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Comprehensive classification of fragility fractures of the pelvic ring: Recommendations for surgical treatment

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ABSTRACT

Due to the increasing life expectancy, orthopaedic surgeons are more and more often confronted with fragility fractures of the pelvis (FFPs). These kinds of fractures are the result of a low-energy impact or they may even occur spontaneously in patients with severe osteoporosis. Due to some distinct differences, the established classifications for pelvic ring lesions in younger adults do not fully reflect the clinical and morphological criteria of FFPs. Most FFPs are minimally displaced and do not require surgical therapy. However, in some patients, an insidious progress of bone damage leads to increasing displacement, nonunion and persisting instability. Therefore, new concepts for surgical treatment have to be developed to address the functional needs of the elderly patients. Based on an analysis of 245 consecutive patients with FFPs, we propose a novel classification system for this condition. This classification is based on morphological criteria and it corresponds with the degree of instability. Also in the elderly, these criteria are the most important for the decision on the type of treatment as well as type and extent of surgery. The estimation of the degree of instability is based on radiological and clinical findings. The classification gives also hints for treatment strategies, which may vary between minimally invasive techniques and complex surgical reconstructions.

When we discuss pelvic ring disruptions, we usually refer to high-velocity accidents, such as motor vehicle and motor car crashes, falls from a great height and crush injuries. Thanks to preventive measures on the road and at workplaces, intensive controls of driver behaviour and severe punishment of violation of traffic regulations, the number of highly unstable pelvic ring lesions is slowly diminishing in industrialised countries. At the same time and related to growing life expectancy, the number of ageing persons is steadily growing. The average age of the population is higher than 40 years in large countries such as China, Japan, Germany, Great Britain and Canada. Many retired persons are still healthy and very active. They are mobile and have high functional demands. Others suffer from one or several morbidities such as diabetes, cardiac insufficiency, peripheral neurovascular disease or dementia. They are less mobile, need help from third parties or are even bedridden. Their functional demands are accordingly lower, but a minimum of mobility is still needed for activities of daily life or personal hygiene. Interrelated to high age and less mobility, the bone stock of many patients is severely diminished. This may be due to osteoporosis, long-term immobilisation, vitamin D depletion or other reasons. As a consequence, we experience a sharp increase in the number of fractures of the proximal femur, proximal humerus, distal radius and vertebral body due to low-energy injuries [1–5]. Similarly, the number of fragility fractures of the pelvic ring is increasing [6,7]. The characteristics of these lesions differ from these in younger adult trauma patients. Until now, there is no comprehensive classification for FFPs. In this article, we describe a new classification system, which is based on morphologic criteria and correlates with the degree of instability. The classification gives also hints for treatment strategies.

Definitions

Loads, which are repetitive and have short and high peaks, are prone to produce fractures. Stress fractures are seen in bone with a normal structure and strength, which is set under repetitive peak loads. On single loading, this stress is not sufficient to create a fracture [8]. A typical example is the metatarsal stress fracture of a military recruit. Another example is the distal tibia stress fracture in the adult jogger [9]. Rarely, stress fractures of the sacrum are seen in adult athletes [10,11].

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Osteoporotic fractures occur in patients with confirmed or suspected osteoporosis. Low-energy accidents such as falls from a standing position are sufficient to produce fractures of the femoral neck, proximal humerus or distal radius [4,12,13]. Often, they are the first sign of undiagnosed osteoporosis. Further, pubic and ischial rami fractures are often seen after a simple fall of the elderly patient [6,14–16].

In insufficiency fractures, the forces leading to a fracture are even lower. These are physiological loads occurring during activities of daily life; the patient's own body weight can be sufficient to produce a fracture. The reason for these fractures is an extreme reduction of bone mass. This can be found in patients with severe osteoporosis, after irradiation [17], long-term immobilisation, long-term cortisone intake [18], vitamin D depletion [19,20] or after bone harvesting for lumbar spine surgery [21,22]. Linstrom et al. described a large series of insufficiency fractures of the sacrum that follow specific fracture patterns [23].

Osteoporotic, fatigue or insufficiency fractures are part of a spectrum of fractures occurring in patients with fragile bone. Therefore, we hypothesise that there may be a similar mechanism of origin in stress fractures, osteoporotic fractures and fatigue or insufficiency fractures. Fragile bone is defined as bone with a significantly reduced bone stock, when compared with the bone stock of the young adult. The common pathophysiology of fragility fractures is the discrepancy between the strength of the bone and the amount of load put on it, ranging from low energy to physiologic load. In many cases, it is not possible to find out the specific formation mechanism of the fracture. We therefore prefer to use the term 'fragility fracture' instead of osteoporotic, insufficiency or fatigue fracture.

Classification systems

Innumerable classification systems have been developed for medical diseases, malignancies and degenerative or posttraumatic conditions. They distinguish between different stages of progression of the disease, aggressiveness and expansion of the malignancy or severity of an injury. The criteria for discrimination are found in the results of laboratory examinations, histological tissue characteristics or the presence or absence of markers. In the field of musculoskeletal trauma, classification systems rely on what we assess during clinical examination or what we can read on conventional X-rays or image-guided procedures such as computed tomography (CT), ultrasonography or magnetic resonance imaging (MRI). Worldwide, accepted systems based on such examinations are the Gustilo classification system for grade III open fractures [24], the Neer classification for proximal humerus fractures [25,26] and the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification system for fractures of the extremities [27]. A classification can also be based on the direction of the injuring force, such as the Lauge-Hansen system for ankle fractures [28,29]. To be valid and widely accepted, a classification system of musculoskeletal injuries must be comprehensive, simple, inter- and intra-observer reliable, related to the severity of the injury and connected with treatment strategies and outcome [30,31].

Classification systems for pelvic ring lesions

Two systems are accepted worldwide for the classification of pelvic ring lesions. These are the classification systems of M. Tile (Table 1), adopted by Association for the Study of Internal Fixation/Orthopaedic Trauma Association (ASIF/OTA) [32,33], and of J. W. Young and A. Burgess (Fig. 1) [34]. Both systems are based on radiological and clinical findings. The system of M. Tile [32] is simple to use as it distinguishes between three degrees and types of instability, which are easy to discriminate: stable pelvic ring lesions, rotationally unstable lesions and rotationally and vertically unstable pelvic ring lesions. Further discrimination is based on morphologic criteria and on the direction of rotational instability (Table 1). The classification system has a high inter-observer reliability [35] and is well related to injury severity and outcome [36,37]. The Young–Burgess classification [34] distinguishes between four different categories, which are related to the direction of the disruptive force: antero-posterior compression, lateral compression, vertical shear and combined mechanism injury (Fig. 1). The antero-posterior compression and lateral compression injuries are subdivided into three types with increasing degrees of severity (Fig. 1). Further, this classification system has a high inter-observer reliability and is well related to severity of injury and outcome [35,38]. Both classification systems do not describe bony lesions only, but also take into account injuries to soft-tissue structures such as dislocations of the symphysis pubis, of the sacroiliac joint as well as disruptions of the ligamentous structures of the pelvic bottom and the iliolumbar ligament. The categories display a combination of injuries, which are essential to form one specific entity. The open book lesion (B1 lesion in the classification of M. Tile and APC II lesion in the classification of Young and Burgess) involves a rupture of the symphysis pubis together with a rupture of the pelvic bottom structures (sacrospinal and sacrotuberal ligaments) and a rupture of the ventral sacroiliac ligaments. A unilateral vertical shear injury (Type C1 in the classification of M. Tile or VS in the classification of Young and Burgess) involves a complete rupture of the anterior pelvic ring in combination with a complete rupture of the pelvic bottom structures and a complete rupture of the dorsal pelvic ring.

Table 1
Classification of pelvic disruptions of M. Tile [32].

Type A:	Stable
	A1: fractures of the pelvis not involving the ring
	A2: stable, minimally displaced fractures of the ring
Type B:	Rotationally unstable, vertically stable
	B1: open book
	B2: lateral compression: ipsilateral
	B3: lateral compression: contralateral (bucket handle)
Type C:	Rotationally and vertically unstable
	C1: unilateral
	C2: bilateral
	C3: associated with an acetabular fracture

Fragility fractures of the pelvic ring

Fragility fractures of the pelvic ring represent a spectrum of pathologies. Numerous combinations of fractures, dislocations and fracture-dislocations of the anterior and posterior pelvic ring are possible [7,39–43]. However, there is an important difference with the pelvic ring lesions of the younger adults. In elderly patients with fragile bone, the strength of the bony structures of the pelvis is lower than that of the surrounding ligaments. Fragility fractures of the pelvis are mainly characterised by a disruption of bony structures only. The thick dorsal sacroiliac, sacrotuberal and sacrospinal ligaments remain intact and form anatomical borders. Fracture fragments can move within these borders only [44,45]. On the contrary, open book lesions (Type B1 of Tile and types APC I, II or III in the Young–Burgess classification) and vertical shear injuries (Type C in Tile and VS in the Young–Burgess classification) are characterised by the rupture of some or all of these ligaments. As a consequence, the amount of instability in FFPs is not comparable with that of an open book or vertical shear lesion in younger adults. Some fragility fracture patterns of the pelvis therefore do not fit into the classification systems of Tile [32] or Young and Burgess [34].

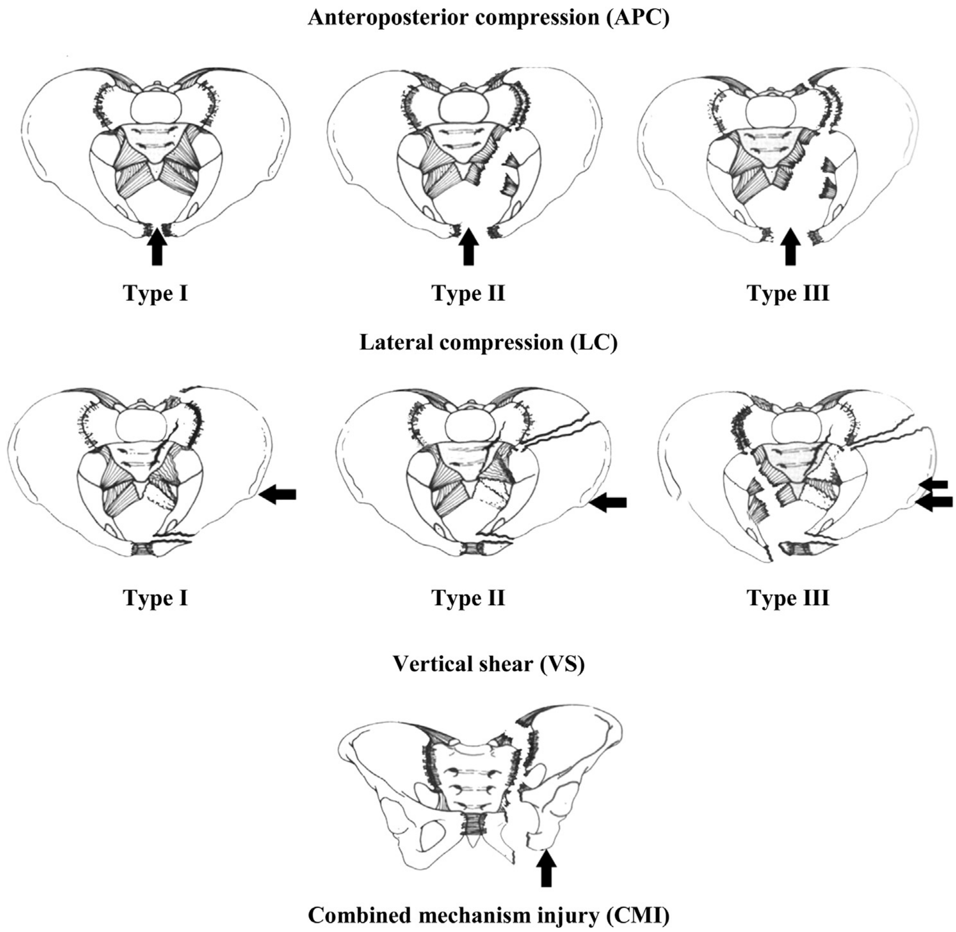

Fig. 1. Classification of pelvic disruptions of Young–Burgess [34].

Diagnostic work-up of fragility fractures of the pelvic ring

Many patients present with spontaneous pain in the groin or with lower back pain. When manual pressure is applied simultaneously on both iliac crests, patients report severe pain in both the dorsal and the ventral half of the pelvic ring. Radiological examinations are conducted to confirm suspected fractures. The three conventional views (pelvic antero-posterior (a.p.), inlet and outlet views) are the first step of the diagnostic work-up to detect pubic and ischial rami fractures, symphysis pubis disruptions and rotational and vertical displacements. Special attention should be given to the sacral ala, as most lesions of the dorsal pelvis are located there. Because dorsal pelvis visualisation is limited with conventional views, we always perform CT imaging for all these patients. Coronal reconstructions may be more informative than reconstructions in the transverse or sagittal plane. In a few cases, the origin of pelvic pain remains unclear after conventional X-rays and CT examinations. In these cases, MRI of the pelvis is recommended to exclude other reasons. A bone bruise in the sacral ala is sometimes detected. We believe that such bone bruises correspond to the onset of a disruption of the cancellous structure of the lateral sacrum, and the lesion is the first stage before a fragility fracture occurs [46].

Materials and methods

We retrospectively identified a consecutive series of patients with pelvic ring injuries who were aged over 65 years at the time of admission and treated between 2007 and 2012 in our department due to a low-energy injury or a spontaneous onset of pain in the pelvis. Patients with known history or suspicion of cancer as well as those in whom an initial CT scan was not available were excluded from further analyses. We identified 245 patients meeting these criteria (mean age 79.2 years, females = 198, males = 47) (Fig. 2A). We analysed the morphological appearance of fractures and identified the common characteristics using both the three standard X-rays (a.p., inlet and outlet views) and the CT scan. Usually, the conventional X-rays did not allow for accurate fracture estimation of the dorsal part of the pelvis. However, they provided an overall impression about the amount of dislocation and the deformity of the pelvis. The history of injury (e.g., fall from a sitting or standing position or even a spontaneous onset of pain) was recorded and related to the morphological type of the fracture. Despite the enormous dislocation of fracture fragments in some patients, none of the patients sustained a life-threatening injury or a haemodynamic instability. Pain in the back or in the groin was the most frequent leading symptom. The patients were treated according to the presentation of the clinical symptoms. Non-displaced fractures were usually treated conservatively. However, when patients could not be mobilised out of bed during the first 3–5 days despite pain therapy or if increasing dislocation of fracture fragments during the early follow-up period was noticed, operative treatment was performed whenever it was possible. Complete bilateral fractures and fractures with significant displacement were treated surgically. At this point, there is no well-accepted protocol available for the treatment of FFPs, yet. According to the morphological criteria in our series of patients and the severity of their complaints, we developed a classification system that reflects the amount of pelvic instability and the need for surgical intervention.

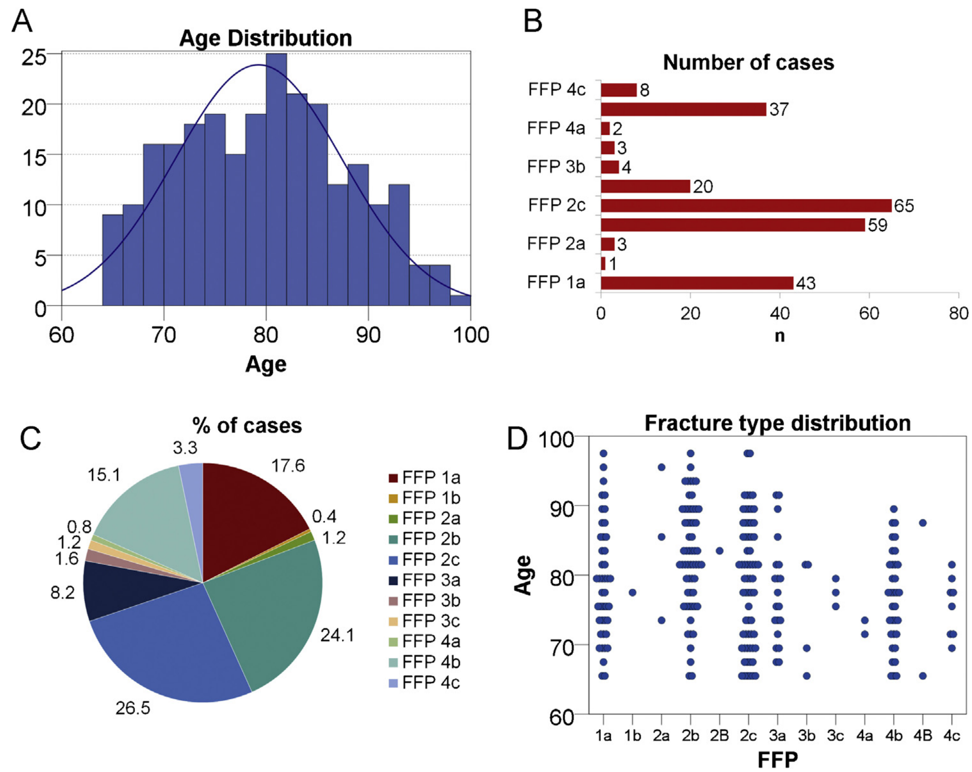

Fig. 2. (A) Age distribution of the study population (*n* = 245, mean age 79.2 years, w = 198, m = 47). (B) Distribution and numbers of FFP fracture types detected in our study population. (C) Percentage of the respective FFP fracture types within the study population. (D) Distribution of FFP fracture types in different age groups. All fracture types are equally distributed among different age groups.

Results: comprehensive classification of fragility fractures of the pelvic ring

This classification is based on the degree of instability. Also in the elderly, this criterion is the most important for the decision on the type of treatment as well as type and extent of surgery. The estimation of the degree of instability is derived from radiological and clinical findings. Instability is defined as the inability of a structure to withstand physiologic loads without displacement. We distinguish slight, moderate, high and highest instability as major categories (Figs. 2b,c and 3a–d). The categories are FFP Type I, FFP Type II, FFP Type III and FFP Type IV. FFP stands for fragility fracture of the pelvis. Within each FFP type, we distinguish several subcategories. The discrimination is given by the localisation of the injuries and the presence of fracture displacement. These characteristics can be found on conventional X-rays, CT views and/or MRI images.

Non-displaced lesions are characterised by a crush zone or a fracture without deformation of anatomy. Due to low bone density, fracture lines sometimes can hardly be followed in CT images. They are more clearly recognisable in MRI (Fig. 4). Displaced lesions are characterised by a crush or a fracture with deformation of the anatomical landmarks. In the event of a fracture, conventional X-rays show a displacement of fracture fragments, whereas CT scans clearly show fracture lines as signs of enhanced instability.

Within FFP Type I lesions, we distinguish two different entities (Fig. 3a). An FFP Type Ia lesion corresponds to a unilateral anterior disruption. On conventional X-rays, we detect unilateral pubic and/or ischial rami fractures [16]. The patient expresses pain in the groin but not in the back. An FFP Type Ib lesion corresponds to a bilateral anterior disruption. No lesion of the dorsal pelvis can be detected. The prevalence of pure FFP Type Ia and Ib lesions is much less common in the elderly than in younger patients. In many cases, the CT scan uncovers non-displaced fracture lines or a crush zone in the posterior pelvic ring despite negative findings in conventional X-rays. Therefore, for a precise classification of these injuries a CT scan is required. In a retrospective study on 177 patients who received CT examination, only 3.2% were found to have an isolated anterior pelvic lesion [47]. In the series of Lau and Leung of only 37 patients, this was present in 41% [42]. In all FFP Type I lesions the anterior pelvis is broken only; there is no crush or fissure fracture in the dorsal pelvis.

In FFP Type II lesions, there is a moderate instability. We distinguish three subcategories (Fig. 3b). An FFP Type IIa lesion is a non-displaced and isolated unilateral sacral fracture. They are best seen in CT imaging. Linstrom et al. [23] describe a series of these fractures with unique and consistent fracture morphology. Most fractures run vertically through the sacral ala, lateral from the neuroforamina and medial from the sacroiliac joint. Other fractures have an atypical fracture pattern. They are more frequent in patients with implants in (e.g., prosthesis) or nearby the hip joint (e.g., dynamic hip screw) [23]. In an FFP Type IIb lesion, pubic and ischial rami fractures are combined with a crush zone of the sacral ala without displacement [42]. Alternatively, bone bruise of the sacral ala is detected on MRI [44,45,48,49]. In FFP Type IIc lesions, pubic and ischial rami fractures are combined with a non-displaced sacral ala fracture. Whereas a sacral ala crush zone is situated ventrally only (FFP Type IIb), there is a disruption of the ventral and dorsal cortex in sacral ala fractures (FFP Type IIc). In our case series, these two types were the most frequent in patients with an acute injury (Fig. 2B and C). These morphologies reflect the typical mechanism of injury, which is a fall from a standing position. The FFP Type IIb and FFP Type IIc lesions correspond with the LC Type I lesion of the Young–Burgess classification [34]. The sacral lesion can be bilateral. As shown by Linstrom et al., different morphologies and combinations of sacral lesions exist [23]. Vertical shear sacral fractures in adults typically run through the neuroforamina. In fatigue fractures of the pelvic ring, they

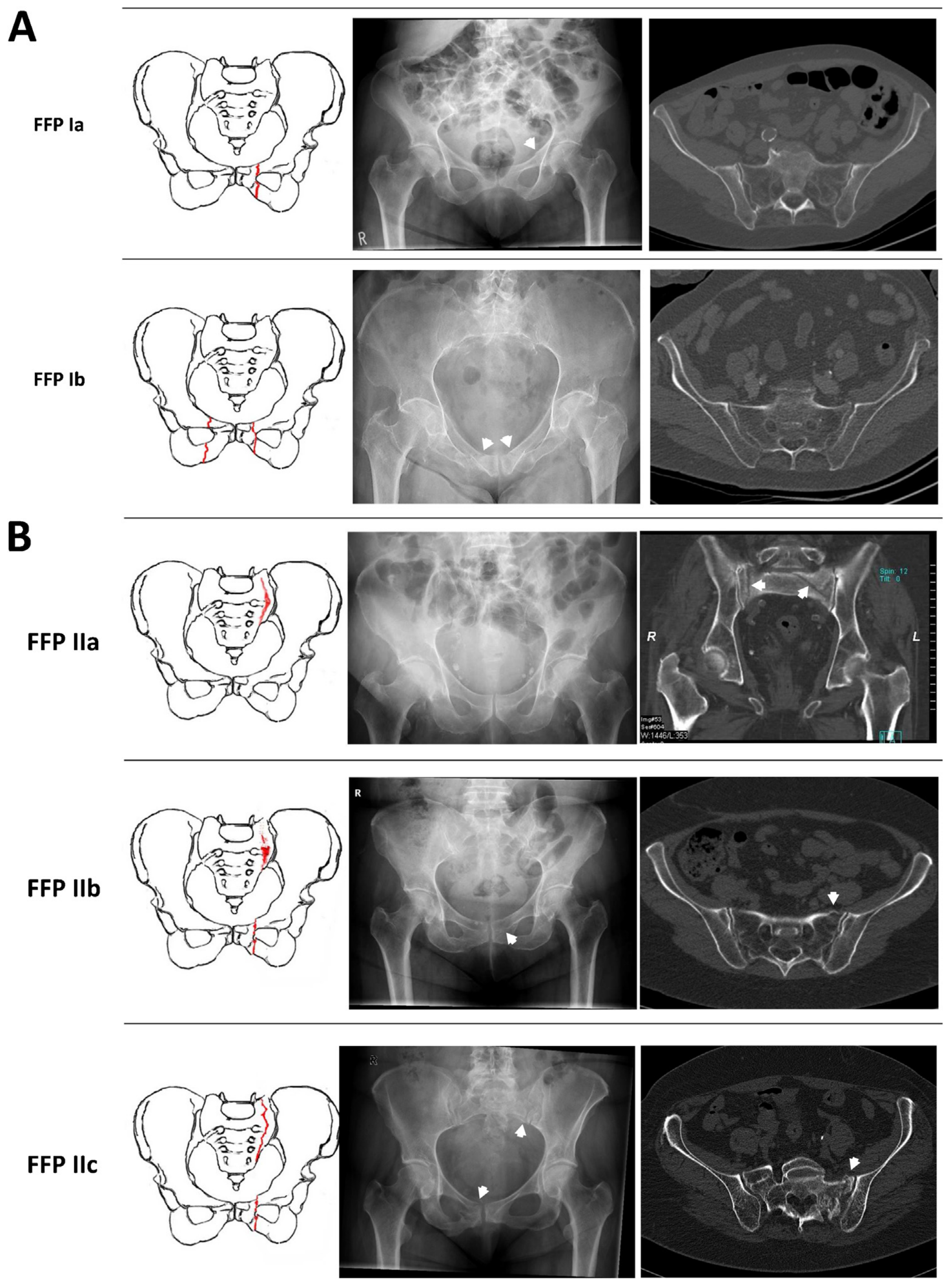

Fig. 3. Classification of fragility fractures of the pelvis (FFP). (A) FFP Type I – Anterior injury only. Type Ia: isolated unilateral anterior disruption. Type Ib: isolated bilateral anterior disruption. (B) FFP Type II – non-displaced posterior injury. Type IIa: isolated, non-displaced sacral fracture without involvement of the anterior pelvic ring. Type IIb: non-displaced sacral crush with anterior disruption. Type IIc: non-displaced sacral, iliosacral or ilium fracture with anterior disruption. (C) FFP Type III – displaced unilateral posterior injury. Type IIIa: displaced unilateral iliac fracture. Type IIIb: displaced unilateral iliosacral disruption. Type IIIc: displaced unilateral displaced sacral fracture. (D) FFP Type IV – displaced bilateral posterior injury. Type IVa: bilateral iliac fracture or bilateral iliosacral disruption. Type IVb: bilateral sacral fracture, spinopelvic dissociation. Type IVc: combination of different dorsal instabilities.

always run through the sacral ala. The transition between FFP Type I and FFP Type II lesions is fluent. As already mentioned, Schreyerer et al. found posterior pelvic ring lesions in 96.8% of elderly patients with pubic rami fractures [47]. Clinical and radiological findings will give hints regarding which FFP type specific lesions should be classified. Moreover, we believe that a lesion can move from a category with a lower instability to a category with higher instability, if not treated adequately.

FFP Type III lesions have a high degree of instability (Fig. 3c). They are subdivided depending on the localisation of the dorsal injury. We distinguish disruptions running through the iliac bone, through the sacroiliac joint and through the sacrum. In the anterior pelvic ring, there is a complete uni- or bilateral disruption at the pubic and ischial rami or at the symphysis pubis. In FFP Type IIIa lesions, there is a complete unilateral iliac disruption combined with a complete anterior disruption. The dorsal disruption starts at the inner curve of the ilium and runs laterally through the iliac wing to reach the iliac crest at different levels. In their morphology, FFP Type IIIa lesions are similar to a more severe type of lateral compression injury (Type B2 of Tile and Type LC II of Young and

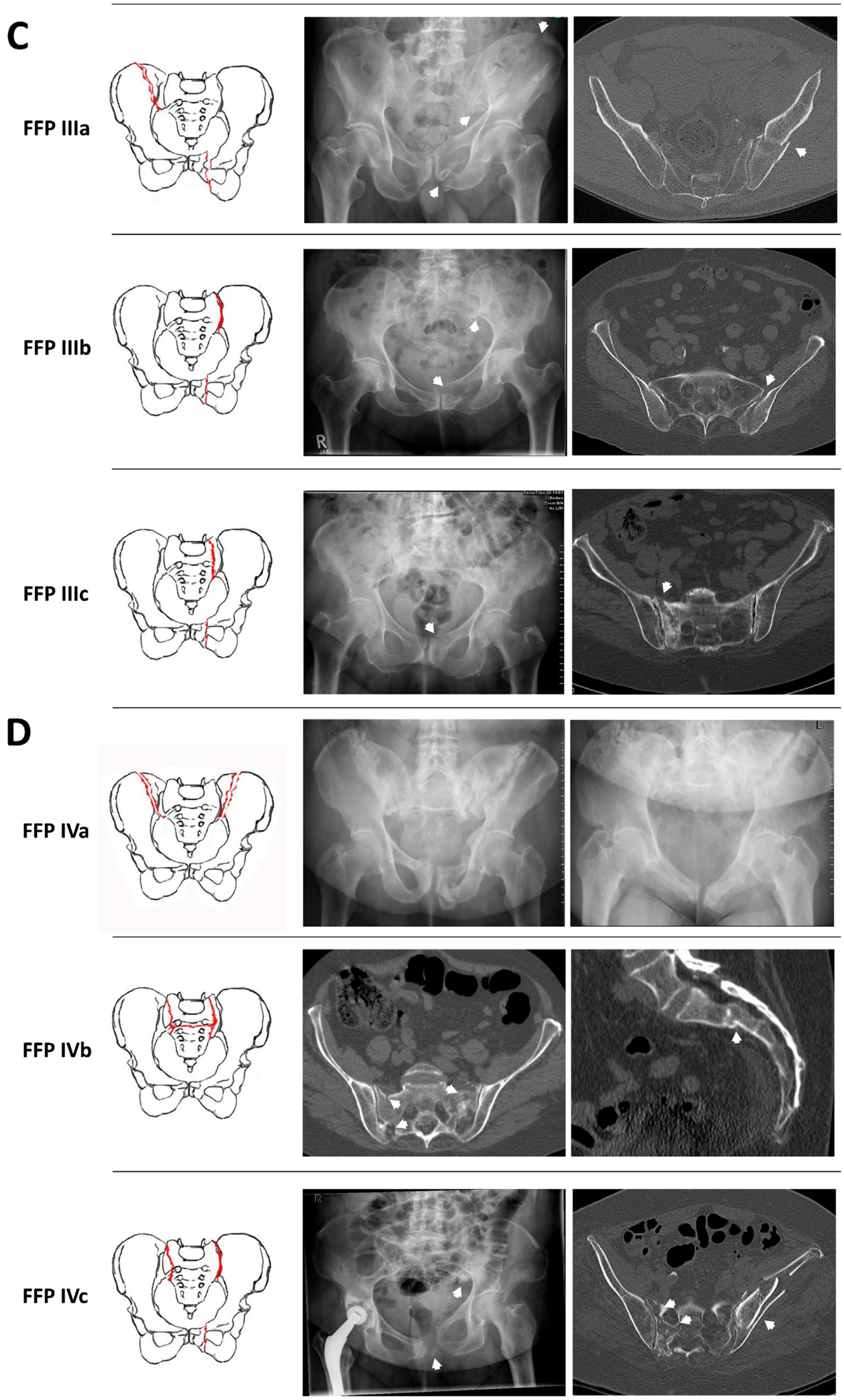

Fig. 3. (*Continued*).

Burgess) [32,34]. However, the severity of the soft-tissue destruction is not comparable [50,51]. In an FFP Type III b lesion, there is an iliosacral disruption combined with a complete anterior disruption. Smaller parts of the dorsal ilium (crescent fracture) can remain attached to the iliosacral joint. Nitrogen bubbles in the joint are a sign of joint instability. In an FFP Type IIIc lesion, there is a complete unilateral sacral disruption combined with a complete anterior disruption. These kinds of FFP Type III disruptions may be associated either with displacement or with a widening and gap formation between fracture fragments resulting in a higher grade

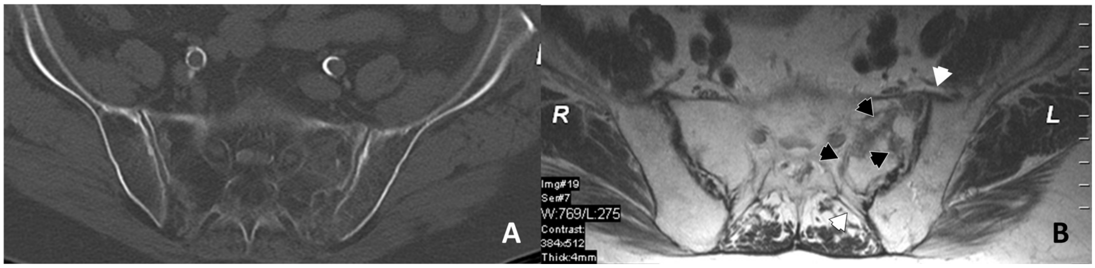

Fig. 4. CT (A) and MRI (B) images of the sacrum of an 80 years old woman after a low-energy fall from a standing position. The fracture lines are better recognisable in the MRI.

of instability as compared with FFP Type II lesions. The onset of hypertrophic callus formation is also often detected in such cases. As between FFP Type I and FFP Type II lesions, the transition between FFP Type II and FFP Type III lesions is fluent. In our case series, the FFP Type II injuries were detected mostly in patients representing with an acute injury or with an acute onset of pain in the pelvis. In clear contrast to this group of patients, we found a long history of pain, typically 4–6 weeks, in patients with FFP Type III injuries. Thus, as shown in our documented case series, a lesion can move from a category with a lower degree of instability to a category with a higher degree of instability, if not treated adequately.

FFP Type IV lesions have the highest instability (Fig. 3d). They are distinguished from all other categories because of one specific characteristic: the complete dissociation between the iliolumbar spine and the pelvic ring. There always is a bilateral and complete dorsal disruption, which may be combined with different morphologies of uni- or bilateral anterior disruption. These lesions ask for a specific fixation, which connects the lumbosacral spine with the dorsal pelvic ring. Three different types of disruptions are observed. In an FFP Type IVa lesion, there is a bilateral iliac fracture, starting from the inner curve of the ilium and running to the iliac crest. The iliolumbar spine including the total sacrum and dorsal parts of the ilium are separated from the rest of the pelvic ring. In FFP Type IVb lesions, there is a bilateral and complete sacral ala fracture. The sacral bodies, together with the bony structures around the neuroforamina (Region II and III in the Denis classification of sacral fractures), are separated from the sacral ala (Region I in the Denis classification of sacral fractures). A horizontal fracture line may connect the two vertical sacral ala fractures. This horizontal fracture line is typically situated at the level of S1 or S2. The bodies of S1 or S1 and S2 remain connected with the lumbar spine, but are separated from the rest of the sacrum, which is still connected to the pelvic ring. The iliolumbar spine is slightly intruded into the pelvic ring. Thanks to the iliolumbar and iliosacral ligaments, which are still intact, the displacement is limited. This last type is similar to the suicide jumper's fracture of the younger adult. In our case series of 245 patients, this was the most common type of fracture in patients representing with a long history of pain in the pelvis (Fig. 2B and C). The duration of the pain period was at least 4–6 weeks, or even several months. In FFP Type IVc lesions, there is a combination of

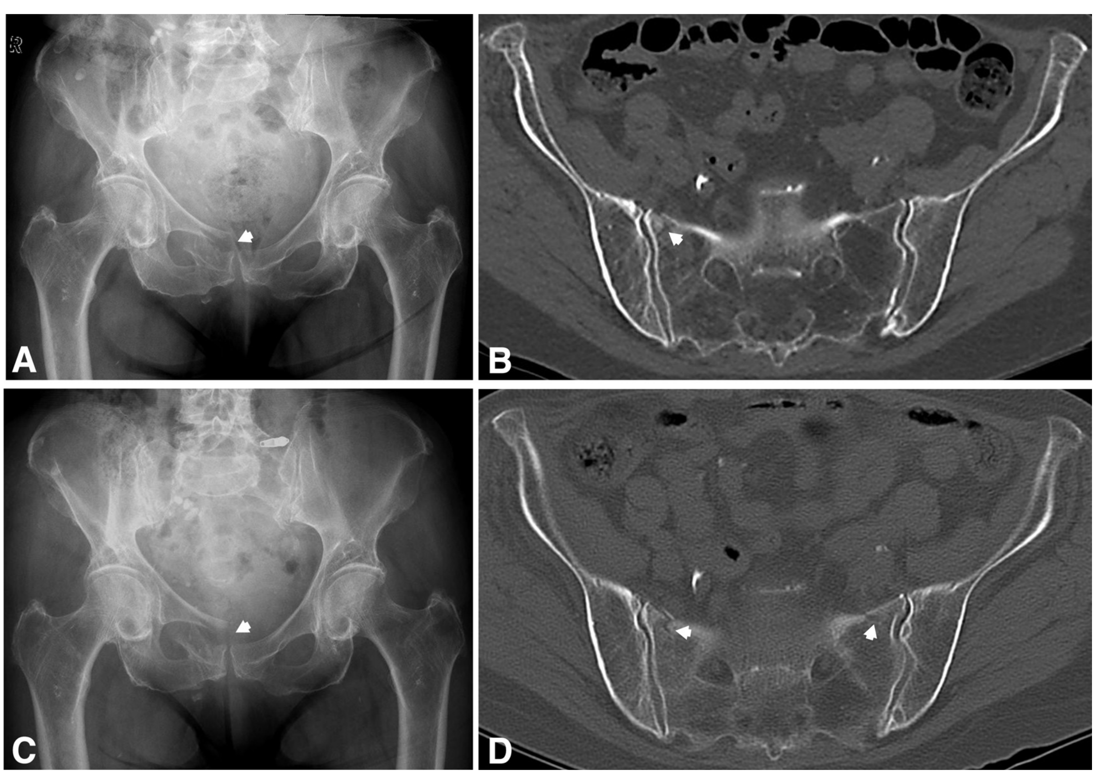

Fig. 5. Patient presenting with severe low back pain and groin pain after a fall from a standing position. Conventional a.p. (A), inlet, and outlet radiographs revealed a displaced fracture of the anterior pelvic ring. The CT-scan showed a very thin fracture line in the sacral ala on the right site (B). During the next three weeks the patient was not able to bear weight due to therapy-resistant low back pain. Conventional X-rays showed a slight increase of fracture displacement of the anterior part of the pelvis (C), and bilateral fracture lines in the sacral ala become obvious (D).

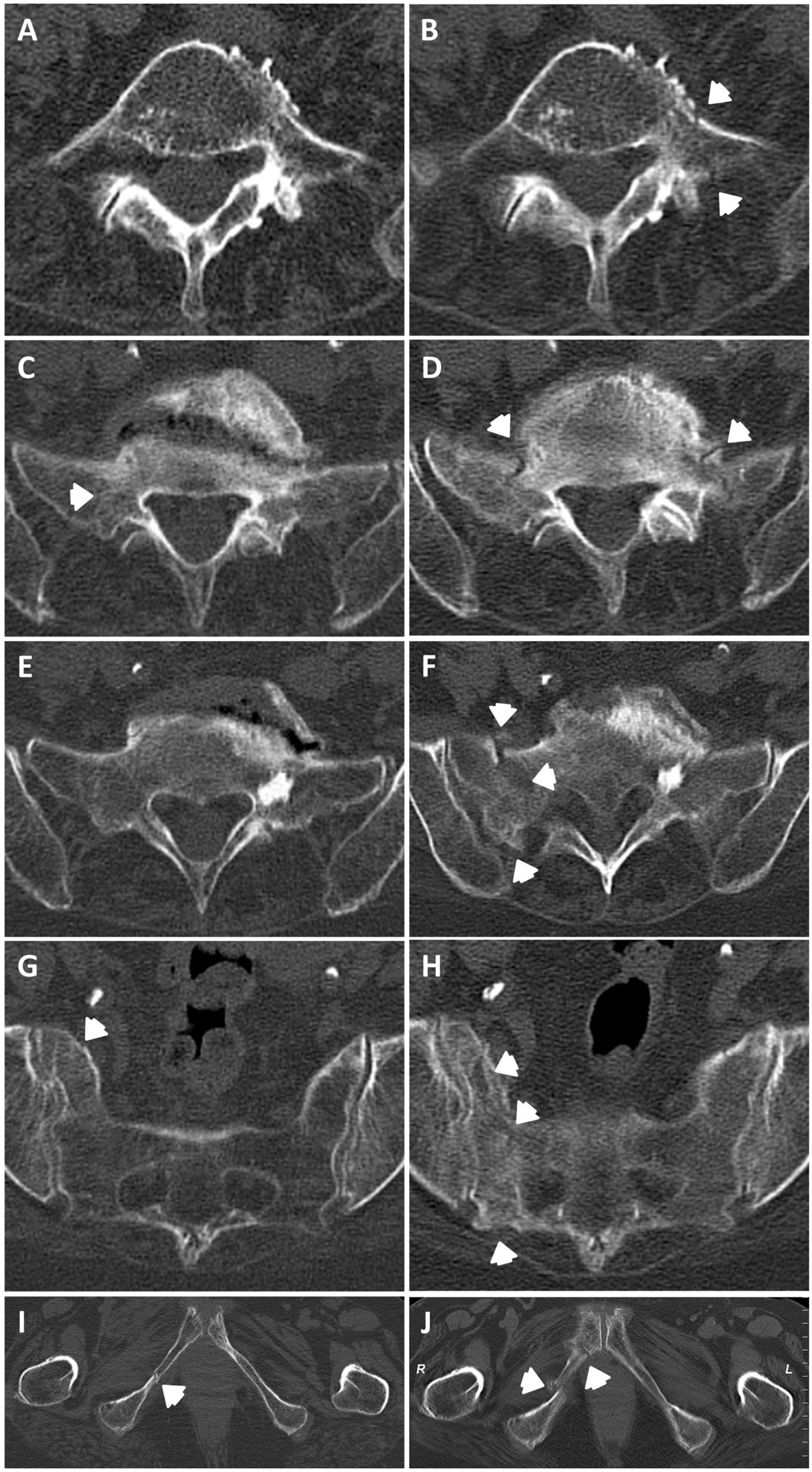

Fig. 6. Natural course of a creeping collapse of the pelvis during conservative treatment of a fragility fracture. CT scan examinations were performed in an 82 years old woman after a fall from a standing position (A, C, E, G, I) and four weeks later (B, D, F, H, J). The latter CT scan was performed due to a persisting severe pain and inability to get out of bed. Fracture lines can be hardly identified in the initial CT-scan (arrows), whereas four weeks later, additional fracture lines and fracture line widening become evident in the latter CT scan (arrows).

different instabilities in the dorsal pelvis: a transiliac instability on one side combined with a trans-sacral instability on the other side, a trans-sacral instability on one side combined with a transiliosacral on the other or a transiliac instability on one side with a transiliosacral instability on the other.

In our case series, the fracture types were equally distributed in all age groups (Fig. 2D).

Recommendations for surgical treatment

This comprehensive classification gives hints of which type of surgical therapy can or should be performed for which category of lesions. In FFP Type I lesions, no surgical therapy is needed. The fractures are situated in the anterior pelvic ring only. They are lesions with limited instability. Treatment consists of bed rest and pain medication, followed by mobilisation out of bed and increasing weight bearing of the injured side. The degree of osteoporosis and bone metabolism should be investigated, and an adapted drug therapy started [52,53]. Multiple options and combinations of drugs are available. They are not the focus of this contribution and will not be discussed further. Pain can persist for as long as 6–8 weeks after the trauma. In the case of increasing pain during therapy, we recommend repeating conventional pelvic overviews or additional CT examinations to exclude fractures or displacements that may not have been visible or present at admission (Fig. 5).

In FFP Type II lesions, there is an isolated posterior or a combination of anterior and minor posterior instability. Revalidation time with conservative treatment will be longer and more problematic than in FFP Type I lesions. With early mobilisation, there is a risk of increasing instability or nonunion (Fig. 6). Therefore, surgical fixation should be considered. The surgery can be performed in a minimally invasive way (Fig. 7).

Sacroplasty is increasingly used to treat incomplete and isolated sacral ala fractures (FFP Type IIa) [54–60]. A small amount of bone cement is inserted in the fracture area. By the force of application, the fluid cement is distributed throughout the cancellous bone in and around the fracture site. As the cement hardens, the fracture site gets stabilised. Pain relief is significant and early mobilisation possible. However, complications due to cement leakage have been described [61]. Up to date, experience is limited and the precise role of sacroplasty has not been elaborated.

Non-displaced fractures of the sacrum can also be fixed with percutaneous iliosacral screws [62,63]. Two screws are inserted in the vertebral body of S1 (Fig. 7), alternatively one screw in S1 and a second screw in S2 [62]. Because the density of the cancellous bone is higher in the central part of the sacrum than in its ala, the tip of the screws should reach the midline [64]. Moderate compression can be put on the fracture parts by tightening the screws. Placing a washer below the screw head prevents the latter from perforating the lateral cortex of the dorsal ilium. Nevertheless, the low purchase of the screws in the osteoporotic bone presents a risk of loosening. To avoid this, cement augmentation of iliosacral screws has been recommended [65]. This technique combines iliosacral screw fixation with sacroplasty. In a biomechanical study, three methods of fixation of osteoporotic fractures of the sacral ala (sacroplasty, short iliosacral screw and long iliosacral screw) have been compared. Although no significant differences have been found between the groups, there was a tendency of enhanced motion in the sacroplasty group [66].

In the anterior ring, retrograde screws are inserted from the pubic tubercle through the pubic rami towards the iliac bone medially and cranially of the acetabulum (Fig. 7). The screws have a diameter of 6.5 or 7.3 mm and a length between 60 and 100 mm [62,67]. The procedure is carried out on both sides in the case of bilateral fractures. If done early, only incisions of a few centimetres are needed. Reduction of the fracture is possible by closed means by tilting the symphysis fragment with the drill inside the ramus. When closed reduction is not possible, a small suprapubic incision is made. With the index, the retropubic space is explored and the fracture(s) directly reduced. Retrograde screw placement is performed consecutively.

In FFP Type III lesions, an open surgical procedure will be needed in most cases. In the anterior pelvis, we distinguish

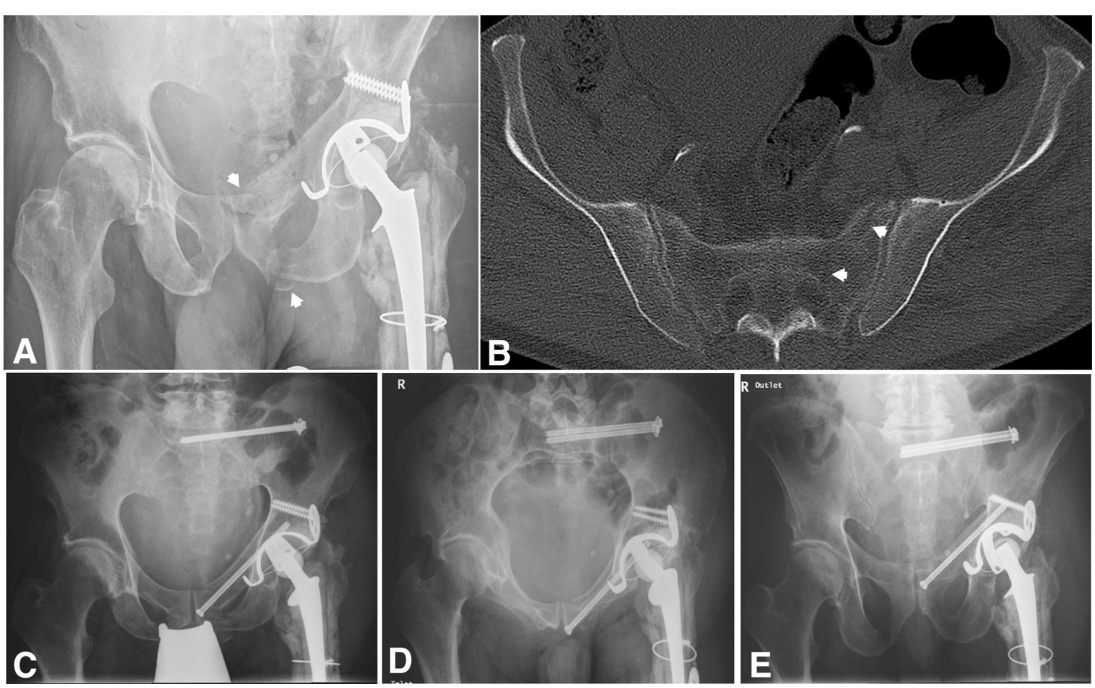

Fig. 7. FFP IIIc fracture in a patient with severe osteoporosis was treated using minimally invasive iliosacral and retrograde transpubic screw osteosynthesis. Conventional a.p. radiograph showing the disruption of the anterior pelvic ring (A). Additional CT-diagnostic reveals an additional fracture of the sacral ala on the left site (B). (C–D) Postoperative a.p., inlet, and outlet views.

between pubic rami fractures and symphysis pubis disruptions. For pubic rami fractures, the percutaneous retrograde screw insertion, as described above, is performed whenever possible (Fig. 7). When the pubic fractures are situated very lateral or perforate the anterior lip of the acetabulum, a plate osteosynthesis is considered as an alternative to retrograde screw placement. Instabilities of the symphysis pubis are fixed with a bridging angle stable-plate osteosynthesis [68]. Pubic fractures, which are situated very closely to the symphysis, are also fixed with a bridging angular stable symphysis plate. In FFP Type III lesions, anterior fixation must always be combined with posterior fixation, and vice versa.

In the posterior pelvis, we distinguish between iliac fractures, iliosacral disruptions and sacral fractures. Iliac fractures are reduced and fixed through an incision over the iliac crest (Fig. 8). The muscles of the abdominal wall and the iliacus muscle are mobilised and the inner side of the fracture is exposed. The fracture is reduced with forceps or clamps. Along the iliac crest, one or more lag screws hold the fracture. Along the sacroiliac joint and the inner curve of the ilium, a large fragment angular stable plate with screws, which is used as an internal fixator, is inserted (Fig. 8). In the case of bilateral pathology (FFP Type IVa), the procedure is performed on both sides.

Sacroiliac disruptions can also be exposed through the above-mentioned approach. The joint is debrided and may be filled with cancellous bone grafts of the ipsilateral iliac crest. Two three-hole large fragment plates with each one screw in the sacral ala and two screws in the ilium rigidly bridge the joint. Sacroiliac disruptions also can be fixed trough a dorsal approach (see below).

In the case of sacral fractures, a dorsal approach is compulsory. The patient is placed in the prone position. When the lesion is older, the instability is opened, debrided and closed under compression with forceps or clamps. It may be filled with cancellous bone grafts from the ipsilateral dorsal ilium. Three types of osteosynthesis are possible: iliosacral screw osteosynthesis, placement of a trans-sacral positioning bar and placement of a dorsal internal fixator.

The placement of a trans-sacral positioning bar is done as follows: a long-threaded 6-mm bar is positioned from one dorsal ilium through the vertebral body of S1 towards the opposite dorsal ilium (Fig. 9). Washers and nuts are placed on both ends of the bar [69,70]. Tightening of the nuts provides compression between the fractured parts. The compression obtained is equal to the force the washers put on the lateral cortices of the dorsal ilium. It does not depend on the strength of the cancellous bone of the sacrum, as is the case for iliosacral screw osteosynthesis. Because the implant is locked on both sides, loosening is prevented. Experience with this technique is still limited. In the published series, most patients can be mobilised soon after stabilisation and have good functional outcomes [69,70].

Dorsal internal fixators are large angle stable plates which are inserted between the two dorsal iliac crests at the level of the inferior posterior iliac spines [71,72]. The plate acts as a bridging and locking implant, but no compression is generated in the

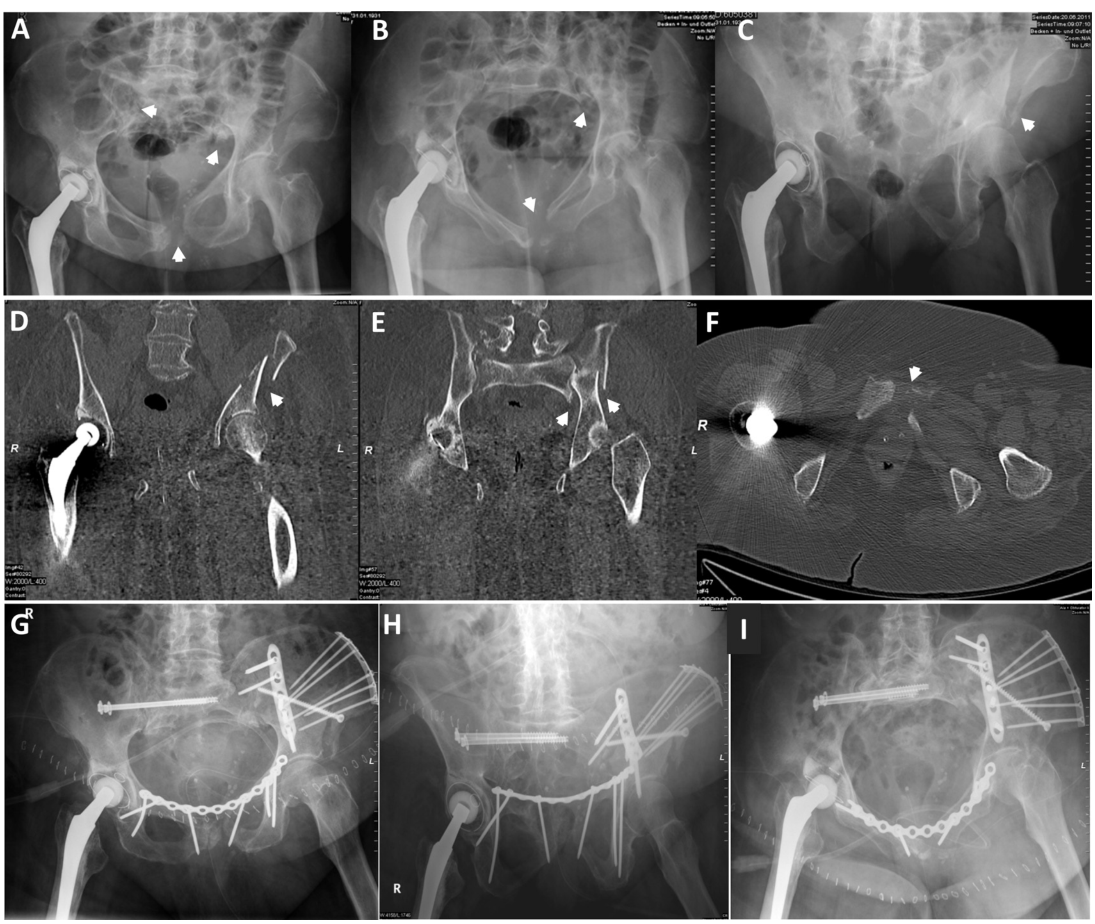

Fig. 8. FFP IVC fracture with a combined instability of the anterior and posterior parts of the pelvic ring. Conventional radiographs in a.p. (A), inlet (B), and outlet (C) views as well as the CT-scans (D–F) show severe dislocation of the left hemipelvis. Postoperative a.p. (G), inlet (H), and outlet (I) views demonstrating the result after iliosacral screw osteosynthesis on the right site, open reduction and internal fixation of the dorsal disruption on the left site using a bridging angular stable plate and a conventional plate, and a bridging plate osteosynthesis of the anterior part of the pelvis.

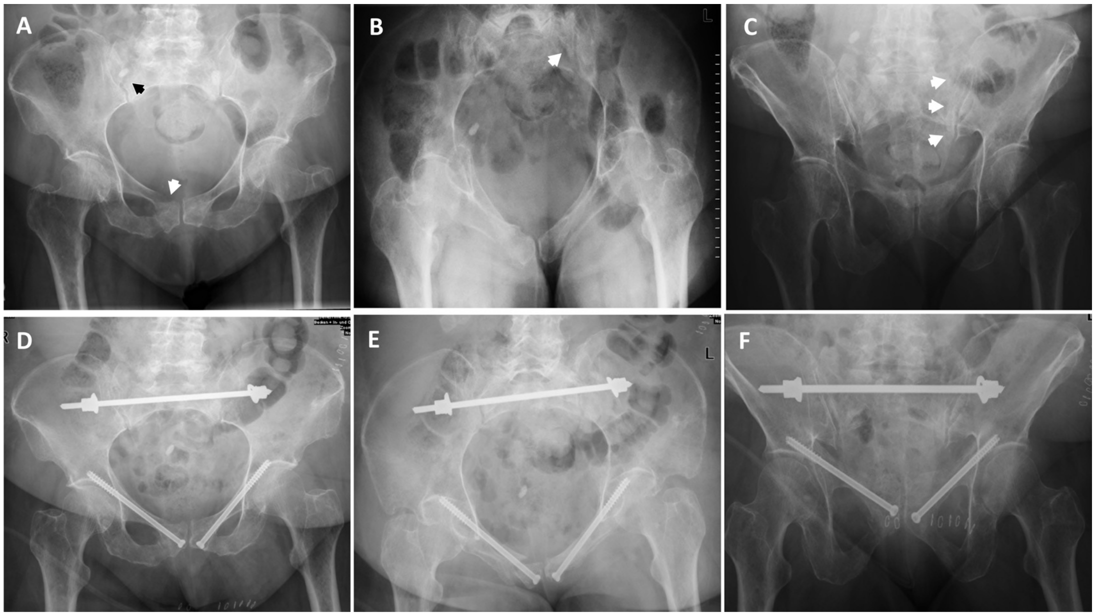

Fig. 9. Percutaneous stabilisation of a FFP IIIC fracture using a transsacral positioning bar and retrograde transpubic screw osteosynthesis (a.p. (A and D), inlet (B and E), and outlet (C and F) views).

fracture areas. It can be inserted as an additional stabiliser together with iliosacral screw osteosynthesis.

Spinopelvic dissociations (FFP Type IVb) ask for a specific type of osteosynthesis. As the lumbosacral spine is disrupted from the pelvic ring, an iliolumbar fixation will be needed [73–75]. Pedicle screws are placed in the pedicles of the third and fourth or fourth and fifth vertebral bodies and in the dorsal iliac crest at the level of the superior posterior iliac spine. The screws are connected with bent bars, and the bars are connected with a small transverse bar.

In the case of different forms of instability in the dorsal hemipelvis, a combination of osteosynthesis techniques may be needed. Iliolumbar fixation can be combined with iliosacral screw osteosynthesis, the placement of a trans-sacral positioning bar or the placement of a dorsal internal fixator. For bilateral fractures of the ilium, ventral plate and screw fixation are done on both sides. Further, bilateral ventral plate fixation of sacroiliac joints in combination with iliolumbar fixation is possible. Anterior instability must always be fixed as well. The ultimate goal is to establish an adequate rigid fixation for every type of pelvic ring instability.

Conclusion

Fatigue fractures of the pelvic ring form a specific entity and are not comparable with high-energy pelvic fractures of the adult. They represent a different spectrum of pathologies and instabilities. A new comprehensive classification system for fatigue fractures of the pelvis is presented. It is based on clinical and radiological criteria and reflects four categories of increasing instability. Lesions within the groups are distinguished by the localisation of the instability. The first group contains isolated anterior pelvic ring lesions. The second group includes isolated non-displaced sacral fractures or the combination of anterior and minor posterior instabilities. In the third group, there are anterior and displaced unilateral posterior instabilities. The fourth group collects all bilateral displaced dorsal instabilities. The classification system gives hints for the extent of surgical therapy and type of fixation. Whereas in the FFP Type I lesions no surgical therapy is needed, in FFP Type II lesions percutaneous screw fixation is recommended. In FFP Type III lesions, open reduction and internal fixation is the rule. In FFP Type IV lesions, iliolumbar fixation or a combination of osteosynthesis techniques is required.

Conflict of interest

We disclose no financial and personal relationships with other people or organisations that could inappropriately influence (bias) our work.

No benefits of any kind have been received or will be received by the authors from a commercial party related directly or indirectly to the subject of this article.

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