outcomes like full rehabilitation. Clinicians reviewing these PROMs will need

to be able to interpret these results in the context of treatment decisions and evaluation. PROMs outcomes may aid clinicians to quickly identify which of their patients experience improved or deteriorated health outcomes over time. This will highlight any consistent patient complaints, which would suggest refinements to care pathways (3). For a PROM to be a valuable tool for outcome assessment, they should be reliable and valid. Reliability and validity are important psychometric properties of a PROM. Reliability is the extent to which a measure yields similar results each time it is administered while the construct being measured has not changed. Validity refers to the extent to which an instrument measures what it was intended to measure and not something else (2). With the growing focus on patient-reported outcomes, there was an increasing need for high-quality measurement instruments, which resulted in the development of multiple instruments. Where generic PROMs tend to measure a variety of healthcare conditions at once, there is also a wide range of disease-specific PROMs available. In the systematic review presented in **chapter 2** of this thesis, all the currently used generic and disease-specific PROMs after pelvic ring injuries have been discussed. A staggering number of nine different PROMs were used of which five were generic and four disease-specific. Moreover, none of the disease-specific PROMs were validated. This limits the contribution of these studies to clinical practice and also complicates the comparison of results between studies. Of the five generic PROMs, two assessed physical functioning and three assessed QoL. All are validated for the use in patients with pelvic ring injuries. An additional advantage of a generic PROM is that it enables comparison to normative data, as these data are often available for different (inter)national populations.

Recommendation:

As long as no pelvic-specific validated PROM is available, generic validated PROMs should be used.

Of all the pelvic-specific outcome scores, the**Majeed Pelvic Score (MPS) served as the holy grail in pelvic ring injury assessment.** The MPS was, and still is, the most frequently used outcome measure for pelvic ring injuries. It was developed by the name giver in 1989 (4) and assesses five factors: pain, standing, sitting, sexual intercourse and work performance. Patients can score up to a maximum of 100 points, with higher scores indicating better function. Originally, Majeed provides scores categorized into excellent, good, fair and poor, weighted by work status. For patients not working at the time of the injury, 20 points normally assigned to work activity is removed and thus a maximum score of 80 can be obtained (4). The MPS is often used as a PROM, even though it actually is a physician-administered questionnaire. The domain 'standing' is objectified by the physician and is divided into three categories: walking aids, unaided gait and walking distance. The other domains are completed together with the patient. An important limitation of the MPS is that it has not been validated until today. A possible explanation for its frequent use could be the compact length and the ability for comparison of results to other studies. Multiple inaccuracies in the use of the MPS recently came to light (5). Only 26% of studies that used the MPS to assess outcomes after pelvic ring injuries included methodology on the scoring and only 7% reported scores for patients not working as adjusted to a maximum of 80 points. Moreover, only 11% of articles categorized from excellent to poor following the original guidelines provided by Majeed. Due to the 30-year time lapse since its creation and the high variability and potentially inaccurate reporting of the MPS, results should be interpreted with caution and literature should only be compared if the methodology is clear. For the Lithuanian population, the MPS was recently tested for psychometric properties (6). Although the MPS showed limited ability to measure functional outcome two months after a pelvic ring injury, it can potentially be used after one year of follow-up. Further studies on psychometric properties should provide more insight into the value of the MPS for the evaluation of physical functioning after pelvic ring injuries. Recently, attempts have been made to introduce a new outcome measure

for the evaluation of pelvic ring injuries. At the end of 2020, the New Pelvic Score System was proposed (7). It includes six categories: pain, work, sexual function and sexual satisfaction, balance-sitting-walking, and psychological status, overlapping both the constructs measured by the MPS and the Short Form-12 (SF-12), a generic measure for overall QoL. The new score showed some favorable qualities compared to the MPS and SF-12 with generally less time needed to complete the score, a high correlation with the injury classification by Tile and higher inter-observer as well as intra-observer agreement. However, similar to the MPS, it is a physician-administered questionnaire with associated limitations. Most importantly, there is a risk of "social desirability bias", a form of response bias in which a respondent will choose socially acceptable answers, rather than to reply truthfully. This has already showed to result in over reporting and thus overestimation of physical activity (8). The limited time available in the doctor-patient setting may be an additional factor that can lead to inconsiderate answers by the patient.

Recommendation:

Patient-reported outcome measures should be preferred over physician-administered questionnaires

Some of the limitations of current research that came to light in **chapter 2** were addressed in **chapter 3.** By performing a large retrospective cohort study, differentiating in AO injury types and including also the long-term (>5 years) follow-up, we wanted to gain more insight into the consequences of pelvic ring injuries on the patients' daily life. Moreover, validated PROMs were used and the outcomes were compared with normative data. Even at long-term, physical functioning and QoL of these patients turned out to be decreased compared to their peers. This was especially the case in patients aged 30 years or older. Even though young patients (<30 years old) sustained more frequently severe type C injuries, no significant differences were found in perceived physical functioning and QoL between the young and older age groups. This finding is in line with another recent study (9). It is interesting to speculate on an explanation and it could be two-sided: 1) older patient suffer from more comorbidities with especially decreased rehabilitation capacities in patients >65 years old, and 2) younger patients may have better coping mechanisms to deal with the challenges they face after the pelvic ring injuries. A few other recent studies evaluating outcomes after pelvic ring injuries dealt with some of the limitations addressed in **chapter 2,** using validated PROMs (although next to the MPS) at long-term follow-up (9,10) and differentiating between injury types using the widely used AO classification (8). Comparable scores were found for physical functioning and QoL (9) and scores were also significantly decreased compared to normative data (10). Patients with posterior ring injuries report worse scores compared to patients with anterior ring injuries (10). Also, residual displacement of the sacroiliac joint and symphysis pubis can both affect physical functioning next to associated injuries. Comparable to our findings, no association between method of treatment (operative vs. non-operative) and outcome has been shown (10).

Although studies focusing on outcomes after specifically type A and type C pelvic ring injuries remain scarce, **type B injuries have been widely assessed in recent literature**, in particular type B2.1 (lateral compression injuries type 1; LC-1). This type of fracture is characterized by a lateral force usually leading to pubic rami fractures of the anterior pelvic ring and sacral compression fractures without vertical instability. The fact that these injuries are often the subject of interest is not surprising, as LC-1 injuries represent the most common type of pelvic ring injury with a reported prevalence of as much as 63% of all pelvic ring injuries at all ages (11). There is no general consensus on the (in)stability of these injuries and thus controversy exists worldwide whether these injuries should be treated operatively or non-operatively. The recent studies focusing on outcomes after these type B injuries report similar outcomes after operative and non-operative treatment (12–15),

although pain and functional outcome can be slightly improved after operative treatment in patients with fracture displacement over 5 mm (16). Furthermore, physical functioning is decreased in patients that use an assistive walking device prior to the injury (17) and about a quarter of patients not utilizing assistive ambulatory devices prior to their injury necessitate these at long-term follow-up. Increased age, complications and falls within 30 days after the injury are associated with the continued use of assistive walking devices.

Recommendation:

Subgroup analysis of patients with type A, B and C pelvic ring injuries can help to gain more insight into the effect of injury severity on patient outcomes

Besides the effect of a pelvic ring injury on physical functioning in general, **it is not uncommon that sexual function is affected**, although only sparsly investigated. Recent studies shined a light on sexual dysfunction, uncovering rates of 25-62% in females (18) and between 37% and 53% in men (19,20). The highly unstable vertical shear injuries turned out to be the most frequently associated with erectile dysfunction in men, which is independently associated with a decrease in QoL (20). On the other hand, anterior-posterior compression injuries are most commonly associated with sexual dysfunction in both men and women (21). Next to erectile dysfunction, urinary dysfunction can also be present and can even get worse over time (22). Injury severity and severe pelvic ring injuries (type C) can predict urinary dysfunction in men, while urinary tract injuries at admission is a common predictor in women (22). Concerning sexual dysfunction, neurologic injury and anterior fixation of the pelvic ring are significant predictors in men, whereas urological injuries are important in predicting female sexual dysfunction (22). Sexual function and sexual bother are both important predictors of overall mental well-being in men. These findings suggest that sexual and urinary dysfunction deserve special attention and that sexual health should be included in the standard evaluation of outcomes after pelvic ring injuries. In this way, it is possible to get a better understanding of the problem, as well as to provide potential methods for rehabilitation. A multidisciplinary team with gynaecological, urological and psychological expertise may benefit patients with sexual dysfunction.

Recommendation:

Evaluation of sexual health should be incorporated in patient-centered care pathways after pelvic ring injuries

The study presented in **chapter 3** showed that patients of all age groups and with all types of pelvic ring injuries suffer from decreased physical functioning and QoL compared to normative data. Still, the retrospective nature of that study made it difficult to figure out the actual cause of this decreased physical functioning and QoL. Did patients already experience deteriorated physical functioning and QoL prior to the injury? Hence, performing prospective studies including the recalled pre-injury score seemed mandatory to evaluate the actual outcome after pelvic ring injuries. This was done in **chapter 4**, by performing a large two-year prospective cohort study including the recalled pre-injury score. This study showed that physical functioning and QoL decrease strongly six weeks to three months after the injury, but then increase at least up to two years after the injury. One year and two years post-injury, 61%, respectively 75% of patients were fully recovered (i.e. regaining the pre-injury level) in terms of physical functioning. Patients were not only bothered by physical inabilities, but also the **mental effects of the injury**. After one, respectively two years, only 65% and 68% recovered in the domain 'mental and emotional problems'. Moreover, concerning QoL, 52% and 71% fully recovered after one and two years. About 40%, respectively 30% of patients, reported to experience difficulties with the mental

effects of the injury after three months and one year such as feeling physically disabled. Female gender, high-energy trauma and operative treatment were all strong independent predictors for patients not fully recovering at one year.

Several other recent studies included the important assessment of baseline PROMs (23–25). Similar to what we found, physical functioning seems most decreased around three months after the injury and similar SMFA scores have been reported after three months and two years of follow-up (23). Long-term follow-up revealed that although patients get close to full recovery, most did return to baseline scores five years after the injury (24), although patients with type B injuries seem to have improved outcomes compared to patients with type C injuries (24). Next to problems with physical inabilities, we found that patients were just as bothered by mental and emotional effects in the first year after the injury, a finding that is supported by other recent literature (25,26). In patients with type C injuries, functional outcome and mental wellbeing (in terms of depression and anxiety) were negatively correlated (26). Alcohol use and pain level were high in the first year following a pelvic ring injury compared to baseline, and the decrease in physical functioning and mental health indicateted a lowered QoL (25). Compared to the general population, patients that sustained a pelvic ring injury had higher levels of posttraumatic stress disorder (PTSD), depression and problematic alcohol use one year after the injury (25). These findings suggest that the patients' mental health condtion should be treated in posttraumatic rehabilitaiton in case the results of the PROM reveal its necessity. A psychologist can possibly be a valuable addition to the multidisciplinary team.

Recommendation:

Addressing the patients' mental health should be integrated in the posttraumatic care after pelvic ring injuries

The mental aspects of a pelvic ring injury can possibly be linked to 'resilience', which is a positive adaptation to return to a healthy condition after a stressful situation such as an accident or illness (27). It represents the ability of a person to successfully adapt to change, thereby resisting the negative impact of stressors. The higher the resilience, the more focus on personal strengths and qualities and the lower the vulnerability. Resilience can be strengthened, contributing to the advancement of health (27). Through the need for a dynamic description of health that highlights the human capacity for reslilience and coping with new situations, **the concept of positive health** has been introduced in 2011 by Huber et al. (28). The concept is as follows: 'Health as the ability to adapt and to self manage, in the face of social, physical and emotional challenges'. It involves the patient's own perception of functioning and participation and was proposed because the traditional WHO definition of health ('Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (29)) was considered no longer adequate. In the concept of positive health, the patient is more than his illness and the focus is on the patient's strength, rather than on his weakness (30). The concept of positive health can be measured using the 'spider web' including six dimensions: 1) bodily function, 2) mental functions and perception, 3) spiritual/existential dimension, 4) quality of life, 5) social and societal participation and 6) daily functioning (figure 1).

Positive health should receive attention to improve patient communication and shared decision-making. The web diagram can be an instrument to help clarify in which domain the patient wishes to improve his or her situation. This approach might be empowering for the patient, being in charge of his own health or in other words to 'self-manage'. Consequently, the actions undertaken by patients to act on certain aspects of health should be the subject of interest in future research to evaluate whether physical functioning, QoL, as well as coping abilities or 'resilience' improve.

Huber et al. recommend the development of a validated measurement for the various dimensions and aspects of 'positive health' (30). In the wish to develop a reliable and valid instrument for the assessment of pelvic ring injuries, the concept of Huber et al. can inspire to integrate all dimensions and evaluate the patient recovery through a holistic approach.

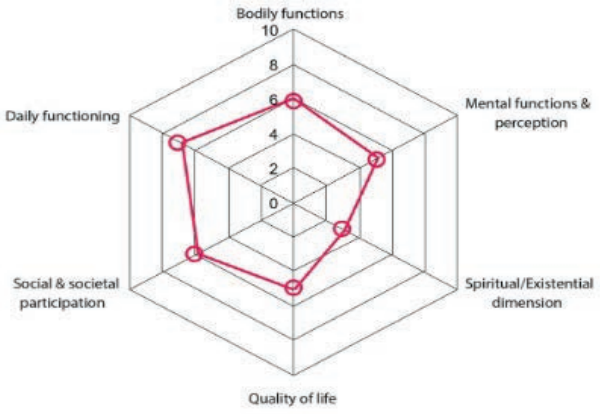

Figure 1. *The six dimensions of health on a subjective scale, indicating a fictional estimation of a person's state of 'positive health'* (30)

Recommendation:

The concepts of resilience and positive health can inspire physicians in a holistic approach towards the assessment of pelvic ring injury rehabilitation and help patients to stay in charge of their own health

PART II: ZOOMING IN: SPECIFIC ENTITITIES OF PELVIC RING INJURY IN THE ELDERLY

Pelvic ring injuries in the elderly differs from pelvic ring injuries in the younger patients. As elderly patients are more prone to a fall from ground level and possibly have deteriorated bone quality, there is obviously an increased risk of a pelvic ring injury as a result of a low-energy trauma. On the other hand, elderly patients may have lower demands regarding their level of physical functioning due to their age and general physical decline. In **chapter 5**, the characteristics of pelvic ring injury in elderly patients aged 65 years and older were evaluated. Results revealed high mortality rates of 10% on the day of injury, 20% within 30 days, 27% within one year, and 41% within three years. Patients over 85 have severely decreased survival with 71% of patients passed away at final follow-up of 10 years after the injury compared to 37% (65-75 years) and 52% (75-85 years). When comparing mortality rates of these patients to those of their Dutch peers, mortality of patients sustaining a pelvic ring injury was highly increased. Higher age, injury type C as well as the injury severity score (ISS) turned out to be independent risk factors for mortality. Physical functioning and QoL were both decreased at a mean follow-up of 3.4 (SD 2.7) years compared to normative data. Thirty percent of patients needed to be admitted to a nursing home after leaving the hospital.The elderly population has been, and still is increasing worldwide. Due to prolonged and increased mobility of the elderly, the risk of injury is also increasing. Since 1993, the rate of elderly patients sustaining an injury increased every year by 1.7% (31). Elderly often have inferior pre-injury functional capacities and diminished physiological reserves compared to younger patients. While younger patients often sustain high-energy trauma like traffic accidents, mechanisms of injury in the majority of elderly patients (64%) are low-energy trauma (31,32). Still, about 40% of severely injured patients are elderly (31) and close to half of all polytrauma patients (patients with an ISS greater than 15) are older than 60 years (32). Moreover, older polytrauma patients are more at risk of sustaining serious head injuries and have

doubled mortality rates (32). Although it has been suggested that the "wait and see approach" that is frequently applied in the elderly should be transformed into more aggressive treatment to improve outcome (31), no real evidence exists for this approach when it concerns pelvic ring injuries.

Recommendation:

Elderly patients may be frail and can present with severe injuries even after minor trauma. Clinicians should be aware of their vulnerability when presenting to the trauma department

Fractures occurring after low-energy trauma are often caused by diminished bone quality, for example as a result of osteoporosis, and can lead to disability. Thus, **fractures should be prevented from (re)-occurring** if possible. Appropriate treatment during post- fracture care, can help prevent new fractures from occurring (33). Experimental programs have been performed in patients aged 50 years or older with a low-energy fracture of the pelvis, hip, vertebra, wrist or humerus. Based on future fracture risk, treatment was initiated that consisted of at least one of the following: 1) started on osteoporosis medication, (2) referred to an osteoporosis consultant, or (3) assessed for treatment change if they were already on osteoporosis medication at the time of the fracture. By coordinating a fracture prevention program, the odds of applying the appropriate treatment increase by almost four times. Besides, patients that entered the program were almost four times more likely to complete bone mineral density testing, and 25 times more likely to complete osteoporosis blood testing. The program can also help to enroll patients in fall prevention assessment (33). Next to fracture prevention programs, initiatives have been taken on **multifactorial intervention programs** for elderly patients after various types of fractures. In patients with related hip fractures, standardized care pathways revealed that preoperative fasting time and length of hospital stay could be reduced (34), but that functional outcome after six months remained unchanged (35). The pathway consisted of adaptions in protocols regarding the emergency room (ER), ward, operating room, at discharge and in the outpatient clinic. Among others, the focus was on limiting the time in the ER, standardized nursing protocols, fixed operating times and treatment protocols, multidisciplinary rehabilitation programs and a special hip fracture outpatient clinic. Other intervention programs revealed that the number of readmissions within 30 days after discharge can be reduced (36) and that gait recovery can be improved by home exercise targeted gait and balance training delivered by a physiotherapist in primary healthcare (37). Furthermore, next to physical exercise programs, education on nutrition even showed to reduce mortality (38). A recent randomized controlled trial (RCT) for multifactorial intervention for patients with hip fractures and pelvic ring injuries has been proposed (39). It includes a four-month intervention consisting of an individually tailored, progressive home exercise program and long-term counseling that addresses unmet care needs, recreational activities and caregiver issues if needed. The results of this RCT are supposed to not only give insight into functional performance, but also in secondary parameters such as fear of falling, fall-related self-efficacy, QoL, depression and ADL. These findings can contribute to building a pathway of care for elderly patients with pelvic ring injuries.

Recommendation:

The elderly patient with a pelvic ring injury is likely to benefit from multidisciplinary care pathways similar to those for hip fractures which should be tested for effectiveness

A specific entity of pelvic ring injuries can be seen in elderly patients with a low-energy trauma, called fragility fractures of the pelvis (FFPs). **Chapter 6** zoomed in on this type of pelvic ring injury, that were treated non-operatively in 98% of patients. Of the four types of FFPs, ranging

from type I (least severe) to type IV, type I was most common accounting for 60% in the study population. These resulted in a high rate (70%) of patients being able to walk after six weeks. Osteoporosis or osteopenia were frequently present in these patients, which confirms the outcome that the trauma that precedes these fractures would normally be too low to fracture normal bone. Sixteen percent of patients died within the first year following the pelvic ring injury. Moreover, physical functioning and QoL were decreased with 27%, respectively 20%, compared to normative data. Type II FFPs also resulted in 80% of patients being able to walk after six weeks, mortality was similar to type I (16%) after one year. Physical functioning and QoL were both 20% decreased compared to normative data. Type III and IV FFPs are relatively rare and about half of these patients were able to walk after six weeks. Mortality rates were high after one year with 69% in patients with FFP type III and 33% in FFP type IV.

Literature on FFPs is increasing and numerous studies have recently been performed. However, some contradictive results have been found, such as the presence of mostly type II injuries, instead of type I (40). Moreover, where our study showed that walking abilities were mainly good after six weeks, some other studies reported worse outcomes (40). For instance, one study reported that one year after the injury, only 40% of patients maintained standing ability similar to their pre-injury status, 36% maintained walking ability and 38% maintained walking distance ability (40) . The lack of walking capacity can result in a loss of independence with a significant decline in physical function and, subsequently, a high risk of institutionalization (41). This can lead to a serious, long-lasting deterioration of patient-reported QoL and activities of daily living, comparable to that of patients with hip fractures (42). The pre-injury level of nursing care, mobility, general medical status and age revealed to be independent predictors for decreased activities of daily living and QoL. Simultaneously, QoL shows to be improved in male patients as well as when more time has passed since the injury (42). The latter could be related to the so-called 'healthy worker effect', a phenomenon that refers to 'the consistent tendency of the actively employed to have a more favorable mortality outcome than the population at large' (43). In the context of functional outcome after pelvic ring injuries, it could mean that there is a bias regarding outcome evaluation. Given the fact that it is likely that patients with deteriorated health passed away within a shorter period of time after the injury, they cannot be included in follow-up analysis with PROMs. The "healthy" patients who survive and remain available for follow-up analysis can thus give a distorted image of the actual outcomes following (pelvic ring) injuries.

Based on the work by Rommens et al. (44), a **multidisciplinary treatment protocol** was proposed in **chapter 6** that could help to improve the care pathway for patients with FFPs. In this protocol, an recommendation is provided on type of treatment (operative vs. non-operative), depending on the type of injury. Although another protocol has recently been published (42), it is not nearly as comprehensive, as it only advises on operative vs. non-operative treatment. Treatment for FFPs goes beyond deciding on operative or non-operative treatment and should include aftercare with consultation of other physicians and paramedics to optimize treatment. Moreover, extensive metabolic assessment is included in the protocol, in order to recognize osteoporosis and secondary contributors to impaired bone healing, with appropriate treatment where necessary. Recent findings suggests that teriparatide, a medicine based on human parathyroid hormones that is used in osteoporosis treatment, can improve physical performance after pelvic ring injuries (45). Although fracture healing was not improved and pain was not reduced, the findings are hopeful and future studies with larger groups of patients need to provide more insight in the positive effects of osteoporosis treatment in patients with pelvic ring injuries.

Recommendation:

The proposed multidisciplinary treatment program for fragility fractures of the pelvis should be tested for its potential effectiveness on pelvic injury outcomes

The debate on the optimal treatment for FFPs is still a topic of interest among surgeons, given the extensive number of recent publications on this subject. Still, it seems that no consensus is reached regarding the treatment of these fractures. In line with our findings, most FFPs are reported to be treated non-operatively (40) although some authors suggest that a more aggressive indication of operative treatment should be considered following the guidelines defined by Rommens et al. (44). Varying effects on mortality have been described after non-operative and operative treatment. Some revealed lower mortality rates after operative treatment (46), some showed higher mortality rates within the first two years but lower rates at long-term(47) , and some did not find any differences at all (48). After operative treatment, more complications, higher pain levels at follow-up and dependency in terms of activities of daily living can occur (46). Mobility was improved in one study after operative treatment of FFPs type III but not type IV (48), whereas another study revealed decreased mobility after operative treatment (46). So far, no improvement in physical functioning and QoL could be revealed after operative treatment (42,43,44). Further research is necessary to determine indications for operative treatment.

In the fragile elderly patients, not only osteoporosis is a relevant comorbidity that deserves special attention. A possible explanation for a decreased physical status in the elderly might be the **loss of skeletal muscle mass and strength (sarcopenia)** and an **increase in inter- and intramuscular fat (myosteatosis**). Impaired lower extremity function as a result of sarcopenia and myosteatosis may increase the risk of falls. In elderly patients, pelvic ring injuries are frequently caused by low-energy trauma such as a fall from ground level. Myosteatosis has already been related to an **increased risk of falls** (49). Due to fatty infiltration of skeletal muscle, age-related losses in skeletal muscle function appear to occur, resulting in loss of muscle strength and reduced lower extremity performance. These confer into increased risk of loss of mobility, falls and skeletal fractures (50). Fatty infiltration into muscle is also associated with metabolic disorders that may increase risk of falling owing to impaired vision and/or limb pain (50). In addition, impaired muscle strength and reduced physical function may cause loss of bone strength owing to lower skeletal loading from reduced weight bearing and muscle loading. In patients with muscle weakness, the odds of falling is almost two times higher and the odds of recurrent falls is almost three times higher. Besides, muscle weakness also increases the odds of serious falls (51). There is evidence that myosteatosis is associated with increased risk of hip fracture. It appears to account for the association between reduced muscle strength, physical performance, muscle mass and risk of hip fracture (50). Next to a relation between bone mineral density and risk of hip fracture, the gluteus maximus muscle volume is higher in patients without hip fractures than in patients with hip fractures. Assessing gluteus maximus muscle volume may help to reduce the risk of hip fracture (52). Moreover, skeletal muscle loss can negatively affect hip bone strength in elderly patients with sarcopenia. Implementing strategies to increase SMI in the elderly population may be useful for reducing the vulnerability to hip fracture (53). Lower muscle density and lower SMI, indicating myosteatosis and sarcopenia, have both been associated with longer length of hospitalization in patients with proximal femur fractures(54). However, sarcopenia and myosteatosis have only been sparsely addressed in trauma and orthopedic literature. In general, there is evidence that myosteatosis has a negative impact on overall survival and complications related to underlying diseases, possibly explained by metabolic dysfunction (e.g. insulin resistance, systemic inflammation) (55). A decreased size of the psoas muscle, indicating sarcopenia, has recently been associated to one-year mortality in patients with pelvic ring injuries and other long bone fractures (56). In addition, myosteatosis is shown to be related to decreased mobility function in both the upper and lower extremities and poorer recovery of shoulder function (57–59). Based on these outcomes, it is very likely to expect a negative impact of sarcopenia and myosteatosis in the patient with a pelvic ring injury. Hence, in **Chapter 7** the rates

of sarcopenia and myosteatosis in elderly patients with pelvic ring injuries and the possible relation with mortality, physical functioning and QoL were investigated. The results of this study showed that half of elderly patients with pelvic ring injuries have sarcopenia, myosteatosis or both. Mortality rates were increased three years after the injury compared to patients without sarcopenia and/or myosteatosis. Besides, over 50% of patients that had deceased at one, three and five years after the injury suffered from sarcopenia and/or myosteatosis. Although overall mortality was highest in patients with both sarcopenia and myosteatosis, they did not turn out to be risk factors for mortality, whereas age and comorbidity were. Sarcopenia was negatively associated with mental and emotional problems, but not with other domains of physical functioning and QoL.

Recommendation:

The priority in future research on sarcopenia and myosteatosis in patients with pelvic ring injuries should be to test the hypothesis that they affect patient outcomes

While it is generally acknowledged that sarcopenia and myosteatosis are unfavorable for the patient,**optimal treatment is still unknown.** RCTs have been performed on supplements with fish oil, vitamin D3 and leucine, but did not show changes in muscle characteristics (60). On the other hand, exercise can significantly improve muscle quality (61). Immobilization can induce a decline in basal energy expenditure, reduced insulin sensitivity, anabolic resistance to protein nutrition and muscle strength, all of which impair clinical outcomes (62). The latter is important in the patient with a pelvic ring injury, given the likely (limited) period of immobilization directly after the injury. In case of operative treatment, preoperative nutritional assessment together with appropriate intervention with the goal to restore energy deficit, avoiding weight loss and improving functional performance can optimize patient outcomes (62). Furthermore, exercise and pharmacological interventions have been suggested to decrease fat infiltration in muscle, and thus to improve muscle strength and performance (65, 66). Besides, nutritional interventions may improve muscle quality and function and as a consequence could delay physical disability and mortality in older people (64).

Recommendation:

Research on intervention programs with the focus on nutrition and strength exercise training should clarify the potential benefits for the patient with sarcopenia and/or myosteatosis

Although the effects of muscle loss and decreased muscle quality have been the focus of interest over recent years, there is still **a lack of diagnostic cut-off values for sarcopenia and myosteatosis**. To date, several imaging modalities, including dual-energy X-ray absorptiometry (DXA), computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US), have been used to assess muscle mass and quality. With different extent, these modalities can all provide quantitative data, being thus reproducible and comparable over time. Using these modalities, the diagnosis of sarcopenia and/or myosteatosis can be achieved, but there is a lack of consensus on actual cut-off values for diagnosis. DXA and abdominal CT are the most commonly used modalities in clinical practice (55,65). DXA has the advantage of being accurate and widely available, and also being the only radiological tool with accepted cut-off values to diagnose sarcopenia (65). CT and MRI are considered the reference standards, and can be used interchangeable (66). This allows for the evaluation of muscle quality and fatty infiltration, but their application is so far mostly limited to research. Moreover, CT is constrained by the long time needed for muscle segmentation and the absence of validated thresholds (65). US has always been regarded as a minor tool in sarcopenia and has never gained enough ground. There is significant heterogeneity in the diagnostic methods and cut-off values for sarcopenia and myosteatosis. In a recent systematic review, 32 different cut-off values were used in 73 studies (55).The most commonly assessed muscle or muscle groups were

total abdominal wall musculature at the level of the third lumbal vertebra (L3) and total thigh musculature (67), but cut-off values vary across studies. Research on the use of only the psoas muscle for diagnosis of sarcopenia and myosteatosis showed that this could lead to an underestimation of the prevalence given the fact that the radio density in the psoas muscle was significantly greater than whole L3 slice density (68). There is new evidence that the cross-sectional muscle area of the first lumbar vertebra (L1) is favorably compared to L3. The additional advantage is that assessment of sarcopenia and myosteatosis allows for using both chest and abdominal CT scans (69). Recently developed sex-specific diagnostic cut-off points based on CT measurements of trunk muscles (70) should be further investigated to show whether they are useful in diagnosis, treatment and prevention of sarcopenia and myosteatosis.

Recommendation:

There is a high need to establish a gold standard for proper diagnosis of sarcopenia and myosteatosis with accurate cut-off values that can be used in pelvic ring injury research

PART III: A GLANCE INTO THE FUTURE: TREATMENT IMPROVEMENT

Nowadays, there are an increasing number of studies on **the implementation of 3D technology in pelvic ring injury surgery.** Fracture treatment can be considered the main goal of orthopedic and trauma surgeons. However, for a variety of subtypes of pelvic ring injuries, there is no actual consensus on what type of treatment to apply and many different surgical techniques exist. In **chapter 8**, a systematic review is presented evaluating possible advantages of 3D-assisted operative treatment for pelvic ring injuries compared to conventional 2D techniques. Although overall quality of studies was moderate, it can be cautiously concluded that 3D-assisted treatment has a positive impact on operation time, blood loss, fluoroscopy time, frequency and dose as well as screw malposition rate. Due to lack of evidence, a positive effect of fracture reduction and functional outcome could not be determined.

Not surprisingy, our findings in the systematic review are mirrored in the recently released literature, as **studies on 3D operative techniques are skyrocketing**. These studies showed positive results on operating time, blood loss, screw malposition rate, fracture reduction and functional outcome (71,72). Compared to 2D-assisted conventional techniques, there is subsequent evidence that 3D-assisted techniques can reduce screw malposition rate (73), operating time (73–75) and fluoroscopy frequency (75). Moreover, promising outcomes of long lasting effects of decreased pain, reduced disability as well as increased daily function and improved QoL in patient that require SI joint fusion can be expected (76). Also, 3D-fluoroscopy can possibly suffice as a post-operative control examination with accuracies similar to that of post-operative CT (72,77), reducing radiation exposure to the patient. Still, not all study results point in the same direction. It is known that fracture reduction of pelvic ring injuries influences functional outcome and that patients benefit from anatomical reduction (78). Nevertheless, conflicting evidence exists on the benefits of 3D-assisted surgery for fracture reduction (71,74,75). Further, although some beneficial (73,74,79) effects on functional outcomes were shown, in other studies the evidence on this subject was lacking (75).

Recommendation:

Future comparative studies are needed to establish consistent findings regarding the possible beneficial effects of 3D-assisted pelvic ring injury surgery on fracture reduction and functional outcome

Next to 3D-assisted techniques for pelvic ring injury surgery, there has been an increase **in robot-assisted surgery.** Using a robot, fluoroscopy frequency (80,81) as well as fluoroscopy time (81,82) can be reduced in pelvic ring injury surgery. Robot surgery is further superior in terms of operation time, incision length, anesthesia time, blood loss and hospitalization time (81,82). Also, screw malposition can be kept to a minimum (80) and results yield towards improved functional outcome (80,82), although another study did not reveal any differences (81).

3D-assisted techniques are also used in surgery for **associated acetabular fractures.** 3D printed models of the pelvis and acetabulum provide more information regarding fracture pattern with satisfied surgeons, improved trainee education and patient counselling as a result (83). However, consistent objective findings concerning the benefits regarding time-to-surgery, operating time, blood loss, fracture reduction, infection rate and QoL are lacking (83). Reduced operating time, blood loss and fluoroscopy freqency have been exposed, but not improved fracture reduction and functional outcome (84). Next to 3D printed models, personalized implants are used in acetabular fracture surgery (85,86) and revealed to reduce operation time and blood loss (85). Although fracture reduction and functional outcome were reported to be good (86), no improved reduction and functional outcome has been objectified so far compared to conventional treatment (85).

Next to direct patient benefits, it is interesting to speculate on **the societal impact of the increased use of 3D-assisted surgery techniques** such as the reduction in medical costs as health budgets are increasingly under pressure. Although studies concerning 3D-assisted techniques did not focus specifically on the societal impacts, results showed that 3D-assisted surgery for pelvic ring injuries can reduce complication rate (74), operating time and that robot assisted surgery reduces hospitalization time (82). These factors can all be beneficial in reducing healthcare related costs. For acetabular fractures, a new technique was recently introduced using a new type of 3D-printed custom titanium implant (87). Compared to conventional revision hip arthroplasty, the new implant reduced costs by 1266 euros and delivered a health benefit of 0.05 QALY for a patient aged 65 years. Similar cost-effectiveness studies on 3D-assisted pelvic ring injury surgery should reveal whether these benefits also concern patients with pelvic ring injuries.

LIMITATIONS AND FUTURE PERSPECTIVES

The majority of **limitations** of this thesis arise from the retrospective nature of several studies (**chapters 3 and 5-7**). These studies are susceptible to the inherent constraints such as the absence of baseline PROMs of physical functioning and QoL. This leaves us guessing about the patients' physical health prior to the injury and to what extent decreased physical functioning and QoL should be attributed to the injury itself. Beside the missing baseline PROMs, the retrospective nature makes studies prone to survivorship bias. This is especially relevant in the studies of part II of this thesis that concerned elderly patients (**Chapters 5-7**). Since mortality rates in these fragile patients are high, it resulted in the fact that many patients could not be included in the follow-up analysis with PROMs. Hence, the "more healthy" patients still alive were evaluated, which may have resulted in an overestimation of the actual perceived physical functioning and QoL since patients with deteriorated health passed away. This so called "healthy worker effect" might also be a possible explanation for the fact that no relation could be established between functional outcomes, sarcopenia and/or myosteatosis (**Chapter 7**); 58% of the patients that were deceased before our cross-sectional study with PROMs was performed, were shown to have sarcopenia and/or myosteatosis.

In the systematic reviews presented in **chapter 2 and 8**, the restrictions of language enabled us to only include studies published in English, German, Spanish, French or Dutch. This might have led to selection bias, since a compelling number of Chinese articles had to be excluded from further analysis. Additionally, the heterogeneity of included studies in the reviews in terms of patient samples, injury types, treatment methods and methodological quality prevented us from constructing a meta-analysis for reliable comparisons. The heterogeneity in terms of the study samples also concerned the studies described in **Chapters 3-7**, including patients of all ages, with all types of pelvic injuries, treatment methods and comorbidities. This complicates drawing a real conclusion in terms of injury outcomes. However, this is the reality of clinical practice in patients suffering from pelvic ring injuries. The limited sizes of the study samples largely restricted the ability to perform more in-depth subgroup analysis (**Chapters 4, 5 and 7**). Another subject of discussion may be the single center study design (**Chapters 3-5**) and the fact that studies only concerned patients of level 1 trauma centers (**Chapters 3-7**). Nonetheless, given the possible severity of the injury and risk of associated injuries, most pelvic ring injuries are treated in level 1 trauma centers. Some specific limitations of **Chapter 6 and 7** should be addressed since both studies required the availability of a CT scan for inclusion of the patient. The absence of a CT scan in a great number of patients has led, unavoidably, to a high exclusion rate and possibly subsequent selection bias. However, a CT scan is mandatory for an accurate (sub)classification of FFPs (**Chapter 6**). In **Chapter 7**, the absence of accurate cut-off values for diagnosis of sarcopenia and myosteatosis is likely to have influenced results. Appropriately, it might be that not all patients have been correctly diagnosed, which may have led to and underestimation, respectively overestimation of patients with sarcopenia and myosteatosis. Consequently, this can influence analysis of mortality and patient-reported outcomes.

Hence, some **recommendations for future research** can be proposed. First, reliable and valid PROMs should be used at regular time intervals in order to provide reliable and valid outcomes regarding pelvic ring injuries. A challenging task remains in validating existing pelvic-specific PROMs and to develop a uniform PROM for pelvic injuries worldwide. Secondly, implementing further prospective studies including important baseline PROMs can overcome the important limitations of studies with a retrospective nature. Third, studies on larger groups of patients with pelvic ring injuries are needed, in order to enable subgroup analysis, thus limiting heterogeneity and simultaneously distinguish even better in differences of physical functioning and QoL between patients of varying ages, injury types and injury severity. Fourth, the use of a multidisciplinary treatment protocol for patients is encouraged and should be evaluated for its efficacy. It should cover both the potentially physical as well as mental impact of the injury. Fifth, regarding fragility fractures of the pelvis, future prospective studies might elucidate which patients can benefit from early operative treatment in terms of clinical and functional outcome and which patients are better off treated non-operatively. A CT scan is recommended in all elderly patients with a low-energy trauma for proper diagnosis of an FFP. At last, proper cut-off values need to be developed for sarcopenia and myosteatosis that can be used worldwide. Subsequently, intervention studies evaluating the effects of nutrition and muscle exercises should reveal possible advantages.

CONCLUDING REMARKS

Sustaining a pelvic ring injury is a life event that is likely to have a major and long-lasting effect on the patient's daily life. The physical and mental consequences require a holistic approach to both treatment and outcome evaluation. Valid and reliable PROMs on physical and mental functioning and quality of life should be the most important aspects in evaluation of treatment and rehabilitation protocols. Ideally, rehabilitation should be approached multidisciplinary and involves trauma surgeons, rehabilitations physicians, physiotherapists, psychologists and dieticians. Special attention should be paid to the fragile elderly patients with additional consultation of geriatric medicine. Increased general awareness of the use of patient-reported outcomes after pelvic ring injuries among clinicians and patients may be an important step toward further improving these rehabilitation programs. By encouraging the patient to stay in charge of his own health, the focus can shift towards the patient's strength rather than his weakness, and subsequently improve resilience.

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Summary

Pelvic ring injuries vary from stable non-displaced fractures to severely unstable displaced fractures involving multiple pelvic bones and ligaments. These injuries affect people of all ages and are caused by varying injury mechanisms, ranging from simple falls to high-energy traffic accidents. As a result, long-term physical impairment may occur with a subsequent effect on the patient's state of mind, asking for intensive rehabilitation. Over the past decade, the evaluation of pelvic ring injuries gradually shifted from traditional outcome measures such as radiographic imaging to more clinically relevant patient-reported outcome measures (PROMs). The level and speed of recovery of patient-perceived physical functioning and quality of life (QoL), however, is largely unknown and still underrepresented in current literature about pelvic ring injuries.

The general aim of this thesis was to gain more insight into the patient's perception of functional recovery and quality of life after pelvic ring injuries. It provides the foundation for more personalized care with optimal treatment and best possible outcomes. The first part of this thesis focused on outcomes in patients of all ages. The second part is dedicated to pelvic ring injuries in the elderly. The third part provided future perspectives regarding three-dimensional aided operative techniques used in pelvic ring injury surgery.

Part one of this thesis
In order to provide an overview of current knowledge of physical functioning and QoL after pelvic ring injuries, a systematic review was performed in **chapter 2**. Forty-six studies published between 2008 and 2019 were evaluated and assessed for their methodological quality. Studies turned out to be heterogeneous, with small cohorts of patients, a variety of injury types, treatment methods and use of nine different, often non-validated, outcome measures. Moreover, the overall methodological quality was moderate to poor. Although the outcomes revealed fair physical functioning and QoL which improved over time, the above-mentioned factors hamper to elucidate the actual effects of pelvic ring injuries on a patient's life. Therefore, prospective longitudinal studies are needed, using valid and reliable PROMs on large cohorts of patients, minimizing heterogeneity. In the end, there is still a challenging task to validate existing pelvic-specific PROMs and develop a uniform PROM for pelvic ring injuries worldwide.

Chapter 3 aimed to evaluate patient-reported outcomes after pelvic ring injuries in adult patients by means of a large retrospective cohort study. Patients received questionnaires to evaluate physical functioning (SMFA-NL) and QoL (EQ-5D). Of the 413 identified patients, 279 were eligible for follow-up and 192 responded at a mean follow-up of 4.4 (SD 2.6) years. Overall PROMs scores were about 75-85% of the maximum achievable scores. There were no differences in physical functioning and QoL between patients treated non-operatively or operatively. Compared to normative data of the general Dutch population, patients showed a significant decrease of 1-23% in different domains of physical functioning (SMFA function index) and of 4-12% in QoL (EQ-5D). These results indicate that pelvic ring injuries have a significant personal as well as societal impact, even years after the injury occurred.

In order to evaluate the recovery of patient-perceived physical functioning and QoL over time after a pelvic ring injury, a prospective longitudinal cohort study was performed in **chapter 4**. Patients filled in the SMFA-NL and EQ-5D questionnaires at different time points (recalled pre-injury score, six weeks, three months, six months, one year and two years) following their pelvic ring injury for assessment of physical functioning and QoL. Of the 297 identified patients of which 189 were eligible for inclusion, 154 patients responded to at least one of the questionnaires. Both

physical functioning and QoL decreased directly after the injury but then gradually improved over a two-year period. After two years, median SMFA Function Index score was 88 out of 100 and median EQ-5D score was 0.85 out of 1. Compared to the recalled pre-injury score, about 75% of patients showed a full recovery at one year following the pelvic ring injury. Female gender and high-energy trauma were shown to be independent predictors for not fully recovering. Both physical and mental problems were present after three months, with 54% and 44% of patients reporting severe difficulties with recreational activities or feeling physically disabled respectively. These problems continued to be present after one and two years. Hence, it was concluded that these pelvic ring injuries have a large impact on the patients' daily life in the first two years following the injury.

Part two of this thesis

The second part of this thesis focused on pelvic ring injuries in the elderly patient. The elderly population will continue to grow rapidly in the next decades. About one third of all fractures and 73% of all pelvic ring injuries occur in the elderly. This population is vulnerable due to the age-related reduced physical condition and comorbidities. By means of a retrospective cohort study in **chapter 5**, the aim was to evaluate mortality as well as physical functioning and QoL. Mortality rates of the 153 included patients with a mean follow-up of 3.4 (SD 2.7) years ranged from 20% at 30 days, to 27% at one year and 41% after three years of follow-up. Increasing age, fracture type C and increased injury severity score (ISS) were all independent risk factors for mortality. By means of the SMFA and EQ-5D, physical functioning and QoL were analyzed and these measures revealed scores between 60-70% of the achievable maximum. Overall, physical functioning and quality of life showed to be significantly decreased in comparison to their age-matched peers from the general population.

A specific entity of pelvic ring injuries can occur in the elderly after low-energy trauma, these are called fragility fractures of the pelvis (FFPs). These fractures are caused by injuries that would normally not result in a fracture of non-osteoporotic bone. A multicenter cross-sectional study was performed in **chapter 6** with the focus on FFPs. Types of FFP, treatment, mobility, mortality and clinical outcome in terms of physical functioning (SMFA) and QoL (EQ-5D) were assessed in 187 patients with a median follow-up of four (IQR 2-7) years. FFP type I turned out to be most common type of injury in 60% of cases. Almost all injuries were treated non-operatively, which resulted in good mobility after six weeks. Mortality at one year was 16% for type I and II, 47% for type III and 13% for type IV. Physical functioning and QoL was about 20-30% decreased compared to the general population. A diagnosis and treatment algorithm for FFPs was presented in this chapter with the focus on multidisciplinary care, which may possibly improve patient satisfaction and outcome.

In the elderly patient, a gradual decline in skeletal muscle mass and strength (sarcopenia) may occur. Besides, an increase in intermuscular and intramuscular fat (myosteatosis) is expected. Since literature on sarcopenia and myosteatosis in the patient with a pelvic ring injury was lacking, we evaluated the prevalence and subsequent influence on mortality as well as physical functioning (SMFA) and QoL (EQ-5D) in **chapter 7**. A multicenter retrospective cohort study was conducted and computed tomography (CT) imaging was used for measurements of sarcopenia and myosteatosis. One third of patients suffered from sarcopenia, one third from myosteatosis and 15% had both. Mortality rates in patients at 1 and 3 years without sarcopenia and myosteatosis were 13% and 21% compared to 11% and 36% in patients with sarcopenia, 17% and 31% in patients with myosteatosis, and 27 and 43% in patients with both. Increased age and comorbidities turned out to be risk factors for mortality. In patients with sarcopenia, mental and emotional problems were

significantly increased. Future prospective longitudinal studies on larger groups of patients should be performed to evaluate whether sarcopenia and/or myosteatosis are potential predictive factors for decreased physical functioning and QoL. Moreover, intervention studies for the effects of muscle training and dietary adaptions could be explored in future research.

Part three of this thesis

The last part of this thesis was dedicated to innovative treatment techniques for pelvic ring injuries. A systematic review was performed, including studies published between 2010 and 2020. All available 3D techniques in pelvic ring injury surgery were assessed in **chapter 8**. A total of 18 studies with moderate quality fulfilled the inclusion criteria evaluating 988 patients. Techniques included 3D virtual fracture visualization and preoperative planning', '3D printed model assisted surgery', 'pre-contouring of osteosynthesis material', '3D printed surgical guides', and 'intra-operative 3D imaging'. It turned out that 3D-assisted pelvic ring surgery can have a positive effect on operation time, blood loss, fluoroscopy dose, time and frequency, as well as accuracy of screw placement. Due to the limited available data, no improvement in clinical outcome in terms of fracture reduction and functional outcome has been established so far. Future high-quality comparative studies are necessary to further establish possible advantages of 3D-assisted surgery in the treatment of pelvic ring injuries.

Recommendations for future research

A national or even collaborative international registry, with valid baseline and follow-up PROMs, would enable carrying out large studies with less heterogeneity and the possibility to analyze subgroups of patients. Treatment of patients might be improved by a multidisciplinary approach including both physical and mental wellbeing, especially in the elderly patient.

Nederlandse samenvatting

Bekkenringletsels variëren van stabiele, niet-verplaatste fracturen tot ernstig instabiele fracturen met betrokkenheid van meerdere botdelen en ligamenten. Ze kunnen op alle leeftijden voorkomen waarbij de ongevalsmechanismen variëren van een simpele val tot ernstige verkeersongevallen. Als gevolg van het letsel kunnen er langdurige fysieke beperkingen ontstaan met een bijkomende belasting voor de mentale gezondheid welke vragen om intensieve revalidatie. Over het afgelopen decennium is de evaluatie van het herstel na bekkenringletsels verplaatst van traditionele uitkomstmaten zoals röntgenfoto's naar meer klinisch relevante patiënt gerapporteerde uitkomstmaten, de zogenaamde patient-reported outcome measures (PROMs). Zowel de mate als de snelheid van herstel van patiënt gerapporteerd fysiek functioneren en kwaliteit van leven zijn echter grotendeels onbekend en nog steeds ondergewaardeerd in de huidige literatuur over bekkenringletsels.

Het algemene doel van dit proefschrift was om meer inzicht te krijgen in het perspectief van de patiënt aangaande zijn of haar fysieke herstel en kwaliteit van leven na een bekkenringletsel. Het biedt een basis voor meer op maat gemaakte zorg met optimale behandeling en de best mogelijke uitkomsten. Het eerste deel van dit proefschrift heeft zich gericht op uitkomsten van patiënten van alle leeftijden. Het tweede deel is gewijd aan bekkenringletsels bij oudere patiënten. Het derde deel biedt toekomstperspectieven aangaande driedimensionaal (3D) geassisteerde operatieve behandeltechnieken in de bekkenchirurgie.

Deel 1 van dit proefschrift
Om een overzicht te bieden van de huidige literatuur omtrent fysiek functioneren en kwaliteit van leven na bekkenringletsels werd een systematic review uitgevoerd en beschreven in **hoofdstuk 2**. Zesenveertig studies gepubliceerd tussen 2008 en 2019 werden geëvalueerd en onderzocht op methodologische kwaliteit. De meeste studies bleken heterogeen met kleine aantallen patiënten, verschillende typen letsels, verschillende behandelmethoden en het gebruik van negen verschillende, grotendeels niet-gevalideerde uitkomstmaten. Daarnaast was de algemene methodologische kwaliteit van de studies gemiddeld tot slecht. De uitkomsten toonden aan dat zowel het fysiek functioneren als de kwaliteit van leven mettertijd verbeterden. De bovengenoemde factoren maakten het echter lastig de werkelijke effecten van bekkenringletsels op het leven van de patiënt te verhelderen. Daarom kan geconcludeerd worden dat prospectieve, longitudinale studies nodig zijn. In deze studies moet men gebruik maken van valide en betrouwbare PROMs bij een groot aantal patiënten waarbij de heterogeniteit tot een minimum beperkt moet worden. Uiteindelijk blijft het nog steeds een uitdagende taak om een reeds bestaande bekken-specifieke PROM te valideren en om een uniforme PROM voor bekkenringletsels te ontwikkelen voor wereldwijd gebruik.

Hoofdstuk 3 had tot doel om PROMs na bekkenringletsels bij volwassenen te evalueren door middel van een grote retrospectieve cohort studie. Patiënten ontvingen vragenlijsten ter evaluatie van hun fysiek functioneren (SMFA-NL) en kwaliteit van leven (EQ-5D). Van de 413 geïdentificeerde patiënten waren er 279 geschikt voor inclusie waarvan 192 patiënten hebben geantwoord met een gemiddelde follow-up duur van 4.4 (standaard deviatie 2.6) jaar na het ongeval. Over het algemeen waren de PROMs scores ongeveer 75-85% van de maximaal haalbare score. Er waren geen verschillen in fysiek functioneren en kwaliteit van leven tussen patiënten die wel of niet waren geopereerd. Vergeleken met de normdata van de Nederlandse populatie, toonden de uitkomsten een significante vermindering van 1-23% in verschillende domeinen van fysiek functioneren (SMFA functie index) en 4-12% in kwaliteit van leven (EQ-5D). Deze resultaten

laten zien dat bekkenringletsels een significante persoonlijke impact hebben, zelfs jaren na het ongeval.

Om het herstel in patiënt-gerapporteerd fysiek functioneren en kwaliteit van leven na bekkenringletsels over de tijd te evalueren werd een prospectieve longitudinale cohort studie uitgevoerd, beschreven in **hoofdstuk 4**. Patiënten vulden eveneens de SMFA-NL en EQ-5D vragenlijsten in op verschillende tijdsmomenten (fysiek functioneren en kwaliteit van leven zoals herinnerd in de week vóór het ongeval en vervolgens zes weken, drie maanden, zes maanden, een jaar en twee jaar na het ongeval). Van de 297 geïdentificeerde patiënten van wie er 189 geschikt waren voor inclusie, hebben 154 patiënten geantwoord op ten minste één van de vragenlijsten. Zowel fysiek functioneren als kwaliteit van leven verminderden direct na het letsel maar verbeterden vervolgens langzaam over een periode van twee jaar. Na twee jaar was de mediane SMFA-functie score 88 uit 100 en de mediane EQ-5D score 0.85 uit 1. Vergeleken met de score zoals gerapporteerd voor het ongeval, bleek er bij ongeveer 75% van de patiënten sprake te zijn van volledig herstel één jaar na het bekkenringletsel. Het vrouwelijke geslacht en een ongeval veroorzaakt door een hoog-energetisch trauma bleken onafhankelijke voorspellers te zijn voor onvolledig herstel. Na drie maanden waren zowel fysieke als mentale problemen aanwezig. Hierbij gaf 54% van de patiënten aan ernstige moeilijkheden met vrijetijdsbesteding te hebben; 44% had het gevoel fysiek beperkt te zijn. Deze problemen bleven tot twee jaar na het letsel aanwezig. Hierdoor werd geconcludeerd dat bekkenringletsels een grote impact hebben op het leven van de patiënt in de eerste twee jaar na het letsel.

Deel twee van dit proefschrift

Het tweede deel van dit proefschrift richtte zich op bekkenringletsels bij de oudere patiënt (65 jaar of ouder). De oudere populatie blijft snel groeien in de komende decennia. Ongeveer een derde van alle fracturen en 73% van alle bekkenringletsels komen voor in de oudere populatie. Deze populatie is kwetsbaar als gevolg van een verminderde lichamelijke conditie en comorbiditeit. Het doel van **hoofdstuk 5** was om door middel van een retrospectief cohort de mortaliteit alsmede het fysiek functioneren en de kwaliteit van leven te onderzoeken. De mortaliteit onder de 153 geïncludeerde patiënten met een gemiddelde follow-up van 3.4 (standaarddeviatie 2.7) jaar na het ongeval varieerde van 20% na 30 dagen tot 27% na een jaar en 41% na drie jaar. Een hogere leeftijd, fractuur type C en een verhoogde Injury Severity Score (ISS) bleken allemaal onafhankelijke risico factoren voor verhoogde mortaliteit te zijn. Door middel van de SMFA en de EQ-5D werd het fysiek functioneren respectievelijk de kwaliteit van leven geanalyseerd. Deze scores lagen tussen de 60-70% van het maximaal haalbare. Over het algemeen waren zowel het fysiek functioneren als de kwaliteit van leven sterk verminderd vergeleken met leeftijdsgenoten uit de algemene populatie.

Een specifiek type bekkenringletsel kan voorkomen bij ouderen na een laag-energetisch trauma: *fragility fractures of the pelvis* (FFPs), ook wel insufficiëntiefracturen. Deze fracturen ontstaan na een ongevalsmechanisme dat normaliter niet voldoende zou zijn om een fractuur te veroorzaken in gezond bot. Een multicenter cross-sectionele studie met de focus op deze FFPs werd uitgevoerd in **hoofdstuk 6**. De verschillende typen FFPs, behandeling, mobiliteit, mortaliteit en klinische uitkomsten (fysiek functioneren en kwaliteit van leven) werden onderzocht in 187 patiënten met een mediane follow-up van vier (interkwartielbereik 2-7) jaar. FFP type I bleek het meest voor te komen met 60%. Bijna alle letsels werden niet-operatief behandeld, wat grotendeels resulteerde in goede mobiliteit na zes weken. Mortaliteit na een jaar was 16% onder type I en II letsels, 47% onder type III en 13% onder type IV letsels. Het fysiek functioneren en de kwaliteit van leven waren gemiddeld 20-30% lager dan in de algemene populatie. In dit

hoofdstuk werd een diagnose- en behandelalgoritme voor FFPs gepresenteerd. Hierbij lag de focus op multidisciplinaire behandeling, wat in de toekomst mogelijk ten goede kan komen aan patiënttevredenheid en uitkomsten aangaande fysiek functioneren en kwaliteit van leven.

Bij de oudere patiënt kan een geleidelijke vermindering in skeletspiermassa en skeletspierkracht (sarcopenie) ontstaan. Daarnaast is een verhoging van inter- en intramusculair vet (myosteatose) te verwachten. Gezien de literatuur omtrent sarcopenie en myosteatose bij patiënten met bekkenringletsels ontbrak, hebben we de prevalentie ervan en de invloed op mortaliteit alsmede fysiek functioneren (SMFA) en kwaliteit van leven (EQ-5D) onderzocht in **hoofdstuk 7**. Een multicenter retrospectieve cohortstudie werd uitgevoerd en *computed tomography* (CT) beelden werden gebruikt voor de metingen van sarcopenie en myosteatose. Een derde van alle patiënten leed aan sarcopenie, een derde aan myosteatose en 15% aan beide. Mortaliteit bij patiënten zonder sarcopenie en myosteatose na één en drie jaar was 13% respectievelijk 21%, vergeleken met 11% respectievelijk 36% bij patiënten met sarcopenie, 17% respectievelijk 31% bij patiënten met myosteatose, en 27% respectievelijk 43% bij patiënten met beide. Een verhoogde leeftijd en het hebben van comorbiditeiten bleken risicofactoren voor verhoogde mortaliteit te zijn. Bij patiënten met sarcopenie waren mentale en emotionele problemen significant meer aanwezig. Toekomstige prospectieve longitudinale studies onder grotere groepen patiënten zouden uitgevoerd moeten worden om te evalueren of sarcopenie en/of myosteatose potentiële voorspellende factoren zijn voor verminderd fysiek functioneren en verminderde kwaliteit van leven. Daarnaast zouden toekomstige interventie studies gericht op het effect van spiertraining en aanpassingen in dieet meer duidelijkheid moeten verschaffen over potentiele behandelopties.

Deel 3 van dit proefschrift

Het laatste deel van dit proefschrift werd gewijd aan innovatieve chirurgische behandelmethoden van bekkenringletsels. Er werd een systematische review uitgevoerd waarbij studies werden geïncludeerd die gepubliceerd waren tussen 2010 en 2020. Alle beschikbare 3D technieken in bekkenchirurgie werden beoordeeld in **hoofdstuk 8.** Een totaal van 18 studies van gemiddelde kwaliteit voldeden aan de inclusiecriteria met in totaal 988 patiënten. Technieken bestonden uit driedimensionale virtuele fractuur visualisatie en preoperatieve planning, chirurgie op basis van 3D geprinte bekkenmodellen, het voorbuigen van osteosynthese materiaal op basis van een driedimensionaal bekkenmodel, 3D geprinte chirurgische *guides* en het gebruik van intra-operatieve 3D beeldvorming. Het bleek dat 3D geassisteerde bekkenringchirurgie een positief effect had op verkorting van de operatietijd, de mate van bloedverlies, stralingsdosering, stralingstijd en frequentie, alsmede de accuratesse van schroefplaatsing. Mogelijk ten gevolge van de beperkte data kon er nog geen verbetering in klinische uitkomsten (fractuur reductie en functionele uitkomsten) worden geconstateerd. Toekomstige vergelijkende studies van hoge kwaliteit zijn nodig om verdere mogelijke voordelen van 3D geassisteerde chirurgie van bekkenringletsels in kaart te brengen.

Aanbevelingen voor toekomstig onderzoek

Een nationaal of zelfs internationaal samenwerkend registratiesysteem met het gebruik van gevalideerde *baseline* en follow-up PROMs zou het mogelijk maken grote studies met minder heterogeniteit uit te voeren. Daarnaast zou het de mogelijkheid bieden om subgroepen te analyseren. De behandeling van patiënten kan verbeterd worden door een multidisciplinaire benadering met daarbij aandacht voor zowel fysiek als mentaal welbevinden, met name bij de oudere patiënt.

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About the author

Hester Banierink was born on the 21st of February in 1989 as a daughter of Henriette (Jettie) Teutelink and Johannes Gerardus Maria (Jan) Banierink. Her exact birthplace is rather special, she was born on a house-boat situated in a canal in Enschede. She grew up in Oldenzaal. She obtained her high school (VWO) diploma at the Twents Carmel College. After living in Canada for half a year, working as an Icelandic horse trainer, she started college at the Saxion Hogescholen in Enschede to become a nurse. Her internship in the Katutura State hospital in Namibia was one of the highlights. After working as a district nurse for a couple years and gaining her physics and chemistry certificates, she was admitted to the pre-master of medicine studies at the University of Groningen. She quickly learned she had an interest for trauma surgery and got involved in a new research project that focused on outcomes after pelvic ring injuries. After gaining her bachelor's degree, this resulted in the application and admission to an MD/PhD trajectory: combining the medicine master while simultaneously performing scientific research in order to gain a PhD. The PhD was supervised by prof. Dr. E. Heineman, Dr. I.H.F. Reininga, Dr. F.F.A. IJpma and Drs. K. ten Duis. During this trajectory she gave multiple presentations at (international) congresses about her research in the area of patient reported functional outcomes after pelvic ring injuries. She also supervised multiple bachelor and master students in their research internships. She finished her junior and senior internships in the University Medical Center Groningen (UMCG) and the Ommelander hospital in Scheemda. After finishing her final clinical internships in the UMCG at the emergency department and the department of trauma surgery, she gained her medical degree in November 2020. In all these years, she combined her study and her PhD with riding her two Icelandic horses and with being the lead singer in the band *E causa ignota*. In 2021 she offered her PhD called "Pelvic ring injuries – Recovery of patient-perceived physical functioning and quality of life" to the PhD committee. Currently, Hester is working as a medical doctor at the department of surgery in the Gelre hospitals in Apeldoorn.

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