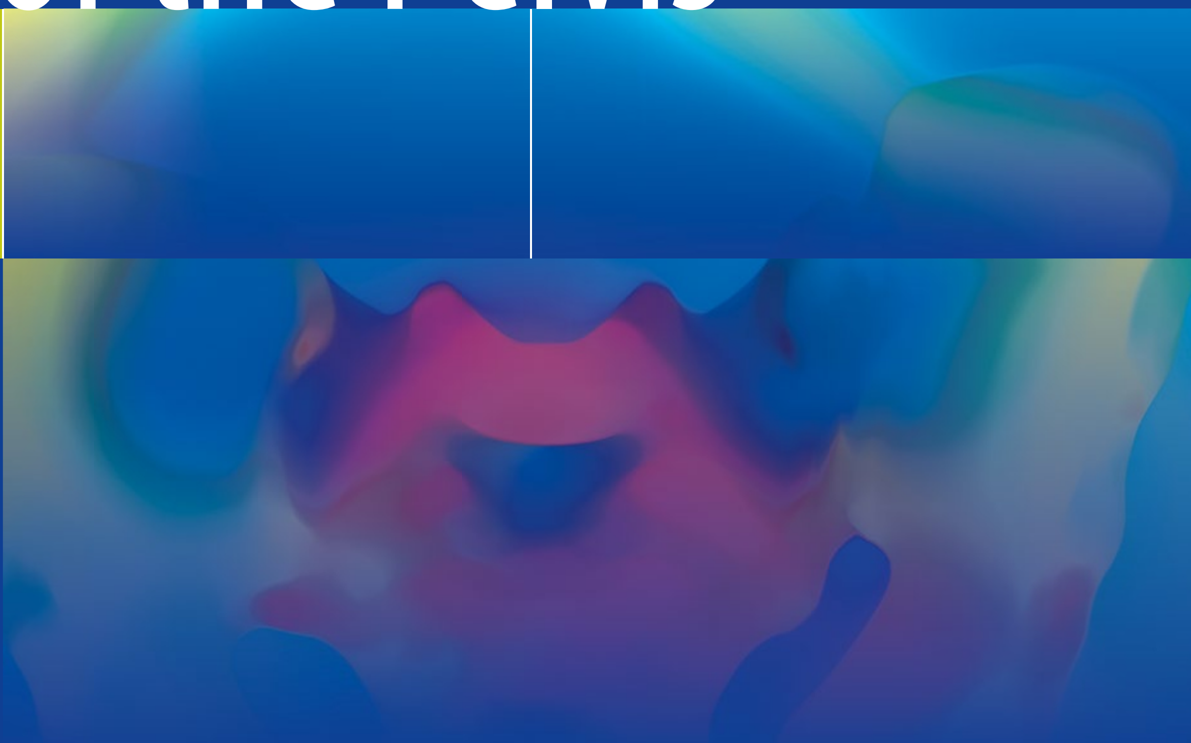
Pol Maria Rommens
Alexander Hofmann
Editors

Fragility Fractures of the Pelvis



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ISBN 978-3-319-66570-2 ISBN 978-3-319-66572-6 (eBook)
DOI 10.1007/978-3-319-66572-6

Library of Congress Control Number: 2017959148

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Movement is life
Life is movement

This book is dedicated to our families

From Pol Maria Rommens
To my wife Kristin
To my children
Pieter, Mimi and Helene and Paul
Karlien, Jeroen and Samuel and Felix
Margot, Tom and Elias and Wout
Mattias and Gloria

From Alexander Hofmann
To my wife Isabelle
To my children Klara and Kathleen Charlotte

Foreword

Our understanding of pelvic ring trauma has been greatly advanced in the past three decades. Much of the original work to understanding this complex injury was done by my mentor, George F. Pennal. My original one-volume book, *Fractures of the Pelvis and Acetabulum* (Williams and Wilkins, 1984), was devoted to that work, describing in detail the radiographic views needed for diagnosis, the classification based on force direction, and the early and definitive treatment. At that time we recognized two distinct demographics, injuries caused by high energy trauma, usually younger patients, and those with minor low energy injuries, usually a fall and often in the old age group. Our subsequent editions (*Fractures of the Pelvis and Acetabulum*, 4th Edition, AO Trauma, Thieme, 2015) have concentrated on the high energy types in order to save lives, prevent high complications, and improve patient outcomes.

As in all fracture demographics (wrist, shoulder, ankle, etc.), as pointed out by the authors, low energy fracture patterns through osteopenic bone are much more common. This is also true in pelvic ring trauma. However, pedestrian injuries are becoming more common in the older age group; those patients often have life-threatening concomitant injuries and a significantly higher mortality rate.

This book addresses this injury, the fragility fracture of the pelvic ring, and greatly adds to our knowledge on this subject.

The authors describe the usual fragility injury as an implosion or lateral compression mechanism, in most cases through inadequate bone. This has been our experience, and in most of those stable fracture patterns, nonoperative symptomatic care usually leads to good outcomes.

However, there are patterns that may displace early, leading to difficult follow-up care and late surgery. The authors have proposed a comprehensive classification and have indicated those injuries that might benefit from early operative stabilization. Several chapters are devoted to details of operative fixation, stressing the importance of minimally invasive techniques, especially in these older patients to minimize complications.

The final chapter on outcome will require more updating as more studies are published, but older studies on stable lateral compression patterns reveal generally good outcomes with symptomatic care, in patients with few comorbidities.

I congratulate Pol Rommens, who has contributed much to our understanding of pelvic ring trauma, and his co-editor, Alexander Hofmann, for their contribution to a subject of growing importance in our ever-increasing elderly population.

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Preface

Pelvic injuries have mainly been associated with high-energy pelvic trauma due to traffic accidents, crush traumas or falls from great height. There is vast evidence about origin, clinical picture, treatment algorithms and outcome of these severe injuries. Damage control techniques to stop bleeding in pelvic trauma are differentiated from definitive surgical procedures, classically open reduction and internal fixation with plates and screws.

Osteoporotic or insufficiency fractures of the pelvic ring have previously been described in case reports and review articles, but they remained marginal reports within the large body of the literature on pelvic trauma. Thanks to better prevention of infections and diseases, higher life quality and improvements of medical care, the mean age of most populations of the globe has increased and remains to do so. With longer lives, the number of age-related diseases, disabilities and injuries also increases. Osteoporosis is a typical age-related disease and widespread in industrialized and emerging countries. It is characterized by a systematic decrease of bone mineral density and ultimately results in "a fracture that is caused by an injury that would be insufficient to fracture normal bone; the result of reduced compressive and/or torsional strength of bone". The last sentence is the definition given by the World Health Organization (WHO) for fragility fractures.

Intra- and extracapsular hip fractures, proximal humerus, distal radius and vertebral compression fractures are well-known fragility fractures with abundant literature, guidelines and recommendations for treatment. Fragility fractures of the pelvis (FFP) are an emerging yet already existing entity, but with a paucity of literature and evidence on diagnostic algorithms and protocols for treatment.

With this book, the editors aim at collecting the current knowledge and experience on diagnostic work-up of and treatment alternatives for these lesions. The characteristics of FFP are very different from pelvic disruptions in adolescents and adults. There rather is a collapse of the pelvic ring than an explosion; fracture morphologies are different, consistent and specific. Instability may increase over time. With a new, comprehensive classification system of FFP, the editors provide a framework, in which the multiple fracture configurations can be differentiated from each other according to their loss of stability. In consecutive chapters, the pathomechanism and clinical picture of FFP are described.

Multiple contributions on treatment modalities represent the creativity of the orthopedic trauma surgeon on the one hand. They are also an indication for the lack of golden standard in surgical therapy. As a common rule, less invasive stabilization techniques are preferred above more aggressive open reduction and internal fixation procedures. The patient with a fragility fracture of the pelvis does not have the same physiological reserves as adolescents and younger adults. The goal of therapy is more focused on recovery of motion and independency than on anatomical reduction.

In less invasive surgery, we primarily rely on preoperative imaging, thorough preoperative planning and high-quality intra-operative imaging. Due to the frequency of fragility fractures of the sacrum and the concept of percutaneous fixation, special attention is paid in diverse contributions to the morphology and bone mass distribution of the sacrum. New findings give a direct insight in the specific fragility fracture patterns of the sacrum and the dimension and shape of transsacral corridors.

Fragility fractures are the result of a systematic disease in a fragile patient. Treatment cannot be focused on stabilization of fractures only. A multidisciplinary approach with input of the geriatrician, physiotherapist and the orthopedic trauma team must improve the general condition of the elderly patient on the short term. An analysis of bone metabolism and correction of deficiencies will prevent consecutive fragility fractures on the long term.

Diagnostic imaging is an indispensable part of daily practice in orthopedic trauma surgery. The editors, together with the authors, paid specific attention to an abundant number of images and commented case presentations. They hopefully will be an important addition and support to the texts that explain background knowledge and surgical methods of treatment. A series of cases at the end of the book is meant for active study and personal discussion.

The editors wish that this book will substantially contribute to the knowledge of the reader on fragility fractures of the pelvis. The book primarily focuses on orthopedic trauma surgeons, but also should be of specific interest for practicing orthopedic surgeons, spine surgeons, geriatricians, family doctors and physiotherapists. Much more biomechanical and clinical studies are needed to shed light on the optimal care for patients with FFP. Consequently, this book cannot be a standard reference, but rather is a compilation of personal experiences. The book is intended to be an incentive for the elaboration of clinical pathways and future guidelines for treatment for this emerging entity of fragility fractures.

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General Aspects

1 Epidemiology and Demographics

Matthew P. Sullivan and Jaimo Ahn

1.1 Introduction

The population worldwide is both expanding rapidly and growing older in age. With this aging comes the sequela of both normal aging and pathologic chronic diseases. Osteoporosis is one such disease that afflicts millions worldwide and can within an instant have life altering consequences. Pelvic fragility fractures have for years taken a lesser role to the more easily diagnosed and more prevalent geriatric hip, vertebral, and upper extremity fractures. However, with the worldwide availability and accessibility of CT scanners pelvic fragility fractures are now becoming recognized as a very important player in the osteoporotic fractures landscape. Osteoporosis, fragility fractures in general and pelvic fragility fractures specifically are increasing as older individuals are living longer. Modern medicine thus far has had only a modest impact on stemming the rapid rise of pelvic injuries in the elderly. Women are disproportionately affected; some reports indicate a ratio as high as nine female pelvic fragility fractures to one male pelvic fragility fracture. Through this chapter, we hope that the reader will gain a better understanding of the epidemiology and demographics of osteoporosis and osteoporotic fractures as they relate to pelvic fragility fractures. Appreciating the subtleties of risk factors, age, and associated conditions will certainly aid those caring for the elderly.

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1.2 Osteoporosis

Classically, osteoporosis is a disease of aging [1–3]. As the aging population worldwide continues to expand, so does the prevalence of osteoporosis [4, 5]. It has been projected that the world's population over age 65 years will double between 2010 and 2040 [2]. These data are mirrored in the United States, as the American population over age 65 years is expected to double between 2005 and 2030 [1].

The health impacts of these projections are astounding. Up to 85% of aging individuals worldwide over 65 years will be diagnosed with at least one chronic disease [6]. As of 2010, roughly 10 million individuals over age 50 years in the United States carried the diagnosis of osteoporosis [1, 3]. As a function of their respective populations, half of women over 50 years old have a T-Score of the femoral neck within the osteopenic range (−1.0 to −2.5) and 11% in the

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_1

osteoporotic range (<−2.5). Likewise, one-third of men over age 50 years old have osteopenia and 2% have osteoporosis (based on the same criteria) [5, 7]. Worldwide projections similarly describe the majority of older individuals with low bone density. Interestingly, Cooper et al. expect a relative increase in individuals diagnosed with osteoporosis in Asia and Latin America as compared to North America and Europe over the next 25–50 years [8]. Though the absolute number of individuals with low bone mineral density is rising, the percentage of patients with osteopenia and osteoporosis as a function of the entire population appears to be on the decline [5]. This parallels the widely published data suggesting declining population adjusted, while increasing absolute rates of hip fractures [9, 10].

One's risk of sustaining a fragility fracture is multifactorial, which is likewise true for the acute exacerbation of many chronic conditions. There is substantive literature linking low bone mineral density to osteoporotic fracture risk [11–14]. In addition, body mass index, and likely more importantly, lean body mass, is inversely proportional to one's fracture risk [15–17]. De Laet and colleagues describe a twofold greater hip fracture risk in patients with a body mass index of 20 kg/m^2 as compared to 25 kg/m^2. Interestingly, body mass index is only protective to a certain degree, at which point obesity may become a risk factor for osteoporosis [18–20]. Other important risk factors for osteoporosis include tobacco and alcohol exposure [21–24] as well as patient sex [25–27].

1.3 Fragility Fractures in General

Osteoporotic fragility fractures are extremely common in the United States and worldwide with roughly two million patients per year sustaining an osteoporotic fracture in the United States alone [2, 7]. More than two-thirds of all osteoporotic fractures occur in women, with 90% occurring in Caucasian women [2]. Males also carry a significant risk of fragility fractures as well as worse long term outcomes as compared to women. These injuries have major quality of life as well as economic implications. And though the per-population rate of osteoporotic fractures appears to be falling, the annual incidence of these injuries continues to rise [4, 5]. The hip, wrist, proximal humerus, vertebra and pelvis are at greatest risk for osteoporotic fragility fractures [3, 28].

Much has been written chronicling the declining rates of geriatric hip fractures over the past two decades [9, 10, 29–32]. Fortunately, this has been mirrored closely by other osteoporotic fracture patterns as well [28, 32]. Specifically, population adjusted fracture rates of both the distal forearm and vertebral bodies have been on the decline for the past two decades. Unfortunately, these osteoporotic fractures in the elderly portend an extremely poor prognosis. There have been abundant data reported over the past 10–15 years indicating 12-month mortality rates following geriatric hip fractures in the 25–35% range [4, 9, 33–35]. Similar results have been reported in elderly patients sustaining distal femoral fractures and vertebral fractures [36–38]. Additionally, male sex, advanced age and comorbidities substantially increase mortality rate after osteoporotic fractures [38–40].

The societal implications of these fractures are immense. Database studies from the United States and worldwide indicate incredible financial burden associated with these injuries [41–43]. A recent study by Singer et al. suggests the overall health care dollars spent on osteoporotic fracture care in the United States outweighs that of coronary artery disease, cerebral vascular disease, and breast cancer [42]. Similar data have been described from European countries as well [44–46].

1.4 Fragility Fractures of the Pelvis

Pelvic ring fragility fractures are injuries of the elderly. This is supported by a multitude of case series and population-based studies. The average age at which pelvic fragility fractures occur is in the 8th and 9th decades [47–51]. In addition, the

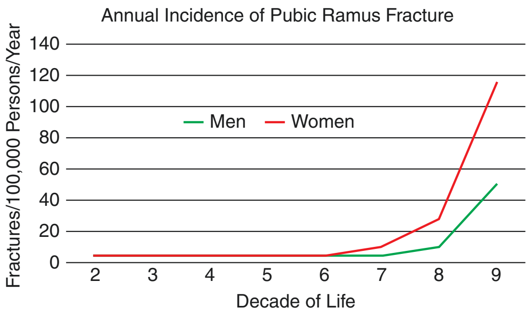

Fig. 1.1 Dramatic rise in pubic ramus fractures with advancing age. Adapted from Hill, et al. [49]

mean age at which these injuries occur appears to be rising. In a Scandinavian population of individuals 80 years or older, the number and age-adjusted incidence of low-energy pelvic fractures increased between 1970 and 2013 from 33 (number) and 73 (incidence) to 1055 (number) and 364 [51]. Their prevalence rises proportionately with increasing age. Annual incidence in patients over age 60 years is 25.6/100,000. This number rises dramatically to over 110/100,000 in patients over age 80 years [49] (Fig. 1.1).

Low energy osteoporotic pelvis fractures account for two-thirds of pelvic ring injuries seen in the general population including all ages. Likewise, pelvic ring injuries in patients over 60 years are low energy and osteoporotic in nature in 94% of cases [51]. An extremely high percentage of patients diagnosed with pelvic fragility fractures have a prior history of osteoporotic fracture at another location. Multiple studies report patient samples in which upwards of 50–60% of patients presenting with a pelvic insufficiency fracture had a prior history of osteoporotic fragility fracture [47, 50]. Not surprisingly, many of these previous injuries were not adequately medically treated for osteoporosis [47]. In their disturbing description of osteoporotic management by orthopaedic surgeons, Freedman et al. reported on women age 55 years and older who sustained a sentinel osteoporotic fracture [52]. They found that less than 3% of patients received a formal osteoporosis work up following injury and only 22.9% of patients received formal pharmacotherapy for osteoporosis following injury.

Various metabolic, rheumatologic, and oncologic disorders have been implicated in pelvic insufficiency fractures. These include low vitamin D [53], antiphospholipid syndrome [54], rheumatoid arthritis [55, 56], juvenile idiopathic arthritis [57], renal osteodystrophy [53], and post-pelvic irradiation [58, 59]. Though not fragility fractures per se, young female runners are similarly at high risk for pathologic pelvic ring fractures. These patients experience cyclic vertically oriented forces through the sacrum resulting in pathologic micro-architectural changes in bone. These bony changes are compounded by sex-hormone dysregulation leading to abnormal osteoblastic-osteoclastic regulation and ultimately fatigue failure of the pelvis [60–62].

Finally, a rare but important clinical scenario of sacral fragility fracture is seen in the geriatric patient undergoing adult spine deformity correction surgery in which thoraco-lumbar instrumentation extends to the sacrum (without iliac fixation). These patients tend to have poor bone quality at base line due both to age and their preoperative functional limitations from their spinal deformity. The massive deformity correction construct then causes a long moment arm that hinges at the sacrum ultimately resulting in stress failure of the sacrum. In certain patients undergoing adult deformity correction surgery, extension of the construct to the pelvis should be considered [63–66].

To our knowledge there have been no epidemiologic studies evaluating the relative prevalence of pelvic fragility fractures as a function of etiology. That said, given the vast majority of persons in the general population with osteoporosis as compared to rare rheumatologic conditions, vitamin deficiencies, and exercise induced hormone deficiencies, it is likely that osteoporosis is the most common pathologic basis for pelvic fragility fractures.

There is a marked female predominance seen in pelvic insufficiency fractures. Some series describe a sex bias as high as 9:1 in favor of women [47–49, 67, 68]. This is consistent with the well-described osteoporosis sex bias. As of 2005 pelvic fragility fractures accounted for 7% of all osteoporotic fractures. By 2025 the overall increase in all osteoporotic fractures is expected to rise by 20%, where as pelvic fragility fractures are expected to disproportionately rise by 56% [3].

The exact reason for this excessive rise in pelvis ring fragility fractures relative to other types of fragility fractures is unknown but may be related to greater access to advanced imaging modalities such as CT and MRI. Conversely, there may be differential improvement in bone quality with the use of anti-resorptive and anabolic drugs (bisphosphonates, recombinant parathyroid hormone, denosumab), in which certain areas (proximal femur and vertebral bodies) see greater improvement in bone mineral density compared to others (pelvic ring and acetabulum) resulting in new and pathologic stresses felt by the pelvis.

There is no question that as the world's population ages the absolute number of pelvic fragility fractures will continue to rise. Furthermore, based on the data presented above, these injuries appear to be increasing disproportionately compared to other fragility fractures. Unfortunately, it is impossible to say whether or not these epidemiologic shifts are real trends that will continue with time or mere transient statistical abnormalities. Without a prospective study in which the diagnostic modality remains consistent through the course of the study period this question may not be accurately answered.

Multiple population-based studies have evaluated the 12-month morality rate in patients with fragility fractures about the pelvis. Mortality rates range from 9.5 to 18.9% in all patients over age 65 years to as great as 39% in elderly patients over age 90 years who sustain a pelvic ring injury [48, 49, 67, 69]. Not surprisingly, a pelvic fragility fracture is an independent risk factor for mortality in geriatric patients when compared to uninjured age-matched controls [49]. Furthermore, advanced age also appears to be a risk factor for mortality in these patients. Krappinger, et al. describe a significantly greater 1 year mortality in patients greater than 90 years old versus patients greater than 80 years old, when compared to age matched uninjured controls [69]. There also appears to be a relationship between pelvic fragility fractures, dementia, and mortality, with dementia being an independent risk factor for 1-year mortality. This most certainly points to the multifactorial nature of this age related disease and the interplay between physiologic and cognitive components of aging [49]. Finally, pelvic ring injuries portend a far worse long term prognosis in patients over 80 years compared to patients younger than 65 years, with octogenarians being 3.6 times more likely to die from their injury [70].

In addition to increased mortality, functional outcomes also appear to be impacted by pelvic ring injuries in the elderly. Koval et al. reported long-term failure to return to pre-injury status in 8% of patients sustaining pubic ramus fractures [67]. This number was dramatically higher in the series published by Hill et al. who described a 40% failure to return to pre-injury functional status in elderly patients sustaining pubic ramus fractures [49].

Conclusion

There is considerable overlap between age, osteoporosis, and pelvic fragility fractures. Worldwide, the adult population is aging as we are living longer, more active lives than ever before. With this comes age related chronic disease; osteoporosis being one of the most significant. Osteoporosis related fractures result in considerable morbidity and mortality and as well as massive financial burden on the already strained health systems throughout the world. The pelvis is one of many recognized danger areas for fragility fracture and in recent years, possibly due to a combination of better diagnosis through advanced imaging techniques (CT and MRI) and an increasingly active older population, these injuries have greatly increased in prevalence worldwide; and there does not appear to be an end in sight to this rapid growth. Furthermore, it is important to understand the impact that these injuries have on patients of various ages, as age independently influences the ultimate outcome of the patient. Understanding these trends will facilitate better clinical care of older patients by medical providers and better allocation of resources by our policy makers.

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2 Personality of Fragility Fractures of the Pelvis

Pol Maria Rommens and Alexander Hofmann

2.1 Introduction

Pelvic ring injuries generally involve severe trauma. Pelvic injury is regarded as a major source of hemodynamic instability. Patients who suffer a pelvic trauma are severely injured, and many severe injuries involve pelvic trauma [1]. Biomechanical studies have proven that forces between 2,000 and 10,000 Newton are needed to disrupt a pelvic ring [2]. These forces only exist in high-velocity traffic accidents, falls from significant heights, and crush trauma. The clinical picture of patients with pelvic ring disruption is very similar to that of severely injured or polytraumatized patients, and their management will follow the same guidelines. Treatment of pelvic ring disruptions includes an emergency phase, with the goal of patient survival, and a definitive phase, with the goal of pelvic reconstruction. The outcome depends on the extent and type of instability, which is visible in the classification of these injuries, and on the severity of concomitant soft tissue injuries in vessels, nerves and intrapelvic organs [3, 4].

We are currently confronted with a completely different type of pelvic ring lesions in our emergency rooms and outpatient clinics. The proportion of the population older than 65 years is continuing to grow [5]. Demographic changes in high-income countries can be attributed to higher life expectancy and lower birth rates. Elderly people are not a homogeneous population. There is a spectrum of subgroups from moderate to very old age, from healthy to extremely sick, and from very active to bedridden. In all subgroups, accidents occur that result in pelvic ring injuries and other fractures.

The most common disease that weakens bone in the elderly is osteoporosis, which results in a generally lower bone mass and an alteration in bone microarchitecture, both of which increase the risk for pathologic fractures [6]. Pelvic fractures in the elderly are very likely to be associated with osteoporosis [7]. Pelvic fractures comprise up to 7% of all osteoporotic fractures [8], and that rate is expected to increase. An incidence of 92/100,000 people aged 60 years or older was calculated for pelvic fractures in Finland [9] whereas an incidence of “only” 25 fractures/100,000 people was found in Scotland [10]. In a Finnish study on individuals 80 years or older, the number and age-adjusted incidence of low-energy pelvic

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_2

fractures increased between 1970 and 2013 from 33 (number) and 73 (incidence) to 1055 (number) and 364 (incidence) [9]. Between 2005 and 2025, it is estimated that pelvic fractures in the elderly will increase by 56% [8, 11].

The “personality” of pelvis fractures in the elderly differs in many ways from pelvic ring lesions in adults. In this chapter, we will explore the most striking differences between pelvic ring lesions in adults on the one and those in the elderly on the other hand.

2.2 Trauma Mechanism

In adults, only high-energy trauma leads to pelvic ring disruptions. The direction of the traumatizing energy dictates the type of injury. Distinctions have been made between antero-posterior forces and between lateral and vertical forces [12–14].

Antero-posterior forces occur in frontal collisions. The forces separate the innominate bones from one another and flatten and expand the pelvic ring. Typically, there is a diastasis of the pubic symphysis due to external rotation of one innominate bone. In cases of higher destructive forces, the pelvic bottom structures (the sacrospinal and sacrotuberal ligaments) and the anterior ligaments of the sacroiliac joint are also disrupted (Fig. 2.1a, b) [15]. Expansion of the small pelvis is a consequence of pubic symphysis diastasis and may be complicated by blood loss [16].

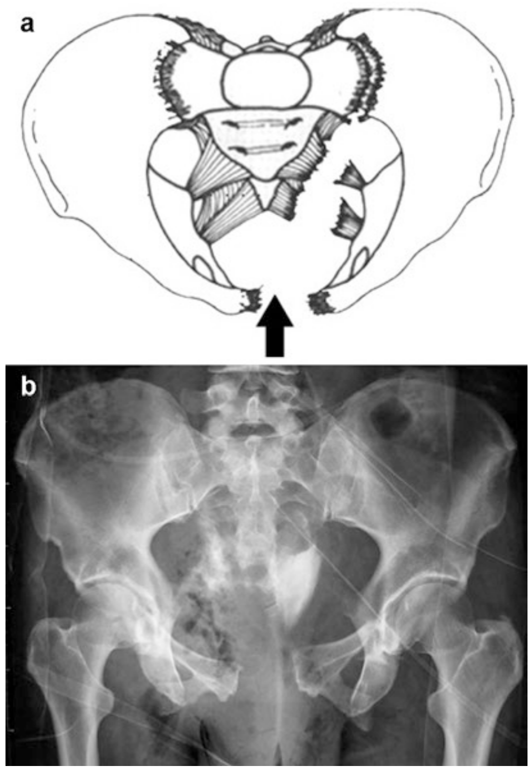


Fig. 2.1 (**a**) Drawing depicting the medchanism of anteroposterior compression injury [12]. (**b**) Pelvic a.p. overview of open book lesion

Lateral forces generate another type of pelvic ring injury. A typical accident is a car collision with a vehicle coming laterally. The ipsilateral innominate bone is pushed toward the contralateral bone, which can result in a horizontal fracture of the superior pubic ramus. The lateral fracture fragment overrides the medial fragment. In the dorsal pelvic ring, there is a crush zone at the anterior part of the sacral ala (Fig. 2.2a, b). All fracture patterns with internal rotation of the innominate bone are defined as lateral compression injuries [16, 17].

Vertical forces create a cranial displacement of one hemipelvis. A typical trauma mechanism is a fall from a height. There is a complete rupture of the anterior and posterior pelvic ring and bottom structures (Fig. 2.3a, b). The fracture planes are vertical. In the anterior pelvic ring, the fracture runs through the pubic bone or through the superior and inferior pubic rami. A rupture of the pubic symphysis is also possible. In the dorsal pelvis, the fracture runs through the sacral neuroforamina (zone II in the Denis Classification [18]). Fractures running through the sacral ala, dislocations, and fracture-dislocations of the sacroiliac joint are alternative locations of dorsal disruption [19].

In falls from significant heights, a spinopelvic dissociation, or suicide jumper’s fracture, may occur. In this specific type of injury, the sacral body of S1, or sometimes S1 and S2, is broken out from the pelvic ring but remains attached to the lumbar spine. The fracture lines run through the sacral neuroforamina S1 or S1 and S2 and the horizontal component connecting both vertical fractures runs between S1 and S2 or S2 and S3 (Fig. 2.4). Three different forms have been described by Roy-Camille et al. [20], and two were added by Strange-Vognsen et al. [21]. Spinopelvic dissociations are frequently combined with neurological damage to the cauda equina.

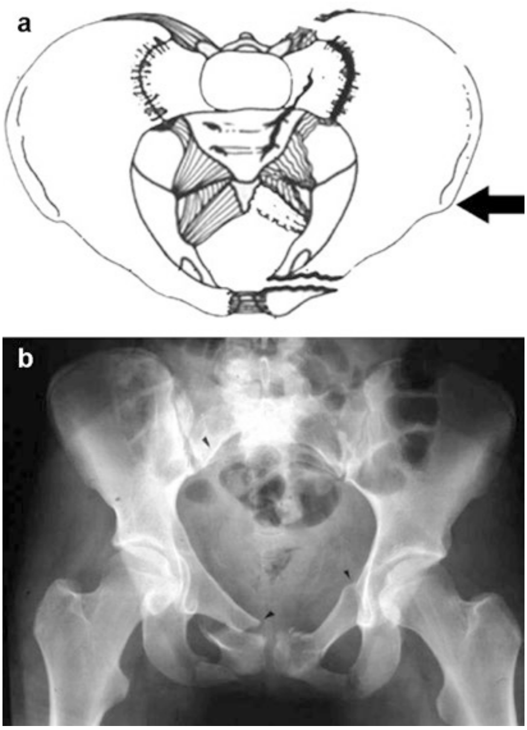


Fig. 2.2 (**a**) Drawing depicting the mechanism of lateral compression injury [12]. (**b**) Pelvic a.p. overview of lateral compression injury

Fig. 2.4 Three-dimensional CT-reconstruction of suicide jumper's fracture. The body of S1 is dissociated from the rest of the sacrum, but remains connected with the lumbar spine. Antero-posterior view

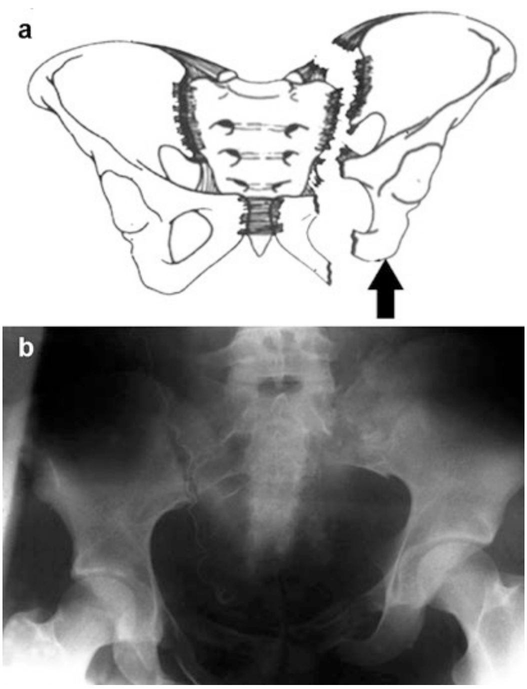


Fig. 2.3 (**a**) Drawing depicting the mechanism of vertical shear injury [12]. (**b**) Pelvic a.p. overview of vertical shear injury

Combined forces create complex forms of pelvic disruptions and often require consecutive reconstruction procedures [22].

Due to the high-energy trauma mechanism, *concomitant lesions* of the soft tissues occur frequently. Morelle-Lavallée lesions are degloving injuries in which the skin and subcutaneous tissue are sheared off the underlying fascia. Such degloving injuries typically occur at the sacral region or over the greater trochanter. Blood and seroma fill the void, and a fluid collection of several liters is possible [23]. Large displacements of bone fragments can rupture veins and arteries; damage neurological structures; and disrupt intrapelvic organs, such as the bladder or urethra. The type and extent of associated injuries dictate the emergency management that is required, the definitive treatment and the long-term results [3, 24, 25]. Although open fractures are uncommon, their outcome is worse than that of complex pelvic trauma [26].

In the elderly, high-energy trauma is the source of only a small percentage of pelvic fractures. High-velocity car and motor vehicle accidents are an exception. Typical accidents with higher energy are over-roll traumas while crossing a street or falling from a ladder while fruit harvesting [27].

Low-energy accidents are the rule. Domestic falls are typical. In some patients, even coughing or sneezing has provoked fragility fractures of the pelvis. In other patients, the traumatic event may not be memorable [28]. In adults, the trauma mechanism leads to an *explosion* of the pelvic ring, while in the elderly there seems to be a *collapse* [29]. Fracture displacement in fragility fractures of the pelvis is small if it occurs at all. As a consequence, concomitant lesions of the soft tissues, neurovascular structures and intrapelvic organs are rare.

2.3 Clinical Picture

The clinical picture of patients with fragility fractures of the pelvis, who are admitted to the hospital is completely different from that of adolescents and adults with pelvic ring disruptions [30]. At admission, elderly patients suffer from pain in the groin or at the pubic symphysis. Some patients may also suffer from deep pain in the lower back or the sacral region. The pain may irradiate to the lower extremities. This complaint may give a false indication of a lesion on the deep lumbar spine [31]. Most patients are immobilized by pain. Others are still able to walk slowly with walking aids. On clinical examination, there is localized pain on stress. Dorsal compression pain near the sacroiliac joint indicates a dorsal pathology. Simultaneous lateral-to-medial compression on both iliac wings may also induce anterior and/or posterior pelvic pain. Gross pelvic instability is not detectable. There is no trauma-related soft tissue damage. In rare cases, an ecchymosis or hematoma can be found [32].

2.4 Hemodynamic Condition

In patients with high-energy pelvic ring fractures, approximately 10% are hemodynamically unstable [33, 34]. By contrast, hemodynamic instability in fragility fractures of the pelvis is rare. Rommens and Hofmann evaluated 245 patients with fragility fractures of the pelvis over a 5-year period, but none of these patients sustained a life-threatening bleeding [29]. Mears et al. reported on 181 geriatric patients with low-velocity pelvic fractures. They found that these fractures led to morbidity and mortality, but they did not describe bleeding complications [35].

Dietz et al. reviewed the literature on hemorrhage in fragility fractures of the pelvis [36]. Only eight case reports were identified. The average age of the patients was 79.5 years (range, 70–89 years). There was a striking prevalence of females among the patients ($n = 7/8$). In all but one patient, the superior pubic ramus was fractured. Prior to fracture, four patients were treated with anticoagulants. The obturator artery and the internal iliac artery were affected in two patients, while the superior gluteal, external pudendal, pubic branch of the inferior epigastric artery and external iliac artery were each injured in one patient. Arteries close to the anterior and posterior pelvic ring have been injured. Clinical onset of shock emerged between 2 and 72 h after admission to the hospital (median, 5 ± 27.73 h). Clinical examination revealed suprapubic/hypogastric swelling/masses in five cases and a hematoma over the hip in one case. In six of eight patients, hemorrhage was treated with angiography and selective embolization. The hemodynamic situation of all these patients was stabilized by this procedure (Fig. 2.5a–e). However, only three of these six patients survived. Two patients were not treated by angiography and selective embolization but rather with the administration of blood and fresh frozen plasma. One of these two patients survived. There must be a high index of suspicion on bleeding in patients with fragility fractures of the pelvis, who are treated with anticoagulants. We recommend hemodynamic monitoring at least during the first 24 h after admission (Table 2.1) [36].

As bleeding complications are rare in fragility fractures of the pelvis, they could be regarded as benign injuries. But, their morbidity should not be underestimated. Van Dijk et al. reported a serious complication rate as high as 20.2% in a case-control study that included 99 patients. The most

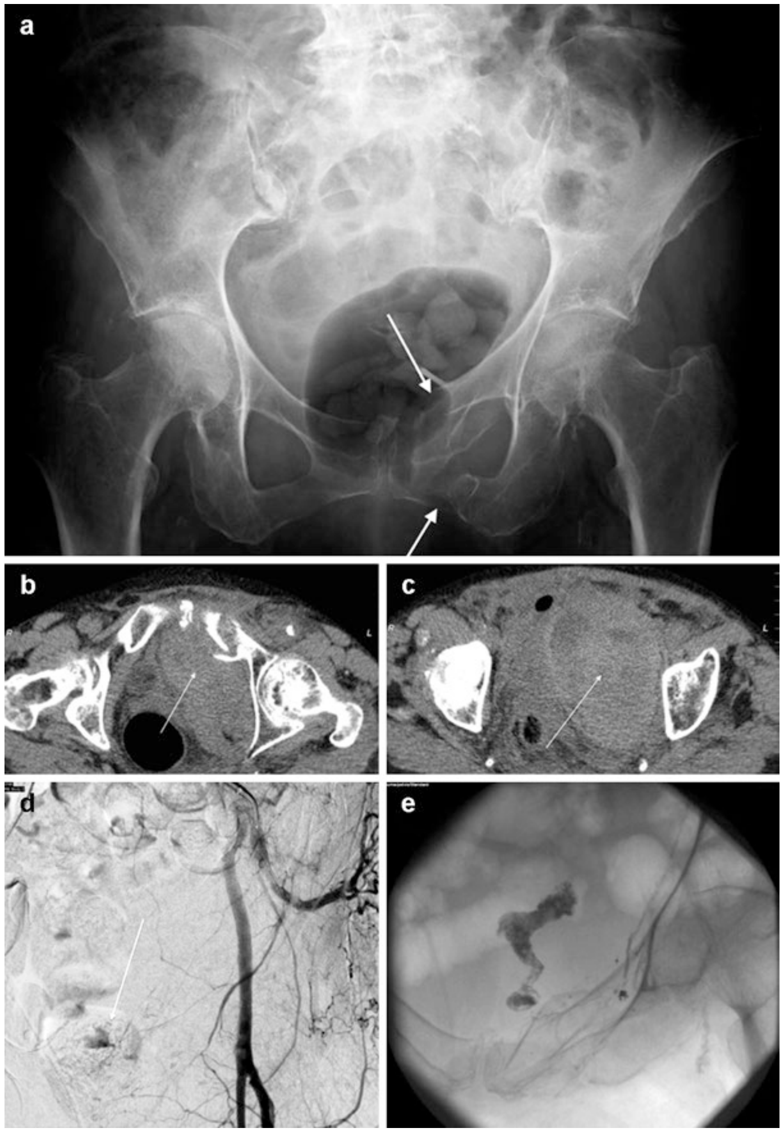


Fig. 2.5 An 81-year-old female patient suffered a left superior and inferior pubic rami fracture after a fall at home (**a**). She was admitted in our institution because of immobilizing pain. A conservative treatment with pain medication was started. In the first hours after admission, the hemodynamic situation of the patient deteriorated. A swelling above the symphysis pubis was noticed. A CT-scan with contrast revealed a large retropubic haematoma, which had direct contact with the fracture area (**b**–**c**). The patient was immediately taken to the angiography suite. An active bleeding of the pubic branch of the left inferior epigastric artery was detected (**d**). A selective embolization and coiling were performed (**e**). The hemodynamic situation of the patient recovered. She was taken to the operation theatre 4 days for operative removal of the hematoma. The patient further recovered well and was discharged 18 days after admission

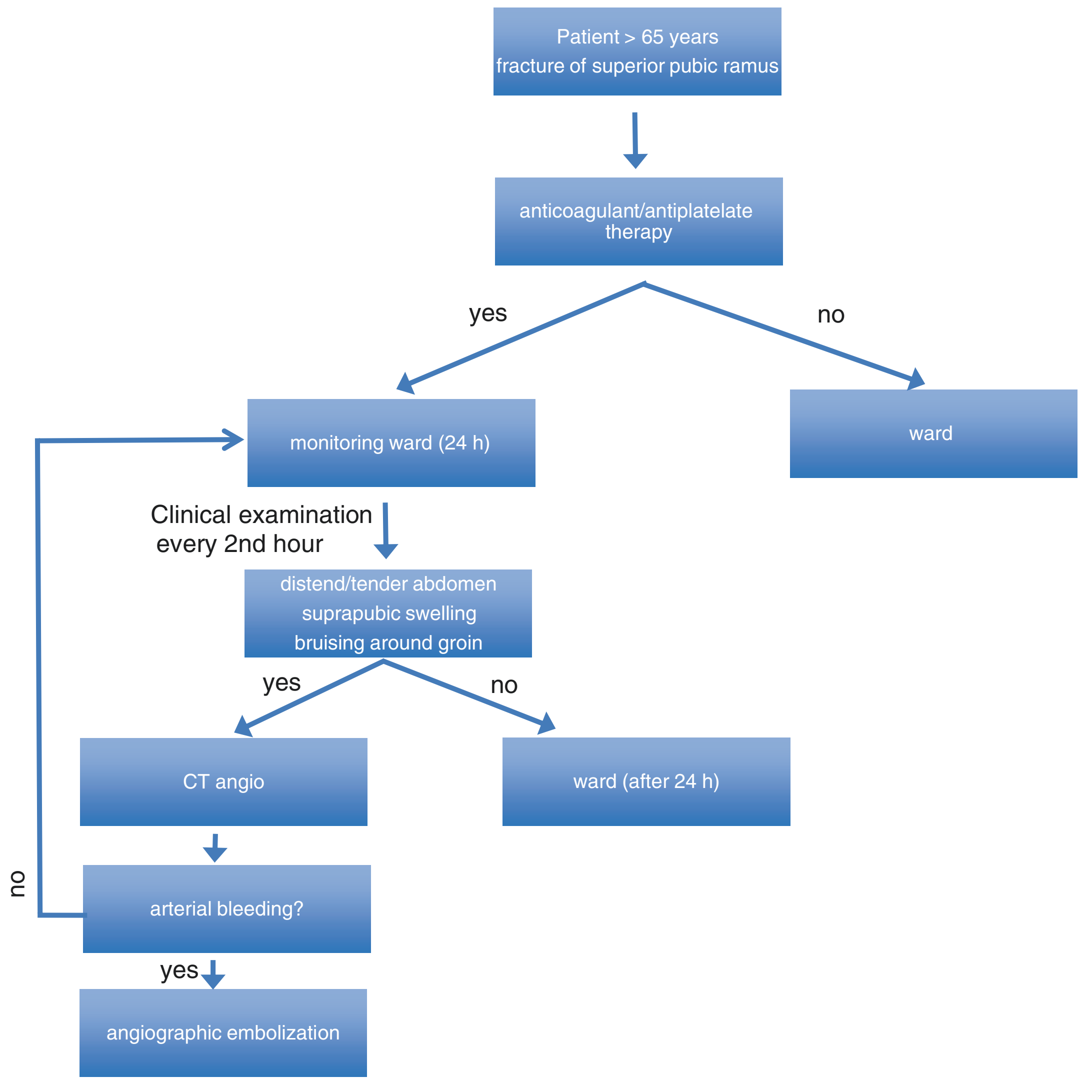
frequent complications were urinary tract infections, pneumonia, serious side effects from nonsteroidal anti-inflammatory drugs, and mechanical ileus [37]. A separate chapter on outcome follows.

2.5 Emergency Stabilization

In severely injured patients with pelvic trauma, emergency stabilization of the pelvic ring is part of the resuscitation protocol. Several procedures and instruments have been described. Their common goal is to diminish the volume of the disrupted pelvic ring, minimize movements of the fracture fragments during transport, and simplify nursing before definitive treatment. Higher pelvic stability reduces the need for blood transfusions by reducing blood loss and enhancing the chance of self-tamponade.

Pelvic sheets are the simplest constructs. A bed sheet is wrapped around the knee joints, holding both legs together. The pelvic sheet is wrapped around the pelvis at the level of the

Table 2.1 Flowchart for clinical and radiological monitoring of patients with fragility fractures of the pelvic ring



greater trochanters. Care is taken not to over compress the broken pelvic ring. This provisional stabilization is very easy to apply and can be used at every location and every stage of resuscitation, including at the accident site, during transport and in the hospital. Due to the high pressure on skin that may be traumatized, pelvic binders cannot remain in place for longer than a few hours (Fig. 2.6a, b) [38].

Pelvic binders are commercially available pelvic sheets and have the same effect. They are made of synthetic material and are washable, reusable and available on most emergency transport vehicles. Similar to pelvic sheets, they are placed around the pelvis at the level of the greater trochanters while carefully tilting up the lower trunk of the patient (Fig. 2.7). Their application is not invasive, but they are as effective as invasive techniques, such as pelvic clamping and external fixation. Direct pressure is applied to the soft tissues of the buttocks and the suprapubic area, which limits the volume of the respective compartments. The disadvantage is that their application time is limited to a few hours [39, 40].

Pelvic clamping, or C-clamping, is an emergency surgical procedure that can be performed in

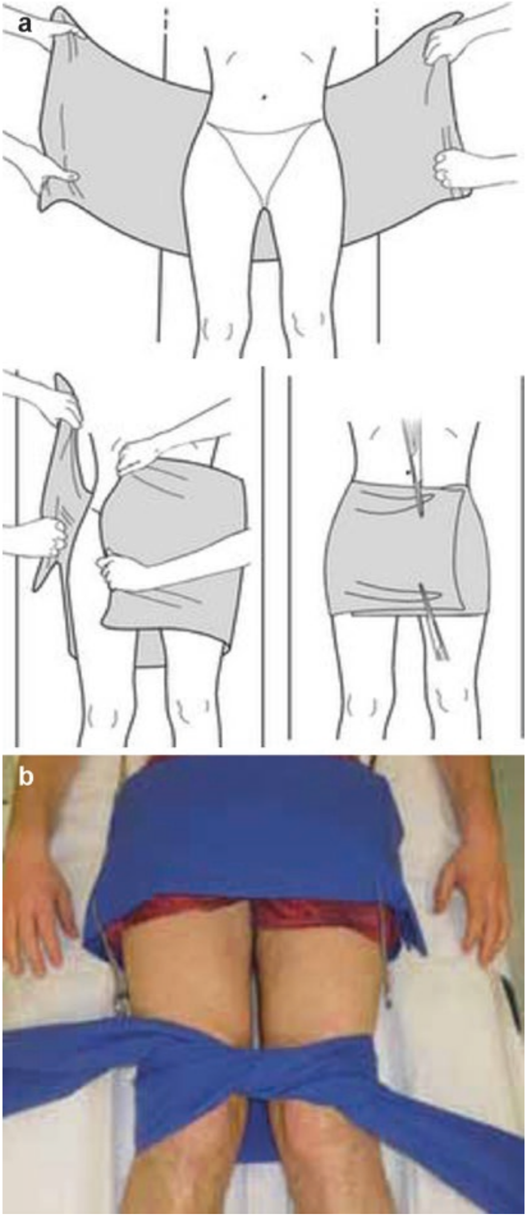


Fig. 2.6 (**a**) Drawing of application of pelvic sheet. (**b**) Application of a pelvic sheet in the emergency room

Fig. 2.7 Application of a pelvic belt at the level of the greater trochanters

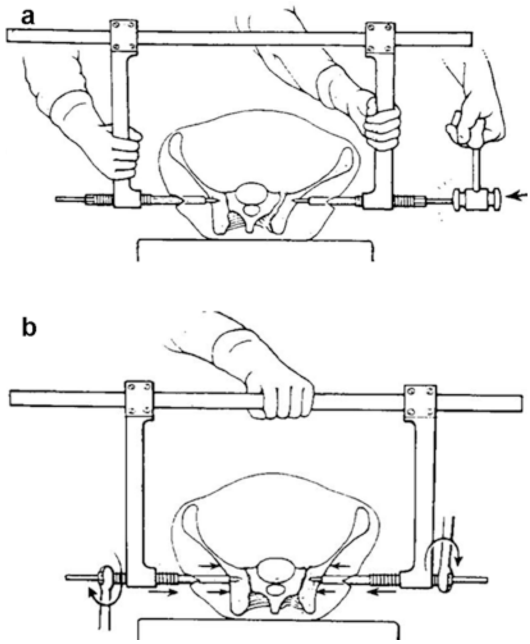


Fig. 2.8 (**a**) Drawing of application of pelvic C-clamp. (**b**) By tightening the frame, a compression of the dorsal pelvic ring is achieved (from [41])

the emergency room or operation theatre but not outside the hospital. After provisional reduction of the disrupted dorsal pelvis by manual traction and internal rotation, the C-shaped clamp is applied. By tightening the frame, stability is restored in the dorsal pelvis (Fig. 2.8a, b). The construct reduces the pelvic volume to its original size and eliminates any movement in the dorsal pelvis. Blood loss originating from fracture fragments is minimized, and the hemodynamic situation is stabilized or improved. The C-clamp creates direct pressure on the bony structures of the dorsal pelvis, but there is no direct pressure on the soft tissues. Therefore, the C-clamp can remain attached to the pelvis for several days until definitive surgery is possible. Pelvic clamping is

Fig. 2.9 Pelvic external fixator placed for fixation of an a.p.-compression lesion

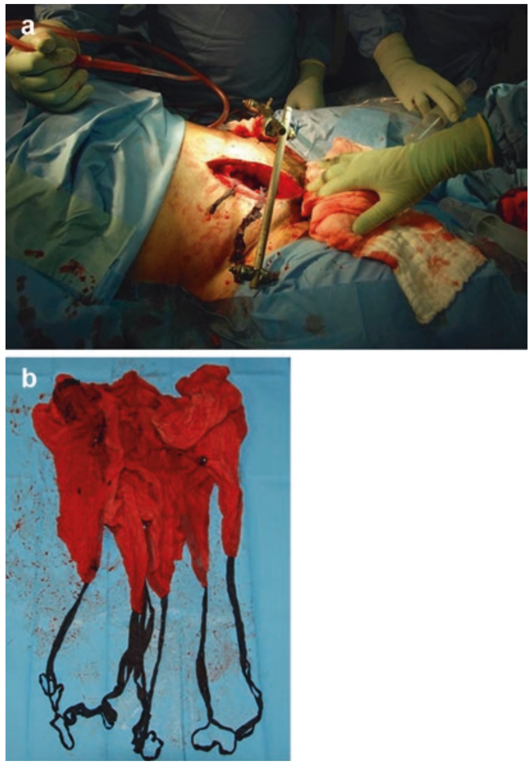


Fig. 2.10 (**a**) Clinical example of pelvic packing after primary stabilization with supra-acetabular external fixator. (**b**) Picture of the used towels at the time of de-packing

technically more difficult than applying a pelvic sheet or binder, and serious complications have been described in several publications [41, 42].

External fixation of the pelvic ring has been performed for decades and can be used for both emergency and definitive treatment of pelvic ring disruptions (Fig. 2.9) [43]. Biomechanical studies have demonstrated moderate stability of the pelvic ring after external fixation. Stability is particularly restored in the anterior pelvic segment. However, there is low stability in the dorsal pelvis. External fixation does not provide enough stability for sitting, standing and walking if the dorsal pelvic ring is ruptured and therefore should not be used as a definitive tool for fixation of complete pelvic disruption [44].

Pelvic packing is another emergency surgical technique for damage control after pelvic trauma. The infraperitoneal space is opened with a Pfannenstiel or midline suprapubic incision, and blood clots and hematoma are evacuated. The void is packed with several towels to create direct pressure on the soft tissues within the small pelvis. Low-pressure bleeding from the veins is controlled in an efficient manner [33, 45]. Counter-pressure is created by the application of a C-clamp or an external fixator. A second operation is needed to remove the towels and perform another debridement (Fig. 2.10a, b). Pelvic binding, external fixation and pelvic clamping are efficient for controlling bleeding in most patients with pelvic ring disruption. Only a small minority will need pelvic packing. The technique is limited to so-called "non-responders" who do not react well or only temporarily to other resuscitation measures.

Angiography and selective embolization are used for patients with arterial bleeding after pelvic trauma [46]. They require a specific infrastructure and personnel expertise, which have to be available on a 24/7 basis. In blunt trauma, arterial bleeding is present in less than 10% of patients. The procedure should not be overused, as it is not effective in patients with only venous bleeding. The challenge is to distinguish patients with arterial bleeding from those with venous bleeding. Indirect signs of arterial bleeding are large displacements of fracture fragments, low base excess at admission, and a persisting blood transfusion of more than 0.5 units per hour [47]. In patients with repeated episodes of hypotension despite resuscitation, there also must be a high level of suspicion of arterial pelvic bleeding [48].

If a full body CT scan with contrast medium is performed in the very early post-traumatic phase, sources of arterial bleeding can be recognized as contrast extravasation near the damaged vessel [49]. Generally, a large hematoma is also visible at or near the active bleeding site. Arteries that are damaged the most frequently in pelvic trauma include the obturator, pudendal and superior gluteal artery. In larger volume bleeding, the internal iliac, external iliac or common femoral artery may also be damaged. If bleeding is recognized early in the full body CT scan, the patient is transported directly to the angio suite, and an angiography with selective embolization is performed. The damaged vessel is identified and closed with coils (Fig. 2.5a–e).

The clinical picture of patients with fragility fractures of the pelvis is far less dramatic. Damage control measures as depicted above are generally not necessary. The main symptom at admission is pain, which should be treated adequately. It is sufficient to monitor the patient's hemodynamic parameters for at least 1 day; perform additional investigations, such as oblique pelvic overviews and/or CT; and observe the spontaneous course during the following days.

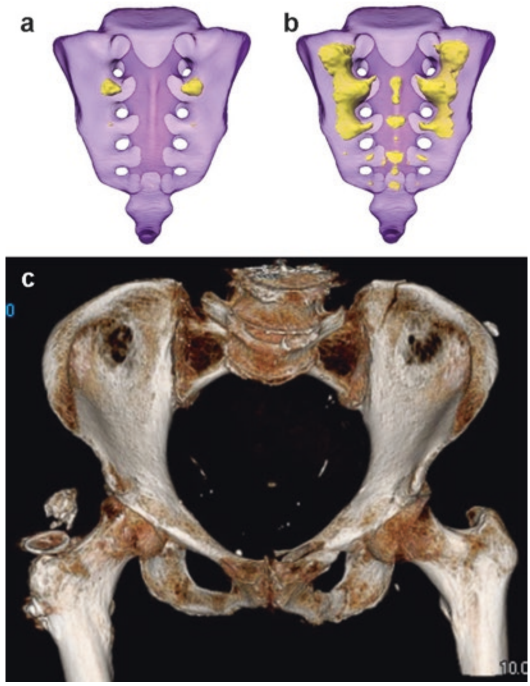


Fig. 2.11 (**a**) Sacral bone mass distribution in an averaged 3D–CT model. In the group with higher bone mineral density in L5, there are small areas of severely reduced bone density below and lateral to the neuroforamina S1 [56]. (**b**) In the group with lower bone mineral density in L5, there are large areas of severely reduced bone density in the sacral ala [56]. (**c**) Three-dimensional reconstruction of the pelvic ring in an 87-year-old female after a fall at home. The very low bone density in both sacral ala and in the center of the iliac wing is clearly visible

2.6 Strength of Bone and Stiffness of Ligaments

Due to the loss of bone mass in elderly patients, there is lower bone strength and an increased risk of pathologic fractures. Osteoporotic fractures frequently occur in specific skeletal regions, such as the hip, vertebral bodies, proximal humerus and distal radius [50–53]. A risk fracture assessment tool has been developed [54].

We have observed a specific loss of bone mineral density in the sacrum in females and with increasing age. The bone loss is not equal throughout the pelvic bones. Using 3D statistical modeling techniques, Wagner et al. demonstrated that the alteration of bone mass is not equally distributed over the sacrum; rather, some distinct regions are more affected than others. In particular, the sacral ala are affected by severe bone loss, leading to alar voids and areas of complete bone loss with a density, measured in Hounsfeld units, that is lower than water (Fig. 2.11a–c) [55, 56]. This explains the specific and consistent fracture patterns of fragility fractures of the sacrum that were observed in a case study by Linstrom et al. [57]. H-type fractures, which are rare in adolescents and adults, comprised 61.2% ($n = 52/85$) of all sacral insufficiency fracture patterns in a study cohort with normal sacral anatomy.

A 3D statistical model for the innominate bone is not yet available. Based on the bone density data gathered from the sacrum, we assume that the bone mass distribution of the innominate bone in the elderly is not uniform but is characterized by areas of lower and higher density. This may explain the specific fracture patterns that we

Fig. 2.12 Seventy-eight-year-old male with Alzheimer's disease and recurrent falls at home. Pelvic a.p. overview shows a fracture of the left ilium beginning at the inner curve of the innominate bone and going up to most proximal curve of the iliac crest. There are also displaced fractures of the left superior and inferior pubic rami

have observed in the ilium of elderly individuals but not in adults. An ilium fracture starts at the inner curve and extends upward and laterally through the iliac wing, reaching the iliac crest at different levels above the anterior superior iliac spine (Fig. 2.12).

To our knowledge, objective data on changes in strength and elasticity of ligaments of the pelvic ring during aging are not available. From studies in the iliotibial tract, we know that ligaments remain strong but become less elastic [58]. We therefore hypothesize that the strength of the ligaments between the sacrum and the innominate bones and ligaments of the pubic symphysis is less affected by age than is the strength of the bony structures. This may explain why ligaments are far less frequently disrupted in fragility fractures of the pelvis than in pelvic ring disruptions in adults. There is a collapse of bony structures while the ligaments remain intact and continue to form an envelope around the failed bone [29, 32]. Only in cases of chronic instability do bone defects, rather than fissures and fractures, occur due to repeated and continuing motion between fracture fragments. Long-term instability increasingly destroys areas of bone and reaches the sacroiliac joint or pubic symphysis (Fig. 2.13a, b).

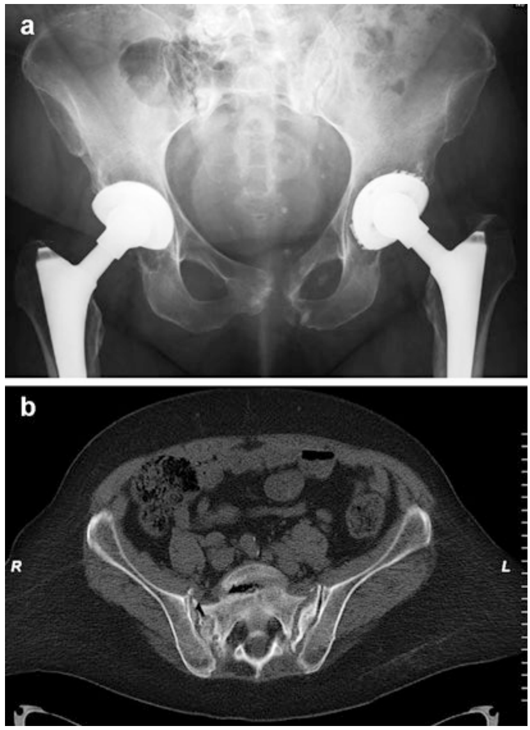


Fig. 2.13 (**a**) A 67-year-old female patient presents with groin pain and pain projecting in both legs 10 months after a domestic fall. The bone defect at the symphysis pubis is a sign of chronic instability. (**b**) Axial CT-cuts reveal a bilateral pseudarthrosis of the sacrum

2.7 Unique Fracture Morphology

The different vectors of traumatizing energy are responsible for typical pelvic fracture patterns in adults, which form the basis of the ASIF/OTA and Young-Burgess classifications [2, 12–14, 59]. *Anteroposterior compression* provokes external rotation of the innominate bone with diastasis of the anterior and posterior pelvic ring structures. *Lateral compression* provokes areas of compression at the sacrum and overrides fracture fragments at the anterior pelvic ring. *Vertical shear* forces provoke vertical fractures or complete dislocations with diastasis and vertical displacement. *Spinopelvic dissociation* is characterized by a breakout of the S1 vertebral body of the pelvic ring [20, 21].

We have observed different fracture patterns in fragility fractures of the pelvis. Large diastasis of fracture fragments is rare. Because the most typical trauma mechanism is a fall from a standing position, a *lateral compression fracture pattern* is common. Also a *H-type sacral fracture pattern* is frequently observed. Several examples will be presented in the forthcoming chapters. Linstrom et al. described 52 out of 85 patients with this fracture morphology in their case series [57]. This H-type fracture pattern resembles the spinopelvic dissociation in adults but has a different morphology and is the result of a completely different trauma mechanism. This frequently observed lesion in fragile elderly patients cannot be classified with the conventional ASIF/OTA or Young-Burgess classifications, and even the classification system of Roy-Camille is barely applicable [12, 20, 59].

Other fracture morphologies, which have been observed in fragility fractures of the pelvis, cannot be classified using the conventional classification systems. These include *bilateral fractures* through the iliac wing and chronic cases with the complex injury pattern of a complete pelvic ring collapse (Fig. 2.14a–c).

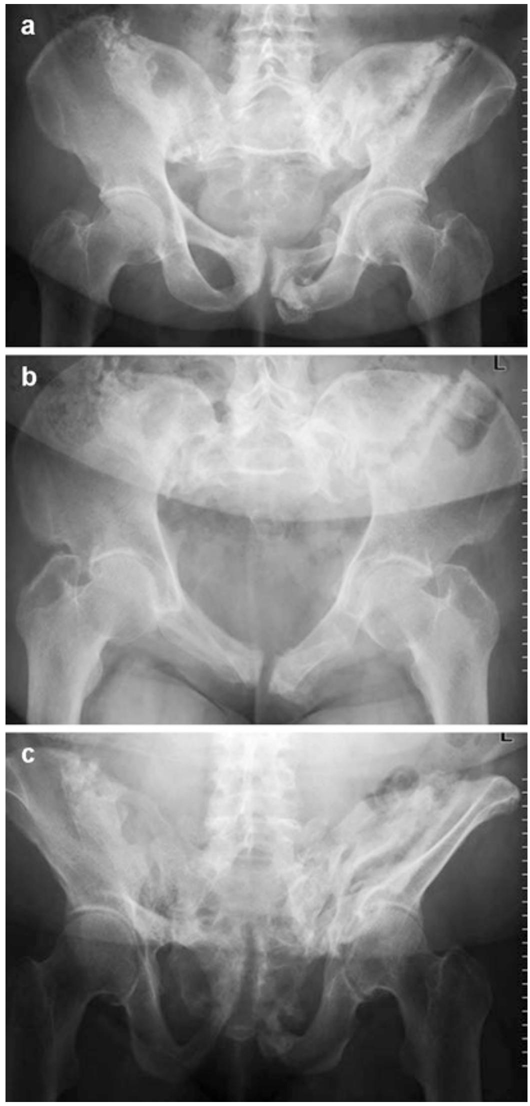


Fig. 2.14 Bilateral fracture of the innominate bone starting at the inner curve of the ilium and extending through the iliac wing to the iliac crest. (**a**) Pelvic a.p. overview (**b**) Pelvic inlet view (**c**) Pelvic outlet view

2.8 Progress of Instability

Once a pelvic disruption has been generated in adults, the fracture morphology does not change. If treatment is not adequate, further displacement of fracture fragments may occur. When fractures or dislocations do not heal, malunion or nonunion develops, but the original fracture morphology remains static [60]. The fracture classification, which is based upon the analysis of the original post-traumatic pelvic overviews and CT data, is definite.

In patients with fragility fractures of the pelvis, we have repeatedly observed that fracture morphology changes over time. We assume that the natural history of these lesions is one of slow but continuous progress. Triggered by repetitive smaller traumas, an increasing number of bone structures are damaged, leading to more complex fracture patterns and greater instability (Fig. 2.15a–d). The process typically begins with a slightly displaced uni- or bilateral pubic rami fracture and a small crush lesion or a non-displaced fracture in the sacral ala. It ultimately develops to a bilateral displaced pubic rami fracture (butterfly fracture) in the anterior pelvic ring and an H-type sacral fracture. Radiological signs of chronic instability include callus formation at the edges of the fracture margins and areas of

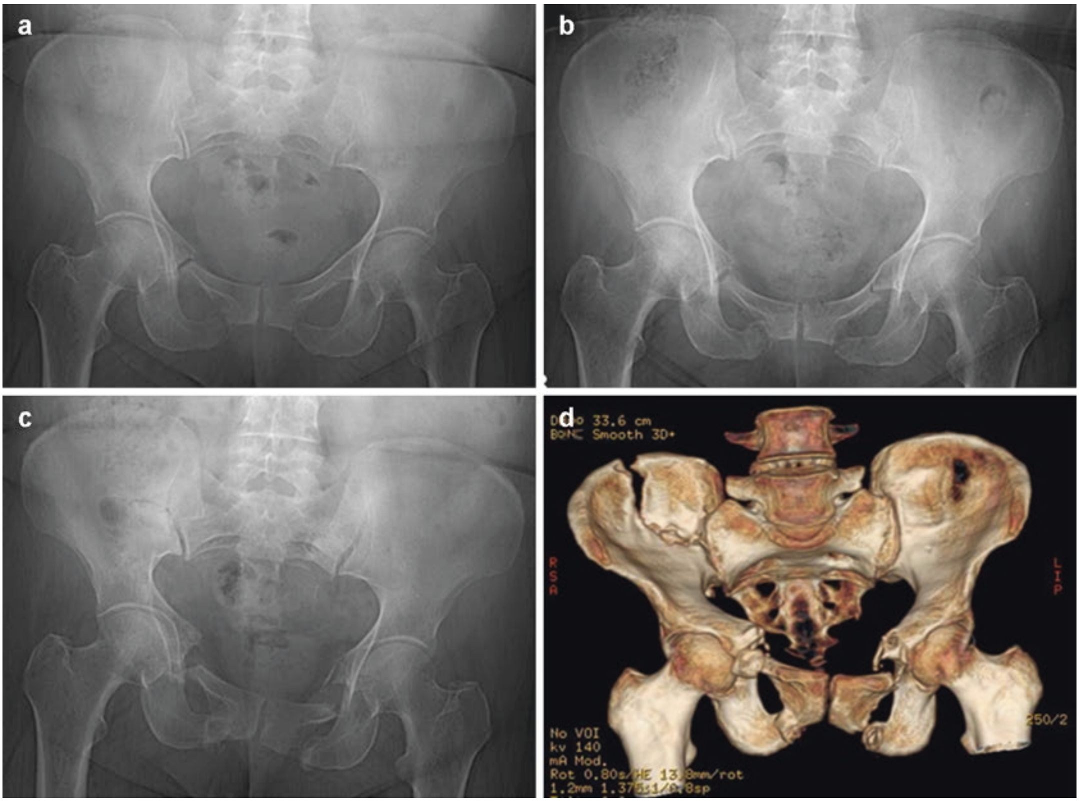


Fig. 2.15 (**a**) Fifty-seven-year-old female with bilateral non-displaced pubic rami fractures after minor trauma, treated conservatively. (**b**) One month after trauma, there is a slight bilateral displacement of the pubic rami fractures. Conservative treatment was continued. (**c**) Three months after trauma, there is a major bilateral displacement of the pubic rami fractures. A slight widening of the right sacroiliac joint with questionable incomplete fracture of the iliac wing are visible. Further conservative treatment was advised. (**d**) After 5 months, there is a complete instability of the pelvic ring due to a complete fracture through the ilium on the right side. An open reduction and internal fixation became necessary (courtesy of Guy Putzeys, Kortrijk, Belgium)

bone loss due to persistent movement between fracture fragments. This bone loss is observed at the pubic symphysis, at the pubic rami or at the sacral ala, where bone loss may finally involve the sacroiliac joint. The complete collapse of the pelvic ring is at the end of a continuous process of increasing instability that began with a simple fracture pattern.

Conclusion

Fragility fractures of the pelvis differ in many ways from pelvic ring fractures in adults. Trauma mechanisms, the hemodynamic situation, the clinical picture, primary and definitive treatments, bone density, fracture morphology, and natural course are unique and not comparable. These are among the many reasons we need to take a closer look at this new and growing entity of pelvic injuries. Only in this way, we can better understand their characteristics and investigate the most appropriate therapeutic options, surgical alternatives and long-term outcomes [35, 61–63].

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3 Sacral Morphology

Daniel Wagner, Lukas Kamer,
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3.1 Introduction

Fragility fractures of the sacrum may cause severe and immobilizing pain. In most cases, they are non- or minimally displaced. Treatment by operative means is recommended when the patient cannot be mobilized within 1 week. Because reduction is usually not needed in these non- or minimally displaced fractures, internal fixation using minimally-invasive methods is the treatment of choice. Open reduction and internal fixation is the exception and only applied in displaced fractures. Iliosacral (IS) screw osteosynthesis is a well-established technique for fixation of non-displaced fractures [1]. These implants enter the posterior ilium from lateral and cross the iliosacral joint as well as the sacral ala. The tip of the screw ends in the sacral body. The use of partly threaded screws allows exerting some compression on the fracture site, if the thread of the screw crosses the fracture line completely. Respecting the individual sacral anatomy, a malposition rate of IS screws of less than 3% has been reported [2]. However, backing out of IS screws is increasingly seen in elderly patients with osteroporosis-related decreased bone mass [3]. Therefore, alternative concepts of transsacral fixation or IS screw augmentation were developed to overcome the loss of screw purchase in the decreased bone mass. The corridor for transsacral implants is smaller than for IS screws, as transsacral implants traverse the sacrum from one side to the contralateral side. This restricts and complicates their use [4]. In S1, transsacral implant positioning was described to be impossible in 11–53% [1, 5–13]. The limitation is caused by the highly variable anatomy of the upper sacrum [14, 15]. In this chapter, the characteristics of the highly variable sacral anatomy and its implications for the use of transsacral implants for the treatment of sacral fractures are discussed.

3.2 Sacral Morphology

The sacrum is a bone formed by the fusion of five sacral vertebrae. During evolution, but also during individual growth, the human sacrum adapted and adapts to mechanical needs owing to erect posture and bipedal locomotion. Abitbol studied the number and consolidation of the vertebrae forming the sacrum using radiographs taken from monkeys of different evolutionary stages, human adults and non-ambulatory children. In primates, the sacrum is less curved, the position within the pelvis is less

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_3

angulated (i.e. the pelvic incidence is smaller) and the sacrum itself consists of less vertebrae with a smaller amount of fusion [16, 17]. Also non-ambulatory children show a lower degree of sacral vertebrae fusion [17]. To achieve an adequate balance in bipedal stance, the center of gravitation should be based over the femoral heads [18]. Several authors, therefore, suppose that the human sacrum is orientated more horizontally within the pelvis and is more curved to bring the center of gravity more ventrally towards the hips [17, 19, 20]. The various stages of sacral development at the lumbosacral level lead to an inconsistent fusion of the first sacral or the last lumbar vertebra [17], sometimes exhibiting lumbosacral transitional vertebrae [21], a lumbarized S1, or a sacralized L5. The load transmission from the central lumbar spine to the hips laterally caused an enlargement of the proximal part of the sacrum during evolution, the so-called "sacral alae" [17]. The sacral alae are formed by the fusion of transverse and costal processes [22]. This process of individual bone development may explain the large morphological variability of the human sacrum, especially in its cranial part [15].

We studied the sacral morphology using a statistical 3D–model, which was based on data of 92 individual sacra [15]. Principal component analysis (PCA) was conducted to assess shape and size variability of the statistical 3D–model [13]. The use of PCA allows the calculation of the principal modes of variation. They were ordered according to their descending amplitude of variation from the mean shape. The largest variation, defined as the 1st principal component (PC), was found for the overall size, the size of the auricular surface, the sacral height and to some extent the sacral curvature. A large variability of the sacral curvature was found in the 2nd PC, representing the second most important variation to the sacral size and shape. There, also the cranio-caudal position of the auricular surfaces and the alar slope varied notably. The 3rd PC revealed a major variation with regard to the vertical position of the auricular surfaces, affecting transsacral corridor S1. The most important variation in the 4th PC was the size of the mammillary bodies. The variation of the sacral width was the 5th PC (Fig. 3.1) [15].

3.3 Corridors

Transsacral implants should be placed completely within the bone to avoid damage to neurovascular structures or intrapelvic organs. The anterior ramus of L4 and the entire nerve root L5 run towards distal and lateral in front of the sacral ala and are in direct contact with its anterior cortex. They, therefore, are at risk during surgical procedures in case of perforation of the sacral cortical borders. Accordingly, the common iliac artery and vein are located anterior to the sacrum and may also be damaged [23]. The S1 nerve root runs through the S1 sacral canal. A urethral injury from a S1 IS screw was reported in a pediatric patient as an unusual complication [24].

Especially the anatomic variability of the cranial part of the sacrum is important when considering the use of transsacral implants. These implants cross the sacrum from one side to another: they enter the iliac bone, pass through the sacral ala into the sacral body S1 or S2, and traverse to the contra-lateral side perforating the contra-lateral iliac bone. Transsacral corridors are limited anteriorly by the sacral cortex, posteriorly by the sacral canal and inferiorly by the next lower sacral foramen. The superior limit in S1 is given by the sacral ala, by the cranial border of the sacroiliac joint or by the iliac fossa [13]. The superior limit of the S2 corridor is the sacral canal of S1.

The vestibule concept was developed to describe the unilateral corridor for the placement of an IS screw in S1 [4]. The isthmus or vestibulum is the narrowest passage, which implants in S1 have to cross to reach the sacral body. It is limited by the sacral canal, the sacral foramen S1, and the sacral cortex. The vestibule is always tilted anteriorly and superiorly. By adjusting the direction of an IS screw perpendicular to the cross-section of the vestibule, its maximum safe space becomes available. Because of the reverse oblique orientation of the isthmus on both sides, it is not possible to insert a transsacral implant perpendicularly to their cross-sections. Consequently, the safe corridor has a much smaller dimension (Fig. 3.2) [4, 5, 25].

Multiple studies assessed the dimensions of the transsacral corridors. The mean diameter of

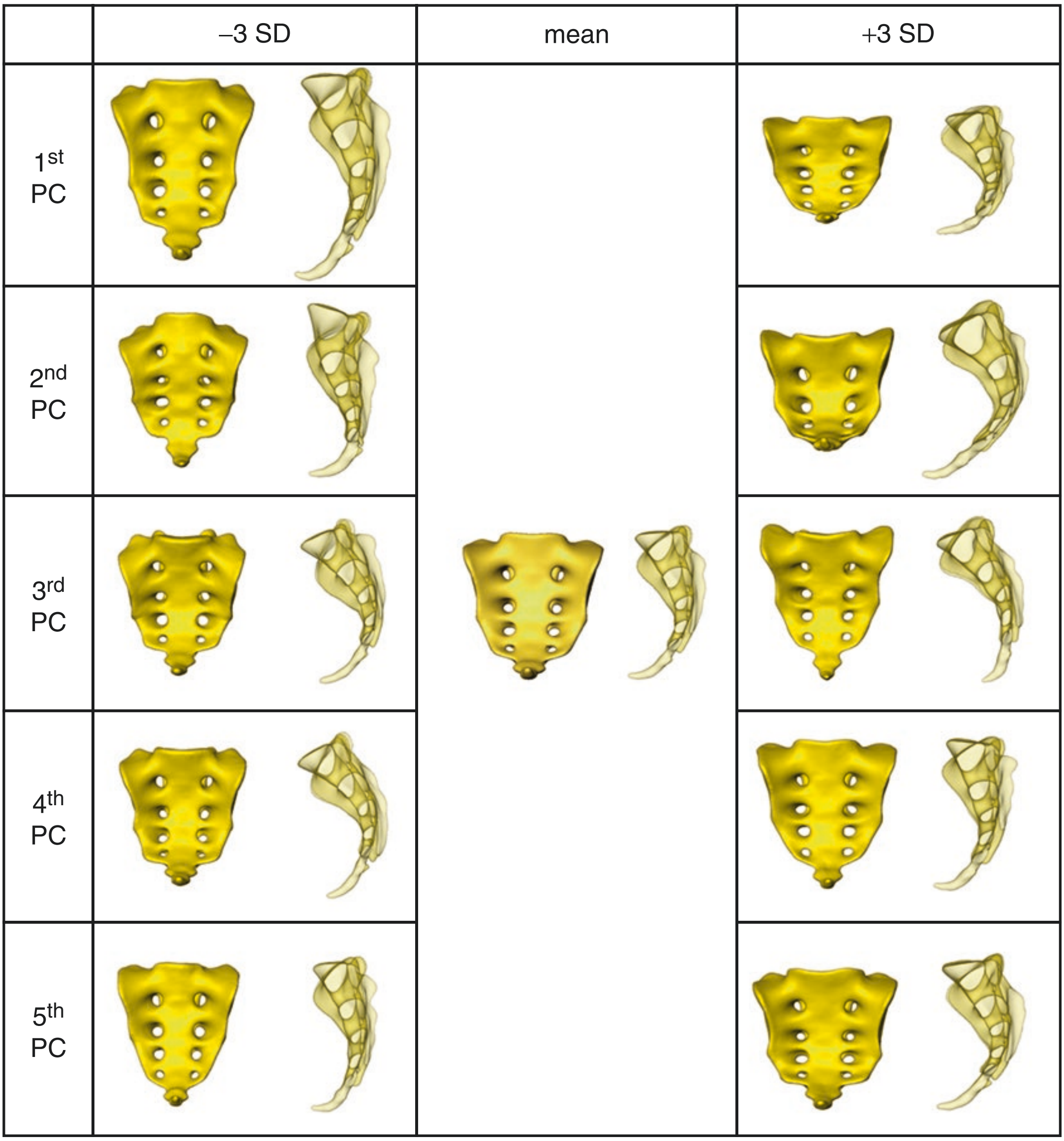

Fig. 3.1 Statistical 3D–model of the sacrum based on CT-data of 92 individuals. The variations in size and shape are represented by principal components (PC) (+/− 3 standard deviations). The PC are ordered according to their descending amplitude of variation of the mean shape. (Reproduced with permission from Wagner et al. [15])

the transsacral corridor in S1 is 11.0–14.4 mm and 8.9–14.0 mm in S2 (Table 3.1). The dimension of the S1 and S2 corridors are larger in males than in females [6, 9, 12, 13, 15]. There is enough space to insert a transsacral implant with a diameter of 7.3–10 mm in 68–85% of the pelves in S1 and in 52–100% in S2 (Table 3.1). Interestingly, the limiting diameters of the transsacral corridors in S1 and S2 correlate inversely [12, 13, 15]. Hence, individuals with limited safe space in S1 have larger transsacral corridors in S2. Pelves, in which a transsacral implant cannot be placed in S1 (also called "dysmorphic" by some authors), have larger corridors in S2 and offer consistently enough space for a transsacral implant in S2 [4, 6, 11, 13, 26].

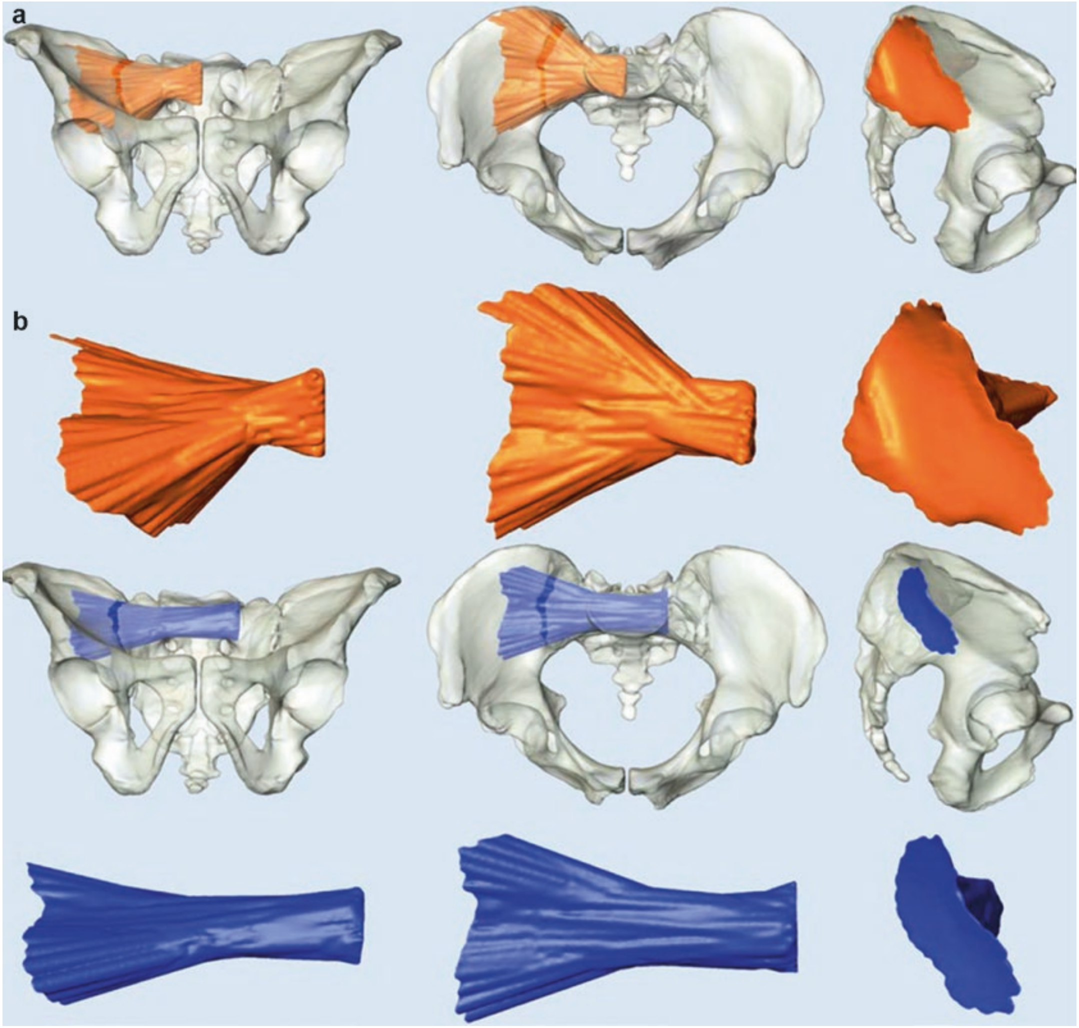

Fig. 3.2 (**a**) Space available for all possible safe IS screws crossing one isthmus only. (**b**) Transsacral implants have to pass the isthmus on both sides, which decreases the volume of possible implant positioning. (Reproduced with permission from Mendel et al. [25])

Table 3.1 Literature overview on transsacral corridors

Publication	Number of subjects	Dimension S1 [mm]	Dimension S2 [mm]	% of transsacral implant possible in S1 (diameter)	% of tran-sacral implant possible in S2 (diameter)
Wagner et al. [13]	156	11.6 ± 5.4 cc	14.0 ± 2.4 cc	74% (8 mm)	100% (8 mm)
		23.2 ± 5.7 ap	17.6 ± 2.4 ap		
Gras et al. [12]	280	12.8	11.6	68% (9 mm)	88% (9 mm)
Gras et al. [11]	84	11.0 ± 2.4 cc[a]	9.6 ± 1.7 cc	76% (>0 mm)	52% (9 mm)
		12.2 ± 2.1 ap[a]	8.9 ± 1.8 ap		
Mendel et al. [12]	125			80% (7.3 mm)	99% (7.3 mm)
Lee [34]	526	14.4 ± 3.8	10.9 ± 3.3	85% (10 mm)	65% (10 mm)

cc cranio-caudal, *ap* antero-posterior
[a]Mean dimension in 64 subjects with available corridor

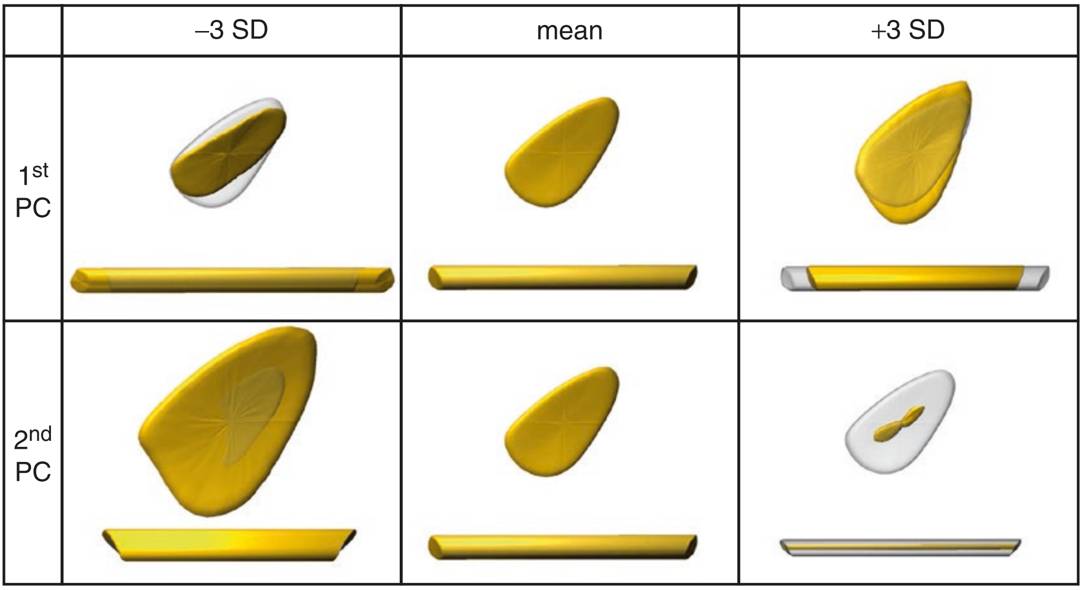

Fig. 3.3 Statistical 3Dmodel of the transsacral corridor S1 based on CT-data from 92 individuals. The main variation, represented by the 1st principal component (PC), consists of the variation of the corridor's length. The 2nd PC reveals high variations in the cross-section. (Reproduced with permission from Wagner et al. [13])

The shape of the transsacral corridor S1 was studied using a statistical 3D–model [13]. The use of PCA made the assessment and visualization of the largest variability in shape and size possible (Fig. 3.3). The mean shape of the transsacral corridor in S1 has an oval cross section with an antero-caudal round curve corresponding to the cranial cortex of the sacral foramen S1. The superior border of the corridor is more flat according to the shape of the sacral ala or the iliac fossa being the cranial limits. The oval corridor's cross section shows a constant inclination in the sagittal plane. All pelves in this study were tilted equally on beforehand to achieve a comparable position in the outlet view. Consequently, the inclination of the corridor was constant within the individual pelves. The 1st principal component, representing the largest variability, varied mainly in the corridor's size. The 2nd principal component demonstrated the large variability of corridor's diameter shape and size, from large spacious corridors to small, flat, almost non-existing corridors. The largest cranio-caudal diameter was consistently located in the anterior part of the corridor. For placement of two transsacral implants in S1, we therefore recommend positioning one implant antero-caudally and the second implant postero-cranially.

In a recent study, the dimensions of the transsacral corridors were additionally studied in correlation to the sacral shape [15]. Sacra with a larger sacral curvature, a higher pelvic incidence and more cranially located iliosacral joints correlated with larger transsacral corridors in S1 (Fig. 3.1). The presence of an accessory articulation of the transverse process L5 with the sacrum (lumbosacral transitional vertebrae type II [21]) was also an indicator for a larger corridor S1.

Limiting to all these studies is the fact, that they were performed on non-fractured pelves. It was shown that the cross-sectional area decreased by 30%, 56%, 81%, and 90% for 5, 10, 15, and 20 mm fracture displacement, respectively [27].

3.4 Radiographic Assessment of the Corridor

The transsacral corridors are difficult to assess intraoperatively using conventional radiographs. The osseous borders are rounded and hence project differently at various projection angles. The S1 corridor's cranial limit is formed by the sacral alae, the cranial edge of the iliosacral joint and the iliac fossa. Both the sacral alae and the cranial border of the iliosacral joint are descending. The projection of the most cranial point of the iliosacral joint depends on the sacral inclination and on the amount of the pelvic inclination in the outlet view. Principal component analysis of the transsacral corridor S1 with all pelves comparably tilted in the outlet view demonstrated that the cranial projection of the sacrum corresponds with the postero-superior limit of the corridor [13]. Hence, an anteriorly placed implant could be located extra-osseous, although it still projects below the cranial border of the sacrum in the outlet view [28]. The corridor's cranial limit is further determined by the ilio-cortical density (ICD) in the lateral view (Fig. 3.4) [29]. Thereby, the image intensifier should be aligned in such a way that both ICD are overlapping. In this projection, the sensitivity detecting an extra-osseous screw is 74% [30]. The caudal corridor's limit is formed by the sacral foramen S1 assessed in the outlet view. The corridor's anterior and posterior borders are assessed in the inlet view [31, 32].

A "dysmorphic" [29] or "dysplastic" [1] phenotype of the sacrum was described by Rout ML et al. using distinct criteria in radiographs and CT

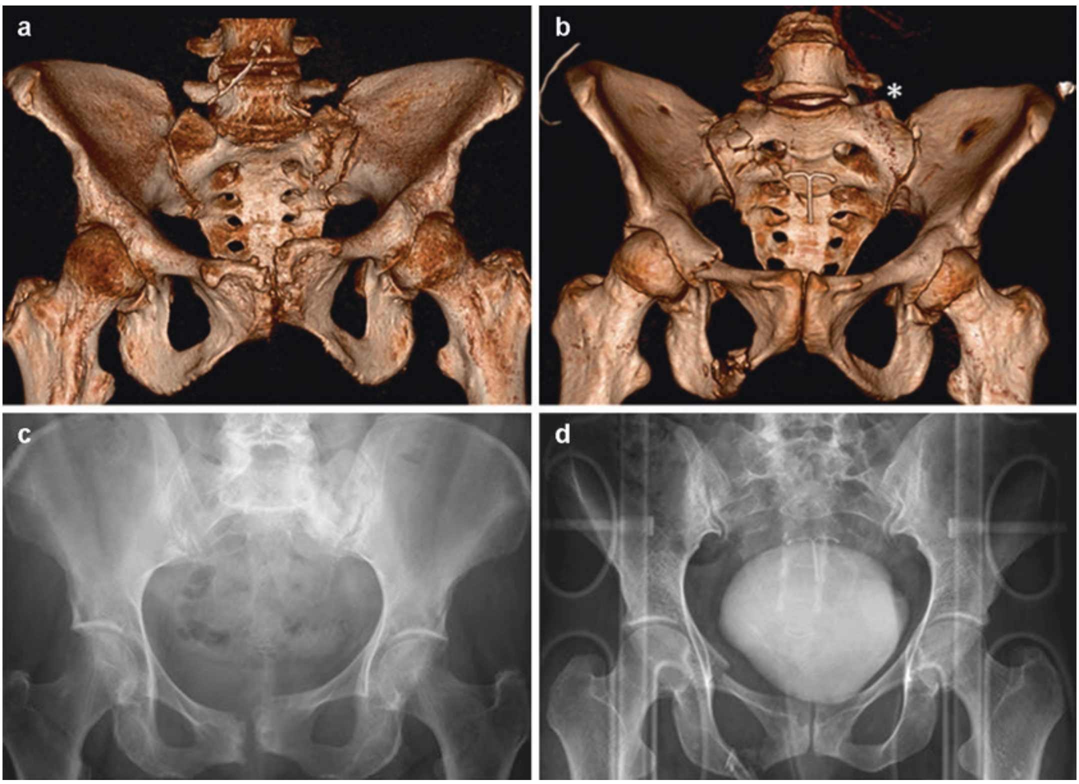

Fig. 3.4 Representative examples of patient A with a large (a, c, e, g, i; 75-year-old female with an FFP type IIIc) and patient B with a small transsacral corridor S1 (b, d, f, h, j; 44-year-old female with an AO/ASIF 61.B2 fracture). 3D–reconstructions of the pelvic rings (**a, b**) show mammillary bodies and descending sacral ala in patient B (*asterisk* in figure **b**). (**c, d**) A-p pelvic views. (**e, f**) Pelvic outlet views. The mammillary bodies are most prominent in patient B (*asterisk* in figure **f**). The first sacral segment is located more cranially in relation to the iliac crest. The sacral foramina S1 are not circular and the disc space S1/S2 is still visible. These signs have been considered typical for sacral dysmorphism (**g, h**) The anterior cortical border of S1 at the level of the sacral foramina is assessed in the inlet views. In patient B, these are more recessed posteriorly, forming an anterior indentation (*arrow* in Figure **h**). (**i, j**) Both ilio-cortical densites are overlapping in the lateral views (*arrowheads* in figures **i** and **j**), demonstrating a more pronounced descending ala in patient B

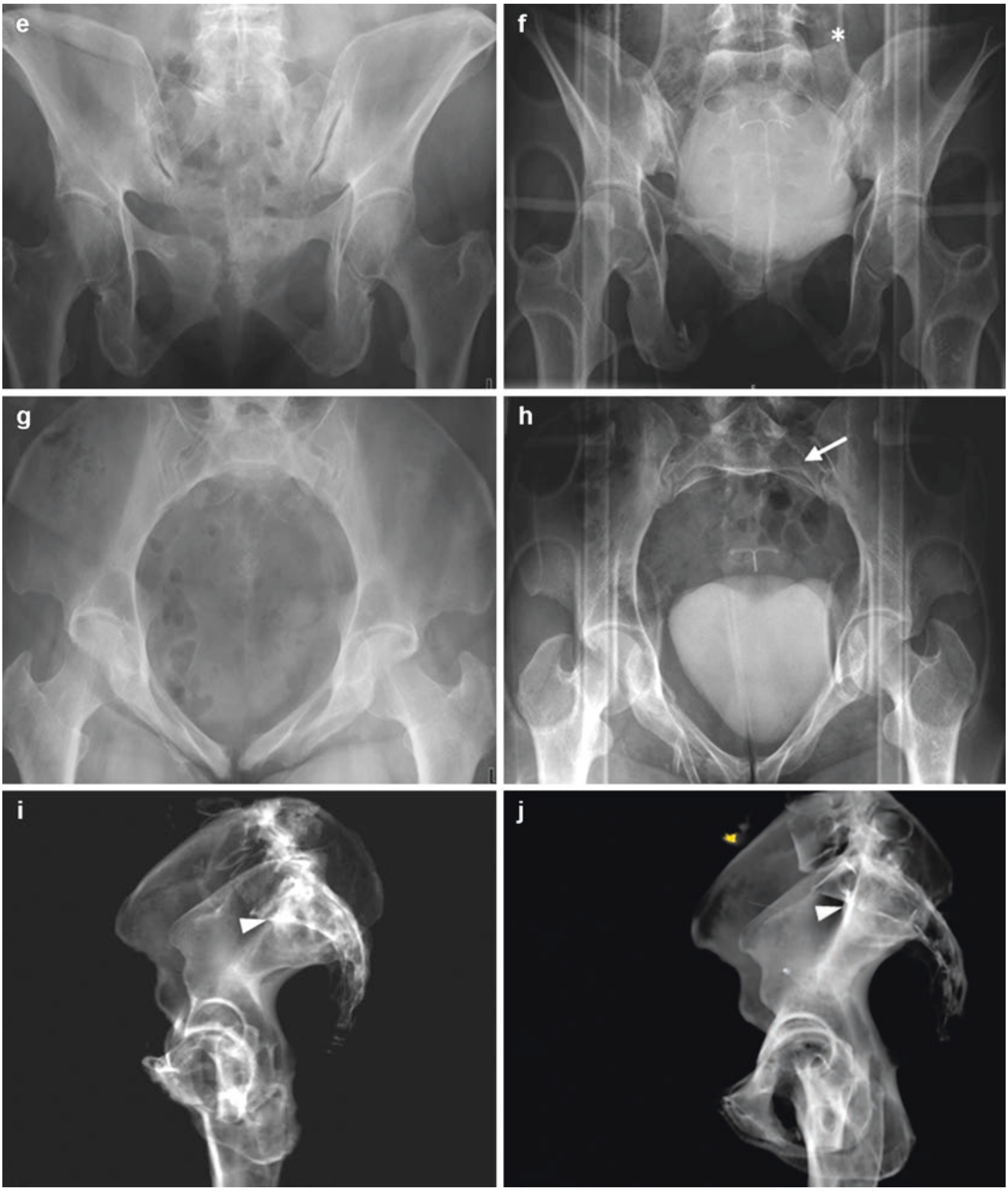

Fig. 3.4 (continued)

scans. These pelves had a narrow safe zone and did offer less or no space to place an implant in S1. Radiographic criteria defining the "dysplastic" sacra were [1] (Fig. 3.4):

1. Sacrum, which is not recessed within the pelvis in the outlet projection (first sacral segment is located at the level of the iliac crests and hence more cranially).
2. Mammillary processes cranial to the sacral ala seen in the outlet view.
3. Dysmorphic sacral foramen S1 (larger, noncircular, misshapen, and irregular when compared to average [29]), assessed in the outlet view.

4. A residual disc space S1/S2 seen in the outlet view.
5. In the lateral sacral view, an acute alar slope is seen (meaning a more descending ala in the cranio-caudal and medio-lateral direction [29]).
6. “Tongue-in-groove” morphology of the iliosacral joint in the axial CT scan. This describes a more extensive interdigitation of the sacral and iliac bone in the iliosacral joint [29].
7. Anterior cortical indentation of the anterior sacral cortex of the S1 segment assessed in the inlet view.

These criteria were tested and an inter-observer agreement rate from 75–81% was found with fair to moderate kappa values. When taken as a cluster, these criteria correlated with dysmorphic sacra. However, the “tongue-in-groove” sign was not more frequent in dysmorphic sacra. No single criterion was clearly associated with a “dysmorphic” phenotype. Additionally, 12% of pelves were of the “minority type”, which means that they do not offer even a 10 mm corridor in both S1 and in S2. These minority type sacra were not correlated to the “dysmorphic” criteria [7].

Another method to determine “dysmorphic” sacra is the “sacral dysmorphism score” [7]. Morphologic features of the sacrum were assessed using PCA. The study population was divided into three groups assessing a transsacral corridor with a diameter of at least 10 mm and a minimal length of 120 mm: majority sacra (47%, corridor in S1 and S2), dysmorphic (41%, corridor in S2), and minority sacra (12%, no corridor in S1 or S2). The largest variability (1st principle component) was explained by the number of the sacral foramina, the cross-section of the S2 corridor at the isthmus, the coronal and axial angulation of the corridor and the pelvic incidence. A “sacral dysmorphism score” was defined as the sum of: (coronal angle of 10 mm corridor in S1) + 2× (axial angle of 10 mm corridor in S1). If this score was >70, no transsacral corridor was found (Fig. 3.5) [7].

The “lateral sacral triangle” method defines a triangle in the lateral view. The ratio of the width of the sacral end plate to the length of the anterior sacral surface above the ICD is calculated [8]. A ratio of ≥1.5 predicts the availability of a transsacral corridor with a minimal diameter of 7.3 mm with a sensitivity of 94% and a positive predictive value of 97%. This method quantifies the descending alar slope in the lateral view.

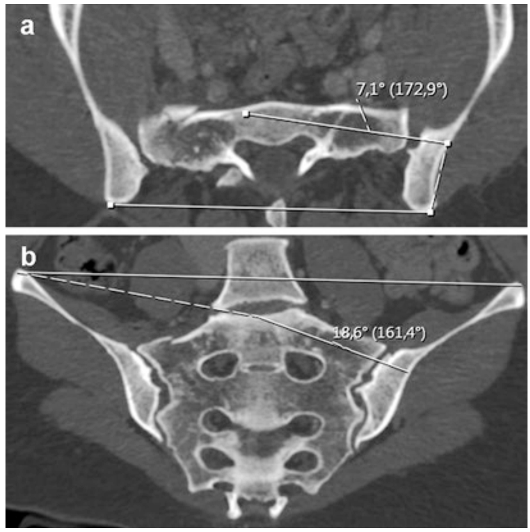

Fig. 3.5 Assessment of the “sacral dysmorphism score” in patient B from Fig. 3.4. The angles of the corridor for an IS screw in S1 are assessed in the axial (**a**) and coronal (**b**) plane after reformatting the axial plane parallel to the endplate of S1. The axial angle is referenced to a line connecting both posterior superior iliac spines. The coronal angle is formed by the corridor’s axis and a line connecting the iliac crests. The “sacral dysmorphism score” is calculated as coronal angle + (2x axial angle). For this patient the score is 33 at the left side

A method to describe and verify the proper placement of the transsacral implants was recently described [30]. Using inlet and outlet views, the position of the implant is measured in the antero-posterior and cranio-caudal direction at the level of the sacral foramen S1. The position is expressed as percentage of the maximal antero-posterior and cranio-caudal distance to the distance of the anterior cortex to the implant and of the sacral foramen to the implant, respectively. If the supero-inferior ratio of the implant is within a differing range of 20% of the antero-posterior ratio, the implant is likely to be entirely in the bone with an accuracy of 93%.

3.5 Author's Preferred Method

Preoperative planning is of outmost importance considering the large morphological variations influencing the availability of the safe transsacral corridors. Pelvic CT data should be reformatted according to the sacral inclination at the level of the sacral body S1 (Fig. 3.6). Then, a virtual axis is positioned in the anterior part of the sacrum superior to the sacral foramen S1. As depicted in the PCA of the transsacral corridor S1 (Fig. 3.3), the largest cranio-caudal diameter is located in the anterior part of the corridor. The availability of a transsacral corridor S1 and its diameter are assessed in the plane of the longitudinal axis of the upper part of the sacrum (coronal sacral plane), as the cranio-caudal diameter is usually the limiting factor [13]. The dimension of the antero-posterior diameter is evaluated in the plane of the sacral endplate to determine, whether or not a second implant can be positioned. If a transsacral corridor is not available, the angles for unilateral IS screws are measured for preoperative planning.

The transsacral corridor S2 can also be evaluated in the coronal sacral plane. However, its biomechanical benefit still has to be proven [13]. A finite element model demonstrated that the sacrum rotates ventro-caudally around an axis running through the center of S2. Sixty-nine percent of fragility fractures of the sacrum show a transverse fracture line between S1 and S2 [33]. In these patients, an implant inserted in S2 would be too caudal to adequately stabilize the "break-out"-fracture of S1. Furthermore, a more caudal position of the implant has a higher risk for injuring the superior gluteal artery or its branches (Fig. 3.7).

Intraoperative imaging and positioning of both the patient and the fluoroscope for insertion of transsacral implants are explained in detail in Chap. 13.

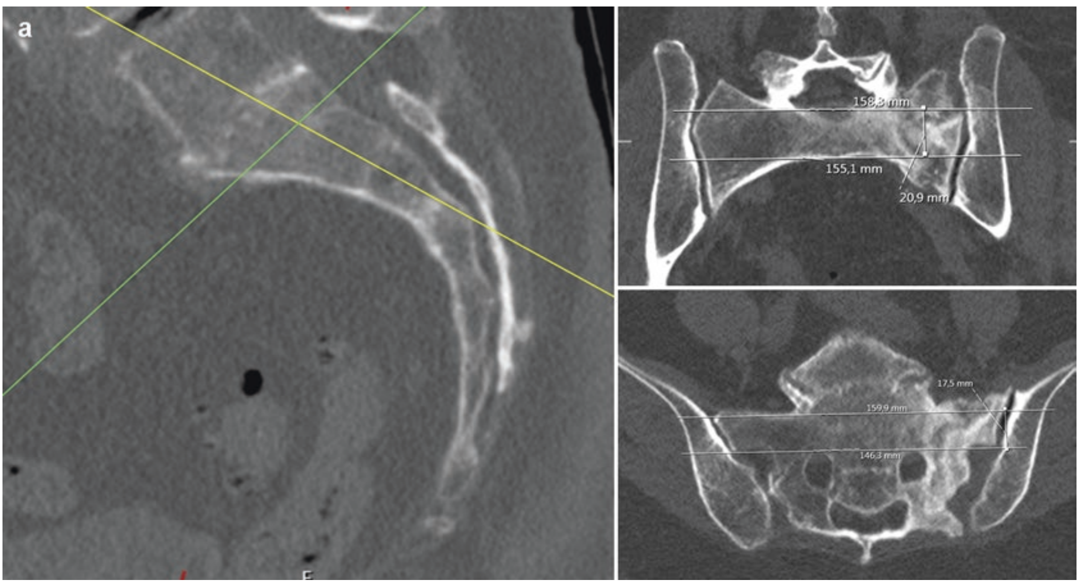

Fig. 3.6 Transsacral corridors are evaluated using multiplanar reconstructions of pelvic CT-scans according to the coronal sacral plane in S1 (*yellow lines*) and axial sacral plane in S1 (*green lines*). (**a**) Patient A from Fig. 3.4 has a large transsacral corridor (antero-posterior diameter 20.9 mm and cranio-caudal diameter 17.5 mm). (**b**) The transsacral corridor S1 in patient B is too small for insertion of a transsacral implant (antero-posterior diameter 12.0 mm and cranio-caudal diameter 3.4 mm)

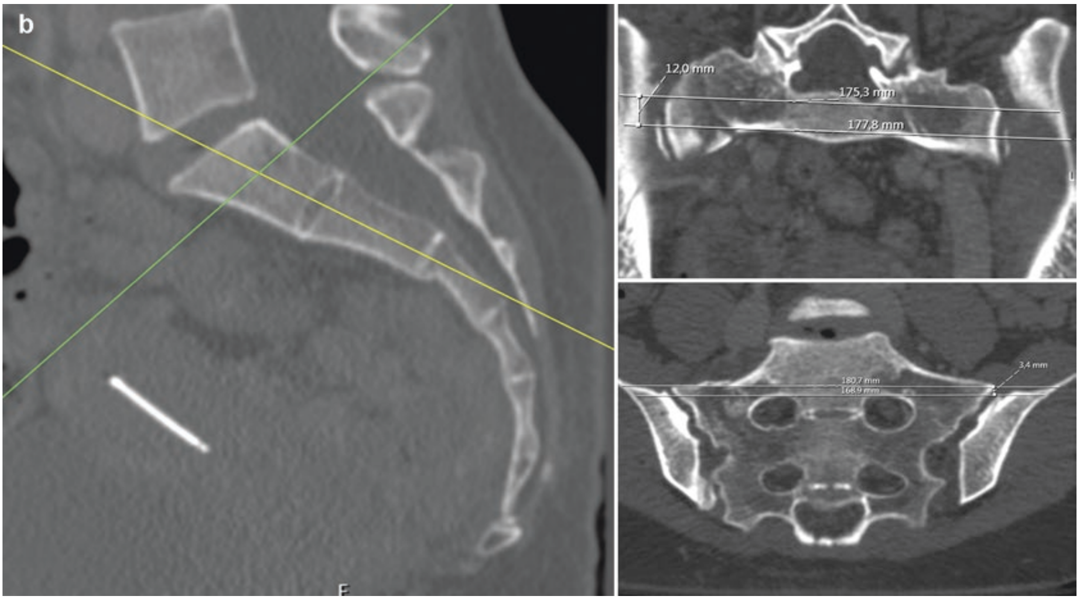

Fig. 3.6 (continued)

Fig. 3.7 CT-angiography of the pelvic ring showing the close relationship of the superior branch of the superior gluteal artery, running towards proximal from the greater sciatic notch (*white arrows*). When using sacral implants, there is an increasing risk of damaging these structures, the more caudally the implants are positioned. The entry point for an IS screw in S2 is tagged as *blue dot*

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Bone Mass Distribution in the Sacrum

4

Daniel Wagner, Lukas Kamer,
and Pol Maria Rommens

4.1 Introduction

Demographic changes are characterized by an increase of elderly persons with more people being affected by osteoporosis [1]. As fragility fractures of the pelvis (FFP) and fragility fractures of the sacrum (FFS) are very likely related to osteoporosis [2], their prevalence is increasing accordingly [3, 4]. FFS were found in 8% of women over 55 years of age admitted with lower back pain [5]. However, the incidence of FFS may be largely underestimated, as an additional fracture of the posterior pelvic ring was present in 54–98% of patients with a fracture of the anterior pelvic ring [6–9]. Patients suffering from FFS are commonly managed non-operatively with bed rest and analgesic therapy [10, 11]. Early mobilization is aimed to prevent immobility-associated complications [12]. Nevertheless, a yet unknown number of patients suffer from longstanding pain, fracture displacement due to mobilization, or development of fracture non-union [13–15].

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Our treatment protocol is to operate FFP in patients with a failure of the conservative therapy, with displaced fractures of the posterior pelvic ring, or with a lumbo-pelvic dissociation (corresponding to FFP IV [6]) [10, 14, 16]. Fractures of the sacrum are usually fixed with iliosacral (IS) screws. In elderly however, IS screw loosening is not uncommon, probably due to the decreased sacral bone mass [17]. Alternatively to operative fixation of the sacral fracture, sacroplasty was described to reduce pain effectively in those patients [18].

4.2 Osteoporosis in Statistical Bone Models

In osteoporosis, the bone mass decreases and the bone microarchitecture changes. Trabecular bone is mainly affected in vertebral bodies, whereas in the femur, also the cortical bone mass decreases due to increased cortical porosity [19–21], also called trabecularization of cortical bone. A decrease in cortical and trabecular bone density increases their vulnerability for fragility fractures. The impact of lowered bone mass on the occurrence of fractures is demonstrated by low local bone density on the contralateral humerus [22] respective femur [23] compared to CT scans of non-osteoporotic individuals.

The trabecular architecture and bone mass distribution of each bone follows biomechanical

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_4

principles and is an adaption to the stress exhibited during lifetime [24]. The study of the bone mass distribution in a large number of individuals is facilitated by using statistical models [17, 25–28]. The grey values obtained from CT scans of a variable number of individuals are transferred within a mean shape of a specific bone [25]. There, the voxels are averaged and a regional map of averaged bone mass is computed. Distinct bone mass distribution in non-osteoporotic and osteoporotic individuals was demonstrated using statistical modelling in proximal humerus [27] and proximal femur [26]. The alteration in local bone mass correlates with biomechanical features. In patients with hip fractures, areas of lower bone density were demonstrated in the intertrochanteric and distal cortical neck region of the femur as well as in the primary compressive strut in the femoral head [29, 30]. Using finite element analysis, the stress was increased in the osteoporotic femora along the primary vertical compressive trabeculae [30] and was less uniformly distributed [31]. The three-dimensional (3D) trabecular structure assessed by CT could predict failure load in osteoporotic proximal femurs [32].

Therefore, investigating local bone mass distribution and its alteration with osteoporosis may have implications on the understanding of fracture patterns and treatment of fragility fractures.

4.3 Bone Structure of the Sacrum

In human sacra, patterns of trabecular orientation were studied based on the hypothesis, that the trabecular arrangement represents the direction of weight and load transmission [33]. The main findings were strong trabeculae extending from the end plate of S1 to the auricular surfaces, bundles of trabeculae extending from the articular processes to the auricular surfaces, from the posterolateral ala at the insertion site of the lumbosacral ligaments to the auricular surfaces and towards the sacral body, as well as trabeculae spreading dorsal from the lateral laminae to the auricular surfaces [33]. These findings were confirmed in sacra with sacralized L5, where a condensation of trabeculae running ventrally from the vertebral bodies to the auricular surfaces in the weight bearing vertebrae L5, S1 and S2 was observed. Between these and those dorsally from the facet joints towards the auricular surfaces an "alar void" was described [34], extending from L5 to S2 [35]. There is a condensation zone subcortically to the anterior cortex with crossing of trabeculae superior to the foramina S1 and S2 [36]. Trabeculae running from the endplate S1 to the anterior cortex were found in the sagittal midline plane [36].

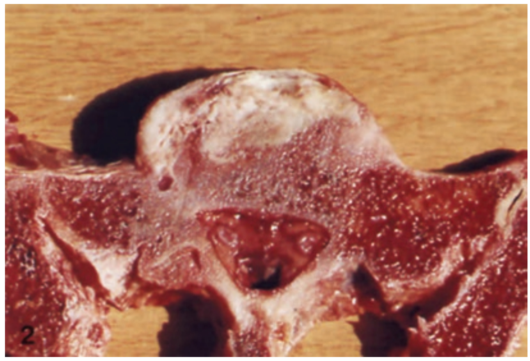

Fig. 4.1 Axial cut through S1 parallel to the endplate in an anatomical specimen. Note the "fatty sphere" in the sacral ala. (Reproduced with permission from de Peretti et al. [37])

The "alar void" was described as loss of trabecular bone in elderly in the lateral parts of S1 [34]. This corresponded to the "fatty sphere" in the sacral ala of S1 seen in anatomical sections of sacra from elderly (Fig. 4.1) [37]. A corresponding region of lower Hounsfield Units (HU) in the sacral ala was demonstrated by CT scans in a young population [37]. The bone mineral density was 32% less in the sacral ala than in vertebral body S1 in young adults measured by quantitative CT. The bone density decreased in caudal direction within the "alar void" on level S1 and was higher in the middle of the vertebral body S1 [38].

4.4 Statistical Model of the Sacral Bone Mass

The authors and colleagues studied the sacral bone mass distribution using a 3D statistical model based on clinical CT scans [17]. Therefore, a mean sacral shape was calculated using techniques of statistical modelling and the grey values in HU

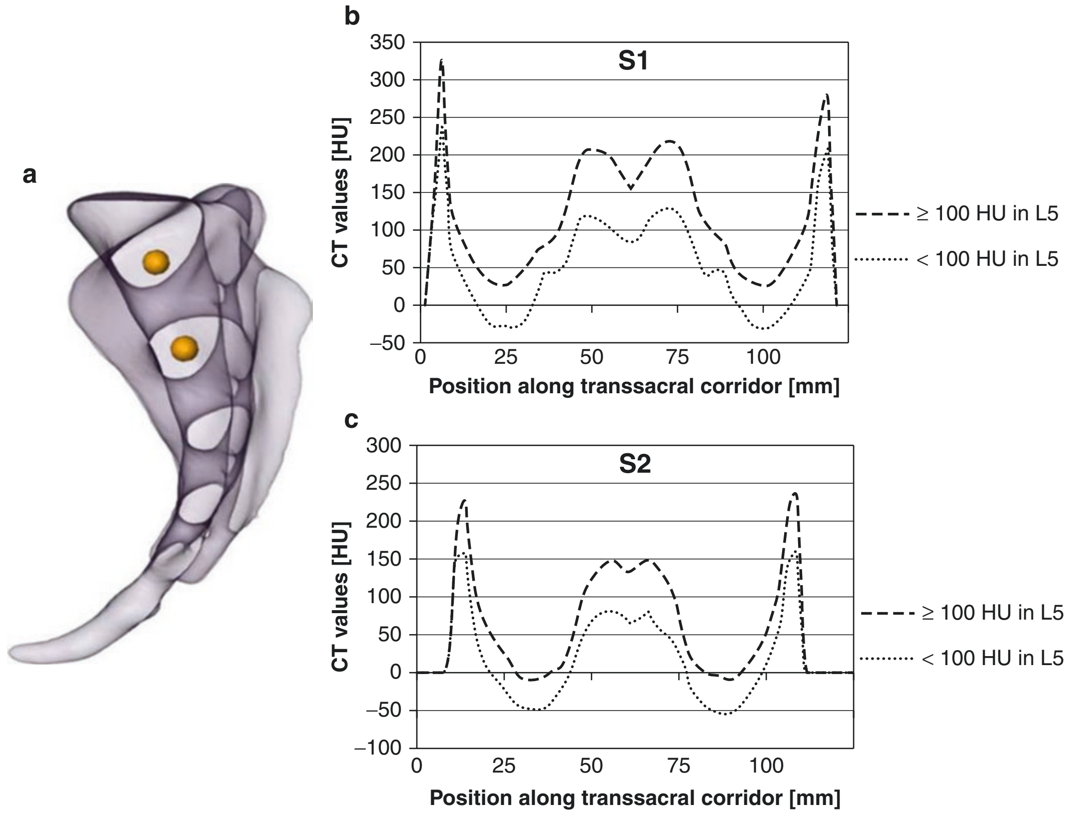

Fig. 4.2 Virtual bone probes (yellow buttons) with a 7 mm diameter along transsacral corridors. (**a**) Position of bone probe in S1 and S2. (**b, c**) There is a distinct bone mass distribution in S1 (**b**) and S2 (**c**) with overall lower values in S2. The largest difference regarding people with general lower bone mass (<100 HU in L5) is found in the area of the sacral bodies (reproduced with permission from Wagner et al. [17])

were averaged within this mean shape [25]. To compare individuals with better and worse general bone mass, the bone mass in vertebral body L5 was assessed and two groups were differentiated using a threshold of 100 HU in L5. Virtual bone probes along transsacral corridors S1 and S2 were used to visualize the bone mass. Further, negative HU were selected within the mean shape [17].

Along the transsacral corridors, there was a distinct distribution of bone mass (Fig. 4.2). High HU were found laterally, corresponding to the cortical bone of the auricular surfaces. This was followed by a prominent decrease representing the sacral ala. More centrally, there were intermediate HU in the sacral bodies. On the lateral edges of the sacral body S1, low peaks of HU were found. We suppose they were representing the trabeculae running from the end plate S1 superiorly towards sacral foramina S1, however, those were described in the median sagittal plane [36]. Similar to the principal compressive trabeculae in the proximal femur [39], they may have an important role in force transmission, as they are even more prominent in the group with general lower bone mass.

There are large areas of negative HU in the sacral alae in the group with worse general bone mass visualized in the mean sacral shape (Fig. 4.3), extending from S1 to S3 with small areas in vertebral bodies S2–S5. As negative HU represent tissue with lower density than water, this area is most probably fatty bone marrow [40]. The overall bone mass along the transsacral corridors is lower in the group with <100 HU in L5 compared to the group with general higher bone mass. However, the largest difference was found in the vertebral bodies. The overall HU in S2 were lower than in S1 (Fig. 4.4).

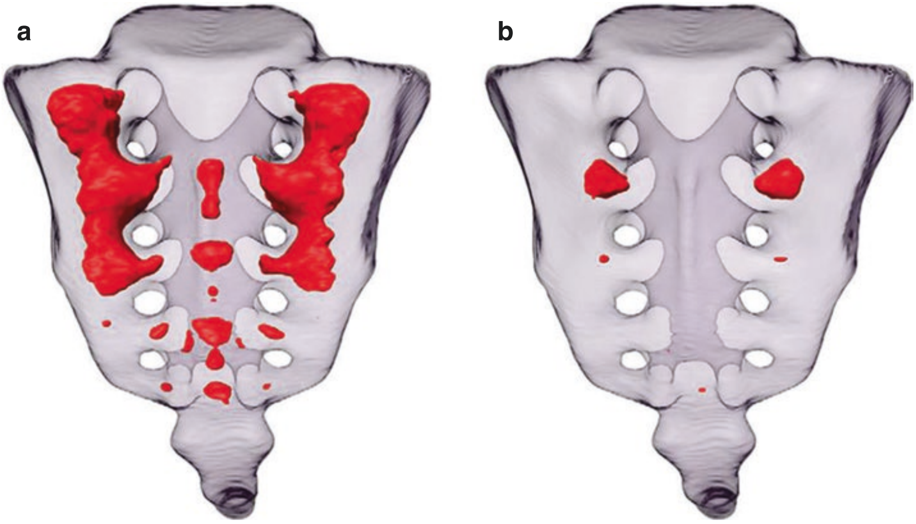

Fig. 4.3 Negative HU selected and visualized in *red* in the sacral mean shape. (**a**) There are extensive areas of negative HU in the population with lower general bone mass (<100 HU in L5). (**b**) The study group with better general bone mass (>100 HU in L5) only shows small areas of negative HU (reproduced with permission from Wagner et al. [17])

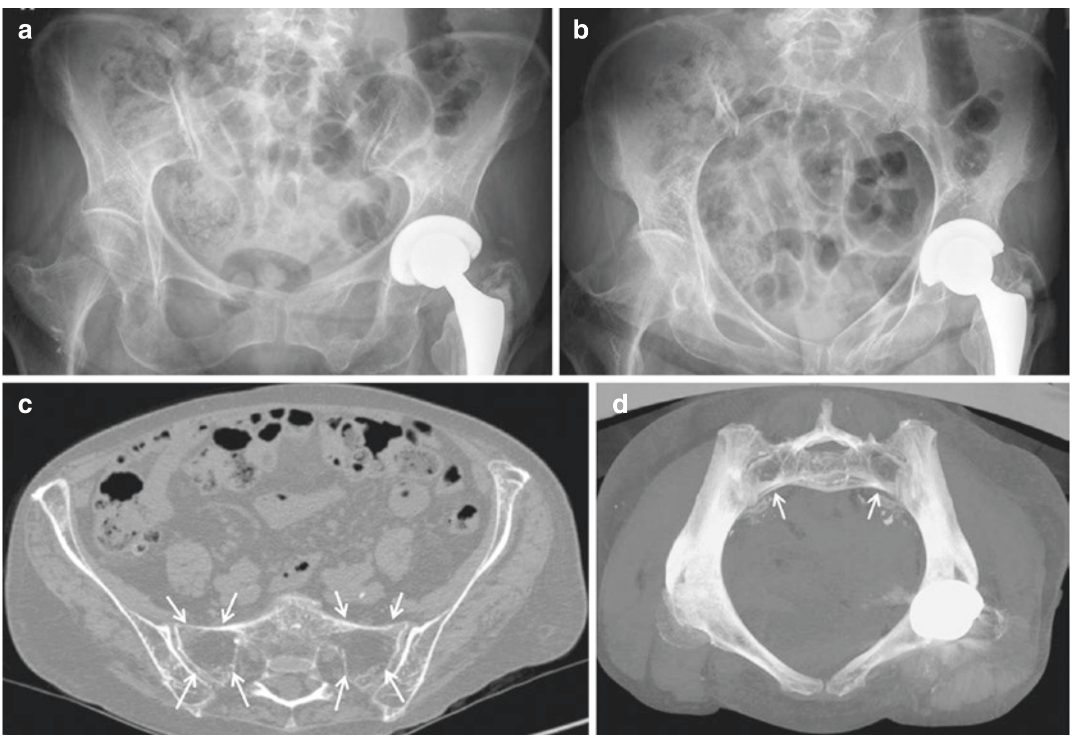

Fig. 4.4 Eighty-nine-year-old female with immobilizing lower back pain. Conventional pelvic views and pelvic CT-scan were carried out to exclude fragility fractures of the pelvis. (**a**) Pelvic a.p. view. No fracture can be detected in the anterior pelvic ring. The posterior pelvic ring cannot be assessed due to low bone density and overlying bowel gas. (**b**) Pelvic inlet view. No fracture can be detected in the anterior and posterior pelvic ring. (**c**) Transverse CT-cut through the posterior pelvic ring displays large alar voids in both the left and right sacral ala (*white arrows*). A fracture of the anterior or posterior sacral cortex is not visible. (**d**) 3D–reconstruction of the pelvic ring showing the small pelvis. The alar voids in the left and right sacral ala are clearly visible (*white arrows*)

4.5 Implications on Fracture Morphology

Fragility fractures of the sacrum usually are located in the sacral ala corresponding to Denis zone I [41, 42], whereas only 50% of high-energy injuries were located lateral to the sacral foramen [42]. The fragility fractures occur uni- or bilaterally. Sometimes, there is a transverse fracture line between S1 and S2, leading to an H- or U-shape of the fracture and creating a spinopelvic dissociation [6, 41]. The underlying low bone mass in the sacral ala may explain the unique and consistent location of fractures in the sacral ala [41]. The transverse fracture lines between sacral body S1 and S2 may be caused by the decrease of bone mass comparing the sacral level S1 and S2. However, biomechanically, the sacral curvature certainly is an additional important factor to create a spinopelvic dissociation. The sacrum was found to rotate antero-caudally with the rotation center being at level S2 [43]. This may lead to high shear forces between S1 and S2.

4.6 Implications for Operative Treatment

The use of IS screws in elderly with osteoporotic bone is complicated by screw loosening with backing out [10, 13, 44, 45]. Sacral fractures treated in patients with a mean age of 77 years with IS screws demonstrated backing out of screws in 14%, as far as follow-up data was available. In 9% the fracture did not heal [45], probably also a consequence of lacking stability. However, a recent study demonstrated in a younger collective (mean age 45.2 years) with high energy pelvic fractures a backing out rate of 17.3% including a failure rate of 11.8% using IS screws. Both were more prevalent in vertical shear lesions without the age being a risk factor [46]. In vertical shear lesions, it was suggested, that the screws are backing out because of rotation around the screw's axis [47, 48]. Due to the better purchase in the cortical bone laterally and lower purchase in the trabecular bone medially, a cantilever effect may induce a rotational moment on the screw. In elderly however, the fractures are often only minimally displaced, not allowing gross interfragmentary movement. As the threaded part of the IS screw is located in the sacral body [49], the loosening and backing out may be explained by the loss of bone mass in the sacral body. The largest difference in bone mass comparing the group with decreased general bone mass with the group with higher general bone mass was notably located in the sacral body [17]. Biomechanically, backing out or "screw out" was accompanied by screw rotation [50]. This was limited by augmentation of the screw tip. For that reason, augmentation of IS screws [51–53] (see Chap. 12) the use of transsacral implants [10, 14, 48, 54] (see Chap. 13) or is advocated in osteoporotic bone. Transsacral implants traverse the sacrum and anchor in the cortical bone of the ilium and the sacrum bilaterally; consequently, they do not depend on a good holding power in the cancellous bone of the sacrum. Furthermore, some compression on the fracture site can be applied by tightening the nuts on both sides when using a transsacral bar [54, 55].

4.7 Sacroplasty in the Light of Sacral Bone Mass Distribution

Sacroplasty is an interventional technique applying PMMA cement into the fractured sacral ala. This is usually done under CT control [18]. The amount of injected cement varies form 2 to 10 mL PMMA per side [56]. The technique seems to be very efficient with a significant decrease in pain after the intervention [57]. However, considering the large zone of negative HU in the population with general very low bone mass (Fig. 4.4), a very large volume would have to be addressed. To our understanding, it seems difficult to stabilize a fracture with such a large zone of lowest bone mass, as negative HU most probably represent fatty bone marrow [40]. In contrast to osteoporotic vertebral fractures, where compression forces are counteracted by vertebroplasty or kyphoplasty, in sacral fractures, the forces have more likely a shear component. Biomechanically, a reduction in micromotion was shown after sacroplasty [58], nevertheless, we doubt the possibility to counteract these shearing forces. Further, we question adequate fracture healing after cement application into the fracture gap. A risk of cement leakage was described in up to one-third of patients [59].

Conclusion

Sacral bone mass distribution follows a specific and consistent pattern in elderly patients. In the sacral ala, areas with a complete loss of trabecular bone are observed. These “alar voids” correspond with fatty spheres and may extend from the first to the third sacral body. The localization of the alar voids explains the specific morphology of fragility fractures of the sacrum. The surgeon should realize that no adequate anchorage of any implant is possible in this area. In sacroplasty, the void is filled with cement and micromotion reduced, but sacral fracture healing may be impeded.

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Part II

Clinical and Radiological Aspects

Clinical Presentation

5

Christian Fang, Tak-Man Wong, Tak-Wing Lau, and Frankie Leung

5.1 Introduction

The incidence of geriatric osteoporotic pelvic fractures is on the rise as the population in many developed countries ages. It is predicted that the incidence of geriatric pelvic fractures will increase by 56% from 2005 to 2025 in the United States [1]. Fragility fractures of the pelvis are the result of low-energy trauma. A pubic rami fracture is the most common differential diagnosis for patients being suspected of having a geriatric hip fracture. Insufficiency fractures, which occur without any trauma are more difficult to diagnose and treat.

Many osteoporotic pelvic injuries seem to be simple fractures of the pubic or ischial bone. Nevertheless, a comprehensive diagnosis of the injury is difficult if only based on plain radiographs. Occult posterior element fractures at the ilium or sacrum are often discovered when meticulous clinical examination and CT scans are carried out [2]. Early hemodynamic evaluation is also needed, as patients may occasionally have significant hemorrhage if the energy of trauma is higher.

A general assessment should always be carried out as age, premorbid functional condition and medical comorbidities are important considerations in planning for any invasive surgical treatment. The treatment objective should be pain relief and early mobilization while balancing complication risks. The majority of these fractures are mechanically stable and best managed non-operatively. Unstable fractures, non-unions and painful insufficiency fractures that are refractory to non-operative treatment can be stabilized surgically by open or minimally invasive means.

5.2 Mechanism of Injury and Patient History

Pelvic fractures in younger patients are most commonly due to a high-energy trauma; these patients are often polytraumatized. In contrast, pelvic fractures in the elderly typically occur after a low-energy fall from standing or sitting position. Pubic rami fractures are one of the most common and important differential diagnosis for patients suspected to have a hip fracture and the presentation is nearly identical. Falls from height and road traffic accidents are uncommon but they are associated with high mortality and morbidity.

The risk factors for falls and fragility fractures are female gender, low body mass, medical comorbidities, cognitive impairment, gait disorders, vision impairment, hearing impairment,

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_5

postural hypotension and the use of drugs such as analgesics, psychoactive and sedative medications. Slower reaction time and suboptimal coordination are inevitable while ageing and falls are an important cause of morbidity and mortality. Elderlies are prone to have multiple fractures in a fall. They are also prone to have multiple falls preceding and subsequent to a fracture.

It is important to assess patient's history related to their fall. The injury can be preceded by an acute cerebrovascular event, cardiac arrhythmia or a coronary artery event. Environmental hazards such as throw rugs, clutter, loose cables, poor lighting, pets, unstable furniture, steep stairways, slopes, ice and poorly maintained walkways significantly increase the chance of falling.

5.3 Non-traumatic Fractures

Pelvic fractures that present without a history of trauma are called insufficiency fractures [3]. They occur commonly in the sacrum when the strength and elasticity of osteoporotic bone is considerably reduced to the extent that failure occurs even under physiological loads. Sacral insufficiency fracture (SIF) is a well-defined subgroup of insufficiency fractures described by Lourie in 1982 as a "spontaneous osteoporotic fracture of the sacrum" [3]. Although several reports of SIF have been published, the true incidence is still not well known because the diagnosis is often missed without detailed history taking, physical examination and advanced imaging.

Atraumatic pelvic fractures occur most commonly in post-menopausal women with osteoporosis [4–7]. Other risk factors include irradiation of the pelvis [8–10], rheumatoid arthritis [11–13], osteomalacia and endocrine disorders [14]. Patients who received thoracolumbar or lumbosacral fusions are prone to these fractures as there is increased stress transfer to the sacrum [15, 16]. In isolated reports, hepatobiliary diseases [17, 18], major organ transplantation [19], antiphospholipid syndrome [20] and adynamic bone disease related to a long-term bisphosphonate use [21, 22] have been reported to be associated with atraumatic pelvic fractures.

Osteomalacia is a result of vitamin D deficiency, which can cause bone weakness and subsequent stress fractures. The radiological features are called looser zones or pseudo-fractures. Common sites are the pubic rami, medial proximal femur and the scapula. In late stages, the shape of the pelvis becomes deformed giving a characteristic tri-radiate pelvis.

Irradiation is a less common cause of pathological fractures of the pelvis. Post-irradiation pelvic fractures are challenging to manage as the vascularity of irradiated bone is compromised and patients usually have a history of local malignancy. Non-unions, bone necrosis and osteomyelitis are more often. Risk factors for complications include female gender, anterior femoral compartment resection, periosteal stripping and high irradiation dose [23]. Surgical fixation is considered when the instability causes intractable pain and inability to walk.

Physicians should keep in mind that insufficiency fractures can co-exist with metastatic disease [24]. Magnetic resonance imaging (MRI) is the most sensitive investigation. It shows reduced T_1 signal intensity in the fracture site and increased T_2 intensity which extends far beyond because of marrow edema. Ironically, the MRI is sometimes over-sensitive and findings can mimic bone metastasis and lead to unnecessary investigations and procedures [25, 26].

5.4 Site of Pain and Fracture Localization

Elderly patients are sometimes unable to accurately describe and localize the site of pain. A detailed physical examination should be performed in all elderlies who present with pain at the hip, thigh, groin, buttock or back after a fall. The exact location of tenderness should be noted by deep palpation and percussion at these regions. The site of pain will vary depending on the site of fracture. The common pubic rami fracture may present with pain at the hip, groin, buttocks or even thigh. Very commonly, there is also tenderness over the sacral region indicating the presence of a concomitant posterior ring fracture. Sacroiliac joint tests such as flexion-abduction-external rotation (FABER) test and the flexion-adduction-internal rotation tests are sensitive clinical tests for painful pathologies at the pelvis or hip region but are less specific for sacral and pelvic fractures. Physicians should also rule out any osteoporotic vertebral collapses. The symptoms and signs overlap considerably with hip fractures, so the two diagnoses should be considered together. Osteoporotic patients are prone to multiple fractures and an associated distant fracture must also be considered.

Atraumatic SIF commonly present with low back pain. The pain is of insidious onset and intractable. Patients may also complain of buttock pain or groin pain without definite history of trauma [3, 5–7, 11]. Symptoms are usually exacerbated by walking and relieved by rest. SIF are often bilateral and may co-exist with pubic rami fractures [27]. This condition may be difficult to differentiate from common lumbar pathologies with similar symptoms and signs.

Neurological complications are mainly associated with fractures in zone 2 or zone 3 according to Denis classification [28]. The incidence of neurological complications is reported at around 2% with sphincter dysfunction and lower limb paresthesia being most common [4]. Cauda equina syndrome has been reported to be a rare association [29]. Unfortunately, because neurological symptoms are easily overlooked in the elderly with multiple medical problems [30], the above figures are likely underestimated.

Whenever the site of pain is localized, the diagnosis can often be made with a good quality anteroposterior radiograph. Plain radiograph is often the initial investigation but less sensitive because of poor projection of fracture lines and bowel gas obscuration [31]. Often, only pubic rami fractures can be demonstrated in plain radiographs. The radiographic features of chronic SIF are sclerotic healing lines, linear fracture lines or a combination of these signs. Because sclerotic features are absent in acute fractures, non-displaced fractures have poor contrast in osteoporotic bone, even with a CT scan, the sensitivity and specificity is only 68% [7].

Both MRI and radionuclide bone scintigraphy are highly sensitive imaging tests for traumatic and non-traumatic pelvic fractures. Technetium-99 m bone scintigraphy is a sensitive imaging modality for SIF. An H-shaped (Honda sign) uptake is diagnostic for sacral insufficiency fractures [31, 32] with bilateral sacral involvement together with horizontal fracture across the sacral body present in around 43% of patients with SIF [4]. Biochemical tests are essential to help physicians in establishing the diagnosis of SIF. Slight increase in alkaline phosphatase often present in case of SIF. Other blood tests including thyroid stimulating hormone, parathyroid hormone, calcium level, liver function tests, renal function test and inflammatory markers are indicated to rule out secondary osteoporosis.

5.5 Comorbidities and General Condition

Elderly patients are prone to becoming decompensated with trauma and a moderate degree of internal hemorrhage. Fortunately, severe associated features such as hemorrhage, hypovolemic shock [33] and visceral injuries [34] are rare in fragility fractures of the pelvis. Patients are likely to have multiple comorbidities affecting their overall well-being. Common pre-existing conditions are cardiovascular diseases, chronic obstructive airway diseases, cerebrovascular diseases, diabetes and renal diseases. The number and type of comorbidities directly affect the outcome of fracture treatment and mortality. Moreover, they also affect the rehabilitation potential of the patient.

The goal of treatment can be significantly altered by the presence of concurrent diseases. As a result, the physical condition of the individual patient should be considered in deciding the best treatment. If surgical treatment is indicated, the patient's general conditions should be optimized in a timely manner. Otherwise, there may be delay in surgery resulting in prolonged pain and discomfort of the patient.

A number of complications may result from prolonged immobility. Deep vein thrombosis should be excluded in all patients with fragility fractures of the pelvis. In patients with more severe fractures and with expected delay in ambulation, thromboembolic prophylaxis should be given. Pulmonary infections, urinary tract infections and sacral sores can develop in immobile patients. Hospitalized elderly patients commonly develop delirium and other psychological problems.

5.6 Fracture Patterns

Fractures at the superior and inferior pubic rami are the most readily and commonly recognized injured zones in geriatric patients with pelvic fractures. The pelvis anteroposterior, inlet and outlet radiographs are able to pick up most of these anterior ring fractures.

Unfortunately, associated posterior pelvic ring fractures are extremely common but easily missed. When patients present with pubic rami fractures, their back should be examined for tenderness at the sacroiliac area and the iliac wing. Plain radiographs have low sensitivity in detecting osteoporotic sacrum and ilium fractures (Fig. 5.1a). CT scans and 3D reconstructions are sensitive in detecting posterior ring injures that are displaced (Figs. 5.1b, c and 5.2). When a routine CT scan of the pelvis is carried out for all patients with pubic rami fractures, more than half may have an additional posterior pelvic ring fracture detected [35]. In MRI, over 90% of patients with anterior pelvic injuries may be shown to have involvement of the posterior pelvic ring.

In the elderly, the most common type of pelvic ring injury is the Young and Burgess lateral compression Type-I fracture where there is a minimally displaced sacral ala fracture associated with pubic rami fractures [35]. Proximal or 'high' pubic ramus fractures occur near the anterior column of the acetabulum and are associated with more symptoms and a poorer functional outcome compared to 'low' ramus fracture which occur distally nearer to the symphysis. The second most common pattern is lateral compression type-II fractures with more significant displacement of the ilium near the sacroiliac joint. Non ring-disruption fractures involving only the iliac wing can also occur.

In general, patients with pubic rami fractures and lateral compression Type-I fractures tend to have a relatively stable pelvis with less pain and can be managed conservatively with adequate analgesia [35]. Patients with lateral compression type-II fractures and displaced iliac wing fractures tend to have more severe mechanical instability, pain and are at higher risk of significant internal hemorrhage. The fractured hemipelvis is internally displaced or externally rotated and the radiograph will show an asymmetry of the ilium. Vertical shear injuries associated with high energy injuries are less common in elderlies.

The aim of any treatment is to allow early mobilization as tolerated. A majority of patients can be managed non-operatively and the rate of successful union is very high for stable lateral compression fractures. Patients are encouraged to walk with full weight bearing and to perform mobilization exercises of the hip joints as early as possible. It is important to recognize the fracture pattern and the injury mechanism as those with a more complex injury pattern and displacement may have a more prolonged course of rehabilitation.

Surgical stabilization is occasionally indicated when mechanical instability is associated with persistent and intractable symptoms. The surgical options include standard open reduction and internal fixation using plates through an ilioinguinal approach (Fig. 5.3), or closed reduction with percutaneous trans-iliac screw fixations and pubic rami screws. Anatomical reduction is sometimes difficult to maintain with plate and screws in osteoporotic bone especially at their thinned iliac wings. Nonetheless, some degree of mal-reduction is often functionally acceptable in low demand patients. Fracture union is likely when bone contact has been restored. Scrutiny is needed because advanced age, multiple comorbidities, poor cardiopulmonary reserve and intraoperative bleeding makes major surgery a difficult undertaking.

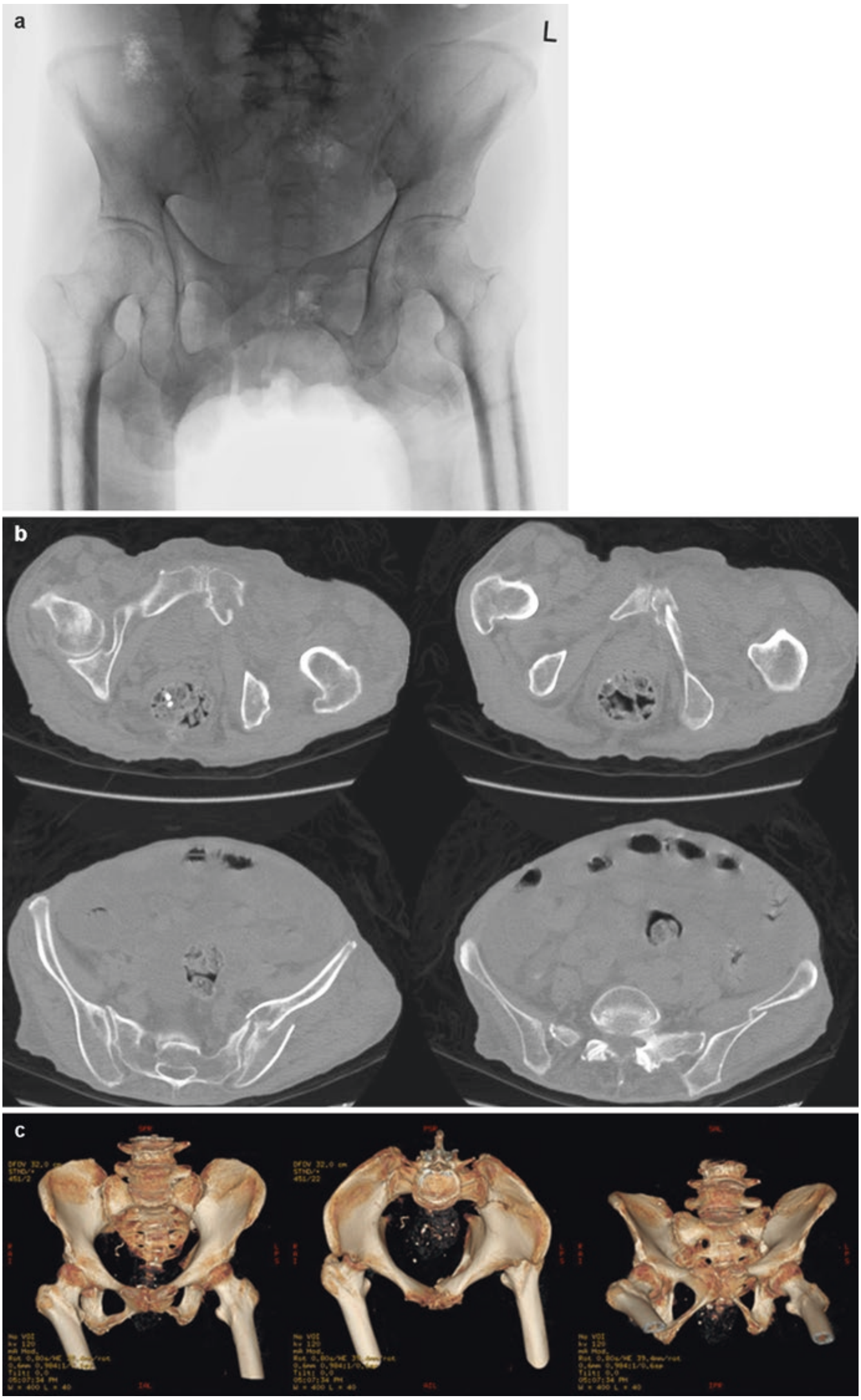

Fig. 5.1 (**a**) Plain radiograph of an elderly with osteoporosis showing subtle asymmetry of the left hemipelvis. There is a suspected fracture at the left superior and inferior pubic rami and the left ilium body. (**b**) The fractures are much more obvious on axial CT images. (**c**) 3D reformatted images in the a.p., inlet and outlet orientations showing internal (medial) displacement of the ilium typical for a lateral compression fracture predisposed by a simple fall

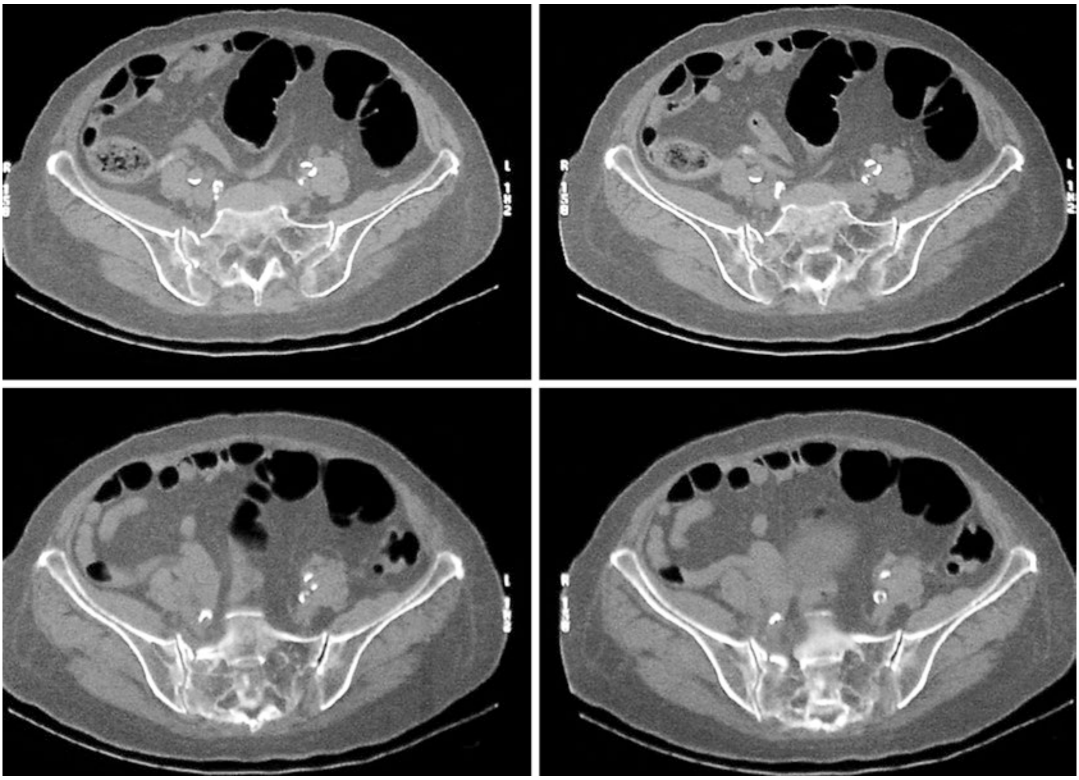

Fig. 5.2 Axial CT scans reliably detect sacral ala fractures with displacement. This CT scan shows a fracture through the right sacral foramen (Denis zone 2). The patient was later diagnosed to have a nerve root palsy related to the injury

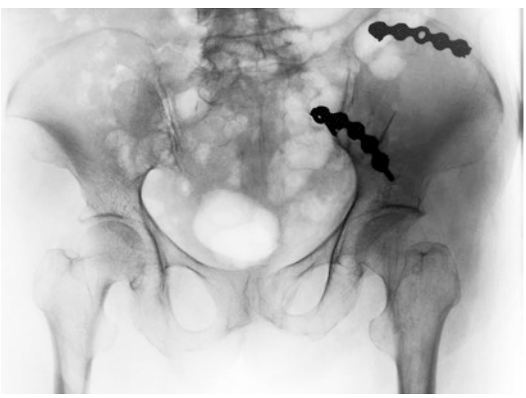

Fig. 5.3 An elderly with a displaced unstable ilium body fracture managed by open reduction and plate fixation

5.7 Massive Arterial Hemorrhage

Patients with low energy pubic rami fractures occasionally present with severe hypovolemic shock even with a benign looking X-ray with minimal fracture displacement [33, 36]. Such massive hemorrhage can be caused by a rupture of the corona mortis artery which is the natural communication between the obturator and inferior epigastric artery behind the superior pubic ramus. Also injuries to other intrapelvic arteries have been shown to be responsible for major blood loss [37]. Shock typically occurs within 6 h of injury, more commonly associated with the use of anticoagulants. Patients who are on antihypertensive drugs such as a calcium channel or beta adrenergic blocker may have a drop in blood pressure without tachycardia. With a high index of suspicion, they are diagnosed by contrast CT scan or angiography. When delayed, patients may present with an enlarging lower abdominal wall hematoma. Fluid resuscitation and urgent angiographic catheter embolization are associated with excellent outcomes for bleeding control and are preferred over open surgery (Fig. 5.4). Although arterial hemorrhage is uncommon, fatalities can occur when missed. All elderlies with stable pelvic fracture should therefore be

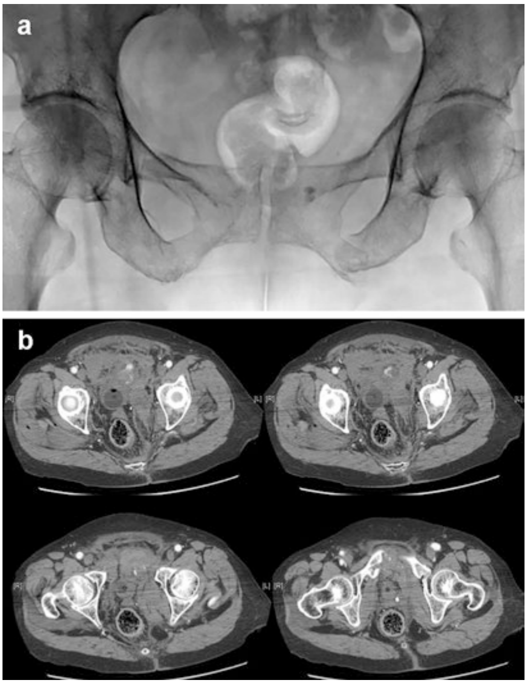

Fig. 5.4 (**a**) An elderly female pedestrian was involved in a low speed motor vehicle accident and suffers minimally displaced bilateral pubic rami fractures. (**b**) This patient had hypovolemic shock 3 h after admission and was discovered to have hemorrhage from the corona mortis vessel. On CT scan, there was active contrast extravasation and an associated large hematoma superior and posterior to the left pubic bone. Hemostasis was later achieved by angiographic embolization

recommended hospital admission and close observation for 24 h [33, 36, 37].

5.8 Pelvic Nonunion

Non-unions are rare in fragility fractures of the pelvic ring. Missed diagnosis is a major predisposing factor for nonunion. First, when injury and acute pain symptoms appear to be too trivial in the cognitively impaired, the injury is easily neglected and fracture healing compromised because of inadequate protection. Second, without advanced imaging such as CT scans, the diagnosis and displacement of the fractures are easily overlooked when based on routine radiographs. Third, in cases with ilium fractures, there is little bone contact and stability between the thin and osteoporotic fragments easily leading to nonunion. (Fig. 5.5).

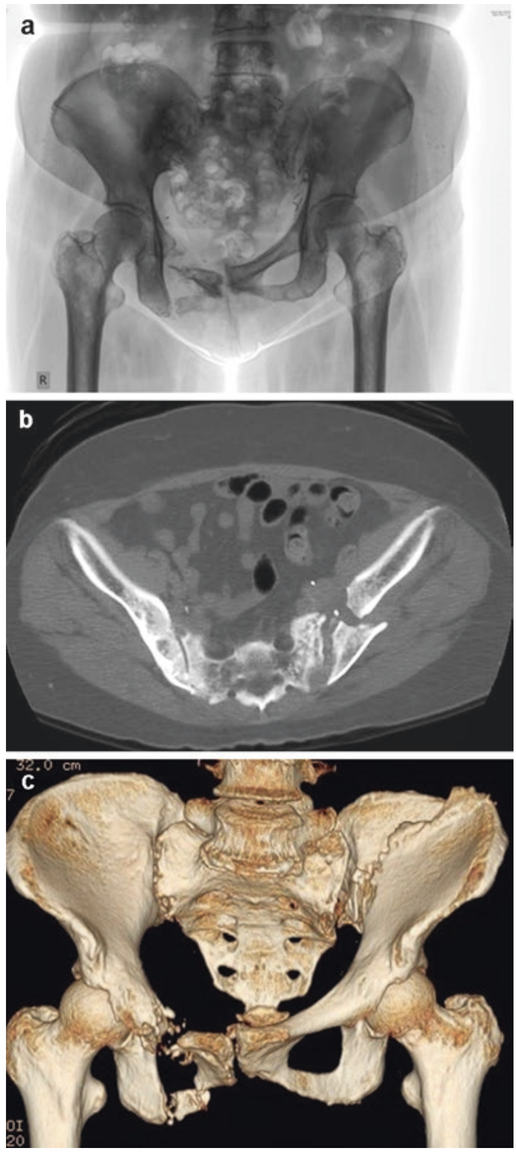

Fig. 5.5 (**a**) Patient with a history of malignancy and irradiation presenting with an atrophic fracture nonunion of the right pubic rami, the left ilium and dissociation of the left sacroiliac joint. Note the rounding off of fracture ends and lack of callus formation. The ilium is seen to be displaced but the status of union hardly visible. (**b**) On axial CT scan and (**c**) on 3D reconstructions, the location of the posterior pelvic ring nonunion and the diastasis of the sacroiliac joint are better identified

In patients with a symptomatic nonunion and persistent pain, surgical fixation may be necessary. For those who are medically fit, posterior sacral bars and locking plates have been applied

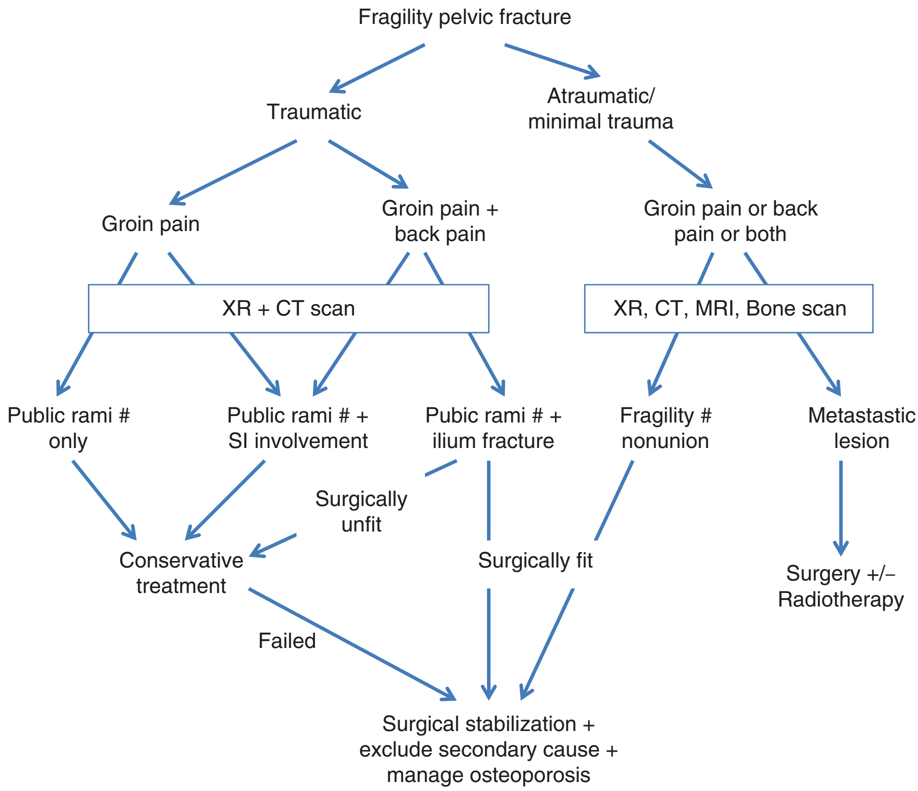

Diagram 5.1 Diagnostic and therapeutic algorithm for fragility fractures of the pelvis

for fixing osteoporotic fractures with some success. Percutaneous fixations are also possible if an acceptable reduction can be achieved using closed techniques. In many instances, in-situ fixation of these non-unions can provide adequate symptomatic relief [38].

5.9 Summary

As the population ages, health care professionals will encounter an increasing number of fragility fractures of the pelvis. Falls are the most important etiological factor. An alert physician should be able to reliably identify posterior pelvic ring fractures and atraumatic insufficiency fractures in addition to the common pubic rami fractures. When there is a high index of suspicion, advanced imaging in addition to plain radiographs provides sufficient information to establish the diagnosis and to guide the treatment. The patient's general condition must also be considered in deciding the treatment strategy. In Diagram 5.1, a diagnostic and therapeutic algorithm for fragility fractures of the pelvis is presented.

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6 Radiological Assessment

Karl-Friedrich Kreitner

6.1 Introduction

Imaging plays a pivotal role in assessment of fragility fractures of the pelvis, as it enables their detection, confirmation and grading [1–3]. Although cross-sectional imaging modalities like CT and MRI have become widespread available, projectional radiography still remains the primary imaging modality in most centers.

6.2 Plain Radiography

In the radiological work-up of fragility fractures of the pelvis, projectional radiography is the first step in many institutions. Usually, three views are obtained: the anteroposterior (a.-p.) view of the pelvis, the pelvic inlet and pelvic outlet views [4] (Figs. 6.1a–c, 6.2a and 6.3a–c). On the *a.-p. pelvic overview*, fractures of the superior or inferior rami, the pubic bone near the symphysis and diastasis of the symphysis are detectable without significant difficulties. In case of a lateral impact, fractures of the superior pubic ramus run horizontally, and there may be a slight overriding of the fracture fragments with medial displacement of the lateral fragment. In case of antero-posterior impact, fracture lines run vertically through the pubic rami or the pubic bone. There is no overriding of the fracture fragments, and a slight diastasis can sometimes be detected (Fig. 6.1a). When the fracture is located far lateral, it may involve the anterior lip of the acetabulum. In this case, additional oblique Judet views (ala and obturator views) exclude more complex acetabulum fractures [4, 5].

The *pelvic inlet view* shows extent and direction of fracture fragment displacement in the anterior pelvic ring and provides hints for the fracture mechanism. Furthermore, pelvic inlet view should carefully be analyzed with regard to cortical irregularities of the inner curve of the innominate bone and of the anterior cortex of the sacral ala. A sclerotic area in the sacral ala may be a sign of a fracture with impaction (Fig. 6.3b, d, e). Last but not least, the width of the sacroiliac joints should be evaluated for assessment of concomitant joint involvement. In both the a.-p. and pelvic inlet views, asymmetry of the iliac wings is an additional hint for involvement of the posterior pelvic ring [4–6].

The *pelvic outlet view* enables the assessment of the dorsal pelvis with regard to the shape and symmetry of the sacrum, neuroforamina and sacroiliac joints. Also cranial displacements of parts of the pelvic ring may be detected (Fig. 6.3c).

Chronic fragility fractures of the sacrum may appear as vertical bands of sclerosis oriented parallel to the sacroiliac joints in the sacral ala. This

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_6

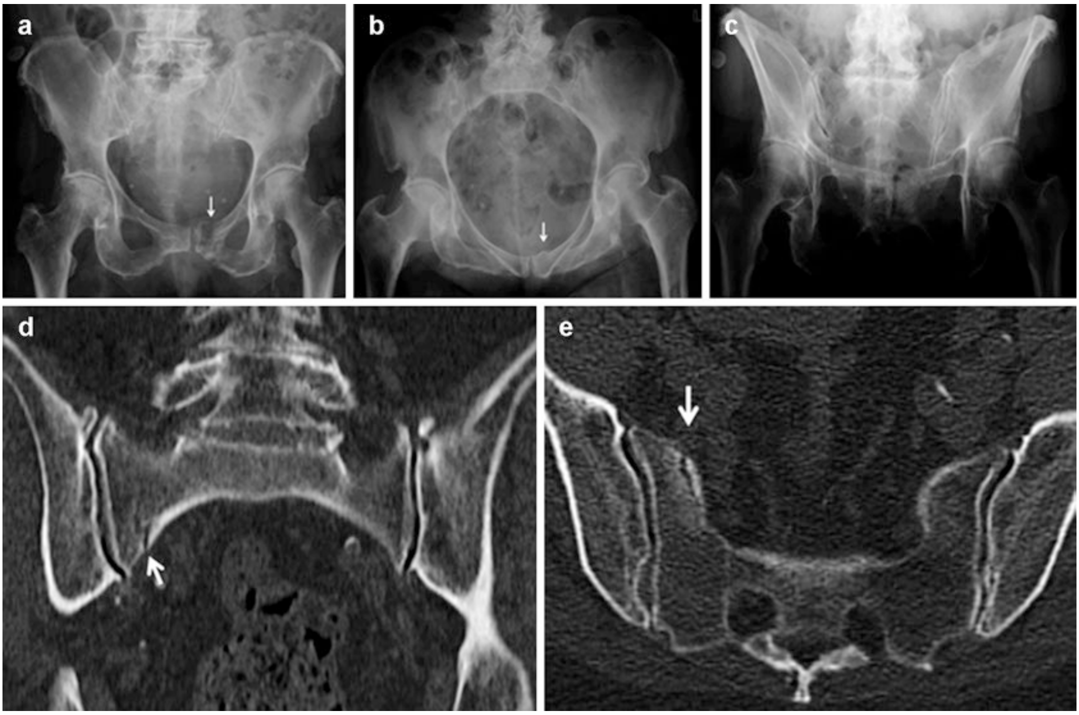
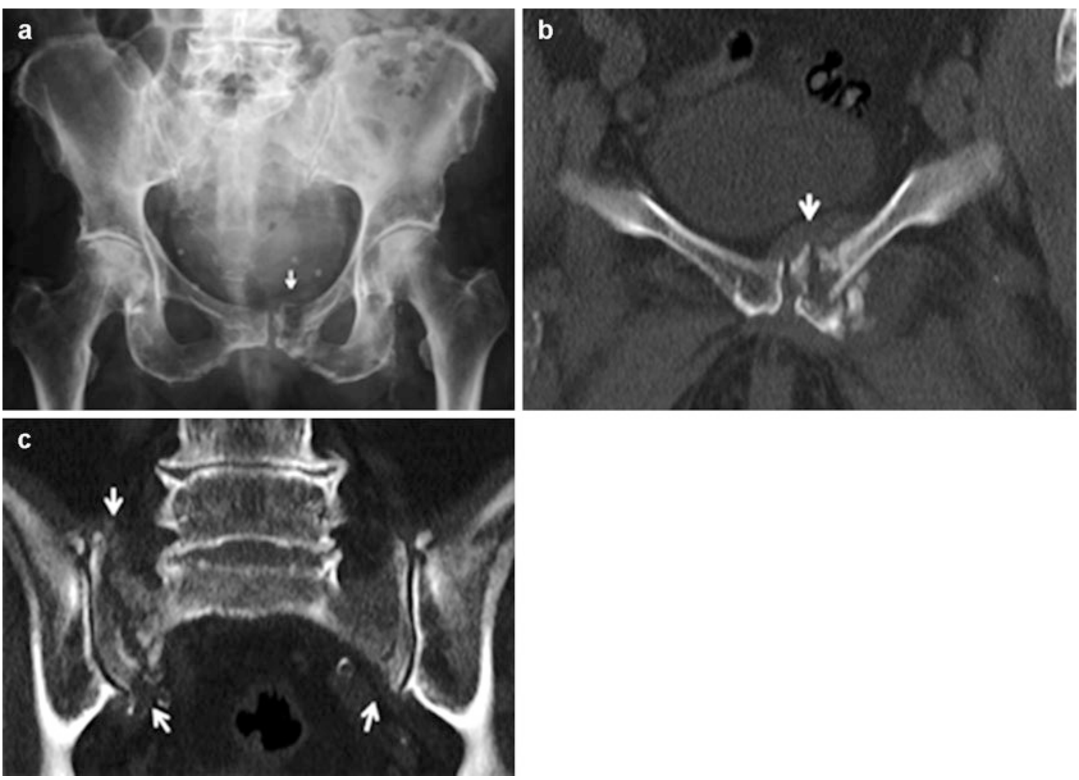


Fig. 6.1 Eighty-five-year-old female with fracture of the left pubic bone (**a**). In the pelvic inlet (**b**) and outlet (**c**) views, an additional fracture in the posterior pelvic ring cannot be detected. Multiplanar reconstructions of the CT scan (**d**, **e**) reveal an interruption of the anterior sacral cortex located in the right sacral ala. The patient was primarily treated non-operatively



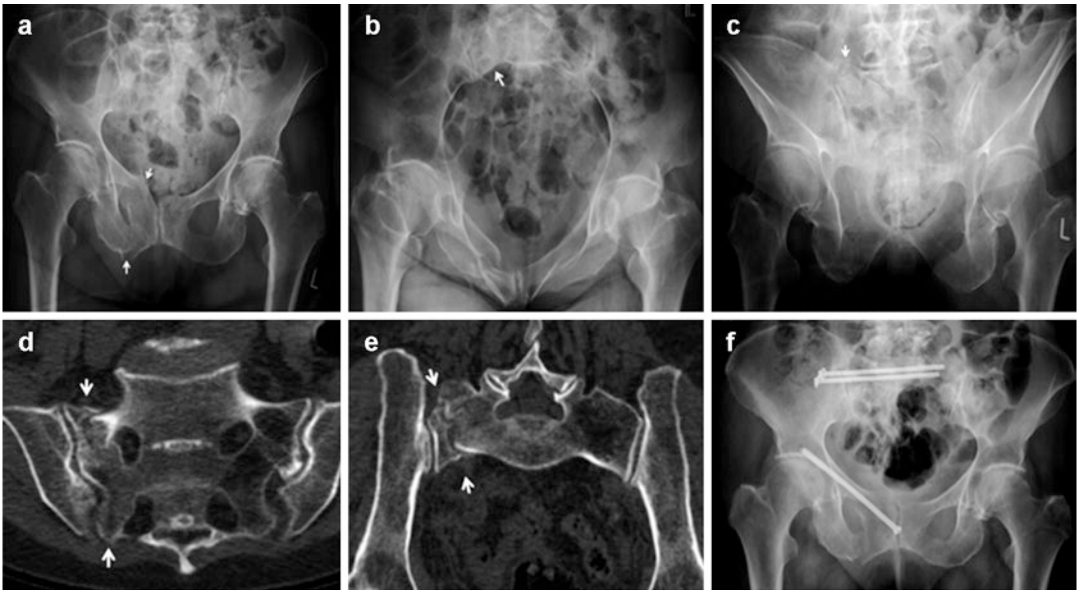


Fig. 6.3 Seventy-four-year-old female suffered a fracture of the right superior and inferior pubic rami after a domestic fall (**a**). The pelvic inlet view (**b**) shows an area of enhanced bone density in the right sacral ala. The outlet view (**c**) shows a fracture line in the right sacral ala near to the sacroiliac joint. Multiplanar CT reconstructions demonstrate a complete right sacral ala fracture with impaction, corresponding to the area of enhanced bone density visible in the conventional pelvic inlet view (**d**, **e**). Postoperative pelvic a.-p. overview (**f**)

sclerosis represents the formation of intraspongious callus and periosteal reaction. Non-united fractures may appear as atypical bony changes. This should not be mistaken for metastatic disease with unnecessary work-up including open bone biopsy. History of radiotherapy due to pelvic malignancies should be ruled out [7–9].

However, assessment of the dorsal pelvic ring may be difficult. Plain radiographs are insensitive for the detection of fractures in the dorsal pelvic ring. This is not only due to disturbing bowel gas and bladder contents. The existing osteoporosis with rarefication of cancellous and cortical structures hampers identification of interruptions within the bony structures due to decreased contrast. The sensitivity of plain radiographs for detecting insufficiency fractures of the sacrum is reported ranging between 20 and 38%. When evaluated retrospectively, the sensitivity for the detection of sacral insufficiency fractures also remains below 50%. Insufficiency fractures of the pubic rami are usually combined with posterior pelvic ring fractures. Therefore, further cross-sectional imaging should be performed when a pubic rami fracture is identified on plain radiographs [5, 7, 8, 10–12].

Depending on clinical presentation and physical examination, plain radiographs of the lumbar spine may be necessary to detect osteoporotic fractures.

Conventional radiography remains the imaging modality of choice in the follow-up of patients with fragility fractures, as it documents fracture healing by the depiction of callus formation, independently of the treatment modality. Plain radiographs in three projections furthermore allow for assessment of the quality of reduction obtained by the operative procedure and of secondary dislocations.

Fig. 6.2 Same patient as shown in Fig. 6.1: a.-p.-radiograph of the pelvis (**a**) and CT scan (**b**) taken after 2 months show no healing of the fractures of the left pubic bone. The fracture of the right sacral ala shows progress and is now complete. There also is a cortical interruption in the left sacral ala, which primarily was not present (**c**). The patient subsequently underwent operative stabilization

Furthermore, problems related to the operative procedure such as implant loosening or failure are well recognized [4].

6.3 Computed Tomography

Multidetector computed tomography (MD-CT) is considered as imaging modality of choice for the evaluation of acute pelvic fractures, if involvement of the posterior pelvic ring is suspected or confirmed. In patients with fragility fractures of the pelvis, CT imaging is regarded as a substantial part in the diagnostic work-up [13, 14]. Compared with projectional radiography, CT provides a far better assessment of fragility fractures of the sacrum with sensitivities ranging between 60 and 75%, if MRI serves as reference [8, 11, 14, 15]. Another advantage of CT imaging is that no special patient positioning is necessary.

In the era of MD-CT, a submillimeter collimation is used, allowing for *multiplanar reconstructions* with overlapping slices and slice thicknesses ranging between 1 and 2 mm, using a bone and soft-tissue kernel for image reconstruction. In our institution, images are reconstructed with a slice thickness of 1 mm and an increment of 0.7 mm. The overlapping slices are the basis for additional multiplanar reconstructions in coronal and sagittal planes. *Coronal reconstructions* allow best assessment of the cranio-caudal extent of sacral ala and innominate bone fractures, which run parallel to the sacroiliac joint. A small crush zone in the sacral ala medial to the sacroiliac joint or an interruption of the anterior cortex of the sacral ala with minor displacement is often seen [16] (Fig. 6.1d). Horizontal components and displacement of sacral fractures are best appreciated on *sagittal reconstructions* (Fig. 6.4). Multiplanar reconstructions are very helpful for appreciation of fracture morphology and degree of instability. Special attention should be paid to the number, localization and displacement of the fractures. Fractures extending through the anterior and posterior sacral cortex are inherently more unstable than those where only the anterior cortex is affected by the fracture (Figs. 6.1d, e, 6.2b, c and 6.3d, e). A bilateral fracture of the posterior pelvic ring leads to a higher degree of instability than unilateral fractures. The detection of a horizontal sacral fracture component reveals the highest grade of instability as there is a complete dissociation between the iliolumbar spine and the pelvic ring (Fig. 6.4e, f).

Modern scanners with appropriate software tools deliver *3D–displays* that simulate conventional radiographs in the standard projections (Fig. 6.4a–c). In an appropriate setting, one may postulate that an unenhanced pelvic CT-scan including the coxal end of both femora may replace conventional radiographs as the first diagnostic step in patients with clinically suspected fragility fractures of the pelvis. However, studies analyzing this aspect have not been published so far.

Three-dimensional (3D) reconstructions provide a complete overview of the fractured pelvic ring, allowing the observer an outside view of the whole pelvis from every perspective, by rotation of the reconstructed image in three planes. They are helpful for assessment of direction of fracture displacement, allowing for a more comprehensive understanding of the fracture mechanism [4, 5, 7] (Fig. 6.5).

In case of chronic insufficiency fractures, areas of sclerotic bone can be detected [4, 5, 7, 11]. They represent intraspongious callus, which are a sign of attempted fracture healing. By recognizing these features, CT is a very good tool in differentiating fragility fractures from radioosteonecrosis, diffuse infiltration by systemic malignant diseases and metastatic disease, respectively (see below). Another, albeit rare finding is the presence of intraosseous gas collections (vacuum phenomenon) in insufficiency fractures (Fig. 6.6). This vacuum phenomenon is a consequence of distraction forces acting at the fracture site. It disappears in case of fracture healing [17].

After operative treatment, MD-CT enables improved assessment in case of implant loosening or failure. Though CT is faced with the presence of metallic artefacts that are caused by photon starvation due to full absorption of the X-ray quanta and by beam hardening due to absorption of low energy quanta, they are generally diminished with the use of MD-CT scanners. Also the composition of the osteosynthetic material (titanium vs. stainless steel) has led to significant reduction of the artifacts. Actually, there are many techniques

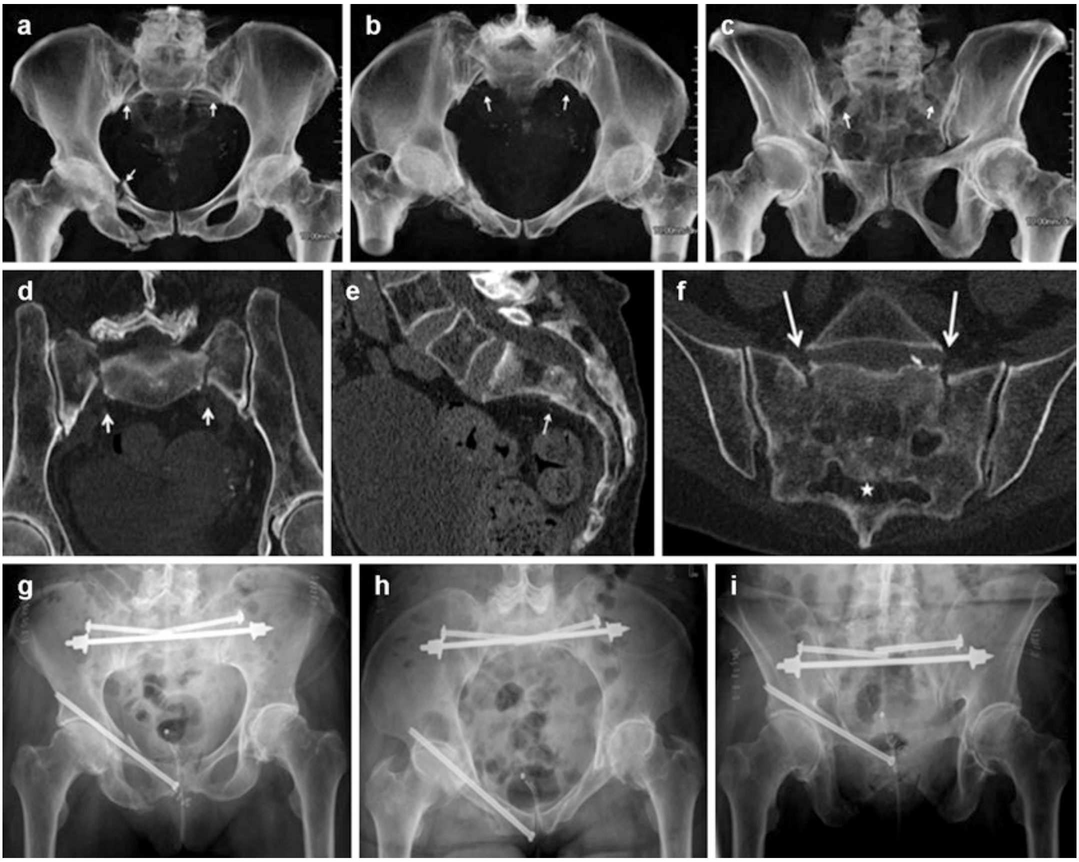


Fig. 6.4 Eighty-three-year-old female with a complex fragility fracture of the pelvis. 3D displays of the CT data set show projections corresponding to the pelvic a.-p., inlet and outlet views (**a**–**c**). Displacement of the bilateral sacral ala fractures is clearly visible in the coronal reconstruction (**d**). Sagittal reconstruction (**e**) reveals a cortical interruption with overlapping at S2-level. Both sacral ala fractures and the horizontal component form an H-shaped fracture of the sacrum (**f**, (*asterisks*) shows the horizontal component). The patient underwent operative treatment using bilateral iliosacral screws and sacral bar fixation and retrograde transpubic screw fixation of the right superior pubic ramus. Postoperative a.-p., inlet and outlet radiographs (**g**–**i**)

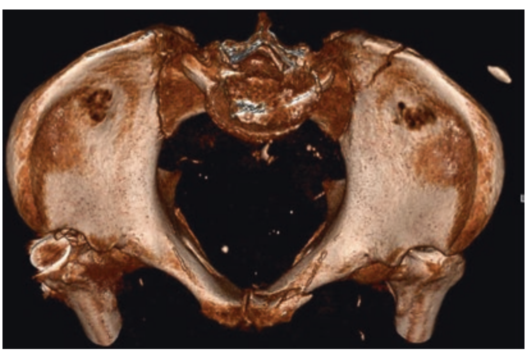


Fig. 6.5 3D-CT-reconstruction of a fragility fracture of the pelvis in an 89-year-old female. There is a horizontal superior pubic ramus fracture with overlapping of the fracture fragments, and an incomplete fracture of the posterior ilium on the left. The trauma mechanism was a fall on the left site. The slight inner rotation of the left hemipelvis indicates a lateral compression injury

available to further decrease these artefacts; widely available techniques comprise the use of higher kVp, reconstruction of thicker slices, and the use of smoothing reconstruction algorithms. Newer techniques comprise the use of advanced iterative reconstruction algorithms, and projection based corrections of artifacts. Although the latter lead to a significant reduction of artifacts in soft tissues, they, however, produce "pseudo osteolyses" in the direct vicinity of cancellous bone. Therefore, they should not be used for assessment of implant-related problems. For such indications, spectral imaging by CT with virtual monochromatic imaging effectively reduces metal induced artefacts. However, this technique is limited to high-end CT scanners that are not widespread [18, 19] (Fig. 6.7).

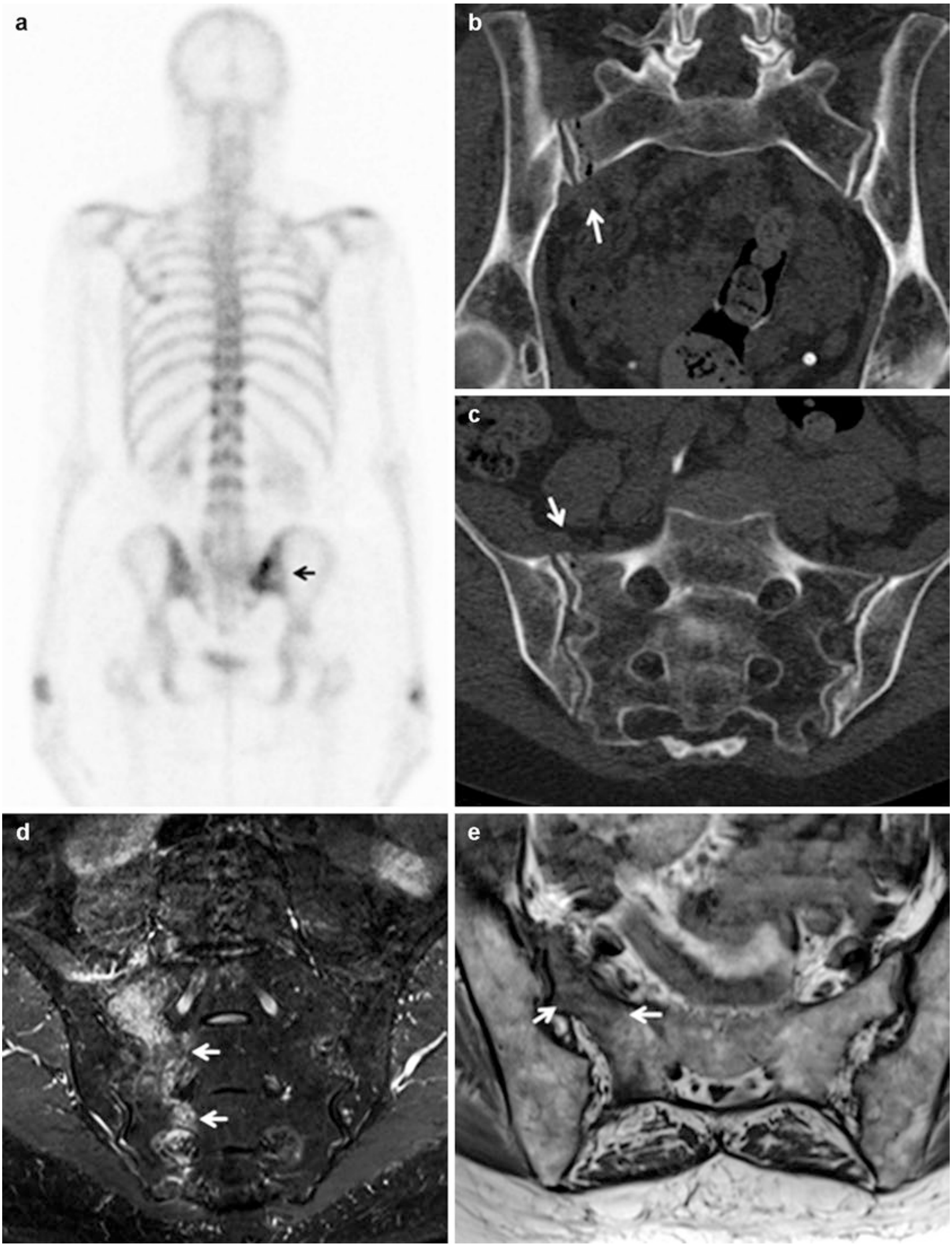


Fig. 6.6 Female patient with newly diagnosed breast cancer. Staging bone scintigraphy revealed tracer accumulation in the left sacrum (**a**, *dorsal view*), which required further imaging studies by CT and MRI. Coronal (**b**) and axial oblique (**c**) reconstructions of CT showed a discrete interruption in the anterior cortex of the sacral bone medial to the sacroiliac joint with intraosseous gas collections, which is suspicious for an insufficiency fracture of the sacrum. MRI with short-tau inversion recovery (**d**) and T_1-weighted (**e**) sequences confirmed the presence of an insufficiency fracture of the sacral ala, with a large edematous zone around the fracture (**d**) and detection of a fracture line in the T_1-weighted image (**e**)

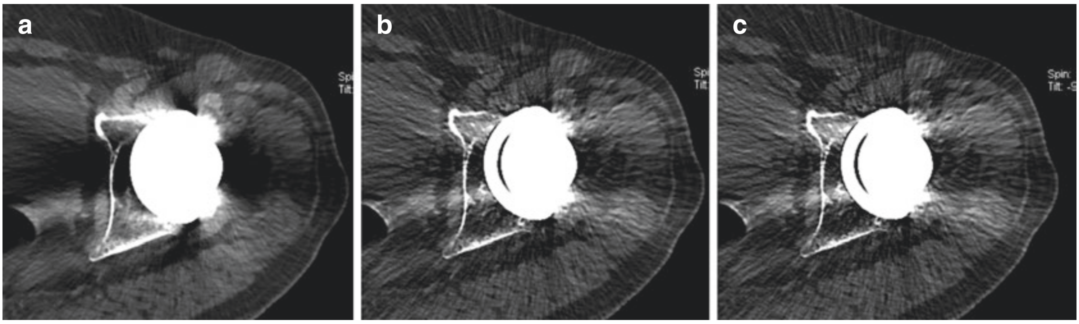


Fig. 6.7 Use of spectral CT for artifact reduction after hip replacement: (**a**) lower energy levels are better suited for assessment of the soft tissues (showing more metal artifacts), whereas higher energy levels are more favorable for assessment of metal and bone ((**b**, **c**) showing more "noise") (Courtesy: Reto Sutter MD, Department of Radiology, University Hospital Balgrist, Zürich, Switzerland)

The main disadvantage of conventional CT techniques is their inability to detect microfractures of cancellous bone, which explains their inferior sensitivity in detecting sacral insufficiency fractures in comparison with MRI. Different methods exist to overcome this drawback: Henes et al. measured the mean Hounsfield Units (HU) in the sacral ala bilaterally in 132 defined anatomic regions at the level of S1, S2, and S3 in 22 patients. Values of less than 35 HU corresponded with occult sacral fractures. Sensitivity was 79% and specificity was 100% with MRI serving as reference. However, these results have not been confirmed in other studies so far [20].

The implementation of *spectral imaging* techniques enables—based on material decomposition algorithms—the calculation of virtual non-calcium images. This is the basis for detection of bone bruises by CT imaging, which correspond to findings at MRI. There are some preliminary studies available with encouraging results for the knee and ankle joints and vertebrae [21–23]. However, no study on fragility fractures of the pelvis have been published so far. An alternative to virtual non-calcium imaging could be hybrid imaging using SPECT/CT in patients with fractures of the anterior pelvic ring without detectable lesions or inconclusive findings in the posterior pelvic ring by conventional radiographs or CT. Scheyerer et al. showed in a small cohort of 17 patients that SPECT/CT delineated traumatic lesions of the posterior pelvic ring in all of them, so that SPECT/CT might be an alternative to virtual non-calcium CT or MRI if these techniques are not available [24].

6.4 Magnetic Resonance Imaging

Magnetic resonance imaging has been proven to be a highly sensitive imaging tool in detecting and characterizing occult traumatic osseous lesions [25]. There are a few reports, in which this technique has been compared with CT imaging for detection of occult pelvic fractures. They demonstrate the superiority of MRI in different patient populations [5, 7, 11, 14, 26]. In the diagnostic work-up of fragility fractures of the pelvis, MRI should be taken into consideration whenever the origin of pelvic pain remains unclear after conventional X-rays and CT examinations, in which no lesion has been discovered. A recent study showed that the incidence of concomitant sacral fractures is much higher in the elderly after a low- to moderate energy trauma than might has been previously suspected, if only CT was used as reference standard [14]. MRI should be taken into consideration when detection of an additional fracture in the posterior pelvic ring has an implication on the choice of the therapeutic procedure.

The MRI protocol for the detection of occult lesions is quite easy: it consists of a combination of T_1-weighted with either edema-sensitive sequences like short tau inversion recovery

(STIR) or T_2-weighted fat-saturated sequences [7, 11, 25, 26] (Fig. 6.6d, e). Sacral fragility fractures demonstrate low signal intensity on T_1-weighted images and—due to local field inhomogeneities—a fracture line is detected in most patients. However, it may be missed in up to 7% of cases. These cases presumably reflect the earliest detectable changes in insufficiency fractures. The extent of the accompanying bone marrow hemorrhage is best assessed by STIR- or T2-weighted fat-saturated images, which shows a hyper-intense pattern (bone marrow edema pattern). Histologically, these areas correlate with microfractures of cancellous bone, edema, and bleeding into the fatty bone marrow. An adjacent soft tissue edema may also be detected. The imaging plane should be parallel or perpendicular to the orientation of the sacrum in the sagittal plane; for appropriate assessment of vertically orientated fractures, imaging should be performed in the oblique coronal plane i.e. parallel to the sacrum. The superiority of MRI over plain radiography and CT has been shown in several studies with reported sensitivities at or near to 100%. Furthermore, it enables differential diagnosis with regard to systemic malignant, metastatic and inflammatory diseases. It is especially helpful in patients with history of cancer for ruling out metastatic disease (Fig. 6.8e–h).

6.5 Bone Scintigraphy

Bone scintigraphy with technetium Tc99^{m} medronate methylene diphosphonate (Tc-99m-labeled MDP) is a very sensitive method for the detection of sacral insufficiency fractures [27]. Various patterns of radiotracer uptake have been described, with the so-called "Honda" sign or H-pattern indicating an H-type fracture of the sacrum. This finding is considered to be very specific for the diagnosis of an insufficiency fracture of the sacrum. In a study performed by Fujii et al. the Honda sign revealed a positive predictive value of 94% [28]. However, this pattern of radiopharmaceutical uptake is seen in only 20–42% of all patients with sacral fractures. Multiple uptake variations have been reported including a unilateral uptake in the sacral ala, a unilateral uptake with a horizontal strut, a bilateral uptake without horizontal strut, and multiple foci of activity. Bone scintigraphy reached sensitivities of up to 96% with a positive predictive value of up to 92% in the detection of insufficiency fractures of the sacrum. The most important drawback is its low specificity as e.g. the inability to reliably differentiate between a fracture and a metastasis (Fig. 6.6). Moreover, the sacroiliac joints may show increased uptake even in normal individuals thus further hampering the interpretation of bone scans [7, 11]. However, with MRI being widely available nowadays, scintigraphy is no longer used to diagnose fragility fractures of the posterior pelvic ring in clinical routine, and it does not play any role in the diagnostic work-up of pelvic fragility fractures at our institution.

6.6 Differential Diagnosis

Stress fractures after radiotherapy are not rare and often pose a diagnostic challenge to differentiate them from metastatic disease. Pelvic stress fractures after radiotherapy are well recognized, common primary pathologies are cervical and rectal cancer. The fracture risk is significantly higher for females than for males. Above 40Gy, fractures occur in increasing frequency with increasing radiation dose. The reported cumulative prevalence is about 45% in female patients after radiation therapy of cervical cancer. Radiotherapy leads to direct cell death and also damages microvascular structures leading to depletion of red marrow and proliferation of fatty marrow. The fatty transformation takes place after a few weeks of bone marrow edema. Radiotherapy can lead to direct bone necrosis, which is usually incomplete and subsequently

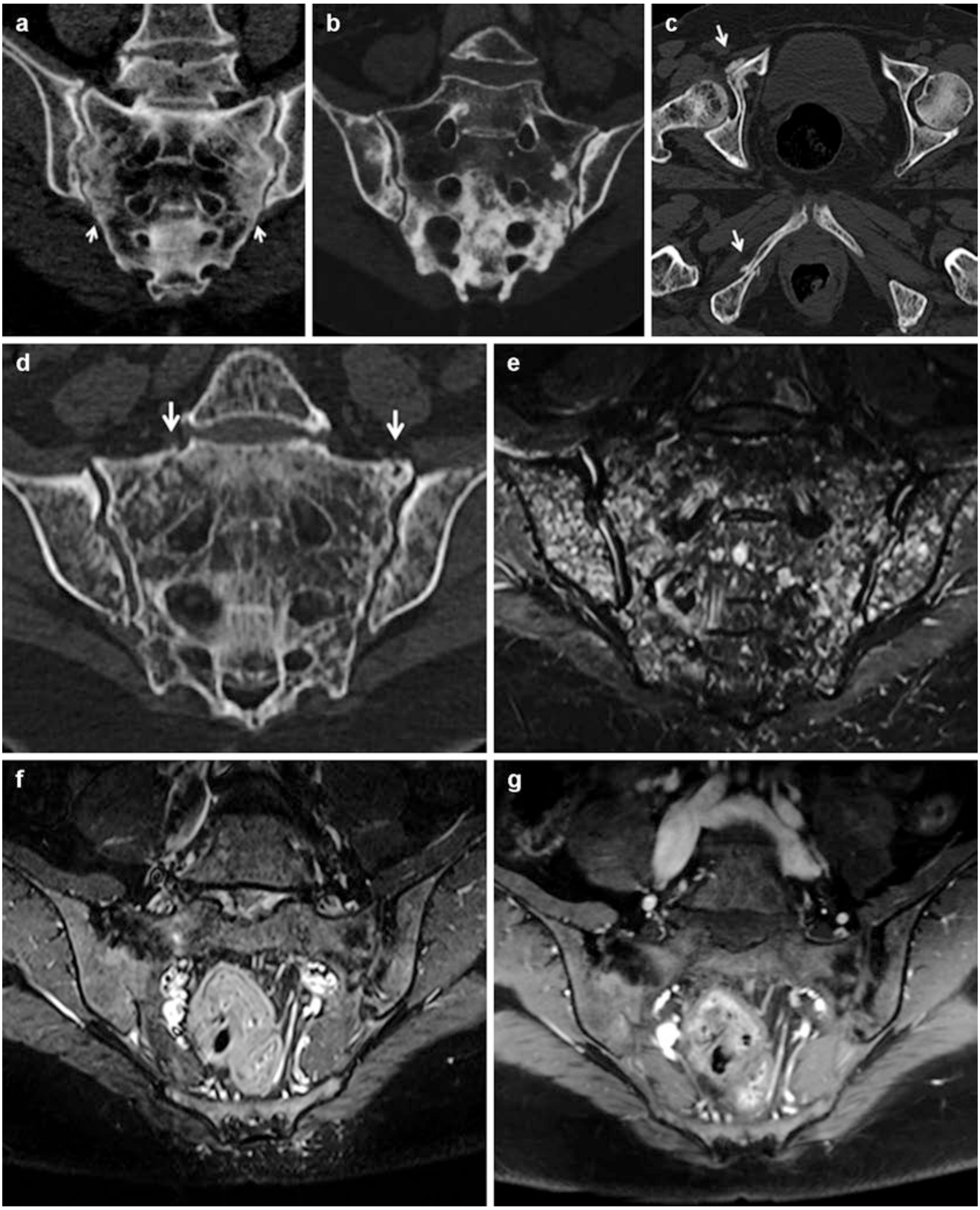


Fig. 6.8 Differential diagnoses of fragility fractures of the sacrum. (**a**) broad sclerotic areas proximal to the iliosacral joints induced by radiotherapy of cervical cancer. (**b**) Osteosclerotic metastases in a patient with breast cancer. (**c**–**e**) CT and MRI in a patient with diffuse infiltration of the pelvic bones by multiple myeloma and fractures of the anterior (**c**) and posterior (**d**, **e**) pelvic ring. (**f**, **g**) Radiographic findings in a young female patient suffering from bilateral ankylosing sacroiliitis

initiates a reactive inflammatory response. This may lead to sclerotic changes of the trabeculae and cortex with reduced mechanical strength and repair capacity making the bone vulnerable to stress fractures. Predilection sites are the sacral ala, sacral body, medial side of the iliac bone, the roof of the acetabulum, superior rami of the pubic bone and femoral head [29–32]. CT and MRI are the most important imaging modalities in assessment of these radiotherapy induced changes: they first begin in the sacrum, are typically bilateral and confined to the field of irradiation. The bone marrow edema-like changes are best appreciated on MR images, while the abnormal bone texture with osteopenia, coarse trabeculation and focally increased bone density and predominant sclerotic changes are best delineated by CT (Fig. 6.8a). There is—if present—only discrete edema in the surrounding soft tissues. With both modalities, there should be a careful search for additional fracture lines. Diffusion-weighted MRI furthermore shows low signal due to unrestricted diffusion of water molecules.

The biggest challenge is the differentiation from *metastatic disease*. Pathological fractures due to metastatic disease can occur anywhere in the pelvis, and there is no symmetry and no confinement to the field of irradiation (Fig. 6.8b). Metastases may appear as solid masses with more or less involvement of the surrounding soft tissues. In diffusion-weighted MR imaging they show high signal due to restriction of diffusion.

Another important differential diagnosis is diffuse infiltration of the bone marrow by *lymphoproliferative disease* e.g. plasmocytoma [33]. There are different patterns of bone marrow infiltration in multiple myeloma including focal infiltration, diffuse disease, salt-and-pepper involvement or combined focal and diffuse patterns. In CT, small osteolytic lesions may be seen surrounded by areas of normal or increased bone density (Fig. 6.8c, d). However, marrow infiltration is best appreciated on MR images (Fig. 6.8e, f). Due to the weakened bone, additional insufficiency fractures may be depicted.

Inflammatory diseases like sacroiliitis in patients with spondyloarthritis primarily lead to enthesitis of the articular fibrocartilage, capsulitis, and osteitis. In advanced disease, structural lesions including periarticular fatty deposition, erosions, subchondral sclerosis, as well as transarticular bone buds and bridges will be visible (Fig. 6.8g, h). MRI very nicely displays these findings in detail. However, due to chronic corticosteroid medication in these patients, fragility fractures of the pelvis may additionally be present [34].

6.7 Diagnostic Algorithm

There must be a high amount of suspicion in diagnosing fragility fractures of the pelvis, as there often is an insidious onset in clinical presentation. In the absence of trauma or following minor trauma, in which a pelvic ring fracture would not be expected, diagnosis may be often delayed. Though conventional radiographs are still the first step in diagnostic imaging today, one should be aware that there is a high risk of missing fractures of the posterior pelvic ring. Therefore, any basic diagnostic work-up comprises the acquisition of a submillimeter collimated CT scan. In the era of multidetector CT scanners with appropriate data acquisition protocols and reconstruction algorithms, 3D displays can be generated that very much resemble the ap.-, pelvic inlet and outlet views. When quickly available and of optimal quality, conventional radiographs become dispensable. However, conventional radiography still plays an important role in the assessment of reduction quality and fracture healing. Due to its superior sensitivity, MRI should be performed in cases with negative conventional radiography and CT; but with a high clinical suspicion of fragility fractures of the pelvic ring. Furthermore, MRI is of great help for differentiating between different causes of fragility fractures of the pelvis.

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Part III

Classification

7 Classification of Fragility Fractures of the Pelvis

Pol Maria Rommens and Alexander Hofmann

7.1 Introduction

The characteristics of fragility fractures of the pelvis differ in many ways from pelvic ring fractures in adolescents and adults. Fragility fractures are the result of low-energy trauma instead of high-energy trauma, which is typical for pelvic ring lesions in adolescents and adults. Consequently, hemodynamic instability is rare, and emergency treatment is usually not necessary. The need for open reduction and internal fixation, which have become the standards of care for high-energy pelvic ring lesions, is not as clearly defined in fragility fracture of the pelvis. Bone mineral density of the sacrum and innominate bones is significantly lower in the elderly, and ligaments remain strong but become less flexible. Fracture morphology reflects the areas of lower bone mineral density, and some fracture types are not seen in adolescents and adults. When a fragility fracture is not treated adequately, the fracture pattern may change over time, and the degree of instability may move from low to moderate or high. These are all arguments in favor of a new classification system that optimally reflects the different fracture morphologies, can be connected with recommendations for treatment, and provides indications of long-term outcome.

7.2 Classification Systems

Innumerable classification systemshave been developed for medical diseases, malignancies, and degenerative or post-traumatic conditions. These classifications 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 can be assessed during clinical examinations or read on conventional X-rays or image-guided procedures, such as computed tomography (CT), ultrasonography or magnetic

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_7

resonance imaging (MRI). Worldwide, accepted systems based on such examinations include the Gustilo classification system for open fractures [1], the Neer classification system for proximal humerus fractures [2, 3], and the Association for the Study of Internal Fixation (AO/ASIF) classification systems for extremity fractures [4]. 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 correlated with treatment strategies and outcomes [5, 6].

7.3 Classification Systems for Pelvic Ring Lesions

Two systems are accepted worldwide for the classification of pelvic ring lesions. The first is the classification by M. Tile [7], adopted by ASIF/AO and the North American Orthopedic Trauma Association (OTA) [8]. The second is that of J. W. Young and A. Burgess [9]. Both systems are based on clinical and radiological findings.

The system of Tile [7], adopted by ASIF/OTA [8], is simple to use because it distinguishes between 3° and types of instability that are easy to discriminate (Fig. 7.1). Type A lesions are stable pelvic ring lesions in which the transmission of body weight from the vertebral column to the lower extremities is not disrupted. Type A1 lesions are avulsions of the innominate bone, Type A2 lesions are from a direct blow of the innominate bone, and Type A3 lesions are caudal transverse lesions of the sacrum. Type B lesions are rotationally unstable. Type B1 lesions are open book lesions that are characterized by an external rotation of one innominate bone. Type B2 lesions are lateral compression lesions in which one innominate bone is internally rotated. Type B3 lesions are characterized by a bilateral rotational instability in which one innominate bone is rotated internally and the other externally. Type C lesions are rotationally and vertically unstable pelvic ring lesions. Type C1 lesions are unilateral injuries. Type C2 are bilateral lesions and have one innominate bone that is rotationally unstable and another that is rotationally and vertically unstable. Type C3 lesions are bilateral, rotationally and vertically unstable lesions. In accordance with the typical ASIF/OTA classification algorithm of extremity lesions, this pelvic ring classification system includes nine categories within the three main types (from A1 to C3) with increasing severity and instability. The system has high inter-observer reliability [10] and is well correlated with outcomes [11, 12].

The Young-Burgess classification [9] distinguishes among four categories that are related to the direction of the disruptive force: antero-posterior compression, lateral compression, vertical shear and combined mechanism injury (Fig. 7.2). Antero-posterior compression and lateral compression injuries are subdivided into three types with increasing degrees of severity, as follows: AP Type I, AP Type II and AP Type III and LC Type I, LC Type II and LC Type III. It has been shown that each lesion type is associated with specific concomitant pathologies, such as severe bleeding, rupture of intrapelvic organs, intra-abdominal lesions and damage to neurological structures. This classification system also has high inter-observer reliability and is well correlated with outcomes [10, 13].

Both classification systems describe fractures as well as injuries to the ligaments and joints, such as diastasis of the symphysis pubis, dislocation of the sacroiliac joint, or disruptions of pelvic bottom structures or the iliolumbar ligament. Each category displays a typical combination of injuries that together form one specific entity. The open book lesion (B1 in the ASIF/OTA classification and APC II in the Young-Burgess classification) involves a rupture of the symphysis pubis together with ruptures of the pelvic bottom structures (sacrospinal and sacrotuberal ligaments) and the ventral sacroiliac ligaments. A unilateral vertical shear injury (Type C1 in the ASIF/OTA classification and VS in the Young-Burgess classification) involves complete ruptures of the anterior pelvic ring, pelvic bottom structures, and dorsal pelvic ring.

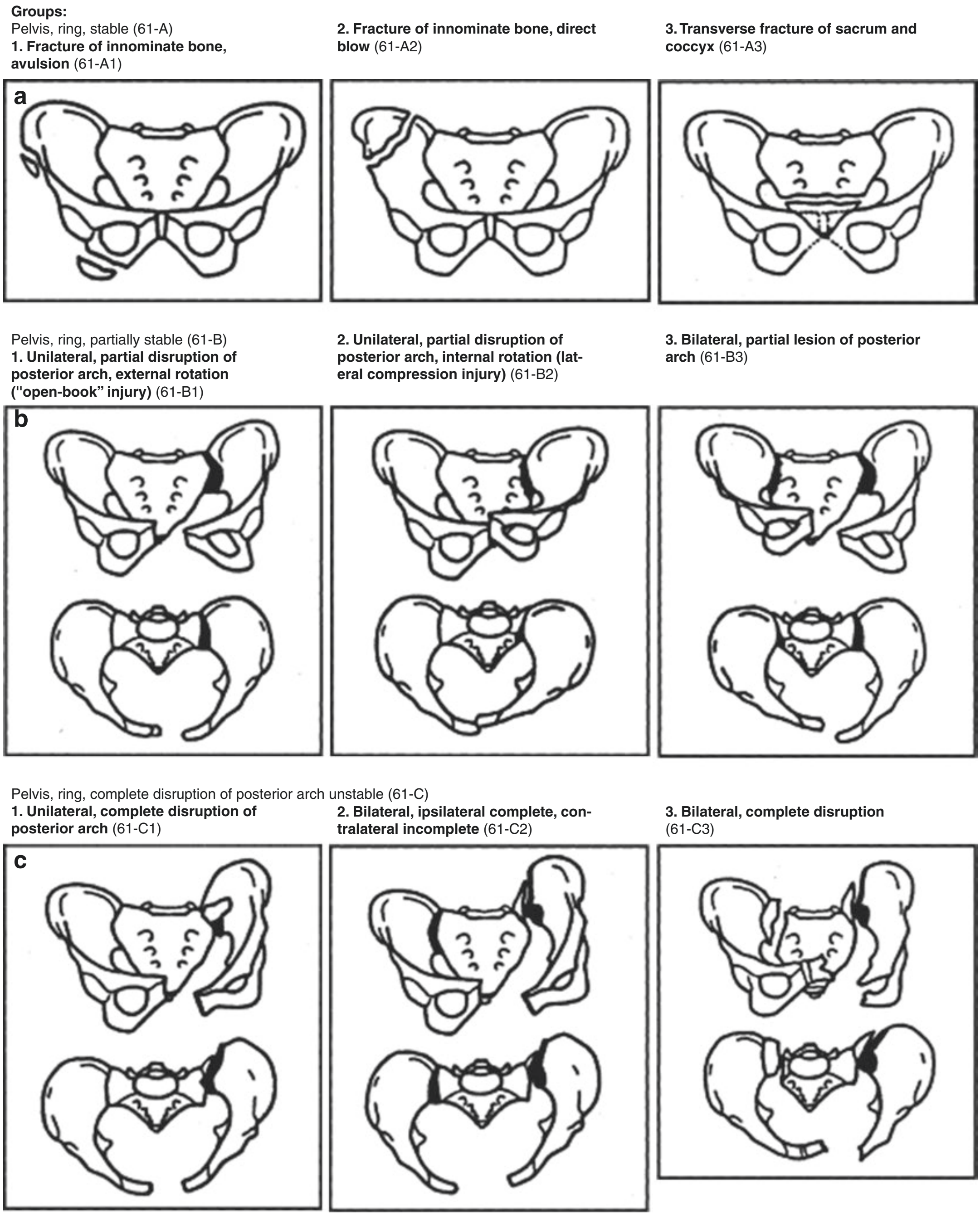

Fig. 7.1 ASIF/OTA classification of pelvic ring lesions (from [8]).

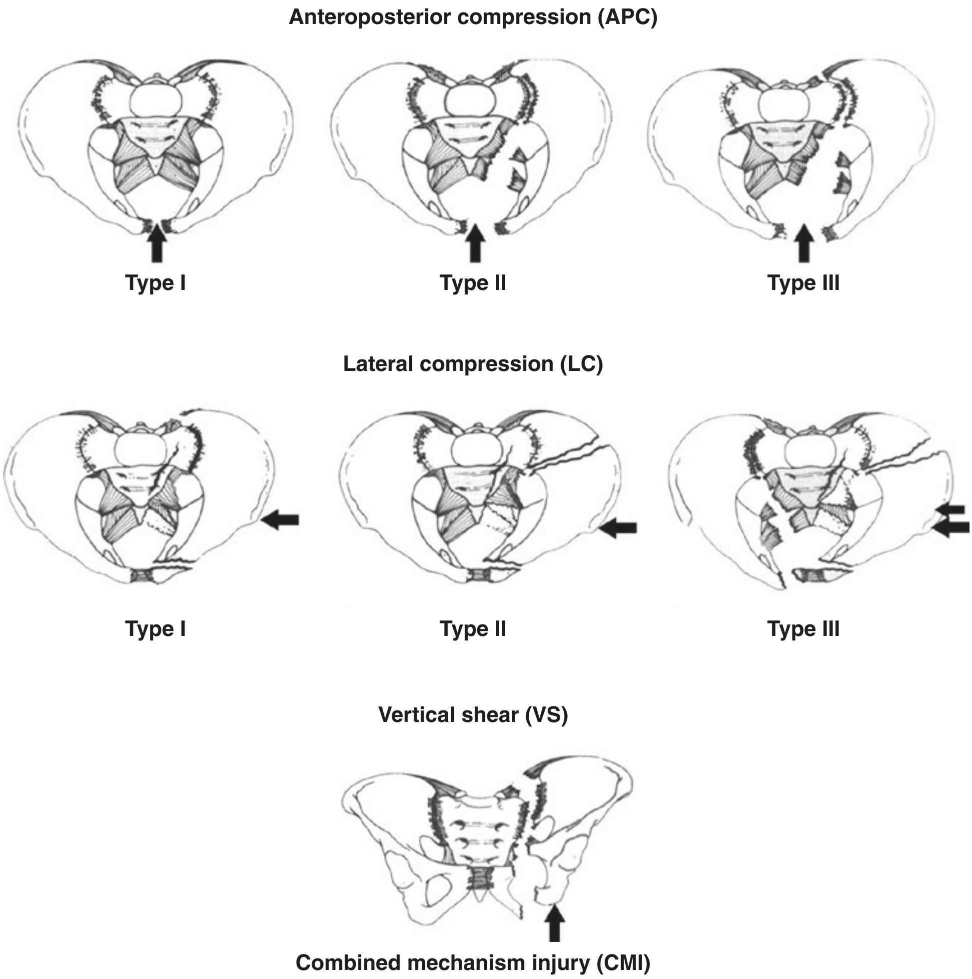

Fig. 7.2 Young-Burgess classification of pelvic ring lesions (from [9])

7.4 Comprehensive Classification of Fragility Fractures of the Pelvic Ring

Classification is based on the analysis of conventional pelvic overviews and a pelvic CT with multiplanar reconstructions [14]. An accurate classification is not possible with only conventional X-rays. Pelvic CT is especially valuable for the detection of any pathology in the dorsal pelvic ring [15].

Three pelvic overviews (antero-posterior (a.p.) pelvic, inlet and outlet oblique views) comprise the first step of the radiological evaluation (Figs. 7.3ac–). Fractures of the anterior pelvic ring are most likely recognizable in the *a.p. pelvic overview*. They can be situated in the pubic bone near the symphysis or run through the superior and inferior pubic rami or the anterior acetabular lip. Anterior pelvic ring lesions can be unilateral or bilateral. Fractures may be non-displaced or incomplete and therefore more difficult to identify. The fracture plane helps identify the vector of the traumatizing force. A vertical fracture is due to an antero-posterior or postero-anterior force, while a horizontal fracture plane is due to lateral force. The extent of displacement is most visible in the *pelvic inlet view*. The inlet view also gives a good estimation of the symmetry of the pelvic ring, and a slight internal rotation of one innominate bone is clear. Moreover, this view gives the best depiction of the anterior cortex of the sacrum, and any impression or interruption, which is typi-

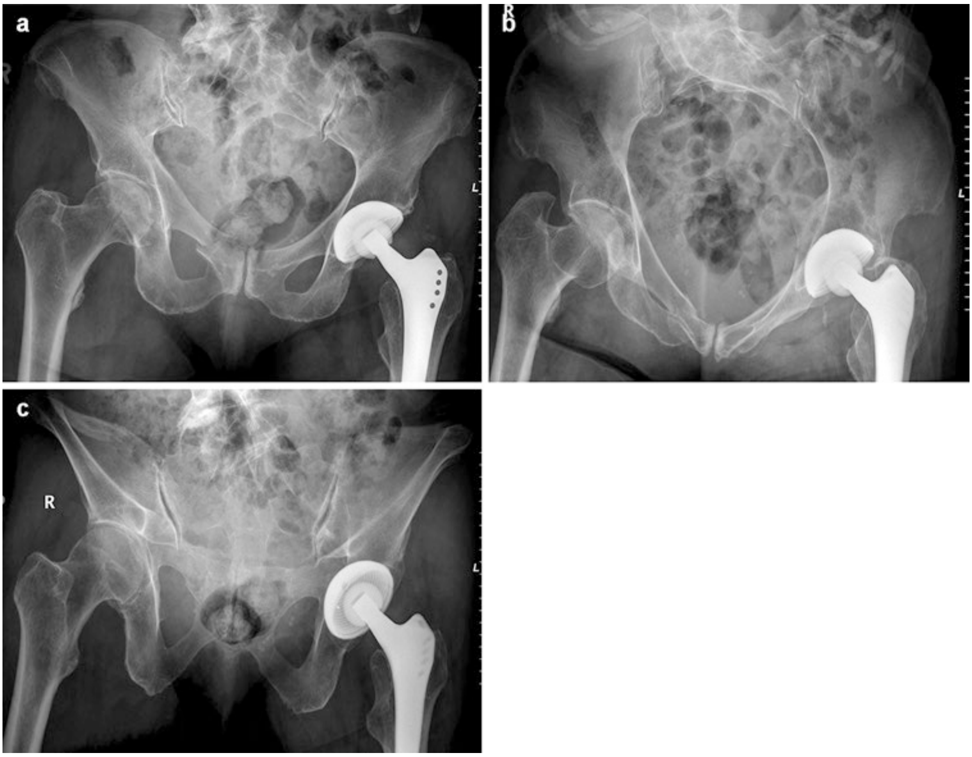

Fig. 7.3 (**a**) Pelvic a.p. overview in an 82-year old woman. There is a slight overriding of the fracture fragments at the right superior pubic ramus. (**b**) Pelvic inlet overview. A slight internal rotation of the right hemipelvis at the fracture of the right anterior pelvic ring is visible. (**c**) Pelvic outlet overview. The fracture of the right anterior pubic ramus is hardly visible. There is no lesion of the posterior pelvic ring

cal for lateral compression injuries, can be detected in an attentive analysis. The *pelvic outlet view* is an antero-posterior view of the sacral body. Vertical displacements between the sacrum and the iliac wing are best identified with this view, as are disruptions or changes in the form of the neuroforamina.

Conventional pelvic overviews are indispensable for the detection or exclusion of a pelvic ring lesion. However, they do not provide all necessary information for a correct classification. The extent and instability of the pelvic ring lesion is easily underestimated, particularly in obese patients, patients with severe osteoporosis, or patients with fissures or non-displaced fractures through the cancellous bone mass of the sacrum. We therefore believe that a CT examination is indispensable for all patients suspected of pelvic ring pathology or in whom pathology is confirmed by conventional pelvic overviews.

Computed tomography is a very practical examination of the sacrum and innominate bones and of the soft tissue structures around and all organs inside the pelvic ring. In particular, the in-depth analysis of the bones and joints is of specific interest for the detection of fragility fractures. Fissures, incomplete and non-displaced fractures, and zones of impression can be observed in the posterior and anterior pelvis and even in the rarefied bone of osteoporotic patients. CT examinations for the detection of any pathology in the dorsal pelvis, such as the sacrum, sacroiliac joint and dorsal ilium, have the most advantages. It is recommended that CT reconstructions be analyzed in different planes. A specific fracture may be more visible on a coronal or sagittal reconstruction than on an axial cut. A horizontal sacral fracture or area of compression at the transition of S1 to S2 may only be visible on sagittal reconstructions. Surface rendering images may add to the understanding of the whole pathology.

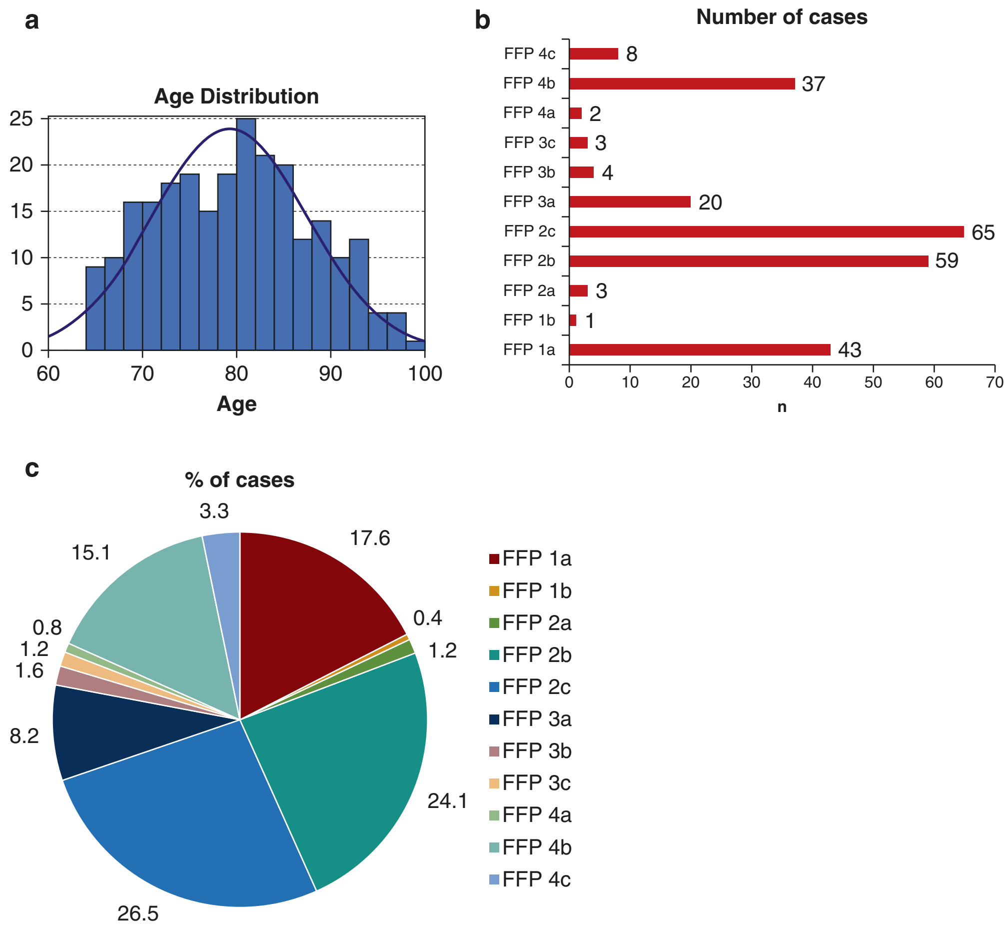

Fig. 7.4 (**a**) Age distribution of the study population (n = 245, mean age 79.2 years, w = 198, m = 47). (**b**) Distribution and numbers of FFP fracture types detected in our study population. (**c**) Percentage of the respective FFP fracture types within the study population [14]

Conventional pelvic overviews and pelvic CTs of a consecutive series of patients with low-energy pelvic ring injuries who were 65 years or older at the time of admission and treated in one trauma unit within a 5-year period were analyzed [14]. Patients with a known history or suspicion of cancer, as well as those for whom an initial CT scan was not available, were excluded from further analysis. Two hundred forty-five patients met these criteria. There were 198 female and 47 male patients with a mean age of 79.2 years (Fig. 7.4). The morphological appearance of the fractures was studied on both conventional pelvic overviews and CT reconstructions.

The fractures were assigned to four different categories of increasing instability: anterior pelvic ring lesions only, non-displaced posterior lesions, displaced unilateral posterior lesions and displaced bilateral posterior lesions. Different subcategories distinguish between the localizations of the instability in the dorsal pelvic ring. The fractures are defined as fragility fractures of the pelvis, abbreviated as FFP. The term "fragility fracture" better describes the underlying problem (fragile bone) than does stress fracture, osteoporotic fracture or insufficiency fracture. Stress fractures are observed in bone with a normal structure and strength, which is determined under repetitive peak loads. On single loading, this stress is not sufficient to create a fracture [16]. A typical example is a metatarsal stress fracture in a military recruit. Another example is a distal tibia

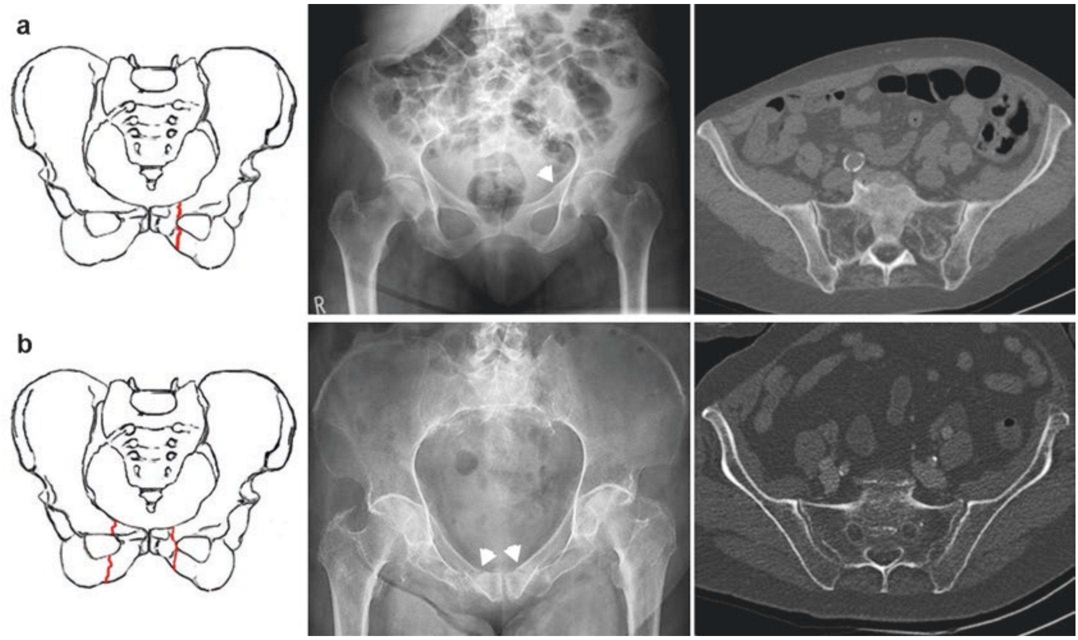

Fig. 7.5 Classification of fragility fractures of the pelvis (FFP) [14]. FFP Type I—Anterior injury only. (**a**) FFP Type Ia: isolated unilateral anterior disruption. (**b**) FFP Type Ib: isolated bilateral anterior disruption

stress fracture in an adult jogger [17]. Stress fractures of the sacrum are rarely seen in adult athletes [18, 19]. Osteoporotic fractures occur in patients with confirmed or suspected osteoporosis. Low-energy accidents, such as domestic falls, are sufficient to produce fractures of the femoral neck, proximal humerus or distal radius [20–22]. They are often the first sign of undiagnosed osteoporosis. Due to osteoporosis, pubic and ischial rami fractures are often seen after a simple fall in elderly patients [23–26]. In insufficiency fractures, the forces leading to a fracture are even lower. These are physiological loads that occur during activities of daily life, and the patient's own body weight and even coughing or sneezing can be sufficient to produce a fracture. The reason for these fractures is the extreme reduction in bone mass, which can be found in patients with severe osteoporosis or after irradiation [27], long-term immobilization, long-term cortisone intake [28], vitamin D depletion [29, 30] or bone harvesting for lumbar spine surgery [31, 32]. Osteoporotic, fatigue or insufficiency fractures are part of a spectrum of fractures occurring in patients with fragile bone. Fragile bone is defined as bone with a significantly reduced bone mass when compared with the bone stock of a young adult. The common pathophysiology of fragility fractures is the discrepancy between the strength of the bone and the amount of load placed on it, which ranges from low energy to physiologic load. We therefore prefer to use the term 'fragility fracture' instead of osteoporotic, insufficiency or fatigue fracture.

The four categories of the new classification system are fragility fracture of the pelvis (FFP) Type I, FFP Type II, FFP Type III and FFP Type IV. The subcategories are identified with the letters a, b or c. Non-displaced lesions are characterized by a crush zone or a fracture without deformation of the anatomy. Displaced lesions are characterized by a crush or a fracture with deformation of anatomical landmarks [14, 33, 34].

FFP Type I lesions are only anterior pelvic ring fractures; FFP Type Ia lesions are unilateral anterior lesions (Fig. 7.5a: FFP Ia) and FFP Type Ib lesions are bilateral anterior lesions (Fig. 7.5b: FFP Ib). Bilateral isolated anterior lesions were very rare in our study (n = 1/245), and unilateral lesions were much more common (n = 43/245). FFP Type Ia and

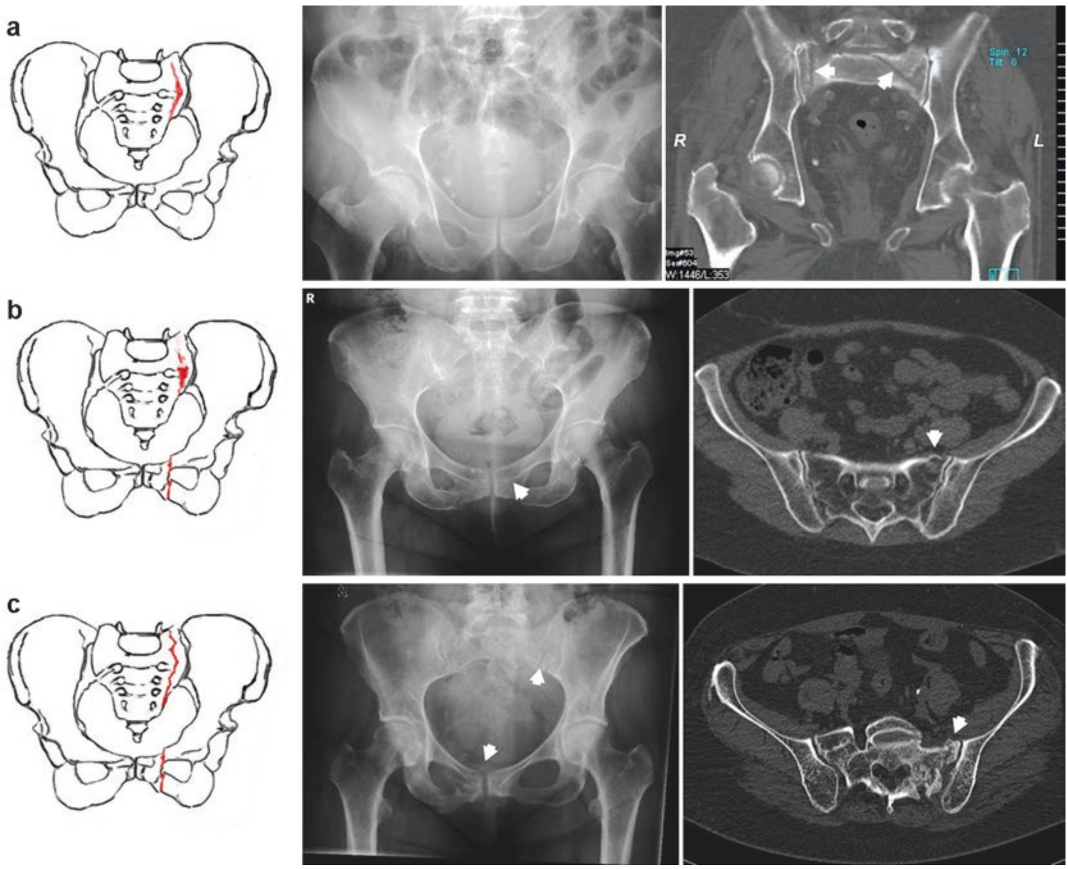

Fig. 7.6 Classification of fragility fractures of the pelvis (FFP) [14]. FFP Type II—non-displaced posterior injury. (**a**) FFP Type IIa: isolated, non-displaced sacral fracture without involvement of the anterior pelvic ring. (**b**) FFP Type IIb: non-displaced sacral crush with anterior disruption. (**c**) FFP Type IIc: non-displaced sacral, iliosacral or ilium fracture with anterior disruption

Ib were far from comprising the majority of all FFPs (43/245 = 17.5%) (Fig. 7.4). These data clearly support the need for CT evaluations of all low-energy pelvic ring lesions in which pubic rami fractures have been detected on conventional pelvic overviews. If only conventional pelvic overviews had been taken in all patients of our study, we would have risked missing posterior pelvic ring lesions in up to 82.5% of cases. Underestimating the instability of the lesion leads to inappropriate treatment and has the inherent risk of increased instability through additional fractures.

FFP Type II lesions are non-displaced posterior lesions; FFP Type IIa lesions are non-displaced posterior lesions without anterior pelvic ring injury (n = 3/245) (Fig. 7.6a: FFP IIa); FFP Type IIb lesions are sacral crush lesions with anterior disruption (n = 59/245) (Fig. 7.6b: FFP IIb); and FFP Type IIc lesions are non-displaced sacral, sacroiliac or iliac fractures with anterior disruption (n = 65/245) (Fig. 7.6c: FFP IIc). Together, FFP Type IIb and FFP Type IIc lesions comprised half of all FFP lesions in our study (124/245 = 50.6%) (Fig. 7.4). FFP Type IIb and FFP Type IIc lesions correspond with the Type B2 lateral compression lesions in the ASIF/OTA classification and with the LC Type I lesions in the Young-Burgess classification. These morphologies reflect the typical mechanism of injury, which is a sideways fall from a standing position. In fragility fractures of the pel-

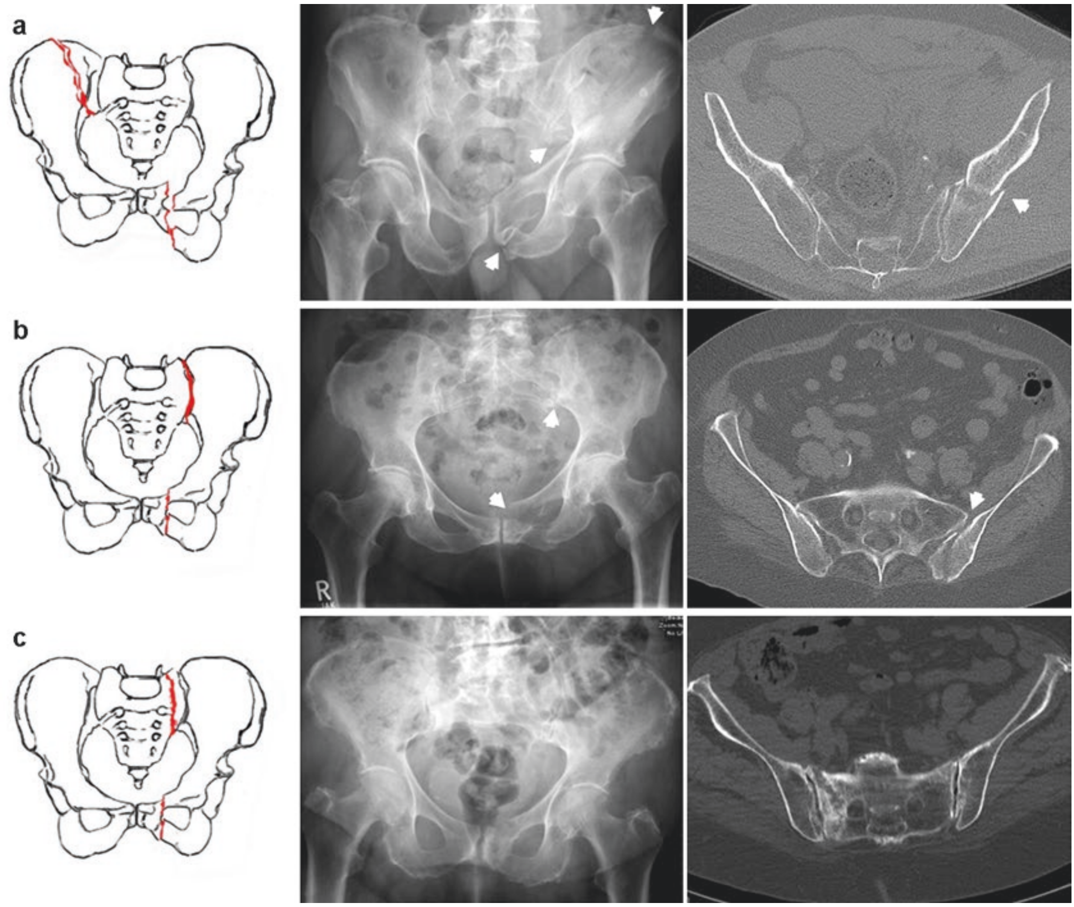

Fig. 7.7 Classification of fragility fractures of the pelvis (FFP) [14]. FFP Type III—displaced unilateral posterior injury. (**a**) FFP Type IIIa: displaced unilateral iliac fracture. (**b**) FFP Type IIIb: displaced unilateral iliosacral disruption. (**c**) FFP Type IIIc: displaced unilateral displaced sacral fracture

vic ring, the sacral fracture or crush zone always runs through the sacral ala, which is the area with the lowest bone mineral density.

FFP Type III lesions are characterized by a displaced unilateral posterior injury combined with an anterior pelvic ring lesion. FFP Type IIIa lesions involve a displaced unilateral ilium fracture ($n = 20/245$) (Fig. 7.7a: FFP IIIa); FFP Type IIIb lesions are displaced unilateral sacroiliac disruptions ($n = 4/245$) (Fig. 7.7b: FFP IIIb); and FFP Type IIIc lesions are displaced unilateral sacral fractures ($n = 3/245$) (Fig. 7.7c: FFP IIIc). Non-displaced unilateral posterior lesions (all FFP Types II, $n = 127/245$) were much more common than displaced unilateral lesions (all FFP Types III, $n = 27/245$), and the FFP Type II versus FFP Type III ratio was 4.7:1 (Fig. 7.4).

FFP Type IV lesions are characterized by displaced bilateral posterior injuries. FFP Type IVa lesions are bilateral iliac fractures or bilateral sacroiliac disruptions ($n = 2/245$) (Fig. 7.8a: FFP IVa). FFP Type IVb lesions are characterized by a bilateral vertical fracture through the lateral mass of the sacrum with a horizontal component connecting them ($n = 37/245$) (Fig. 7.8b: FFP IVb). As the sacral body of S1 or the bodies of S1 and S2 remain connected with the lumbar spine, this fracture morphology reflects a spinopelvic dissociation, or a suicide jumper's fracture, in

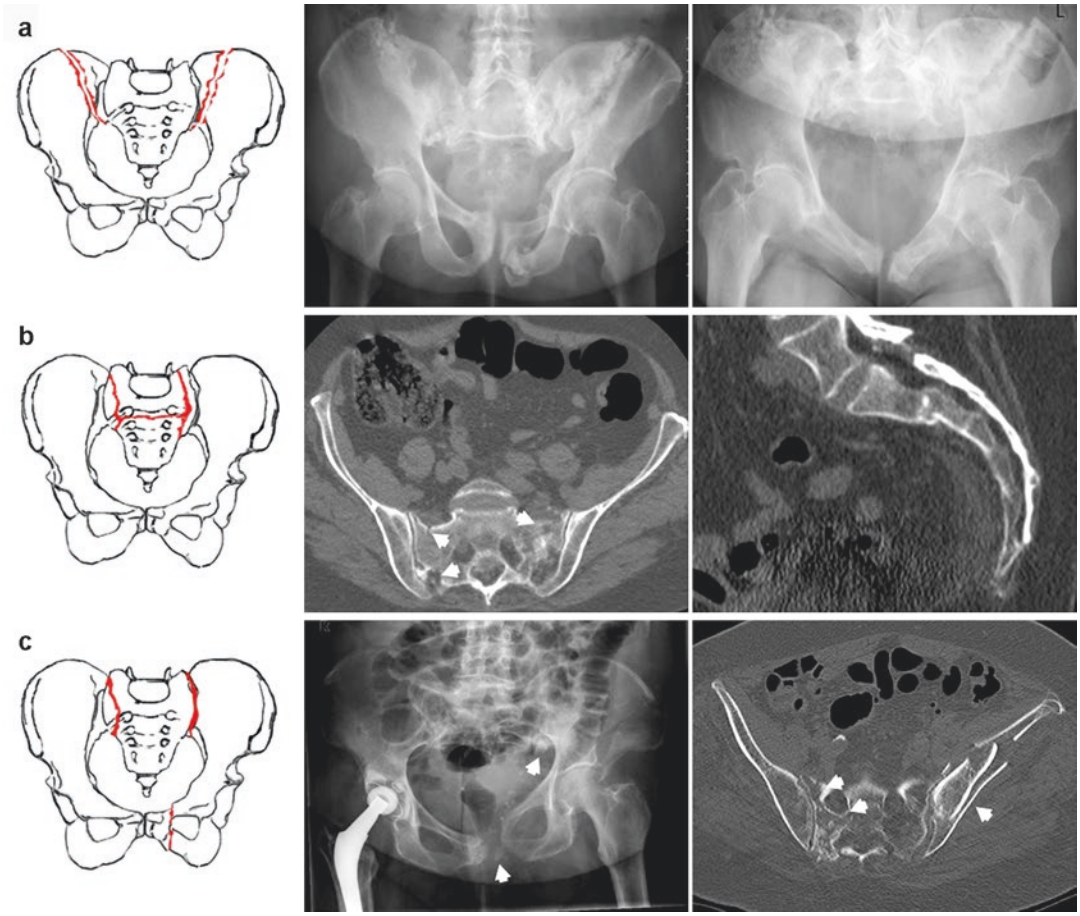

Fig. 7.8 Classification of fragility fractures of the pelvis (FFP) [14]. FFP Type IV—displaced bilateral posterior injury. (**a**) FFP Type IVa: bilateral iliac fracture or bilateral iliosacral disruption. (**b**) FFP Type IVb: bilateral sacral fracture, spinopelvic dissociation. (**c**) FFP Type IVc: combination of different dorsal instabilities

adults. Unlike fractures in adults, FFP IVb injuries are the result of low-energy trauma, and the fracture lines do not run through the neuroforamina but rather through both sacral ala. The frequency of spinopelvic dissociations is striking (37/245 = 15.1%) (Fig. 7.4) but not always visible on conventional radiographs. This again underlines the importance of multiplanar reconstructions of pelvic CTs. Only in the sagittal reconstructions of the sacrum can the horizontal component of an H-type sacrum fracture be identified. Linstrom et al. [35] described typical anatomical patterns in insufficiency sacrum fractures and emphasized that the H-type fracture pattern is not uncommon, comprising 61% of isolated sacral insufficiency fractures. Finally, FFP Type IVc is characterized by a bilateral displaced posterior instability with the morphology of one side being different from that of the other side ($n = 8/245$) (Fig. 7.8c: FFP IVc).

Conclusion

This comprehensive classification system describes the morphologies of fragility fractures of the pelvic ring and categorizes them into 4° of instability. Isolated anterior lesions (FFP Type I) are more stable than are non-displaced posterior lesions (FFP Type II). Displaced unilateral posterior lesions are less stable than non-displaced ones, and displaced bilateral posterior lesions (FFP Type IV) are less stable than displaced unilateral ones (FFP

Type III). Specific and typical fracture patterns, such as fragility fractures of the sacrum or pubic rami fractures, are not regarded as solitary lesions but as part of a pelvic ring pathology. The criterion "instability of the whole pelvic ring", as it is used in this classification, is of utmost importance because it is the leading criterion for determining the type of treatment. It follows that this comprehensive classification can be connected with recommendations for treatment for each category of instability. The subcategories distinguish between different fracture locations in the dorsal pelvis, both non-displaced and displaced. This subcategorization seems logical, as different fracture locations will need different surgical approaches, if surgery is indicated.

This classification system gives the medical care provider a framework with which he or she can estimate the instability of a certain fragility fracture pattern. This will help him or her to select the most appropriate management. As in other classification systems, analysis of only conventional radiographs and CT images is not sufficient to decide on a specific treatment. Anamnesis of the patient and of his or her relatives, a clinical examination, biological age, grade of independence and mobility, functional demands, life expectancy and estimation of long-term outcomes are at least as important for the decision-making process, particularly in this elderly patient population.

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Part IV

Treatment of Fragility Fractures of the Pelvis

Non-Operative Treatment

8

Toru Sato, Naofumi Shiota,
and Takeshi Sawaguchi

8.1 Introduction

Non-operative management has been the treatment of choice for the large majority of fragility fractures of the pelvis (FFP) in the past. Open reduction and internal fixation has been regarded as too dangerous and difficult for this frail group of patients. Long-lasting surgeries with extensive blood loss may trigger haemodynamic instability, coagulopathy and hypothermia, which do more harm than bring benefit for the patient. Only since techniques for minimal-invasive stabilization of FFP have been developed, there is a tendency towards surgical management. Consequently, the question comes up, which patients do well with conservative treatment and which patients are better treated surgically.

For decision-making, several factors should be taken into consideration. Most important are the fracture characteristics: localization of the fracture in the anterior and posterior pelvic ring, extent of displacement and acute or delayed presentation (non-union/delayed union). Moreover, are the duration and severity of pain, the patient's level of activity before injury, the comorbidity and patient's caregiver's expectancies other aspects, which may influence choice of treatment. Thus, a careful evaluation of the patient and its fracture including patient history as well as clinical and radiological evaluation are very important. Clinical and radiological examinations are indispensable in evaluating the instability of the pelvic ring as a consequence of the pelvic fractures.

The comprehensive classification of Rommens and Hofmann gives a framework distinguishing different types and levels of instability (see Chap. 7). As instability is directly related to pain and loss of mobility, the classification is useful for decision-making [1].

Isolated anterior pelvic ring lesions (FFP type I in the classification of Rommens and Hofmann [1]) are usually treated conservatively. However, the hemodynamic status of the patient should be carefully monitored during the first 24 h, because severe hemorrhage has been documented in several reports [2–5]. Severe bleeding with low energy pubic fracture can be attributed to the decrease of the elasticity of the vessels due to arteriosclerosis, which makes the vessels more vulnerable and more likely to rupture while vasospasm is impaired. In addition, geriatric patients are often on anticoagulant medication. Besides hemodynamic monitoring, serial hemoglobin evaluation every 6 h on the first day of admission is recommended [3, 5]. Patients with severe

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_8

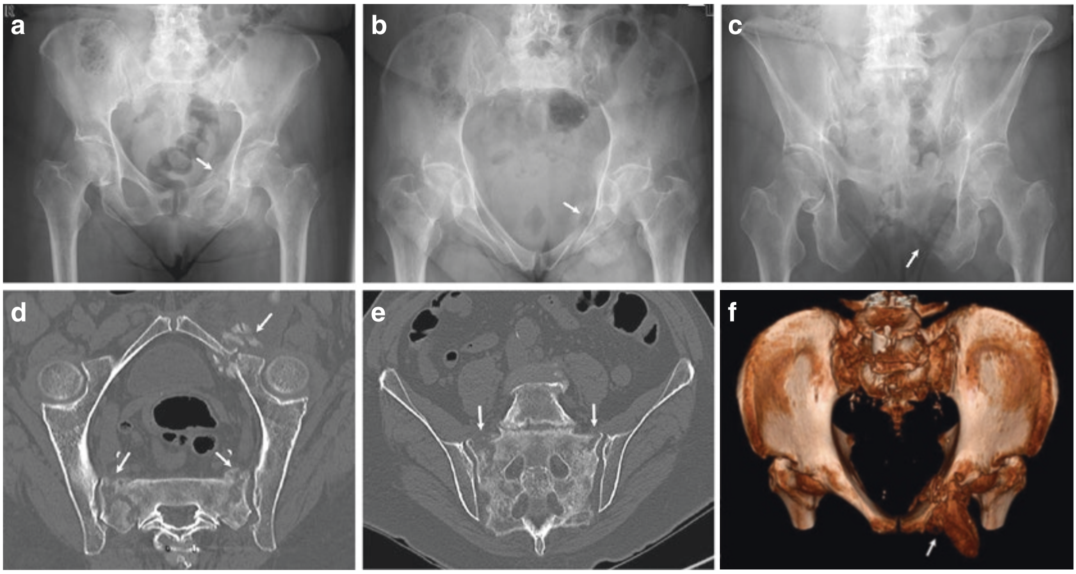


Fig. 8.1 Seventy-five-year-old female with history of pelvic pain after a fall at home. Conservative treatment consisting of analgesic therapy, bed rest and careful out of bed mobilization was carried out. The patient was seen in the out-patient clinic 6 weeks after the trauma for clinical and radiological control. (**a**) Antero-posterior pelvic overview showing abundant callus formation at the left superior and inferior pubic ramus fracture (*arrow*). (**b**) Pelvic inlet view. There is a large callus around the pubic ramus (*arrow*). (**c**) Pelvic outlet view. (**d**) CT-reconstruction showing the pelvic inlet plane confirming the bilateral sacral ala fractures and the left pubic ramus fracture (FFP Type IVb). There is a large callus mass around the left pubic ramus fracture. There also is callus formation at the anterior cortex of the sacral ala fractures (*arrows*). (**e**) Callus formation is also visible on the CT-reconstruction along the longitudinal axis of the sacrum (*arrows*). (**f**) The 3D–reconstruction of the pelvic ring shows a massive callus mass in front of the left superior pubic ramus fracture. At 6 weeks, there is no complete fracture healing

hemorrhage deteriorate rapidly and urgent transcatheter arterial embolization and blood transfusion may become necessary [2–5]. In non-displaced posterior pelvic fractures with or without anterior instability (FFP type II lesions in the classification of Rommens and Hofmann [1]), conservative treatment can also be started (Fig. 8.1).

8.2 Elements of Non-operative Management

8.2.1 Bed Rest

In all FFP, the patients should be admitted to the ward and kept in bed until the pain is under control and the patient can start mobilization. Prolonged bed rest should be avoided in geriatric patients, as it is accompanied with higher risk of deep vein thrombosis, pulmonary embolism, muscle weakness, decubitus, impaired pulmonary function, pneumonia, urinary retention, urinary tract infection, postural hypotension, and decreased cardiac function. It also accelerates the decrease of bone mineral density and causes psychologic dysfunction including delirium, anxiety and depression [6]. Breuil et al. reported that during hospitalization of 60 patients with an osteoporotic pelvic fracture, at least one or more adverse events were noticed in 52.5% of the patients, urinary tract infections in 50%, bedsores in 33% and depression or alteration of cognitive functions in 18% of patients. In addition, two thromboembolic events occurred [7]. Therefore, early mobilization under good pain control is recommended [6]. Assisted physiotherapy should commence as soon as possible even during immobilization. Until the patient is properly mobilized, mechanical deep vein thrombosis prophylaxis and pharmacologic prophylaxis are given according to the local guidelines.

8.2.2 Pain Management

Pain control is another priority. Mobilization of the patient will only be possible with good pain control. Centrally acting analgesics, such as paracetamol and opioids should be used until pain resolves. Peripherally acting analgesics (NSAIDs) are not recommended as they block the activity of prostaglandins, especially PGE2, and are associated with a high risk of delayed union or non-union of long bone fractures [8, 9].

8.2.3 Mobilization

When pain subsides, patients are allowed to start mobilization with weight bearing as tolerated. Mobilization should start with the assistance of physiotherapists and not forced as this may increase the risk of fracture progression or displacement [1]. Usually, it takes a few days in FFP type I fractures and 1 week to 10 days in FFP type II fractures to mobilize the patient out of the bed. The ultimate goal of mobilization must be recovery of independency for activities of daily life rather than regaining range of motion of single joints or improving muscle strength. In order to rule out fracture displacement, conventional radiographs should be taken some days after mobilization. The average hospital stay with FFP is as long as 21–45 days [10, 11]. The length of stay was longer in the subset of patients who were not fully self-sufficient before the fracture occurred [11]. Most published series indicate a significant change in post injury ambulatory status as well as chronic pain after conservative management of these injuries [12].

8.2.4 Medication with Influence on Bone Metabolism

8.2.4.1 Vitamin D and Calcium

Vitamin D deficiency is common and associated with decreased muscle strength in the elderly. Vitamin D level must be assessed on a routine basis [13, 14]. Supplementation of Vitamin D improves lower limb strength and reduces the risk of falling. Vitamin D reduces the fracture risk through its positive effect on bone metabolism and fall risk reduction [15]. Serum 25-OH-VitD levels decline with ageing but the response to vitamin D3 supplementation is not affected by age or by usual calcium dietary intake. According to recommendations of the International Osteoporosis Foundation, the estimated average vitamin D requirement of older adults to reach a serum 25-OH-VitD level of 75 nmol/L (30 ng/mL) is 20–25 μg/day (800–1000 IU/day). Vitamin D intake may increase to as much as 50 μg (2000 IU) per day in individuals who are obese, have osteoporosis, limited sun exposure (e.g. housebound or institutionalized) or malabsorption. For high-risk individuals it is recommended to measure serum 25-OH-VitD levels and treat in case of deficiency [15]. Vitamin D can be administered as cholecalciferol (Vitamin D3).

8.2.4.2 Antiresorptive Agents

Bisphosphonates

Bisphosphonates inhibit the activity of osteoclasts and suppress bone resorption. They increase bone mineral density. The decrease of bone resorption seems to severely alter the physiological sequence of bone turnover with a paradoxical effect of inhibition of bone formation [16]. However, there is no clinically detectable delay to fracture healing via external callus formation following bisphosphonates treatment. Considering the benefit aspects of bisphosphonates for osteoporosis treatment, the use of bisphosphonates is recommended [17, 18]. But, prolonged use of bisphosphonate may be accompanied with a rare side effect of atypical subtrochanteric fracture or osteonecrosis of the jaw [19, 20]. Because of concerns regarding oversuppression of bone turnover with prolonged bisphosphonate therapy, it is recommended to stop osteoporosis treatment with bisphosphonates after a period of 5 years to provide patients a so-called “drug holiday” [20].

Calcitonin

Calcitonin inhibits osteoclast activity and stimulates osteoblastic activity in the bone. It is also an effective analgesic for bone pain. However, its low potency compared to other treatment options limits the use of calcitonin in clinical practice to patients who are unable to take other anti-osteoporotic agents [13].

Raloxifene

Raloxifene is an oral selective estrogen receptor modulator (SERM), which has estrogenic effects on bone and is used for the prevention and treatment of post-menopausal osteoporosis. Raloxifene reduces vertebral fracture risk relative to placebo in post-menopausal women, while its efficacy has not been demonstrated on non-vertebral fractures [21]. Raloxifene is not considered the first line therapy for osteoporosis due to the increasing risk of thromboembolic events [16].

Teriparatide

Teriparatide is a recombinant form of parathyroid hormone (PTH peptide 1–34). It is the only anabolic agent currently approved. When it is given intermittently at low dose, it has been shown to have anabolic effects on osteoblasts. Teriparatide increases bone mineral density, decreases the rate of fractures in osteoporotic patients and also improves fracture healing. Peichl et al. conducted a randomized, controlled study to evaluate the effect of PTH 1–84 on healing of recently sustained pelvic fractures and on functional outcome in postmenopausal women. Patients older than 70 years with a unilateral pelvic fracture who met the WHO-definition for osteoporosis with a T-score < 2.5 at the lumbar spine or proximal femur were included. All patients received a daily dose of 1000 mg calcium and 800 IU vitamin D. There was a total of 65 patients; 21 patients in the PTH 1–84 group and 44 patients in the control group. Evaluation of healing was based on serial CT scans obtained at 0, 4, 8, 12 weeks and at regular intervals until evidence of cortical bridging was noticed. In the PTH1–84 group, fracture healing was noticed at 7.8 weeks as compared to 12.6 weeks in the control group ($p < 0.001$). VAS and Timed 'Up and Go' (TUG) tests improved in the PTH group as compared with the control group ($p < 0.001$). The authors concluded that PTH 1–84 could be used to accelerate fracture healing and to improve pain relief and patient mobilization, thereby decreasing complications related to immobility [22]. Moon et al. also reported the efficacy of PTH 1–34 in two cases of FFP type 2 lesion [23]. Because long-term safety and efficacy are not known, PTH cannot be prescribed for longer than 24 months (Fig. 8.2) [24]. It is contraindicated in patients with hyperparathyroidism, hypercalcemia, unexplained high alkaline phosphatase levels, Paget's disease, risk of osteosarcoma, or who had irradiation of the bone [25].

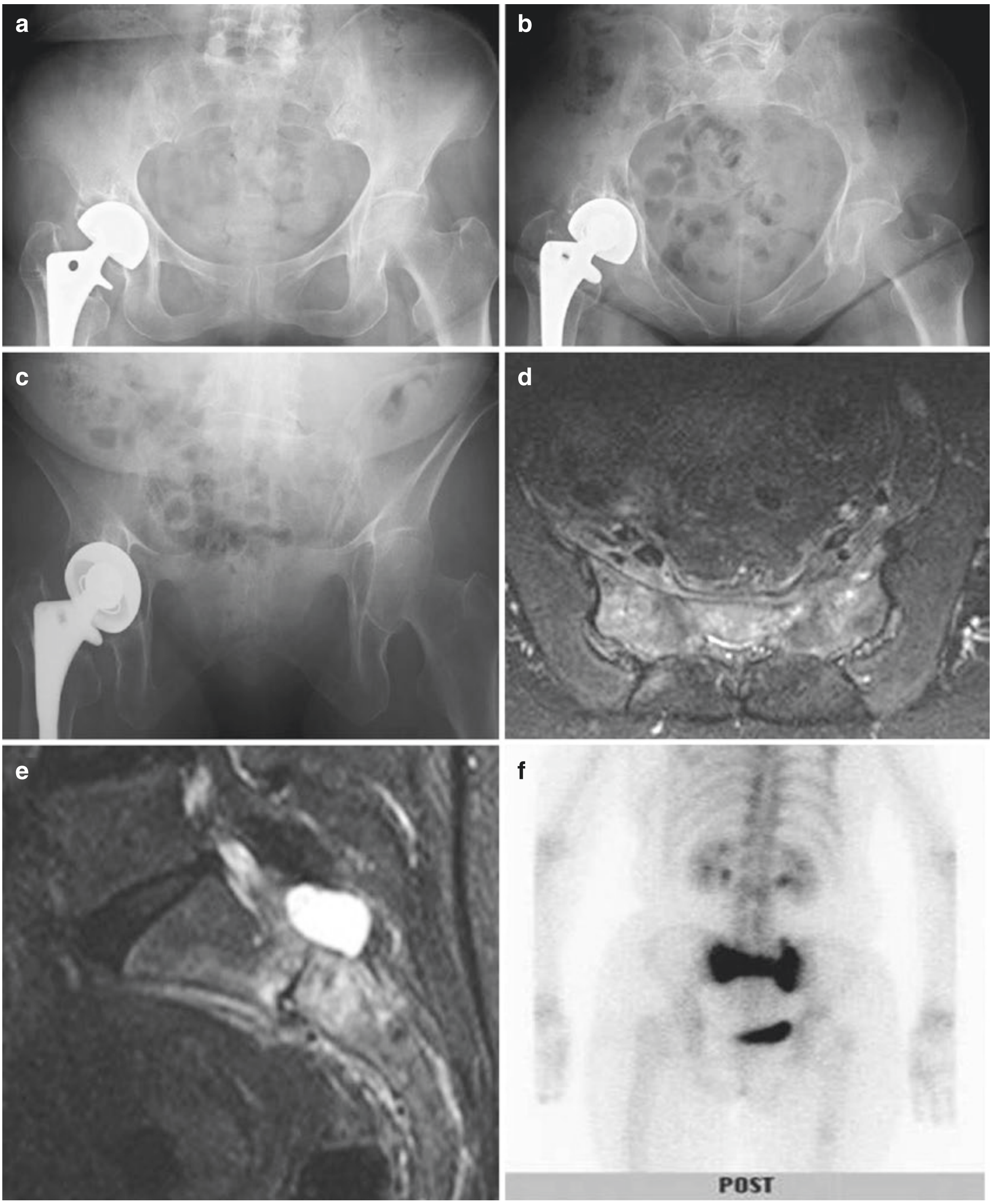
Fig. 8.2 Eighty-six-year-old female who has been suffering low back pain for several weeks. (**a**) A.p. pelvic overview does not reveal any bony or ligament pathology. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. A diagnosis could not be made with conventional radiographs. (**d**) Transverse MRI transsection through the posterior pelvic ring reveals high signal intensity in the complete sacrum in T2-weighted images. (**e**) Sagittal MRI-transsection through the mid-sacrum shows bone bruise at the transition of S1 to S2. (**f**) The bone scan shows a high uptake in H-form in the sacrum and in the right pubis. (**g–j**) Transverse CT-cuts through the posterior pelvic ring and sagittal CT-cuts through the sacrum reveal a U-shaped fracture of the sacrum (*white arrows*). (**k, l**) 3D–reconstruction of the sacrum with view from anterior and posterior. There is an impaction of the S1 fragment into the S2 fragment with slight flexion. The U-shaped fracture is clearly visible in the view from anterior, but not in the view from posterior. This corresponds with an FFP Type IVb lesion. (**m**) The patient was treated with teriparatide. The pain gradually dissolved and the patient regained previous mobility after 3 months. A.p. pelvic overview after 3 months. Meanwhile, the patient suffered a fracture of the right iliac crest due to another fall. (**n, o**) Transverse CT-cuts through the posterior pelvic ring taken after 3 months. Bridging callus formation is visible on both sides (*white arrows*). Teriparatide therapy was continued up to 2 years. (**p**) A.p. pelvic overview 5 years after trauma. No new fractures can be detected. The right-sided iliac crest fracture is healed. (**q, r**) Transverse CT-cuts through the posterior pelvic ring showing complete healing and remodeling of the sacral ala fractures. (**s, t**) Sagittal CT-reconstructions confirm healing of the horizontal fracture in slight flexion and anterior impaction. (**u, v**) Bone scan reveals enhanced uptake at the right pubic bone, but no enhanced uptake in the sacrum anymore

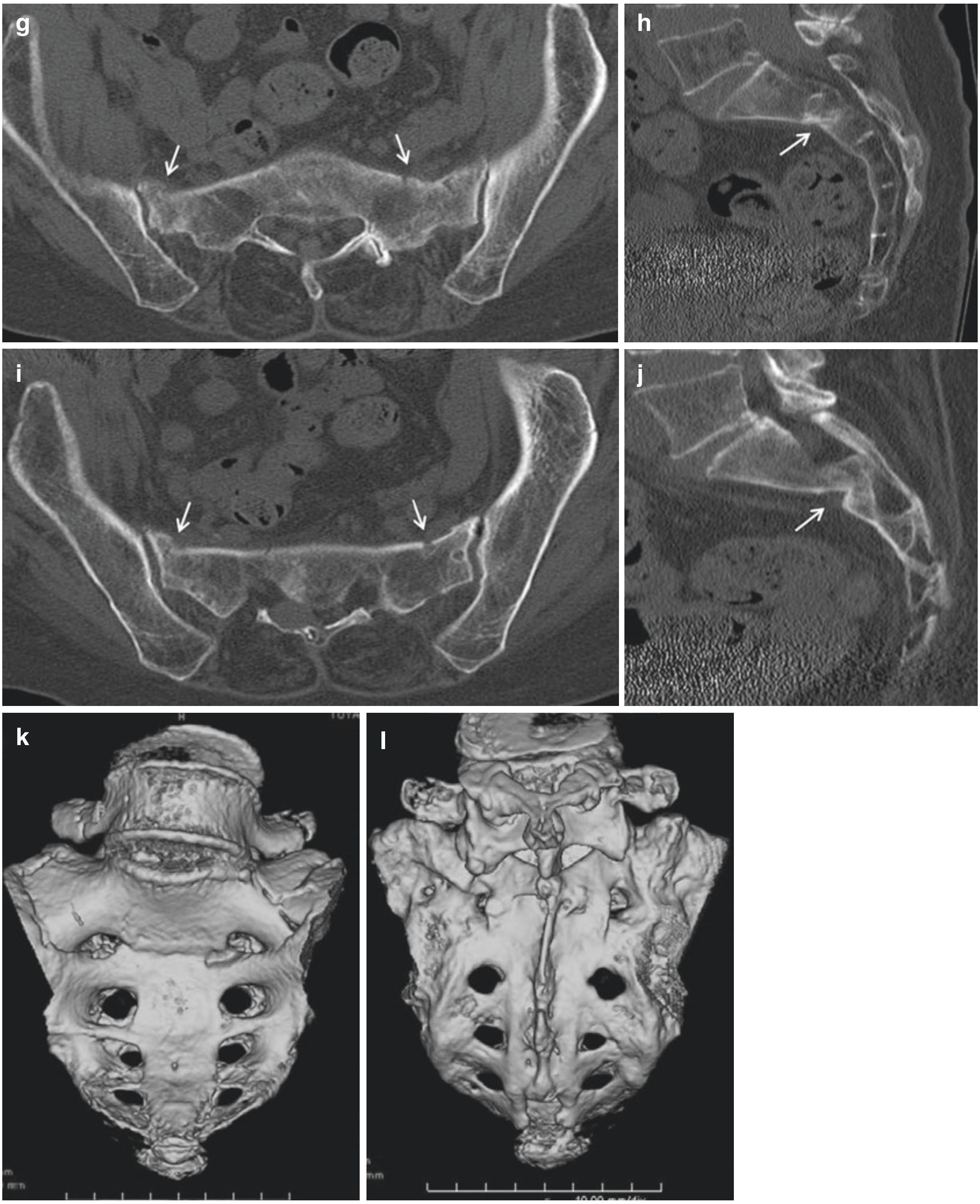
8.2.5 Low Intensity Pulsed Ultrasound (LIPUS)

LIPUS stimulates bone cell activity and promotes fracture healing. It is used in acute fractures and non-unions [26]. However, its effect on FFP has not yet been reported.

8.3 Failure of Conservative Treatment

Almost all cases of geriatric pelvic fractures are primarily treated conservatively [12, 27, 28]. In our country, most of osteoporosis-related pelvic ring injuries are treated by teriparatide.





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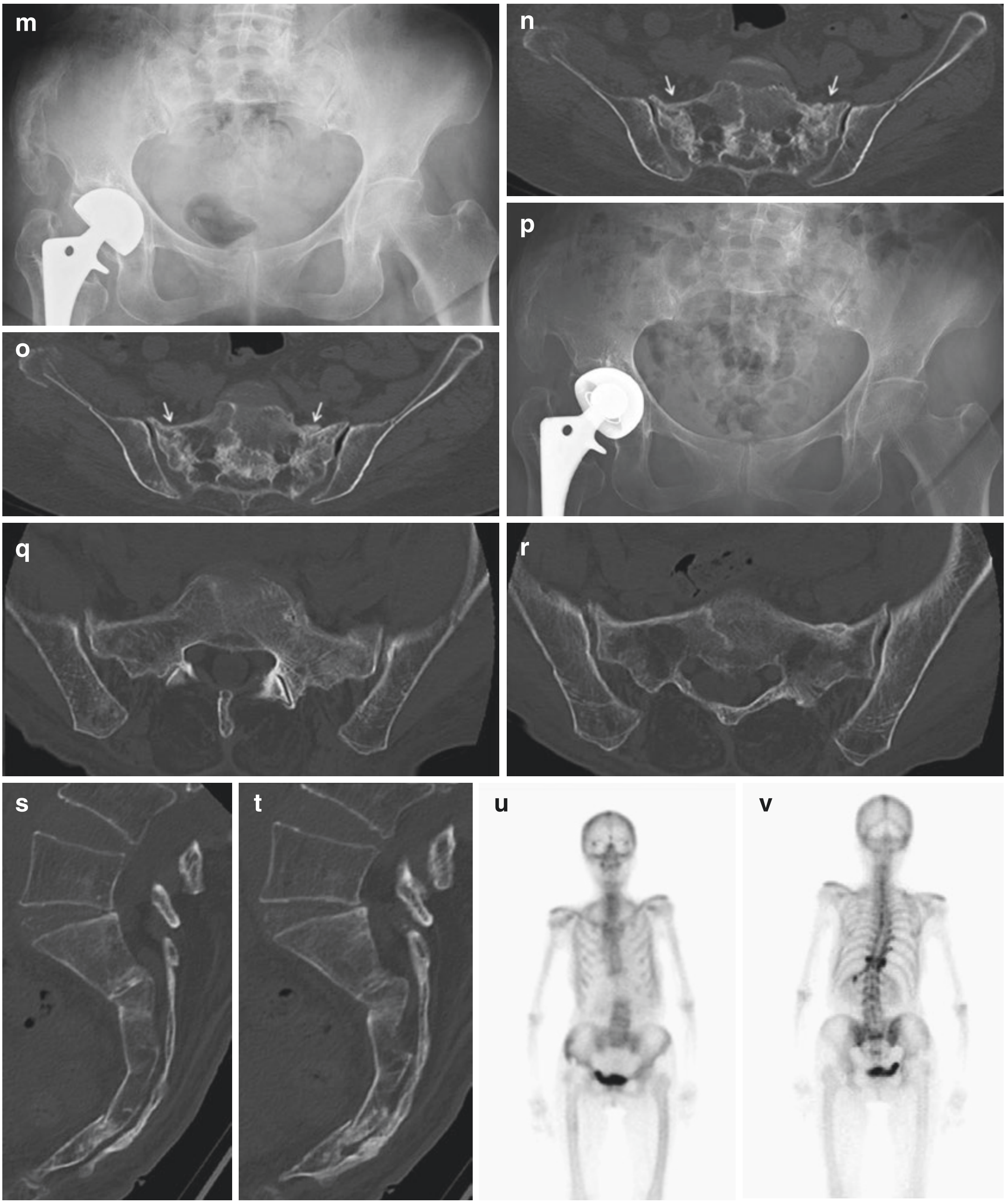

Fig. 8.2 (continued)

Good clinical results have been reported with this therapy, but in approximately 10% of our cases, a progressive disruption of the pelvic ring is observed (Fig. 8.3). Failure of conservative treatment is an indication for switchover to surgical treatment [10, 29]. Surgical treatment should be also considered in case of severe, untreatable pain in acute fractures, in persisting pain after conservative treatment or in delayed/non-union.

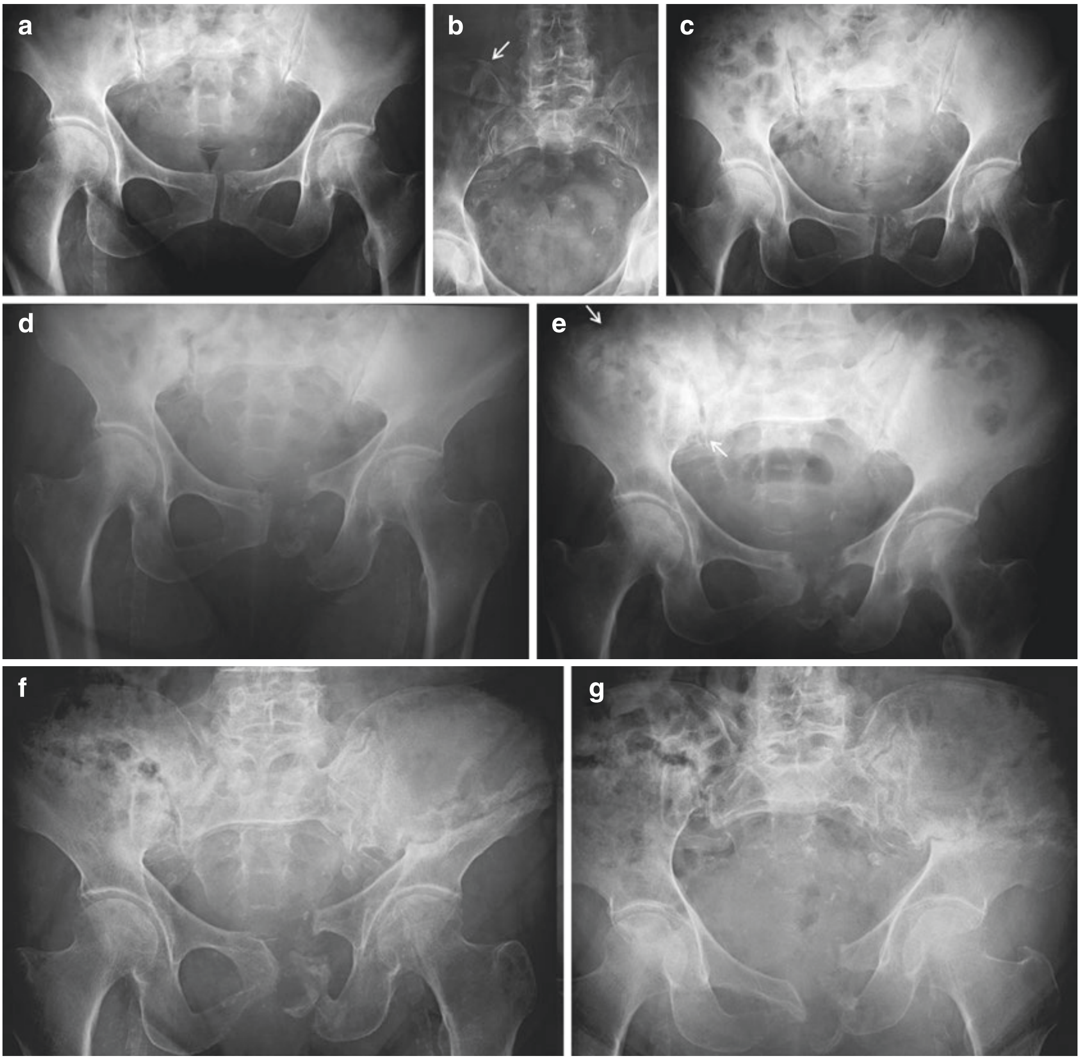

Fig. 8.3 Seventy-four-year-old woman was injured by a domestic fall and complained left-sided pain in the groin. (**a**) A.p. pelvic overview shows a non-displaced fracture of the left pubic bone. (**b**) The a.p. radiograph of the lumbopelvic junction taken the same day reveals a fracture at the right posterior iliac crest (*white arrow*). A conservative treatment was advised. (**c**) After 3 weeks of bed rest, the patient was advised to start sitting and gait exercising as tolerated. But, the patient continued to complain back pain. The a.p. pelvic overview taken after 1 month shows a progress of destruction at the left pubic bone, but no progress was visible at the right ilium. (**d**) After 6 months, the patient continued complaining of severe pain at the pubic symphysis and instability of pubic symphysis was recognized clinically. The a.p. pelvic overview taken after 6 months shows an osteolytic change at the left pubic bone and a widening of the right sacroiliac joint. (**e**) A.p. pelvic overview taken after 9 months. The osteolytic change at the pubic symphysis remains. A right posterior ilium fracture (*white arrows*) and sclerotic changes at both sacroiliac joints are now visible. Gait disturbance progressed and the patient was referred to our hospital at one and a half year after injury. At this point, the patient could not sit or turn over due to severe pain. (**f**) A.p. pelvic overview shows a large bone defect at the left pubic bone and complete fractures running through the iliac bones on both sides. (**g**) Pelvic inlet view. (**h**) Pelvic outlet view. BMD in the lumbar spine was 0.425 g/cm^2 and age-matched 78%. BAP was 26.9 μg/L and NTX was 119 nmol/L. (**i–k**) Different 3D–views of the pelvic ring showing the massive instabilities on both sides. (**l**) Open reduction and internal fixation was done at all fracture sites through bilateral ilioinguinal approaches. For the large bone defect at the left pubic bone, a supplementary autologous bone grafting was performed (*white arrow*). Postoperative a.p. pelvic overview. (**m**) Postoperative pelvic inlet view. (**n**) Postoperative pelvic outlet view. (**o**) A.p. pelvic overview 1 year after surgery. All fractures united successfully and the patient could walk smoothly with one cane

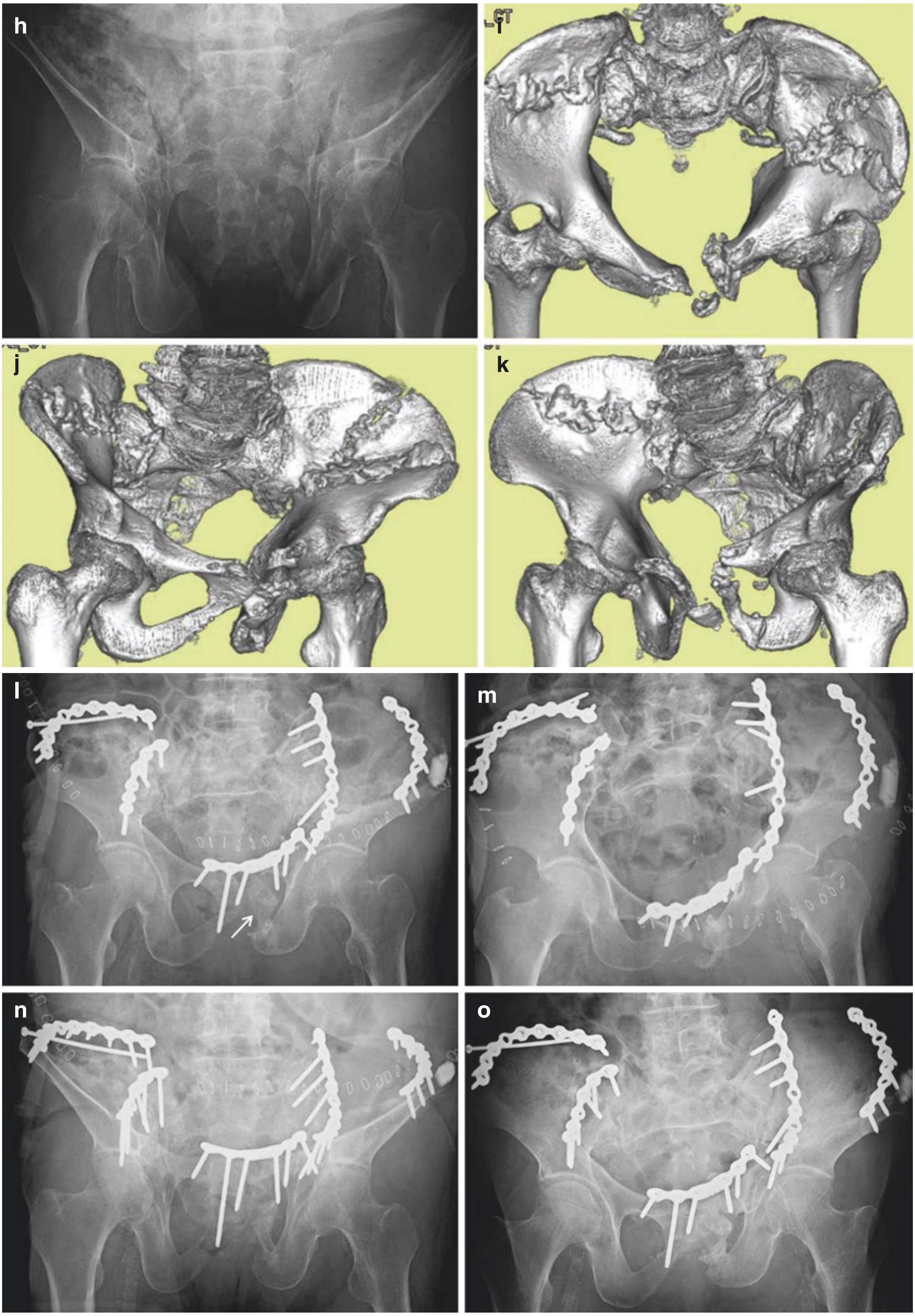

Fig. 8.3 (continued)

8.4 Finite Element Analysis of Stress Distribution in the Posterior Pelvis

A finite element model of the pelvis was made using the 3D–CAD software SolidWorks (Dassault Systems, US) and Mimics (Materialise, Belgium). A pelvic finite element model was derived from pelvic CT images. Boundary conditions and the load condition in standing position were used. The pelvic tilt angle was defined as the angle between the coronal plane and the anterior pelvic plane (the plane connecting the anterior superior iliac spine and the superior edge of the pubic symphysis) (Fig. 8.4).

Pelvic tilt angles of +10° anterior inclination, neutral position with 0° inclination and posterior inclination of −20° and −40° were assessed. The results of our finite element analysis showed that the stress distribution of the posterior pelvis was changed by the pelvic tilt (Figs. 8.5, 8.6, 8.7 and 8.8).

In our experience, elderly persons often have a pelvis in retrograde inclination. In a retrospective study, we calculated a mean posterior tilt of 32.3° (range between 21° and 43°) in patients with osteoporosis-related pelvic ring fractures, whereas the posterior tilt of a comparable population without pelvic ring fractures was merely 6.9° (range between 0° and 16°) (non-published data) (Fig. 8.4). When the pelvic tilt becomes retrograde, the localization of the well-described, typical fracture lines corresponds to the areas of increased stress in our finite element model analysis. In particular, the raise of stress in the sacrum may be related to the sacral fracture pattern often seen in an aged patient [30]. In our model, with increasing pelvic retroversion, stress peaks clearly appear in the roof of the S1 sacral body, in the sacral ala and in the S1–S2 sacral body interval. The bone structure in endplate of the S1 sacral body is very dense and hard to break. But, the sacral ala and the S1–S2 sacral body interval are estimated to break easier due to a weaker bone structure [31].

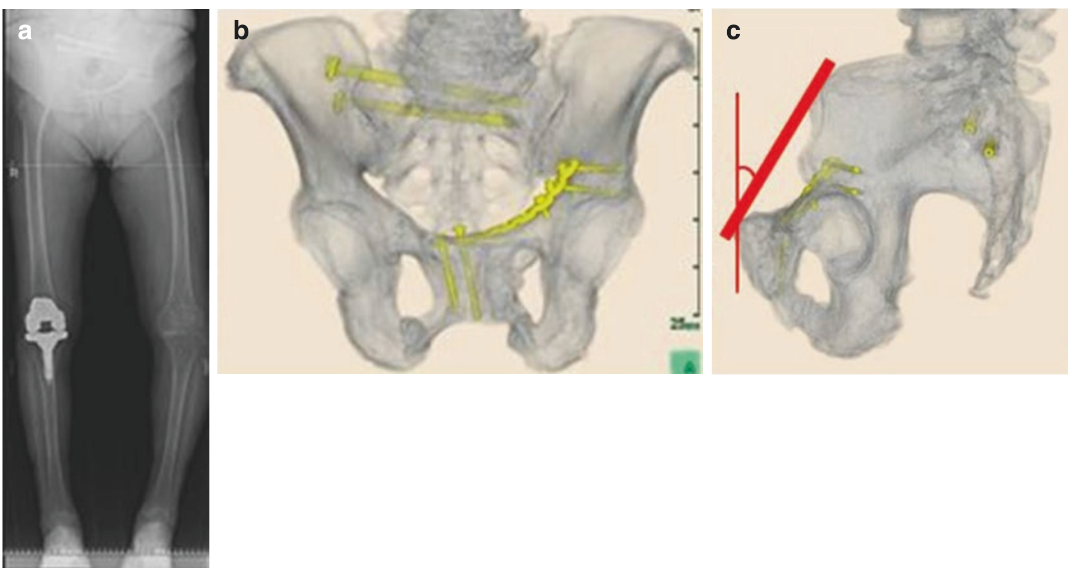

Fig. 8.4 (**a**) Long-leg axis in standing position. (**b**) The tilt of the pelvic ring in standing position as shown in the conventional radiograph is transferred to the 3D–CT-reconstruction of the same patient. (**c**) Lateral view of the same 3D–CT-reconstruction. The pelvic tilt angle, defined as the angle between the coronal plane (*vertical thin red line*) and the plane connecting the anterior superior iliac spine and the superior edge of the pubic symphysis (*oblique thick red line*) can be calculated

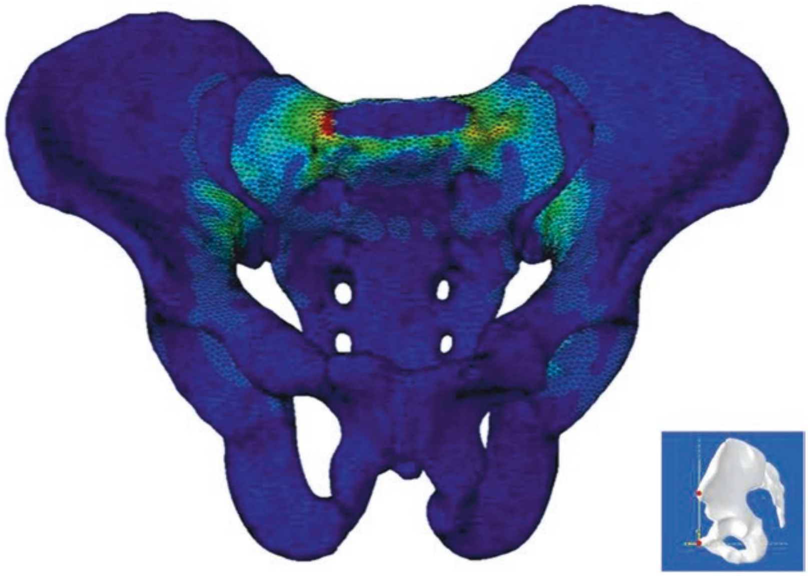

Fig. 8.5 Stress distribution in a finite element pelvic model with a neutral pelvic inclination of 0°. There is a uniform stress distribution at the endplate of the S1 sacral body

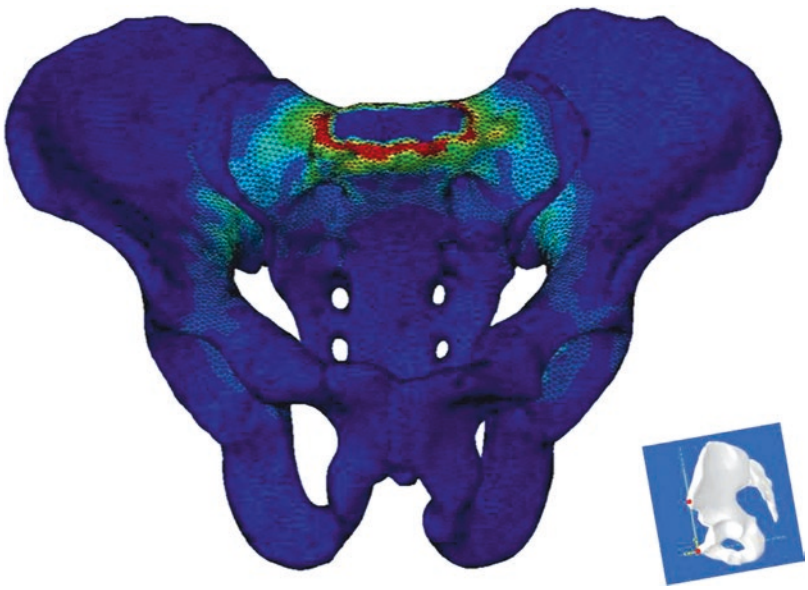

Fig. 8.6 Stress distribution in a finite element pelvic model with an anterior pelvic inclination of 10°. There is a stress concentration at the anterior border of the endplate of the S1 sacral body, but not at the posterior border near to the spinal canal

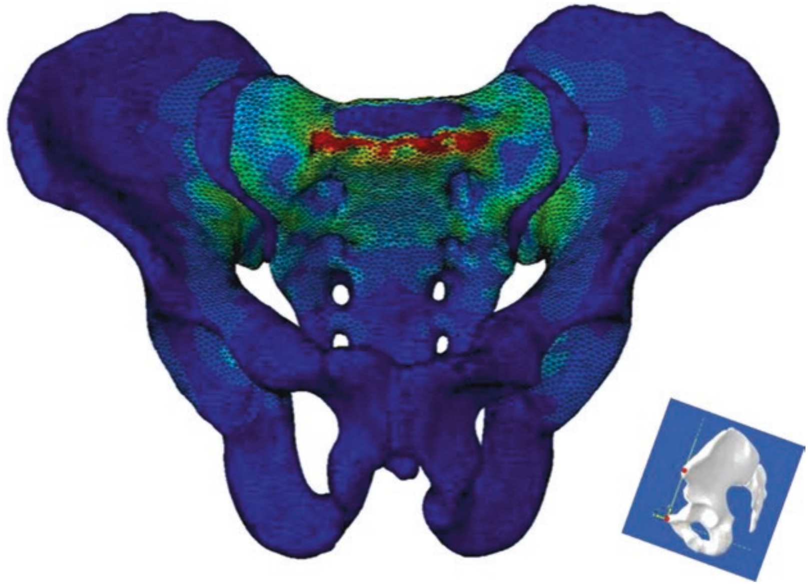

Fig. 8.7 Stress distribution in a finite element pelvic model with a posterior pelvic inclination of 20°. The peak stress primarily concentrated at the anterior border of the endplate of the S1 sacral body. There is also a peak stress at the posterior border near to the spinal canal and at the inner curve of the innominate bone

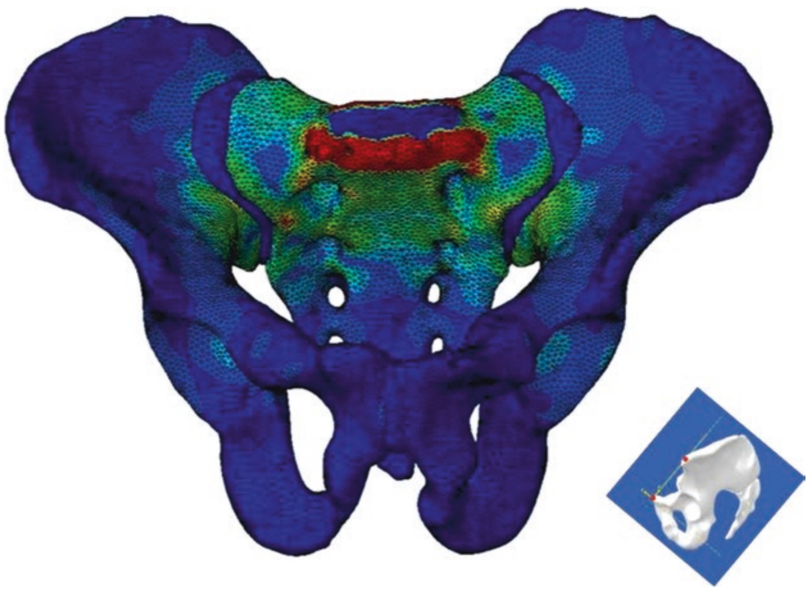

Fig. 8.8 Stress distribution in a finite element pelvic model with a posterior pelvic inclination of 40°. There is a stress concentration at the sacral bodies of S1 and S2, and at the inner curve of the innominate bone. The peak stress at the inner curve of the innominate bone is more pronounced than in case of a posterior inclination of 20°

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9 Operative Management

Peter V. Giannoudis and Dionysios Giannoulis

9.1 General Considerations

Elderly patients with fragility fractures of the pelvic ring represent a special cohort. The patients may have reduced functional capacity, incontinence, intellectual deficits and are prone to iatrogenic complications. A number of them suffer from 'frailty', a unique geriatric syndrome with such clinical characteristics as anorexia, sarcopenia, osteoporosis, fatigue, risk of falls and poor overall physical health [1]. Fried LP in 2001 proposed some criteria for the frailty syndrome: unintentional weight loss, weakness, exhaustion, low energy expenditure and slowness, suggesting a classification pending on the number of the criteria being present (4–5 were characterized as frail; 2–3 as intermediately frail; 0–1 as non-frail) [2]. Makary et al. reported that with major procedures, frail patients develop significant higher number of post-operative complications (43.5% compared to 19.5% in non-frail patients) [3]. These findings should be kept in mind when considering surgical management of pelvic fractures in this special category of patients.

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9.2 Different Phases of Operative Management

The surgical management of elderly patients with pelvic fractures can be divided into 4 distinct phases: (1) initial assessment and resuscitation, (2) the post-resuscitation phase, (3) operative reconstruction, (4) post-operative mobilization.

9.2.1 Initial Assessment and Resuscitation

Initial assessment of pelvic ring injuries should follow the advanced trauma life support (ATLS) guidelines, particularly if the mechanism of accident is high-energy trauma, which is rare in this patient population [4]. Usually, the pelvic injury is the result of a low-energy fall. However, even following this type of mechanism, bleeding and hemodynamic instability may be present if not in the acute phase of treatment, at a later stage, within the first 24–48 h following the injury [5]. The main causes of mortality after unstable pelvic fractures (first 24 h) are either associated injuries or massive bleeding. In addition to this, the presence of a pelvic injury is an additional negative predicting factor for the overall survival rate [6]. The extensive hemorrhage seen in some of these patients represents the final result of blood loss with dilution and disseminated intravascular coagulation added to acidosis and hypothermia, collectively known as

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_9

the "lethal triad". As early coagulopathy has been recognized as an independent predictor of mortality and morbidity within the first 24 h of the injury, treatment should begin immediately after the identification of the injury. One should not forget that a high number of elderly patients are taking blood thinning tablets thus an increased risk of bleeding is present even in the presence of non-displaced fracture patterns [5, 7, 8].

It is of interest that identification of critical injuries could be problematic due to dementia and presence of subtle mental status changes. Shock signs in the elderly may not be obvious. A systolic blood pressure of 130 mmHg may be a sign of hypotension as their blood pressure usually is high and is managed by antihypertensive medication [4]. Elderly patients are also unlikely to mount a tachycardia response. For this reason, it has been found that early invasive hemodynamic and cardiac monitoring with Swan-Ganz catheter improves survival rate [9].

Initially interventions to control bleeding in patients with hemodynamic instability include: volume replacement, blood transfusion (especially red blood cells, platelets and fresh frozen plasma), pelvic binders, anterior and posterior (c-clamp) external fixation devices, pharmacotherapy (tranexamic acid, Factor VII), angiographic embolization and surgical hemostasis. The hallmark of the initial treatment maneuvers is to control trauma-induced coagulopathy together with minimizing blood loss.

9.2.2 Post-Resuscitation Phase

When the end points of resuscitation have been reached and the elderly patient hemodynamically stable, a definitive treatment plan of reconstruction of the pelvic ring should be made. In cases where the pelvic fracture was an isolated injury, adequate pain relief should be prescribed and thromboembolic prophylaxis administered. In cases of associated injuries, the patient might be supported in a critical care environment. It is essential to minimize the length of stay at the ICU as there is an increased risk of prolonged treatment there, which might be detrimental to the patient's survival (increased risk of infection, respiratory insufficiency, development of bed sores) [10].

Consecutively, a strict time management is essential to complete surgical reconstruction as soon as possible and transfer the patient to a ward bed. In case that an external fixator device has been used to control fracture stability, a pin site care plan is essential to prevent the development of pin-site infection. If a pelvic binder has been used, early exchange to an external fixator device or definitive surgical reconstruction is crucial to prevent skin pressure sores.

The intensivist and the geriatrician play an important role for optimization of the patient's physiological condition prior to surgery. Cardiovascular and respiratory abnormalities should be corrected. Overall, a multidisciplinary approach in the post-resuscitation phase is crucial to facilitate early surgical intervention with the best possible physiological patient conditions.

9.2.3 Operative Reconstruction

Operative treatment includes several difficulties for the patient and the surgeon as well as several risks. Therefore, it requires meticulous preoperative planning. The main goals of treatment should be the avoidance of complications related to the injury and surgery (infection, non-union, malunion, heterotopic ossification, neurovascular damage), early ambulation and optimum functional recovery.

Overall three important parameters should be analyzed when considering the surgical management of these fractures: the 'patient', the 'injury' and the 'treatment factors'.

For the 'patient' parameter, the general medical condition of the patient, co-morbidities, the existence of 'frailty', functional level prior to the injury, and functional demands should be examined. For the 'injury' component, careful analysis of the fracture type sustained, the state of the soft tissues and underlying bone quality are essential. Classification of the injury is crucial. In addition to conventional radiological examinations, an early pelvic CT-scan allows careful assessment of both the anterior and the posterior ring elements and an accurate documentation of the topography of the lesion. For the 'treatment' factor, a decision regarding the type of the surgical treatment should be made. The following questions should be addressed. Is a minimally-invasive approach appropriate? What is the anticipated length of surgery? Which implants should optimally be used? Is the quality of the bone suitable for the preferred implant? Is the patient able to follow post-operative instructions? It follows, that an individualized treatment plan is inevitable [11].

The surgical treatment of fragility fractures of the pelvis requires a high level of education and skills from the orthopaedic trauma surgeon. He or she must be able to accurately evaluate and understand the nature of the injury and be familiar with the anatomy of the pelvic ring, its stabilizing structures and resisting forces. Moreover, the surgeon must be familiar with reduction techniques, the use of different reduction tools and have thorough knowledge and understanding of the different image intensifier views for assessing the state of reconstruction during surgery. Consequently, a strong need for a detailed preoperative plan is essential for achieving best outcomes. The proper approach should be wisely chosen by the surgeon in order to achieve the best fracture visualization with the least soft tissue dissection and damage. Repetitive soft tissue manipulation due to poor visualization secondary to an inappropriate approach will lead to difficult reduction, suboptimal implant position and increased risk of infection. The radiation exposure time may also be increased accordingly [12].

Dorsal instability of the pelvis is mostly reported in displaced pubic and ischial rami fractures [13, 14]. In pelvic injuries where an non-displaced fracture of the sacrum (complete or incomplete) is recognized, operative treatment should be considered [11, 15]. In patients with displaced dorsal fractures or fracture-dislocations, surgical treatment is the only treatment option.

When a decision is taken to proceed with surgery, the date and timing of surgery must be clearly defined with the expert surgical team being available to execute the reconstruction. A post-operative bed in the High Dependency Unit (HDU) should be booked for close monitoring of the vital organs.

Post-operative radiographic evaluation is performed before hospital discharge, at 6 weeks, 3 months, 6 months, 1 year post-surgery and annually thereafter as indicated.

9.2.4 Mobilization Phase

A stable fixation with correction of any rotational or vertical pelvic instability in a patient with good bone quality will allow for early full weight bearing on the uninjured side followed by partial weight bearing for 6 weeks after the operation to the injured side [6]. However, in the elderly patient with an fragility fracture, this approach might not be appropriate. Careful consideration should be given to the fracture pattern, the risk of implant failure and fracture displacement. In cases where the bone stock is rather poor and the lesion is bilateral, a period of immobilization (non-weight bearing) post-surgical reconstruction in a wheelchair allows control of painful stimuli, and reduces the risk of early implant failure. Early passive movement of the hip and knee joints and lumbar spine is essential. Static quadriceps and hamstring exercises as well as pelvic floor rehabilitation should be encouraged.

The mobilization regimen should be closely monitored. It is of note that there are reports of delayed healing of pelvic fragility fractures with pain present for a longer time [16, 17, 18]. Too aggressive mobilization must be avoided, as an insufficiency fracture on the opposite site may occur [16, 17]. As operative treatment, the post-operative rehabilitation should be individualized.

9.3 Indications for Surgery and Operative Techniques

After evaluation of the factors highlighted above (the 'fracture', the 'patient' and the 'treatment modality' required), surgery should be considered for such situations as bilateral sacral fractures, combined anterior and posterior ring injuries and combined pelvic and acetabulum fracture patterns. Noteworthy, the Rommens and Hofmann classification of fragility fractures of the pelvis provides clear recommendations for surgery according to the fracture type sustained [18].

Techniques that can be used for pelvic ring reconstruction include iliosacral screw fixation, sacroplasty, transsacral bar fixation, iliolumbar fixation, ventral fusion of the sacroiliac joint with plate osteosynthesis, bridging plate osteosynthesis and anterior ring fixation (plating and/or retrograde transpubic screw fixation). Anterior external fixation devices are rarely used as definitive treatment due to the poor underlying bone stock, early pin loosening and the risk of infection [19].

Use of greater screw length in the transsacral fixation provides more stability in the fixation and also additional safety against vertical shear stresses [20]. The same finding was supported by Gardner and Routt in their study about insufficiency fractures in patients with osteoporosis [21]. In patients with poor bone quality the use of a long transsacral screw placed in the contralateral sacroiliac joint enhances fixation and stabilization and also decreases the possibility of a screw pullout [21]. Transsacral screw fixation has an advantage that it is not affected by poor bone quality and density of the sacrum because the compression potential of the technique is based on the strength of the cortical bone of the ilium which is significantly better [22].

Taking into consideration that fragility fractures of the pelvic ring may include instability in different directions, a combination of different methods of fixation may be used [23, 24]. Frequently applied is the combination of a transsacral positioning bar with iliosacral screws. The transsacral positioning bar or the iliosacral screws can also be combined with ventral plate osteosynthesis. Iliolumbar fixation can be combined with a transsacral bar or iliosacral screws. Fixation of dorsal pelvic ring instability can be combined with the insertion of a retrograde transpubic ramus screw [18].

9.3.1 FFP Type II: Non-displaced Posterior Ring Injuries

For the management of non-displaced posterior ring injuries, no consensus has been reached in the literature till now. In the majority of the cases, the dorsal fracture is localized in the lateral part of the sacrum [25, 26]. Bed rest and adequate analgesia are the first treatment steps. Early mobilization is often problematic and difficult to achieve due to increased pain. Therefore, if pain aggravates within the first week after injury, operative treatment should be considered (Fig. 9.1). As the fracture is non-displaced, a percutaneous procedure is preferred [11]. Apart from a percutaneous fixation with iliosacral screws, other techniques as transsacral bar fixation, bridging plate osteosynthesis and sacroplasty can be considered [11, 18].

Tosounidis et al. found that complete unilateral or bilateral sacral fracture patterns are rotationally unstable, despite the fact that the sacrospinal and sacrotuberal ligaments remain intact. They recommend surgical fixation to facilitate adequate pain relief and early mobilization in these fractures [15]. Adequate compression in the fracture site is difficult to achieve due to bone insufficiency. Therefore, Moed et al. modified the transsacral screw osteosynthesis technique by including a locking mechanism on the far side of the screw that helped in the prevention of screw pullout, regardless of the degree of purchase [27].

In a biomechanical study by Mears et al., three methods of fixation of fragility fractures of the sacral ala were compared: sacroplasty, long sacroiliac screws and short sacroiliac screws. Earlier mobilization was noted in patients treated with sacroplasty, but the results were not statistically significant compared to the other two groups [28].

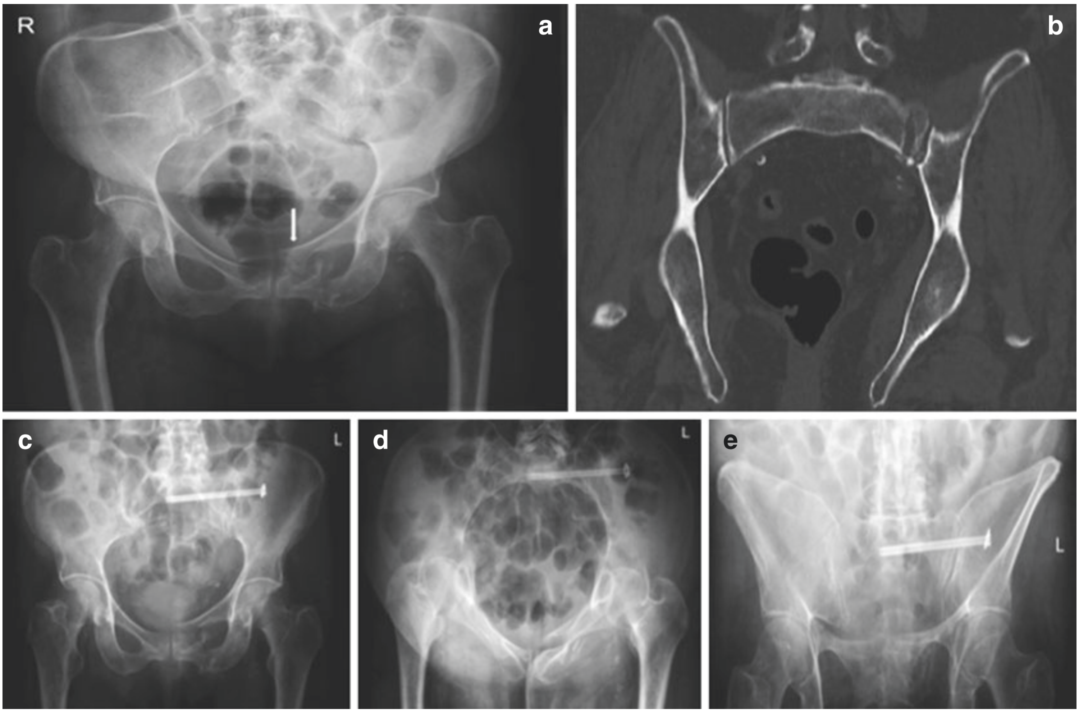

Fig. 9.1 (**a**) A.P. pelvic radiograph of a 70-year-old female patient who sustained a pelvic injury (FFP Type IIb). The radiograph demonstrates a left inferior and superior pubic rami fracture (*white arrow*). (**b**) Coronal reconstruction of pelvic CT scan revealed a non-displaced sacral fracture on the left site. (**c–e**) As the patient was experiencing vast amount of pain and unable to mobilize, a decision was taken to stabilize the sacral fracture. Postoperative pelvic a.p., inlet, and outlet views showing the left sacroiliac screw fixation

9.3.2 FFP Type III: Unilateral Displaced Posterior Ring Injuries

In displaced posterior ring fracture patterns, patients are usually unable to ambulate (Fig. 9.2). The management plan of these injuries includes operative treatment through an open approach. Proper reduction is essential for a good outcome. After reduction is achieved and confirmed by image intensifier, similar methods of fixation as described above can be used [17].

Fractures which are situated in the ilium are fixed by open reduction and internal fixation. The fracture line runs from the inner curve of the ilium to the iliac crest. Angular stable plates are used as they increase pull-out force and decrease risk of screw loosening. The angular plate is inserted parallel to the sacroiliac joint. At the site of the iliac crest, stabilization is achieved with one or more long lag screws inserted between the inner and outer cortex of the crest [11, 17].

9.3.3 FFP Type IV: Bilateral Displaced Posterior Ring Injuries

Bilateral displaced posterior ring fractures require operative treatment for both sides in order to restore mechanical stability, minimize painful stimuli and facilitate mobilization (Fig. 9.3). In the literature, similar methods to the ones described for the

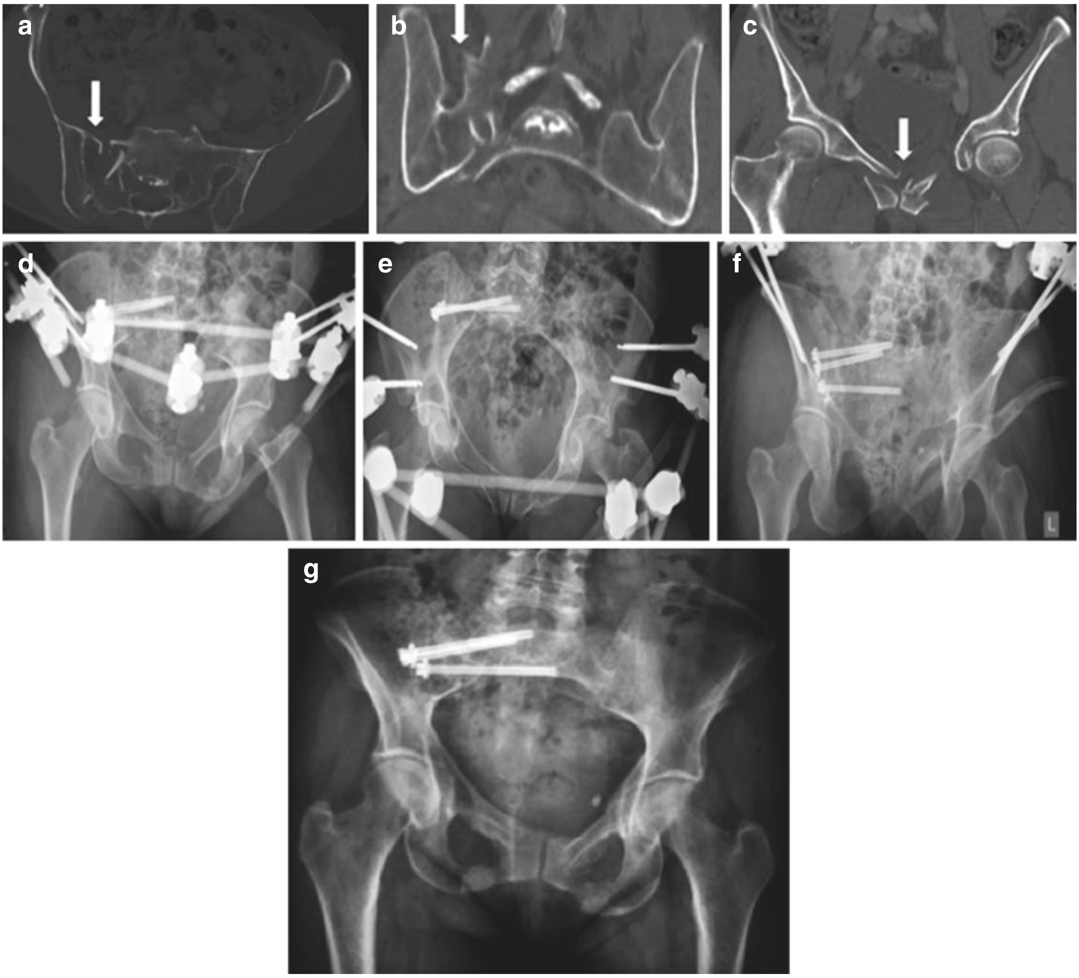

Fig. 9.2 (**a–c**) CT images of a 76-year-old female that sustained a FFP Type IIIc lesion (displaced right sacral fracture and bilateral pubic rami fractures). (**d–f**) A.P., inlet and outlet radiographic pelvic views after fixation. The sacral fracture was stabilized with two S1 and one S2 screws. An external fixator was used for stabilization of the pubic rami fractures. (**g**) A.P. pelvic radiograph at 1 year follow up

treatment of unilateral displaced posterior ring fractures are recommended [17]. Bridging osteosynthesis can also be used as an alternative method as well as the insertion of a transsacral positioning bar with additional iliosacral screws. Treating these injuries with the application of iliosacral screws only bears the risk of implant loosening [11].

Vertically unstable pelvic ring injuries may require the application of long plates used as bridging implants between the two dorsal iliac crests at the level of the inferior posterior iliac spines. By this technique. Increased stability is achieved in the dorsal part of the pelvis providing the opportunity for adequate healing and early mobilization. No compression through the fracture site is achieved by this method, neither neutralization of the shear forces in bilateral sacral ala fractures. Thus, the bridging plate method is suggested as an additional stabilizer after the insertion of iliosacral screws for the compression of the fracture site [17].

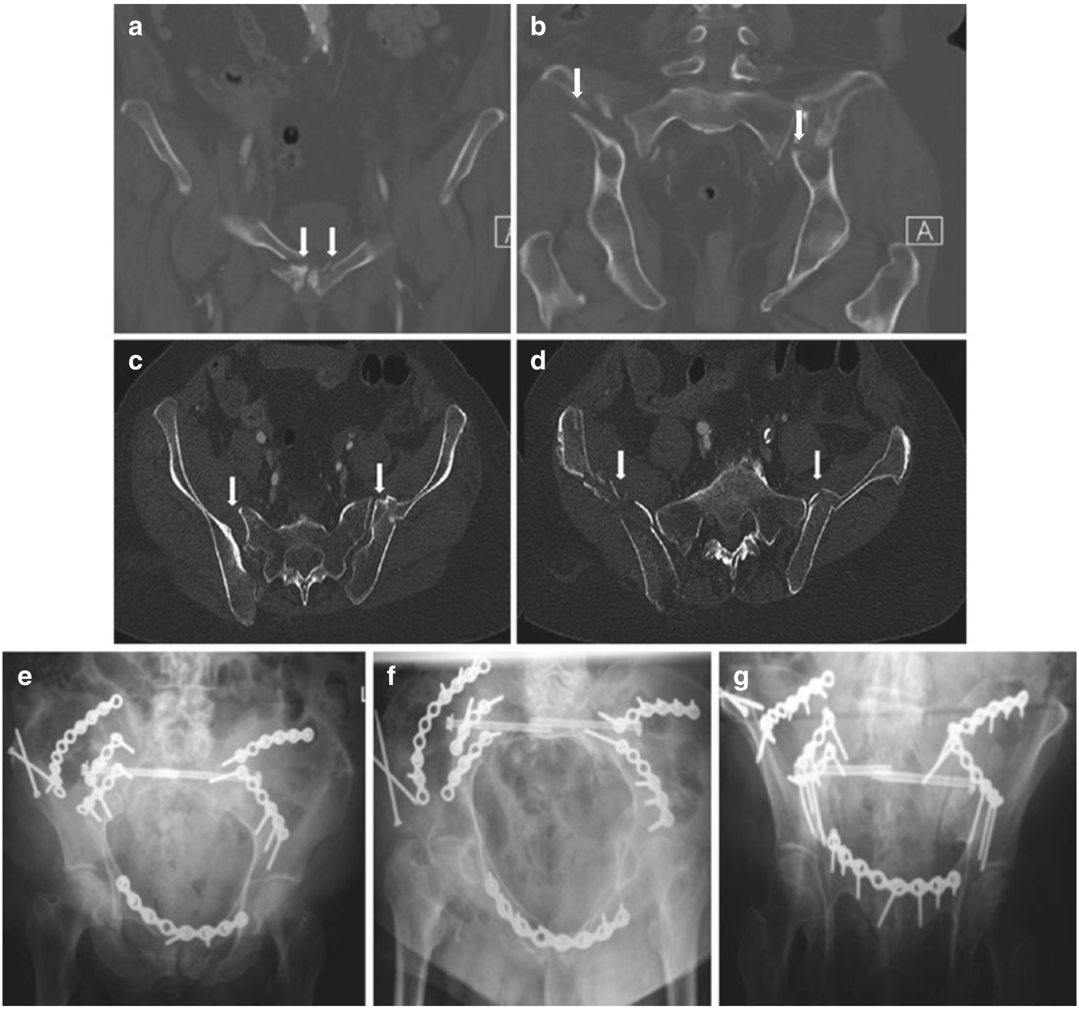

Fig. 9.3 (**a–d**) CT images of a 77-year-old male patient who sustained a FFP Type IVb pelvic ring injury after a low energy fall. *White arrows* demonstrate the anterior and posterior element fractures. (**e–g**) A.P., inlet and outlet pelvic radiographs showing stabilization with sacroiliac screws and plates on both sites of the dorsal pelvic ring combined with plate fixation of the anterior pelvic ring. There is a complete healing of all fractures after 3 months

Conclusion

Before any decision on surgical treatment of patients with fragility fractures of the pelvis is taken, the personality of the patient and the personality of his or her fracture must be assessed. Patients showing hemodynamic instability must be treated along the guidelines of advanced trauma life support (ATLS), just as adults. The condition of patients without hemodynamic problems must be optimized before surgery. Surgery should be scheduled as soon as possible. The type of surgical treatment is dependent on the degree and the localization of instability. Several surgical techniques are available. Minimally invasive procedures should be preferred in non-displaced lesions. Open reduction and internal fixation is performed unilaterally or bilaterally in displaced lesions. Combinations of osteosynthesis techniques are frequently used to enhance stability and minimize the risk of implant loosening. The ultimate goal is early postoperative mobilization. Postoperative management is individualized to optimize outcome and prevent complications.

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Sacroplasty

10

Johannes D. Bastian and Marius J.B. Keel

10.1 Introduction

The sacrum, described as a "shield-shaped flat" or "pyramid-shaped" bone located within the pelvis, consists of a central sacral body and two sacral ala [1, 2]. The sacral alae are exposed to shearing stresses: downward axial forces result from the weight of the trunk and are transmitted through the central sacrum, and upward forces are transmitted through the hip joints [2–4]. In elderly patients, the sacral ala and the lateral parts of S1 contain yellow marrow within an "alar void" [5, 6]. The alar void is an area of very low bone density and bone strength [7, 8]. Fractures occur when shear stresses exceed the reduced strength of the sacral ala [2]. Further risk factors for sacral ala fractures include postmenopausal osteoporosis, pelvic irradiation (osteonecrosis), corticosteroid therapy (e.g. osteopenia due to treatment of rheumatoid arthritis, asthma, polymyalgia rheumatica), previous hip replacement, and mechanical factors (e.g. lumbar scoliosis with the sacral fracture opposite to convex side) [9–12]. Once a sacral insufficiency fracture has occurred, the pelvis is destabilized resulting in sudden onset of pain. Pain increases with weight bearing, decreases with rest, and may radiate to the groin, lower back, buttocks, and thighs. Slow antalgic gait and/or sacral tenderness on lateral compression are further clinical, non-specific symptoms [13].

Different imaging techniques are used to detect sacral insufficiency fractures. Conventional radiographs have a poor sensitivity between 20 and 38%, mainly because of osteopenia and overlying bowel gas (Fig. 10.1) [10, 11, 13]. Computed tomography increases sensitivity up to 58% for detecting insufficiency fractures whilst also allowing for detailed visualization of fracture patterns (e.g. fracture lines extending into the iliosacral joint or neural foramina, presence of vacuum phenomena) [11, 14, 15]. Bone scintigraphy detects sacral insufficiency fractures with a high sensitivity. A "Honda-sign" or "H-pattern" (positive predictive value for sacral insufficiency fracture is 92%) is described for cases with involvement of both sacral alae and a horizontal fracture line connecting them, occurring in up to 62% of patients [10, 16–18]. The highest sensitivity of up to 100% is provided by MRI scans (Fig. 10.2) [13, 15]. Bone marrow edema is visualized by the STIR (short tau inversion recovery) sequence MRI, fracture lines are detected in general, and vertically oriented fracture lines are traced with coronal oblique images in the plane of the sacrum [15, 16, 19]. In summary, MRI is the gold standard for detecting sacral insufficiency fractures, however bone scintigraphy may be used if MRI is not available and/or if patients possess contraindications to MRI (e.g. pacemaker). CT may be used to complement

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_10

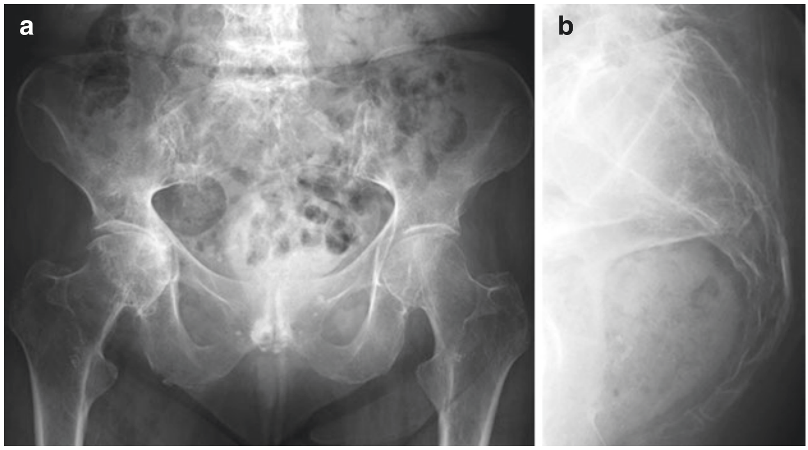

Fig. 10.1 (**a**) Anteroposterior radiograph of the pelvis of an 87-year-old female patient presenting with lower back pain. Plain films do not show any fracture lines or displacement; assessment is limited due to osteopenia and overlying bowel gas. (**b**) Lateral view of the sacrum

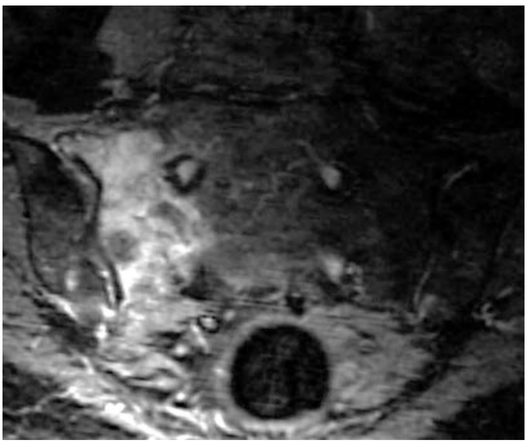

Fig. 10.2 Magnetic resonance imaging presenting a coronal section of the sacrum of a short tau inversion recovery (STIR) sequence of the same patient as shown in Fig. 10.1. Bone marrow edema is detected within the right sacral ala extending from S1 to the superior part of S2

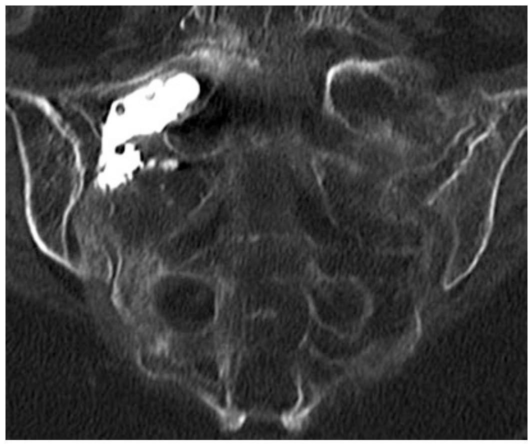

Fig. 10.3 Coronal CT reconstruction performed after sacroplasty in the same patient as shown in Figs. 10.1 and 10.2. Cement has been injected into the fracture site. There is no cement leakage

MRI. For postoperative evaluation of cement distribution, CT is used (Fig. 10.3).

10.2 History and Definition

The "percutaneous intrasomatic injection of acrylic cement" into the spinal column was previously reported in 1987 [20] for the treatment of vertebral angioma. The use of polymethylmethacrylate (PMMA) cementoplasty has also been described by several authors for the management of symptomatic metastatic lesions in the sacrum [21, 22]. In 2001, kyphoplasty and vertebroplasty were introduced for treatment of painful osteoporotic compression fractures and resulted in pain relief and recovery of function [23]. In 2002, Garant introduced sacroplasty as a new treatment method for sacral insufficiency fractures [24]. Sacroplasty consists of a minimally invasive, percutaneous technique for cement injection into the sacral trabecular bone in order to augment fragility fractures of the sacrum. This technique is perceived as an effective procedural extension of vertebroplasty. Nevertheless, the specific anatomical shape of the sacral ala and the presence of a sacral void have to be considered [25, 26].

10.3 Rationale

Treatment of sacral insufficiency fractures aims to improve patient mobility, to increase the rate of discharge to home as opposed to rehabilitation, to decrease length of hospital stay and mortality, and to reduce health care costs. Management of sacral insufficiency fractures is primarily non-operative consisting of pain therapy, early out of bed mobilization and medical treatment of osteoporosis [27, 28]. Non-operative management may finally achieve full pain relief, but this treatment strategy can last for several months. Unsuccessful management may lead to continuous pain, impaired mobility and significant loss of independence [11, 29].

Non-operative management may provoke occurrence of the “fracture disease” with pneumonia, urinary tract infections, muscle weakness, and pressure sores. Further complications include deep vein thrombosis, pulmonary embolism, impaired cardiac function, gastrointestinal tract disorders, mental health disturbances, adverse events secondary to analgesics (e.g. opioid side effects such as dependence), secondary bone loss and delayed fracture healing with slow resolution of symptoms [27, 30–34]. For pelvic insufficiency fractures in older patients, the 1-year mortality rate is reported to be 14%; in addition, one out of four patients requires institutionalization, and 50% fail to regain their previous level of function [29].

Sacroplasty is one alternative to non-operative management of sacral insufficiency fractures [23, 24]. Sacroplasty stiffens fractured areas with as little alteration to the existing bone architecture as possible. It aims to alleviate pain, to reduce the need for pain medication, to facilitate early mobilization, and to decrease length of hospital stay [1, 25, 35, 36].

The therapeutic success of sacroplasty has been attributed to two main mechanisms. Firstly, it has been suggested that motion in the fracture provokes pain by stimulating the periosteal nerve endings at the fracture margins. Sacroplasty achieves short-term pain relief due to thermal injury with neurolysis of these nerve endings [35, 37–39]. Secondly, sacroplasty provides mechanical stabilization of the fracture site reducing painful micromotion [38–42]. Sacroplasty has primarily a local effect. It reduces micromotion between fracture fragments without changing the global stiffness or strength of the sacrum [36, 40]. The amount of cement injected to ensure the above mentioned effect is controversial in literature. One to 3 mL may already be sufficient. However, no correlation has been identified between the volume of the injected cement and either clinical outcome or restoration of strength or stiffness of the sacrum [1, 43–45].

10.4 Procedure

10.4.1 Patient Selection

The rationale for sacroplasty is to treat patients with severe, immobilizing pain related to sacral insufficiency fractures and to prevent complications associated with conservative treatment. Accordingly, patient selection aims to identify patients who will benefit from sacroplasty. This includes understanding of the patient’s activity level and excluding other sources of sacral pain such as sacroiliac dysfunction, lumbar disc herniation with nerve root compression, facet joint arthropathy, lumbar spinal stenosis, tumor, and infection. We have to make sure that the patient suffers from a true sacral pathology rather than from a lumbar pathology [1, 46].

Patients with severe pain, who poorly respond to or badly tolerate pain medication, can be treated with sacroplasty [25, 44, 47]. Other inclusion criteria have been published, which can be utilized for decision making. These are: impending loss of independence, patient’s age over 60 years, pain on percussion over the affected sacral area, documented osteoporosis [48–51]. Sacroplasty is suggested to be contraindicated in case of coexisting systemic or local infection (e.g. decubitus ulcers), cellulitis, hematologic disease, inability to lie in the prone position, or in case of a known allergic reaction to PMMA cement [1, 25, 44, 51, 52]. Indication to perform sacroplasty should also be based on the patient’s response to conservative means as well as on the fracture morphology. Sacroplasty after failed conservative management has been reported to take place between 21 days and several months after diagnosis [48, 49, 52–54]. Fractures within Zone 1 according to the Denis classification are considered most appropriate; whilst more central fractures are at risk of foraminal leakage and S1 nerve root injury and are therefore not generally managed with sacroplasty [35, 41, 52, 55–57].

10.4.2 Surgical Technique

After appropriate patient selection, exclusion of contraindications, and successful standard pre-procedural assessment (hematologic profile, coagulation profile, prior reactions to medications, history of cancer, and cardiac and/or pulmonary disease), the patient is prepared for the intervention. In case of anticoagulation treatment, the INR should be normalized prior to sacroplasty (INR <1.5) [58]. Antibiotic prophylaxis is administered before the intervention (e.g. intravenous cefazolin (1–2 g) or clindamycin (600 mg)) [1, 24, 38, 48, 54, 59, 60]. Local anesthesia only [37, 44, 61], intravenous analgesics [51], conscious sedation (e.g. using intravenous midazolam and fentanyl) [25, 35, 41, 46, 47, 53, 58, 59, 62–66] or general anesthesia [42, 48, 49, 54, 67] can be used.

The patient is placed in prone position on a radiolucent operating table. Cannulas can be placed utilizing a posterior short-axis lateral oblique, a posterior short-axis central oblique [24, 25, 35, 41, 46–48, 54, 55, 58, 62, 64], a posterior long-axis [2, 37, 49, 51, 53, 63, 64, 68] or a lateral transiliac approach [21, 54, 69] (Fig. 10.4a, b). Using the posterior short-axis approach, the needle is inserted perpendicular to the posterior sacral cortex and then advanced in a posterior-anterior direction either medial or lateral to the sacral foramina, in a plane parallel to the sacroiliac joint [24, 55]. In the posterior long-axis approach, the needle is inserted at the caudal sacral level, lateral to the neuroforamina and medial to the sacroiliac joint, into the trabecular bone between the anterior and posterior sacral cortices, and then progressed cephalad within the sacral ala. The utilization of the lateral transiliac approach for bone needle placement is comparable to the technique used for placement of sacroiliac screws [70–72].

Selection of the appropriate approach is determined by the location, length and type of the lesion, and the patient's individual anatomy [1, 73]. In a cadaveric model of osteoporotic sacral bone, the selection of the approach did not influence the strength or stiffness of the sacrum after cement augmentation [43]. The posterior short-axis approach is ideally suited for CT guidance as the axial sectioning plane readily tracks the needle as it is advanced into the sacral ala [25]. However, disadvantages of this approach include the need for multiple needle insertions (required to reach all

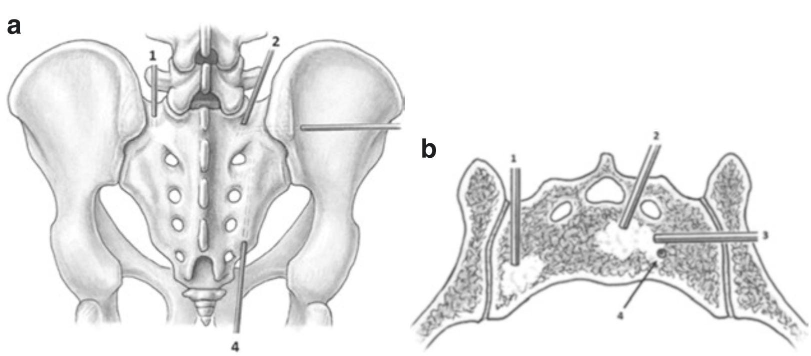

Fig. 10.4 (**a**) Schematic drawing of the pelvis from a posterior view demonstrating various approaches for cement injection: (*1*) short axis lateral oblique, (*2*) short axis central oblique, (*3*) lateral transiliac and (*4*) long axis posterior approaches. (**b**) Schematic drawing of the pelvis with an axial view demonstrating various approaches for cement injection: (*1*) short axis lateral oblique, (*2*) short axis central oblique, (*3*) lateral transiliac and (*4*) long axis posterior approaches

parts of the fracture), which results in a time-consuming and uncomfortable procedure for the patient, and the risk of perforating the anterior sacral cortex [53, 74]. In contrast, the posterior long-axis approach enables the surgeon to complete the sacroplasty with one needle insertion only. This approach enables the application of cement along the entire fracture line, reduces the risk of inadvertent anterior cortex perforation and can be controlled reliably intra-operatively with fluoroscopic images [1, 2, 61]. The cement is injected in a way to form a vertical column within the fracture gap [2, 25, 53]. However, the initial application of the needle may be more difficult and there is risk of penetrating the cephalad margin of the sacral ala due to too deep insertion [2, 61, 63]. For treatment of sacral body lesions, horizontal components of sacral insufficiency fractures, or for cement augmentation of sacroiliac screws; the lateral transiliac approach is used [21, 59, 69]. Concerns connected with this approach are possible damage to the superior gluteal artery upon insertion of the cannula and the penetration of the sacroiliac joint (Fig. 10.5) [54, 74].

10.4.3 Imaging

An adequate imaging technique is paramount for precise localization of the fracture site and for monitoring of the cement distribution. The use of both conventional fluoroscopy [24, 38, 41, 46, 47, 61, 75], computed tomography [37, 42, 50, 53, 59, 60, 67] or even both techniques combined [25, 51, 56, 62–64, 68] has been described. Real-time fluoroscopic imaging is widely available nowadays. It provides a fast and precise detection of cement leakage and is very cost-efficient [38]. However, one of the most relevant limitations of this technique is the difficulty to

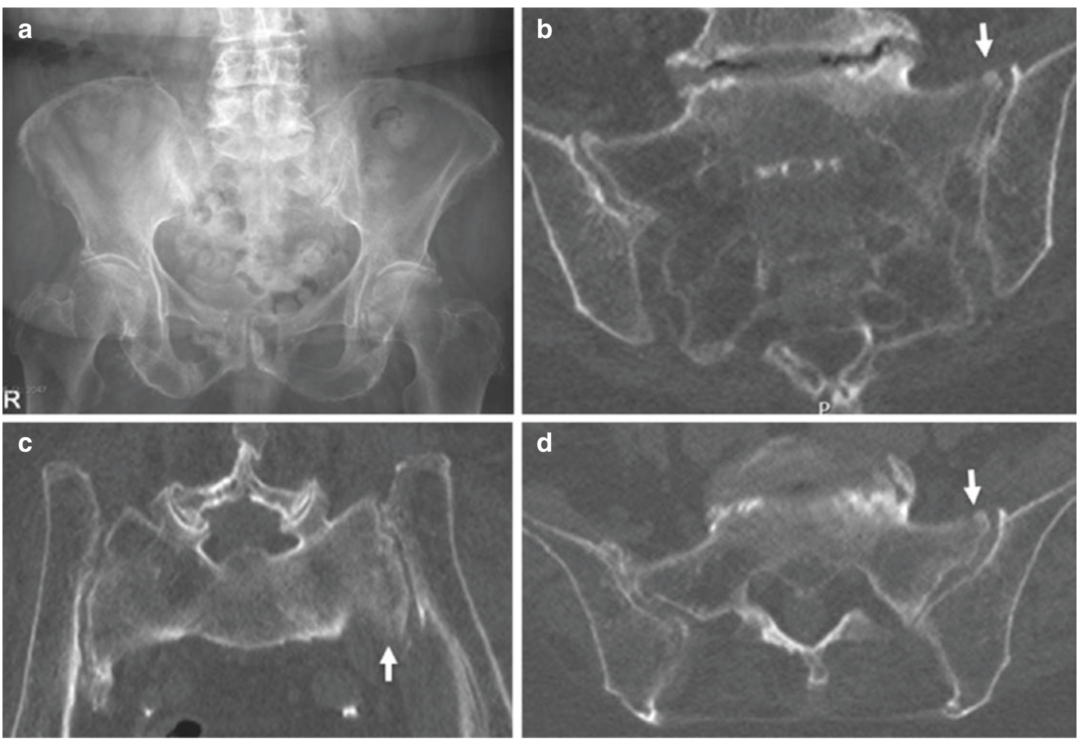

Fig. 10.5 (**a**) Anteroposterior radiograph of the pelvis of an 86-year-old female patient presenting with lower back pain after a fall on the left side. The coronal (**b,** *arrow*) and transverse (**c, d,** *arrows*) CT reconstructions show a non-displaced fracture of the sacrum corresponding to an FFP IIc-lesion. The fracture has been treated with sacroplasty. The postoperative plain radiographs show cement leakage into both the sacroiliac joint (**e**, *arrow*) and presacral venous plexus (**f**, *arrows*) (Courtesy of Rommens PM et al. Mainz, Germany)

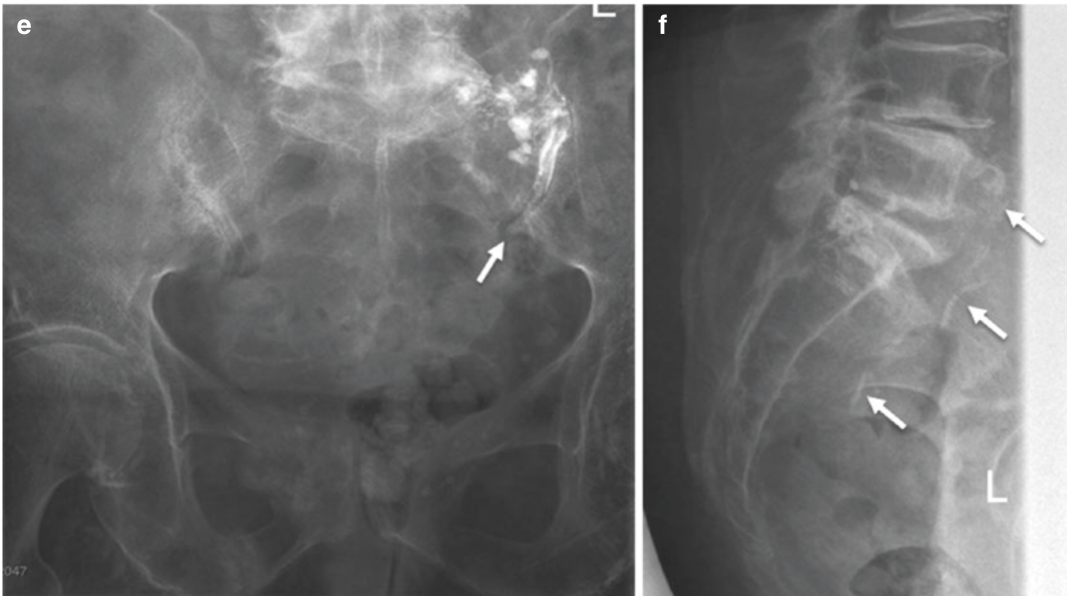

Fig. 10.5 (continued)

visualize the sacral anatomy due to overlying soft tissues and the limited power of the X-ray beam. This may be particularly relevant in the lateral view, which is often used for assessment of cement leakage [49, 61].

In contrast to the fluoroscan, CT-guided sacroplasty provides a precise visualization of fracture lines, allows for identification of all critical landmarks (e.g. sacral foramina) and accurate placement of the sacroplasty needle [1, 42, 44, 55, 67]. However, these benefits may not compensate for the lack of real-time monitoring of cement leakage during injection [1, 62, 67]. Additional intraoperative multiplanar reconstructions are mostly necessary for visualization of the "superior-to-inferior" pathway of the sacral fracture [53]. Greater radiation doses and longer assessment time as compared to conventional fluoroscopy technique may also limit the use of CT-guided sacroplasty [76]. Modern devices, which combine the advantages of the conventional biplanar (anteroposterior, lateral) fluoroscopy and principles of computed tomography (CT-fluoroscopy or C-arm CT- systems) are therefore increasingly used for needle placement and real-time monitoring of cement distribution in the bone [44, 65].

10.4.4 Cement Application

To avoid complications, the surgeon should be familiar with properties of different PMMA cements and have experience with common cement augmentation techniques (e.g. vertebroplasty, kyphoplasty). He or she must ensure proper needle placement with respect to the existing fracture lines [47, 64]. A preoperative CT-scan should be performed and the sacral fracture pattern analyzed. In the presence of fracture lines extending to the sacral foramina or the sacroiliac joint, needles should be placed lateral to the fracture lines and excessive cement application should be avoided near to these structures [2, 42, 51]. In addition, to allow for staged needle repositioning posteriorly, the needle tips should be placed in the ventral aspect of the sacrum during the cement injection. Cement application must be started in the anterior aspect of the sacrum when needle repositioning is planned. Hardened cement in the posterior sacrum may make needle repositioning impossible.

Bone trocars with the cement injection needles have to be placed carefully in osteoporotic bone to avoid misplacement [47]. To ensure that neither the sacroiliac joint nor the anterior sacral cortex is violated, hand force is sufficient to advance the trocar within the trabecular bone [38]. When the needle is placed though the posterior long-axis approach, penetration of the superior cortex of the S1 sacral ala may occur. To avoid perforation with subsequent cement leakage the needle should not be advanced beyond the geometric center of the S1 vertebral body [2]. When the needle is inserted through the posterior short-axis approach, its tip should aim towards the bony bridge between the neuroforamina (e.g. S1 and S2, S2 and S3). This bony bridge may act as a margin of safety, as medially extravasating cement will preferentially leak into the bony bridge rather than into the foramen [38]. Moreover, in the short-axis technique, one should take into account that multiple needle insertions may be necessary, as the volume of injectable cement through each needle is limited. However, multiple needle placements enhance the risk of cement leakage through already used needle tracks. Last but not least, thorough knowledge of anatomic and fluoroscopic landmarks is essential to avoid extra-osseous misplacement of the cannula [77, 78].

Once needles have been placed correctly, injection of PMMA cement is started. Intraosseous application of contrast media before cement application may be used to confirm correct needle placement and to detect potential sites of leakage. However, these potential benefits could not be confirmed in vertebroplasty due to differences in viscosity of cement and contrast media. Moreover, residual contrast media within the bone may impede assessment of consecutive cement distribution [63, 79, 80]. Small volume (e.g. 1 mL) handheld syringes with prefilled cannulas are preferred to avoid injection of large cement volumes at once. They also allow creating high injection pressure, which is necessary for application of high-viscosity cement. The cement should have a toothpaste consistency and injected slowly in small aliquots of 0.1–0.5 mL. The oblique hole of the tip of the trocar is turned away from the sacral foramina to avoid cement leakage into these foramina with damage to the sacral nerves [1, 38, 63, 65]. Injection is observed under biplanar real-time fluoroscopy with repetitive stops. Cement application and distribution can also be monitored using fluoroscopy with alternating views (anteroposterior, inlet, outlet, lateral). This technique is associated with the lowest cement leakage rates [1, 69, 81, 82].

Before injection of further cement aliquots, needles are depressurized and reoriented to allow for a larger area of cement deposition. Further cement application is only started after 30–60 s to allow the previously injected cement to cure at body temperature [69, 73, 81]. This "multiple-step-injection"—technique allows the injected cement to act as a plug, sealing areas of lower resistance (e.g. fracture gap, venous system) before the next injection [69, 81–83]. Another possibility to decrease the likelihood of cement leakage is creating a cavity for the cement through the use of a balloon sacral kyphoplasty [77, 84]. However, no differences in cement extravasation between balloon-assisted and conventional sacroplasties were observed [76]. In addition, the combination of sacroiliac screws to close the fracture gaps prior to sacroplasty did not result in significant reduction of cement leakage rates [69].

The volume of injected cement should be as small as necessary. Three milli litre of cement may be adequate for fracture stabilization with minimal risk of cement leakage [45]. Interestingly, there seems to be no relationship between cement volume (2.5 mL; range: 1–4 mL) and clinical outcome [44].

When cement leakage is detected intraoperatively despite the above mentioned precautions, cement injection has to be stopped, and the bevel of the needle turned opposite to the location of the leakage. The needle is also withdrawn slightly. Cement injection should only be continued if necessary. Therefore, the tip of the needle is placed in a new distant location [37, 49]. However, a cement plug, which is located in the anterior part of the sacral ala, may project anteriorly to the anterior cortex of the sacral body in the lateral fluoroscopic view. This does not necessarily correspond to cement leakage because the anterior cortex of the sacral body projects posterior to the anterior cortex of the sacral ala corresponding to the concavity of the sacrum [38].

Finally, the cement flow should behave as a "growing cloud" [69, 85]. Before removal of the cannulas, the trocar should be inserted into the cannula bore to carefully push residual cement out of the needle into the sacrum. Alternatively, one waits until the cement solidifies within the cannula before removal by gentle rotation and pulling. This allows the cement to break off at the tip of the needle point. In this way, the cement within the needle is removed and no cement remains in the paraspinous muscles [1, 59].

After needle removal, the skin incision is compressed for few minutes to stop bleeding and minimize swelling [1]. Patients can be mobilized 2 h after the procedure at the earliest [46, 51].

10.5 Complications and Outcome

10.5.1 Cement Leakage

In two different studies, cement leakage was noted in 8 out of 108 (7.4%) and in 20 out of 63 (31.7%) procedures, respectively [56, 69]. However, there was little clinical relevance. In case of an injected cement volume of up to 5 mL per side, leakage into the S1 foramen [35], into the sacroiliac joint [46], or into the pre-vertebral space or the sacral foramen [44] was not associated with clinical symptoms. In sacroplasties with an injected cement volume of more than 5 mL per side, asymptomatic cement leakage was also noted at the fracture site [51], into the venous system, into the sacroiliac joint [62], anterior to the sacral cortex [84], and posteriorly into the soft tissues [55].

In the rare cases, where the cement leakage resulted in radiculopathy (Fig. 10.6), the use of analgesics and oral steroids for 3 weeks resulted in complete relief of symptoms [61]. Radiculitis of the S1 nerve root was treated successfully by epidural steroid injection in a case report [38]. When continuing neural pain despite conservative management or a neurologic deficit is due to compression of a neurologic structure by leaked cement, surgical decompression and cement removal should be considered [25, 86].

10.5.2 Clinical Results

The results of sacroplasty treatment, which have been reported from 2002 until 2015 are summarized in detail in Table 10.1. In these studies, sacroplasty resulted in pain relief of varying degrees, improved patients' ability to ambulate, and increased their quality of life.

The presence of residual or recurrent pain after sacroplasty indicates a failed treatment, as sacroplasty aims to achieve pain relief and rapid mobilization. Residual pain after all vertebral augmentation procedures—sacroplasty, vertebroplasty or kyphoplasty—is noted in up to 24%. Interventional techniques such as epidural steroid injections, sacroiliac joint injections and lumbar facet joint injections are suggested for further management [38, 87]. A second sacroplasty may result in relief of residual pain after a prior unsuccessful procedure [63, 67]. Recurrent sacral pain on the contralateral side may occur in cases with unilateral sacroplasty due to occurrence of a new sacral fracture [68].

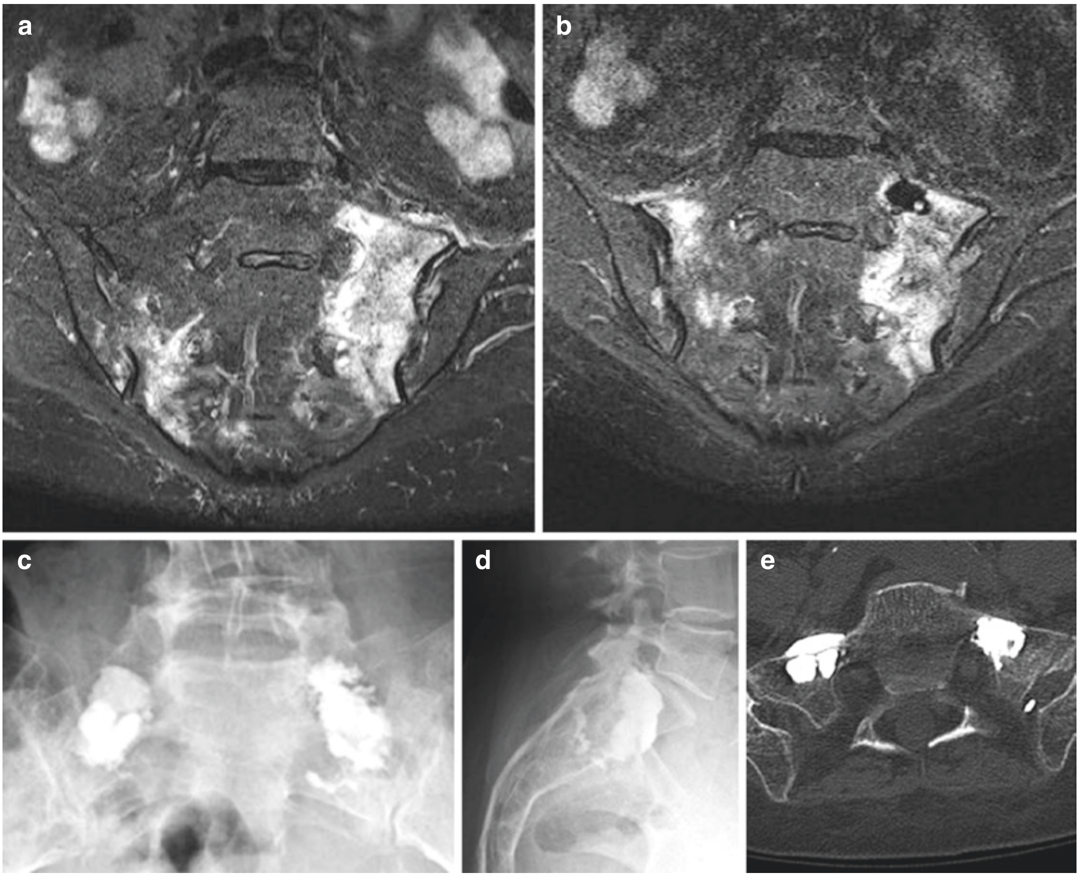

Fig. 10.6 (**a**) Magnetic resonance imaging presenting a coronal section of sacrum of a short tau inversion recovery (STIR) sequence in the 73 year-old female patient (case of Prof. Dr. P. Heini, Bern) presenting with low back pain at the left after a fall from standing position 1 month ago. Bone marrow edema is detected within Denis zone 1 of the vertebral bodies on the left side extending from the S1 to the S2 level. (**b**) Magnetic resonance imaging presenting a STIR-sequence of a coronal section of the sacrum 2 weeks after sacroplasty. Sacroplasty, which has been performed at the levels of S1 and S2 on the left side, achieved immediate pain relief. New bone marrow edema within Denis zone 1 on the right side extending from S1 to S2 levels was noticed. (**c**) Anteroposterior and (**d**) Lateral radiographs of the sacrum performed after the second sacroplasty. (**e**) Transverse section of computed tomography performed after sacroplasty. Cement leakage was noticed at the right of the anterior part of the sacrum. The patient suffered from neuropathic pain in the right foot, probably due to thermal damage to the 5th lumbar nerve root caused by the cement leakage

10.6 Summary and Conclusion

When sacroplasty is performed by experienced hands, it can be recommended in well-selected patients as a secondary treatment for sacral insufficiency fractures after unsuccessful conservative therapy. Whether or not sacroplasty should be performed as primary treatment remains unclear. Comparison of available study data is difficult as indications and postoperative assessments vary broadly. Prospective randomized studies are needed to gain evidence of the benefit of sacroplasty as well as to compare this technique with alternative stabilization methods.

Table 10.1 Clinical results after sacroplasty

Author(s)	Date	Ref. No.	Cases (n)	Age (years)	Outcome
Garant	2002	[24]	1	63	Patient able to sit in bed and bear weight on her right hemipelvis
Pommersheim	2003	[55]	3	71, 74, 76	Immediate pain relief
Brook	2005	[67]	2	65, 93	VAS 10/10 vs. 0/10 (preOP vs. postOP), no pain medication, walking independently
Butler	2005	[62]	6	71 (52–81)	3/6 patients mild pain relief within 2 days, 4/6 significant or complete pain relief at least 2 weeks after treatment
Binaghi	2006	[53]	1	68	VAS 10/10 vs. 2/10 (preOP vs. postOP)
Hess	2006	[75]	2	72, 86	Dramatic pain relief within several hours
Strub	2006	[68]	13	76 (60–88)	Pain relief: complete or moderate ($n = 7$), slight ($n = 2$), unsure ($n = 1$), none ($n = 1$), unknown ($n = 2$)
Layton	2006	[66]	1	86	VAS 9/10 to significant pain relief, able to ambulate without assistance
Frey	2007	[47]	37	77 (61–92)	VAS 8/10 vs. 3/10, 2/10, 1/10 (preOP vs. 3 h, 2 and 52 weeks postOP)
Heron	2007	[35]	3	75, 77, 87	VAS 7/10 vs. 0/10; VAS 9/10 vs. 3/10, VAS 9/10 vs. 2/10 (preOP vs. 1 day postOP)
Whitlow	2007	[40]	12	72 ± 13	Significant decrease in self-reported pain, increase in self-reported ability to ambulate and to perform ADLs, equivalent to vertebroplasty
Frey	2008	[41]	52	76 (57–94)	VAS 8/10 vs. 4/10, 10/10 (preOP vs. 30 min, 52 weeks postOP)
Gjertsen	2008	[63]	5	81 (64–90)	Pain relief: immediately ($n = 3$), 2 days postOP ($n = 2$); recurrent pain ($n = 1$)
Kang	2009	[65]	1	71	Significant pain relief 1 day postOP, able to ambulate without assistance, VAS 1/10 (12 months postOP)
Douis	2009	[42]	1	74	VAS 9/10 to 1/10 1 day postOP, 0/10 7 months postOP
Kamel	2009	[37]	19	78 (58–97)	VAS 8/10 vs. 4/10, 2/10 (preOP vs. 1 and 48 weeks postOP)
Thomas	2009	[52]	1	83	Reverticalised and able to walk without suffering 1 day postOP
Choi	2010	[61]	1	54	Complete pain relief immediately after sacroplasty
Kang	2011	[44]	8	76 (63–82)	VAS 9/10 (preOP); excellent ($n = 6$), good ($n = 2$) improvement 1 month after sacroplasty
Shah	2012	[38]	11	81 (69–87)	VAS 10/10 vs. 1/10 (preOP vs. 48 h postOP)
Trouvin	2012	[50]	6	83 (76–93)	VAS 8/10 vs. 1/10 (preOP vs. 48 h postOP)
Dougherty	2013	[73]	57	75 (61–85)	82% experienced a decrease in pain
Klingler	2013	[49]	4	73 ± 8	VAS 8/10 vs. 2/10, 1/10 (preOP vs. 1 day, 20 weeks postOP)
Kortman	2013	[25]	204	77	VAS 9/10 vs. 2/10 (preOP vs. postOP)

Table 10.1 (continued)

Author(s)	Date	Ref. No.	Cases (n)	Age (years)	Outcome
Eichler	2014	[51]	12	81 (53–85)	VAS 8/10 vs. 3/10, 2/10 (preOP vs. 4 days, 24 and 48 weeks postOP)
Gupta	2014	[64]	53	76	VAS 10/10 vs. 0/10 (preOP vs. postOP)
Ludtke	2014	[60]	1	73	VAS 9/10 vs. 3/10 (preOP vs. 3 days postOP)
Talmadge	2014	[58]	18	80 ± 9	VAS 9/10 vs. 3/10, 3/10, 2/10 (preOP vs. 4, 24, 48 weeks postOP)
Andresen	2015	[48]	20	80 (65–92)	VAS 9/10 vs. 2/10, 2/10, 2/10 (preOP vs. 2 days, 6, 12 months postOP)
Onen	2015	[46]	15	(39–76)	VAS 8/10 vs. 2/10 (preOP vs. postOP)
Prokop	2015	[54]	46	75	VAS 8/10 vs. 2/10 (preOP vs. postOP)

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Part V

Stabilization Techniques for the Posterior Pelvic Ring

11 Iliosacral Screw Osteosynthesis

Pol Maria Rommens, Daniel Wagner, and Alexander Hofmann

11.1 Introduction

Fragility fractures of the pelvic ring (FFP) represent a spectrum of morphologies with various degrees of instability. Fractures of the anterior pelvic ring are very often combined with fractures of the posterior pelvic ring. Scheyerer et al. evaluated 177 patients with pubic ramus fractures due to high-energy as well as low-energy trauma with complete diagnostics, including a CT scan [1]. An injury of the posterior pelvic ring was found in 96.8% in CT imaging, although patients had no obvious other injury than the pubic ramus fractures in the a.-p. pelvis overview [1]. In a prospective study conducted by Alnaib et al. on 67 patients with FFP, 54% and 61% of the patients with a single, respectively double pubic ramus fracture had an associated sacral fracture [2]. In our case series of 245 patients above the age of 65 with FFP, 198 (80.8%) had a combination of anterior and posterior pelvic ring fractures [3]. Consequently, when pubic rami fractures are detected on conventional pelvis X-rays after a low-energy trauma in elderly patients, there must be a high index of suspicion for concomitant fractures in the posterior pelvic ring. Low bone mineral density, retained intestinal contents and bowel gas compromise thorough radiographic analysis of the posterior parts of the pelvis on conventional X-rays. Specific symptoms point towards an involvement of the posterior pelvic ring: spontaneous pain in the low back or posterior pelvis and intense pain in the posterior pelvic ring on direct pressure or on manual compression on the iliac crests. It is recommended performing a pelvic CT scan in all patients with a low-energy pelvic trauma, who have pubic rami fractures detected on conventional pelvic overviews or when clinical examination raises suspicion.

The large majority of fractures of the posterior pelvic ring in FFP is situated at the sacral ala. There is an obvious reason for this: fractures are always situated at areas of highest strain and lowest stiffness [4]. Wagner et al. generated 3D models of the sacrum using CT scans of intact pelves in 92 individuals with a mean age of 61.5 years [5]. Distribution of bone mineral density was calculated in all sacra and averaged. The individuals were subdivided in a group with decreased general bone mass (less than 100 Hounsfield Units measured in L5) and a group with higher general bone mass (more

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_11

than 100 Hounsfield Units measured in L5). In the group with higher general bone mass, there were only small areas of very low bone mass, situated near to and lateral of the neuroforamen of S1 and S2. In the group with decreased general bone mass, large zones of negative Hounsfield Units are located in the paraforaminal lateral region from S1 to S3. Smaller zones of negative Hounsfield Units are located between the neuroforamen at the transition of S1 to S2 and of S2 to S3 (Fig. 11.1). When measuring the bone mineral density in the transsacral corridors, the lowest Hounsfield-Unit-values were present in the paraforaminal region in both groups. The bone mass was higher in the sacral bodies, the bone mineral density of S2 always being lower than of S1 (Fig. 11.2) [5]. The areas with negative Hounsfield Units in the lateral paraforaminal regions are depicted as "alar voids", because there is almost no trabecular bone present in this space anymore (Fig. 11.3). This constant pattern of sacral bone mass distribution explains the "unique and consistent" locations of sacral insufficiency fractures described by Linstrom et al.: uni- or bilateral vertical fractures running through the sacral ala (Fig. 11.4a, b) with an incomplete or complete horizontal component, located at the transition of S1 to S2, connecting the vertical fractures (Fig. 11.4c, d) [6]. Besides the decreased bone mass in the sacral ala, other factors, which contribute to the formation of a sacral insufficiency fracture, have been described: hyperlordotic posture, relaxation of the pelvic ligaments with alteration of the intrinsic stability of the pelvic ring; and obesity or weight gain due to decreased physical activity.

11.2 Rationale

When there is a combination of an anterior with a posterior pelvic ring fracture, there is a loss of stability of more than 30% when compared to the

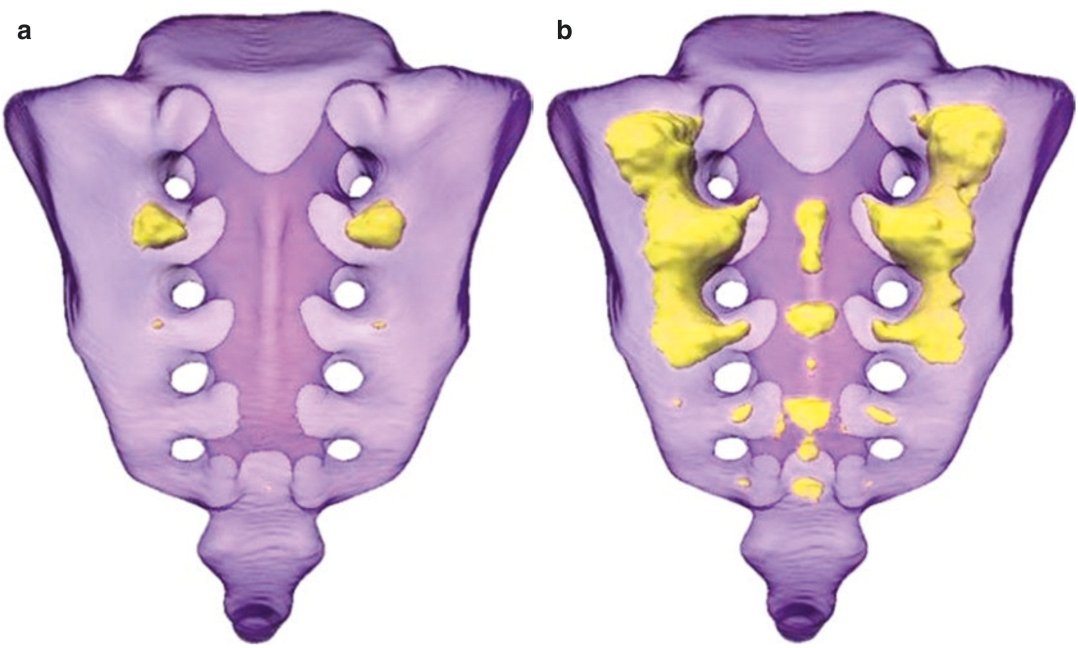

Fig. 11.1 Three dimensional models of the sacrum calculated from CT scans of intact pelves of 92 individuals with a mean age of 61.5 years. (**a**) Individuals with higher bone mineral density (higher than 100 Hounsfield Units (HU) measured in L5). There are only small areas of very low bone mass (*yellow colored* areas correspond with negative Hounsfield Units), situated near to and lateral of the neuroforamina of S1 and S2. (**b**) Individuals with lower bone mineral density (less than 100 Hounsfield Units measured in L5). There are large zones of negative Hounsfield Units (*yellow colored* areas), located in the lateral paraforaminal region from S1 to S3. Smaller zones of negative Hounsfield Units are located between the neuroforamina at the transition of S1 to S2 and of S2 to S3 (From Wagner et al. [5])

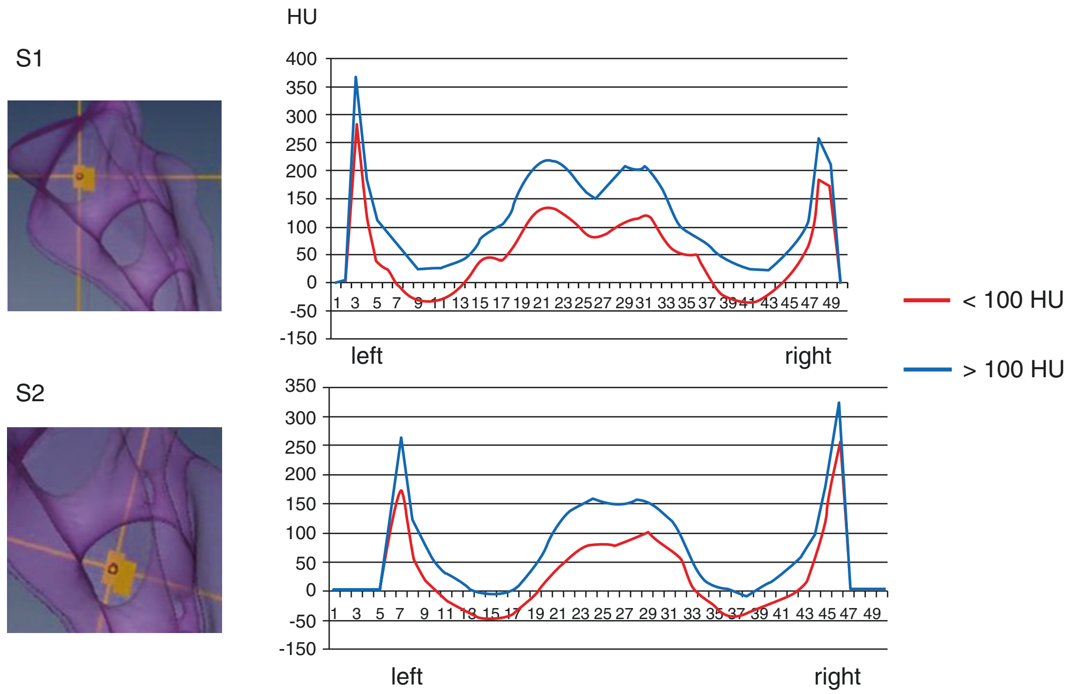

Fig. 11.2 Measurement of the bone mineral density in the transsacral corridors of S1 and S2. The same groups with higher (>100 HU in L5, *blue lines*) and lower (<100 HU in L5, *red lines*) were used as in Fig. 11.1. The lowest Hounsfield-Unit-values (HU) were present in the sacral alae in both groups. The bone mass was higher in the sacral bodies, the bone mineral density of S2 always being lower than of S1 (From Wagner et al. [5])

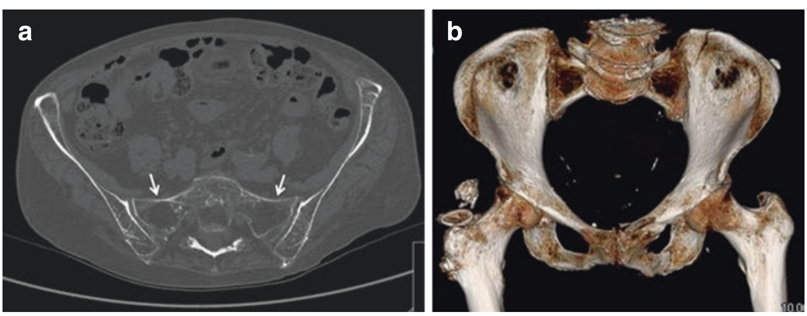

Fig. 11.3 (**a**) Transverse CT cut through the posterior pelvis of 89-year-old female showing large areas without trabecular bone in both sacral alae (alar voids). (**b**) Three-dimensional reconstruction showing alar voids in both sacral alae. There is also an incomplete fracture of the left dorsal ilium starting from the iliac crest downwards

intact pelvis [7]. This combination of fractures was present in our series of FFP in more than 80% [3]. Non-operative therapy may be cumbersome in these patients. Intense pain due to movement of the fracture fragments and side-effects of strong pain therapy can make mobilization problematic and recuperation phase longer. Consequently, operative therapy is recommended in non-displaced fractures of the posterior pelvic ring (FFP Type II), when non-operative treatment is not successful within 1 week [8]. Operative therapy is strongly recommended in displaced fractures of the posterior pelvic ring (FFP Type III and IV). The surgical intervention should be as less invasive as possible. Prolonged surgeries may provoke additional pain and blood loss, and

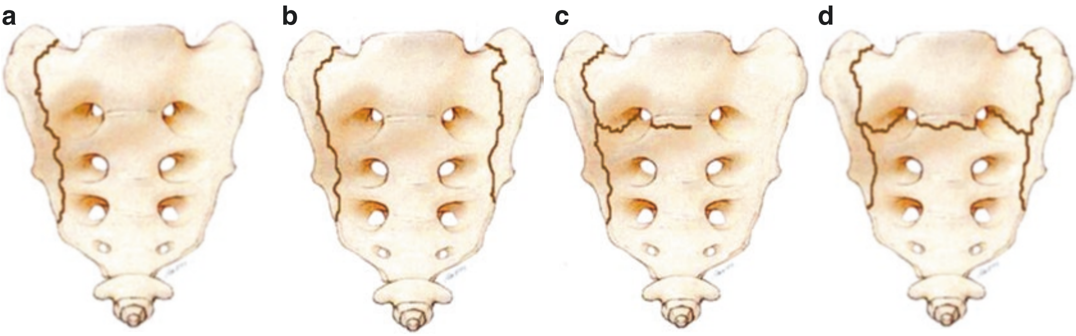

Fig. 11.4 Typical locations of sacral insufficiency fractures. (**a**) Unilateral vertical fracture running through the sacral ala. (**b**) Bilateral vertical fracture running through the sacral ala. (**c**) Unilateral vertical fracture running through the sacral ala with incomplete horizontal component at the transition of S1 to S2. (**d**) Bilateral vertical fracture running through the sacral ala with complete horizontal component located at the transition of S1 to S2, connecting the vertical fractures (From Linstrom et al. [6])

endanger the limited physiological reserves of the patient.

Iliosacral screw fixation is such a less invasive technique [9]. Screw insertions can be done through an incision of a few centimeters with minimal blood loss. The screws are inserted from the outer cortex of the posterior ilium in the direction of the body of S1 or S2, perpendicular to the sacroiliac joint or to vertical sacral fractures. The technique has been established in the 1980s [10, 11] and is widely accepted in high-energy pelvic trauma for fixation of pure sacroiliac disruptions, fracture-dislocations of the sacroiliac joint (crescent fracture) [12] and fractures running through the sacral ala or through the neuroforamen (Denis zone I and II) [13, 14]. The technique was originally conceived as an open reduction and internal fixation procedure. Later, percutaneous fixation under fluoroscopic control followed [15–17]. More recently, CT-assisted screw placement [18, 19], and both 2D and 3D navigation were propagated giving more accuracy and less radiation exposure [20, 21].

11.3 The Iliosacral Corridor

The pelvic ring is a complex three-dimensional structure, of which the morphology varies between individuals. Especially, the surgical anatomy of the posterior pelvic ring is variable. Variations of the sacral anatomy, of the iliosacral joint and dorsal ilium inclination, of the localization and plane of the sacral fracture, make optimal iliosacral screw placement challenging.

Carlson et al. introduced the “vestibule concept” for description of the safe corridors of S1 and S2 iliosacral screw placement [22]. The vestibule is the narrowest part of the bony corridor from the lateral ilium to the S1 sacral body. Its orientation and dimension is different from individual to individual. It is consistently ovoid in shape and extends from the roof of the S1 neuroforamen to the alar slope. It measured on the average 534 mm^2 in male (n = 16 CT-measurements) and 450 mm^2 in female (n = 14 CT-measurements), the anterior-posterior diameter being larger than the superior-inferior. The vestibule always pointed towards anterior and superior, the superior inclination being between 19° and 45°, the anterior inclination between 0° and 25° [22]. The whole bone area for iliosacral screw placement has the form of a diabolo with the vestibule being its narrowest passage (Fig. 11.5).

Most of the sacral fractures in FFP run vertically in the sagittal plane (Fig. 11.4). Optimal orientation of the iliosacral screw is perpendicular to the vertical fracture. In dysmorphic sacra, this may not be possible. In these cases, the iliosacral screw will have to be oriented towards cranial and anterior, which is perpendicular to the plane of the vestibule (Fig. 11.6). Due to this orientation, the entry point for the iliosacral screw at the outer cortex of the posterior ilium

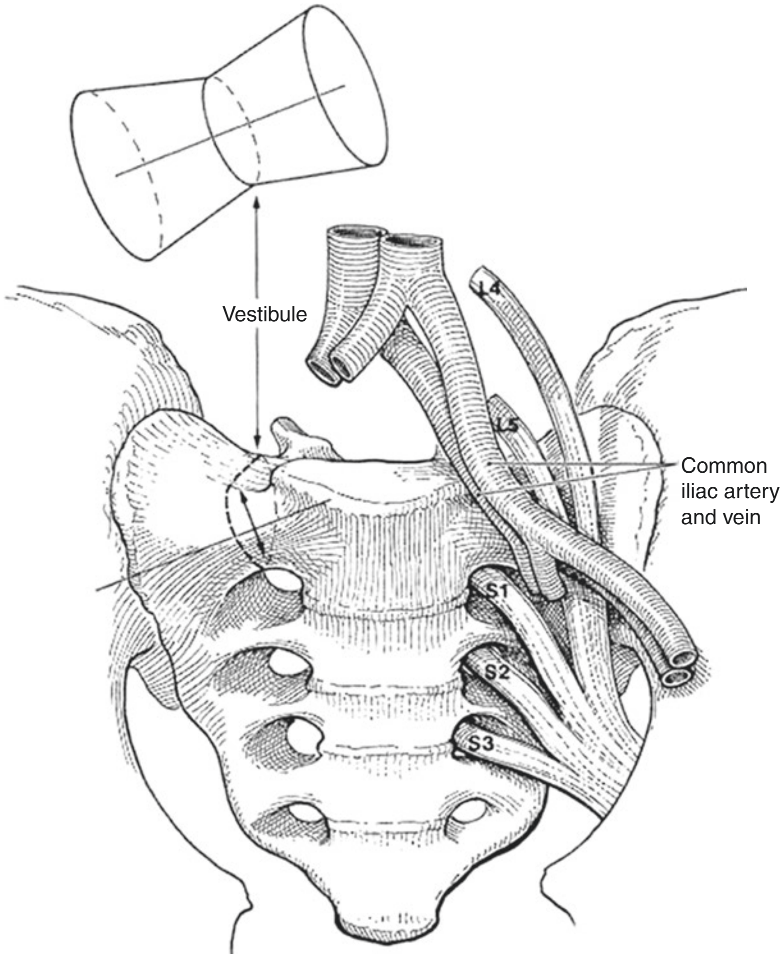

Fig. 11.5 The bone area for iliosacral screw placement has the form of a diabolo with the vestibule being its narrowest passage. Its orientation and dimension is different from individual to individual. It is consistently ovoid in shape and extends from the roof of the S1 neuroforamen to the alar slope. The vestibule always points towards anterior and superior (From Carlson et al. [22])

will have to be more dorsal and more distal (see Sect. 11.5). Also in dysmorphic sacra, there iliosacral corridor is large enough for at least one S1 screw [23, 24].

It is highly recommended to analyze the conventional pelvic views and CT-reconstructions in different planes before performing iliosacral screw fixation. Especially in dysmorphic sacra, it is beneficial using computer navigation for exact screw placement [25].

11.4 Biomechanical Studies

Iliosacral screw osteosynthesis was first described in the 1980s [10, 11]. Biomechanical studies of different types of fixation of the posterior pelvic ring have been performed soon thereafter. The tests simulated the fixation of high-energy pelvic trauma, such as pure sacroiliac dislocations or transforaminal sacral fractures in combination with anterior pelvic ring instability. It could be shown that each method of posterior ring fixation could achieve reliable stability, when combined with stable fixation of the anterior pelvic ring [26–28]. Iliosacral screws with a long thread have higher pull-out strength than screws with a shorter thread; long iliosacral screws have higher pull-out strength than short iliosacral screws [29]. Stability of iliosacral screw fixation is significantly higher with two screws than with one [30].

We assume that the results of these biomechanical studies are transferable to low-energy pelvic fractures. Nevertheless, the strength of cortical and trabecular bone is reduced in elderly persons, which may influence the stiffness of different types of internal fixation. To date, only a few studies were conducted in osteoporotic pelvic bone.

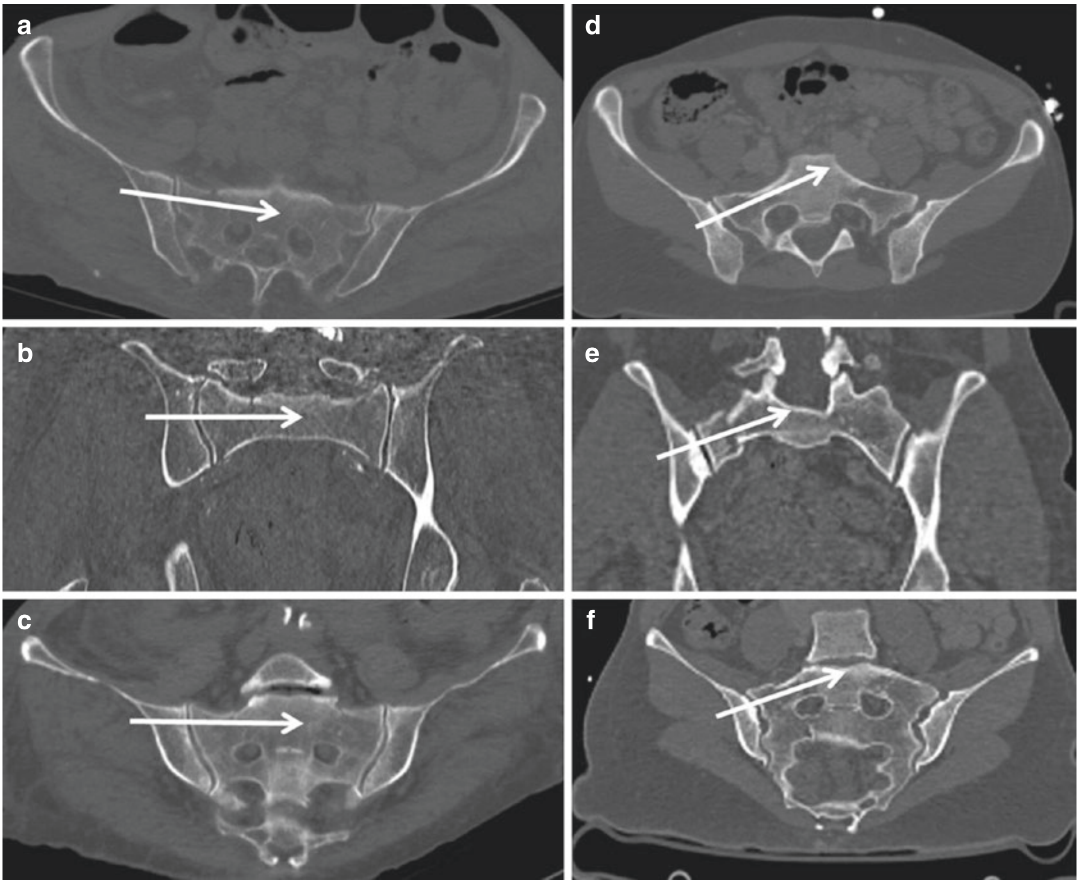

Fig. 11.6 Transverse (**a**, **d**), coronal (**b**, **e**) and oblique (**c**, **f**) CT-reconstructions through the dorsal pelves of two different individuals (*individual 1*:**a**–**c**, *individual 2*:**d**–**f**). The *white arrows* show the trajectories for safe iliosacral screw placement. Patient (**a–c**) has a normal sacral morphology; patient (**d–f**) has a dysmorphic sacrum. Whereas the iliosacral screw in patient (**a–c**) can be positioned in a coronal and horizontal plane, the iliosacral screw in patient (**d–f**) has to be placed from posterior to anterior and from caudal to cranial

Gorczyca et al. compared the strength of transiliac bars with iliosacral screws in 8 cadaver pelvis with a mean age of 75 years, which had a sacral ala fracture and disruption of the pubic symphysis. The pubic symphysis was fixed with a double plate osteosynthesis in all specimen (four hole plate superiorly and two hole plate anteriorly). There was no statistically significant difference between both types of fixation of the posterior pelvis [31].

Nork et al. support surgical stabilization of U-shaped sacral fractures with slight displacement using bilateral long iliosacral screws and report excellent clinical and radiological healing [32]. Although the study was conducted in patients with high-energy trauma, slightly displaced U-shaped sacral fractures are regularly seen in FFP.

In a finite element model of a bilateral transforaminal sacral fracture, Zhao et al. compared the stability of two kinds of iliosacral screw fixation. One long iliosacral screw reaching the opposite sacroiliac joint provides higher stability than two shorter iliosacral screws, inserted from both sides and reaching the midline in the sacral body [33].

Mears et al. performed a biomechanical comparative study of three methods of fixation of a sacral ala fracture in an osteoporotic pelvis without fracture of the anterior pelvic ring: sacroplasty, one short iliosacral screw and one long iliosacral screw. After stabilization, motion was similar to that of the intact pelvis. After cyclic

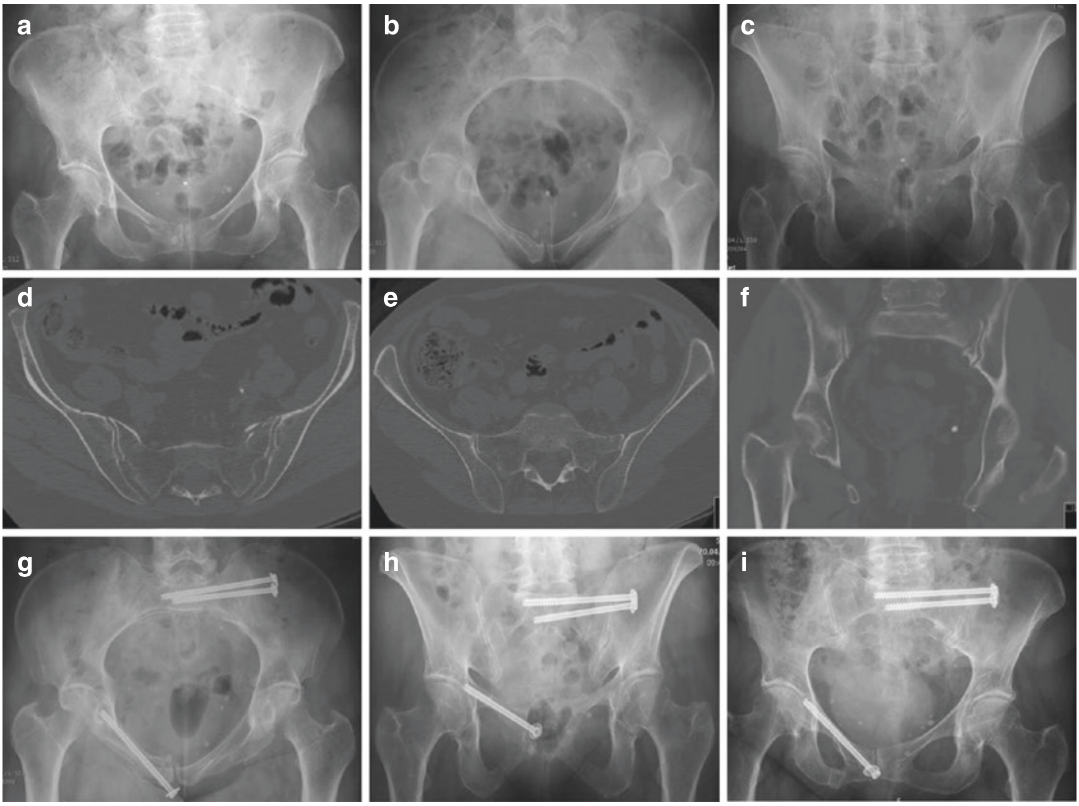

Fig. 11.7 A 78-year-old female patient suffered a domestic fall. There was continuing disabling pain 3 weeks after trauma. (**a**) The pelvic a.p. overview reveals a right-sided pubic ramus fracture. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. A fracture of the sacrum cannot be identified. (**d, e**) Transverse CT-cuts through the sacrum shows a crush lesion at the left anterior sacral ala. (**f**) Coronal CT-cut through the dorsal pelvis shows a complete fracture of the left sacral ala near to the iliosacral joint, corresponding to a FFP Type IIc lesion. (**g**) Postoperative pelvic inlet view. The sacral fracture has been stabilized with two long iliosacral screws into S1. The thread of the screws is situated in the trabecular bone of the sacral body, ensuring the most stable anchorage. The pubic ramus fracture has been stabilized with a retrograde transpubic screw. (**h**) Postoperative pelvic outlet view. (**i**) Pelvic a.p. view 6 years after trauma. There is a slight loosening of the retrograde transpubic screw, but not of the iliosacral screws. The patient is symptom-free

loading, motion increased but was similar in the three treatment groups [34].

Bastian et al. used the DensiProbe™Spine device to measure the breakaway torque of iliosacral screws at different sites of their pathway through the posterior pelvic ring.

Five human cadaver pelvises with an average age of 87 years were used. The breakaway torque was the lowest at the sacral ala and higher in the center of the S1 body or at the sacroiliac joint. The breakaway torque was also higher when the screw was placed in the upper part of the S1 sacral body [35].

From these biomechanical studies, we may conclude that iliosacral screw insertion in osteoporotic bone increases local stiffness and diminishes motion. Long screws with their thread in the S1 sacral body should be preferred. Two screws realize higher stability than one (Fig. 11.7). Transsacral implants, reaching from one sacroiliac joint to the other, provide higher stability than bilateral iliosacral screws in bilateral sacral fractures. In case of very low bone mineral density or more complex fracture patterns (e.g. U- or H-shaped sacral fracture), it is advisable to combine iliosacral screw fixation with another stabilization technique such as cement augmentation, transsacral bar osteosynthesis or iliolumbar fixation (Fig. 11.8). It also is important performing an additional stabilization of the anterior pelvic ring, if it is broken as well.

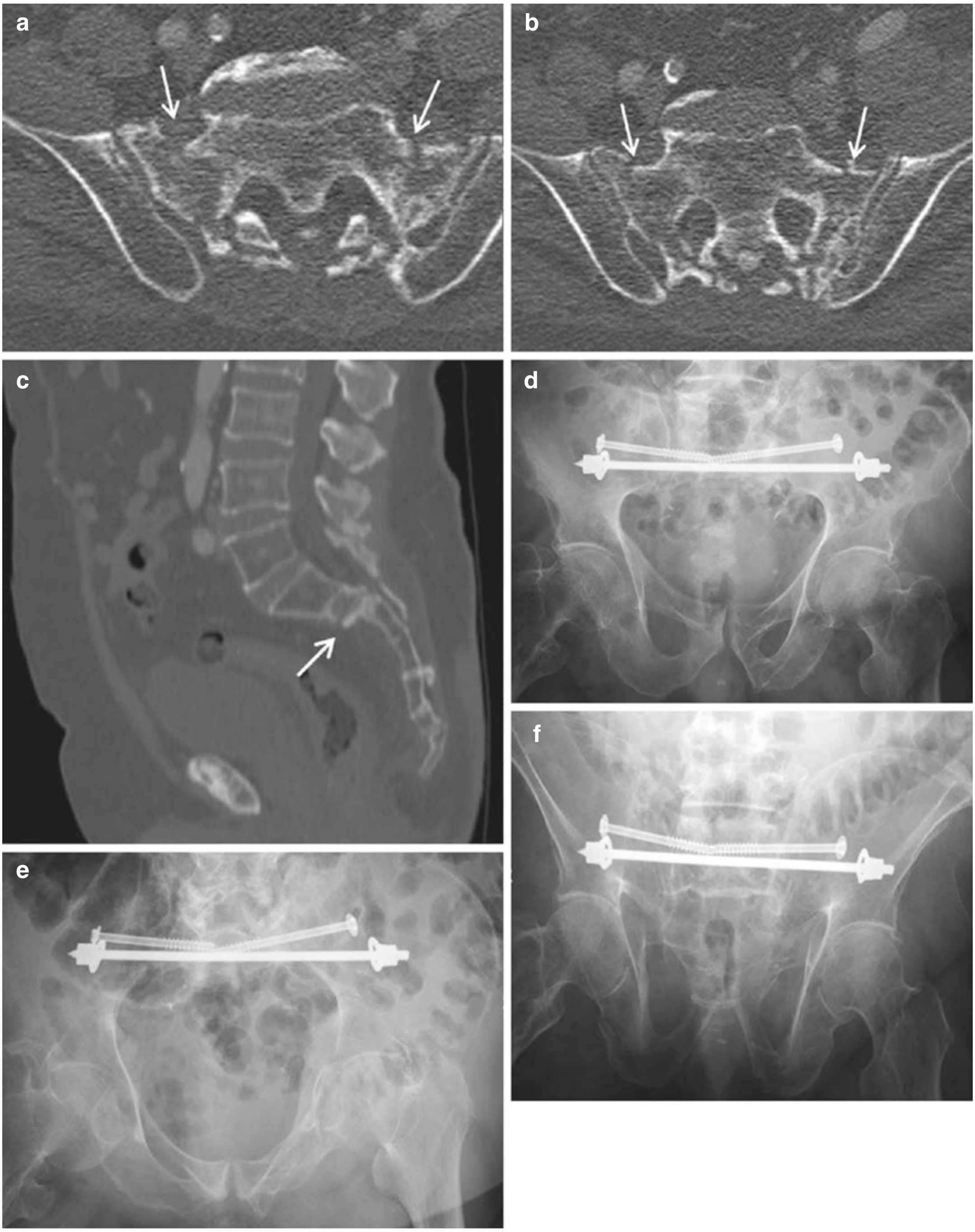

Fig. 11.8 Seventy-one-year-old male with immobilizing pain after domestic fall 4 months before surgery. There is a history of prostatic cancer, which has been treated with radiation therapy. (**a, b**) Transverse CT-cuts through the dorsal pelvis showing bilateral displaced sacral ala fractures (*white arrows*). There is an H-type fracture pattern of the sacrum corresponding to a FFP Type IVb lesion. (**c**) Sagittal CT-reconstruction through the midline of the lumbosacral junction. There is a displaced horizontal fracture at the level of S2 (*white arrow*). (**d**) Postoperative pelvic a.p. view. The sacral ala fractures were stabilized with a transsacral bar. On both sides, an additional iliosacral screw was inserted to increase (rotational) stability. There is no fracture of the anterior pelvic ring. (**e**) Postoperative pelvic inlet view. (**f**) Postoperative pelvic outlet view

11.5 Surgical Technique

As mentioned in Sect. 11.3, the morphology of the upper sacrum and its transition to the lumbar spine and dorsal ilium may vary considerably [23, 24]. It is therefore of utmost importance analyzing the anatomy of the sacrum and iliosacral corridors before surgery. Conventional pelvic a.p., inlet and outlet views as well as a pelvic CT-scan with transverse, coronal and sagittal reconstructions are indispensable elements for preoperative planning (Fig. 11.9) [36].

High-quality fluoroscopic images of the injured pelvic side must be obtained before starting the surgical intervention. It may be helpful to prepare the patient on the day before surgery with a rectal washout. The anatomical landmarks of the sacrum and iliosacral joints must clearly be visible on the three pelvic overviews and on the lateral view of the lumbosacral junction. The inlet and outlet views are not in a 45° oblique direction, but rather smaller angles are appropriate. The X-ray beam of the inlet view goes parallel to the anterior sacral cortex, the X-ray beam of the outlet view parallel with the plane of the S1 superior endplate. In a radiological study of Eastman et al. on 24 patients, the average inlet view had an obliquity of 20.5°, the average outlet view of 42.8° [37]. In a prospective study of Graves et al. on 10 patients with non-dysmorphic sacra, the average tilt required to obtain the ideal inlet view was 25°, for the ideal outlet view an average tilt of 42° was necessary (Fig. 11.10) [38].

An optimal lateral view is available when both iliac cortical densities, which are corresponding with the bottom of the iliac fossa, are superimposed [44–46]. The area in the S1 body, which corresponds with the safe corridor for screw insertion in the coronal plane, is identified. The margins of this area are: the iliac cortical densities superiorly, the sacral cortex anteriorly, the transition of S1 to S2 inferiorly; and the sacral canal posteriorly. The following landmarks must clearly be visible on the inlet and outlet views: S1 superior endplate, roof of the sacral ala bilaterally, sacroiliac joints bilat-

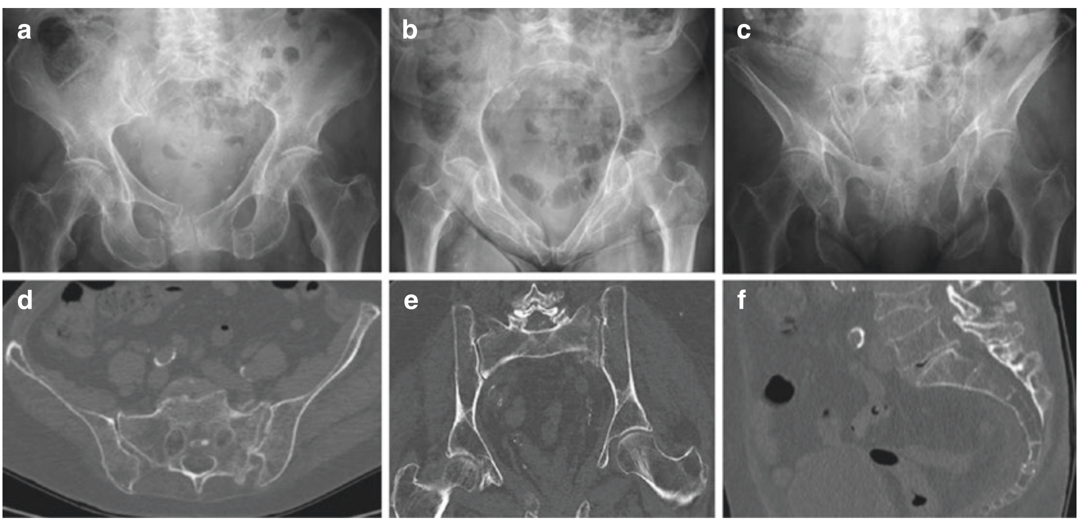

Fig. 11.9 Eighty-two year-old female with history of fall while walking on the street. Due to immobilizing pain in the right groin and left buttock, she presented at the emergency department 3 weeks after trauma. (**a**) A.p. pelvic overview reveals a bilateral pubic ramus fracture. A fracture or displacement of the posterior pelvic ring is not visible. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. (**d**) Transverse CT-cut though the posterior pelvic ring. A left-sided sacral ala fracture with slight impaction is detected. (**e**) Coronal CT-cut through the posterior pelvic ring. The left sacral ala fracture is confirmed. (**f**) Sagittal CT-cut through the midline of the sacrum. There is no horizontal fracture between the S1 and S2 sacral body. The patient suffered a FFP IIIc lesion

erally, neuroforamen S1 with its curved roofs bilaterally, anterior sacral cortex, sacral canal. (Fig. 11.11) [39, 40].

For all views, the orientation of the fluoroscopic image must be the same as the position of the patient on the operation table, as observed by the surgeon. When the patient is in prone position on the operation table, posterior must be above and anterior below on the lateral fluoroscopic view. What is seen on the left and right side of the fluoroscopic view must be the same as what the surgeon sees in reality: when the head of the patient is left, the lumbar spine must be seen on the left side, when the legs of the patients are right on the table, the sacrum must be seen on the right side of the image intensifier view.

The patient can be placed in the supine or prone position. Iliosacral screw osteosynthesis with the patient supine is only recommended, when a favorable context exists. The sacral fracture or sacroiliac fracture-dislocation must be minimally or not displaced. This is mostly the case in FFP. Moreover, the patient should be thin. In the supine position, the soft tissues of the buttocks are pushed off towards laterally, which makes access to the posterior ilium more difficult. In obese persons, the distance between the skin and the bony structures becomes so large, that customized instruments must be very long. Also is the accuracy of drilling lower, which enhances the risk of screw malposition. It therefore is recommended to perform iliosacral screw osteosynthesis with the patient in the prone position in displaced fractures and in obese patients.

11.5.1 Supine Position

The patient is placed with the injured side on the margin of the radiolucent table enabling free orientation of the drill bit. A large skin area between the pubic symphysis and the umbilicus on the medial side, and reaching very posteriorly at the gluteal region at the lateral side, is disinfected and draped. This area gives the surgeon a good exposure of the surgical site and a good overview of the body axis of the patient on the table. The

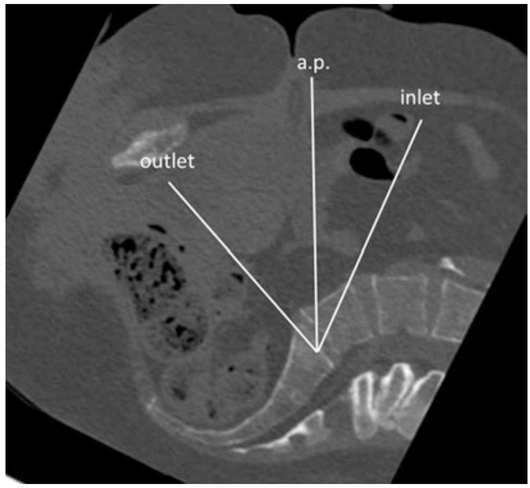

Fig. 11.10 Sagittal CT-reconstruction through the midline of the lumbosacral junction of a patient in supine position. The vertical line (a.p.) shows the direction of the X-ray beam of the fluoroscope in the anteroposterior direction. The oblique line coming from distally (outlet) shows the direction of the X-ray beam, which is parallel with the end plate of the S1 vertebral body. The angle between the a.p. line and the outlet line is about 40°. The oblique line coming from proximally (inlet) shows the direction of the X-ray beam, which is parallel with the longitudinal axis of the sacrum. The angle between the a.p. line and the inlet line is about 25°

ipsilateral lower extremity must not be draped free, as reduction manoeuvers are not necessary.

In the lateral view, the ideal insertion point for the iliosacral screw in S1 is identified. Ideally, the iliosacral screw is placed perpendicular to the plane of instability: transverse for vertical sacral ala fractures, oblique with the entry portal being more posterior for sacroiliac fracture-dislocations [44–46]. Also in case of sacral dysmorphism, the screw direction must be oblique from lateral posterior towards medial anterior and from lateral distal towards medial proximal, because no other corridor is available (Fig. 11.6). Under fluoroscopic control, a vertically directed 2.8 mm diameter drill guide is glided along the skin of the injured side, until its tip indicates the ideal insertion point of the screw. The drill is hold in this position. In case of oblique screw insertion, the entry point is localized at the transition of the S1 to S2 sacral body and at the posterior margin of the sacral body, just in front of the sacral canal. In dysmorphic sacra, the insertion point may even be more posterior, local-

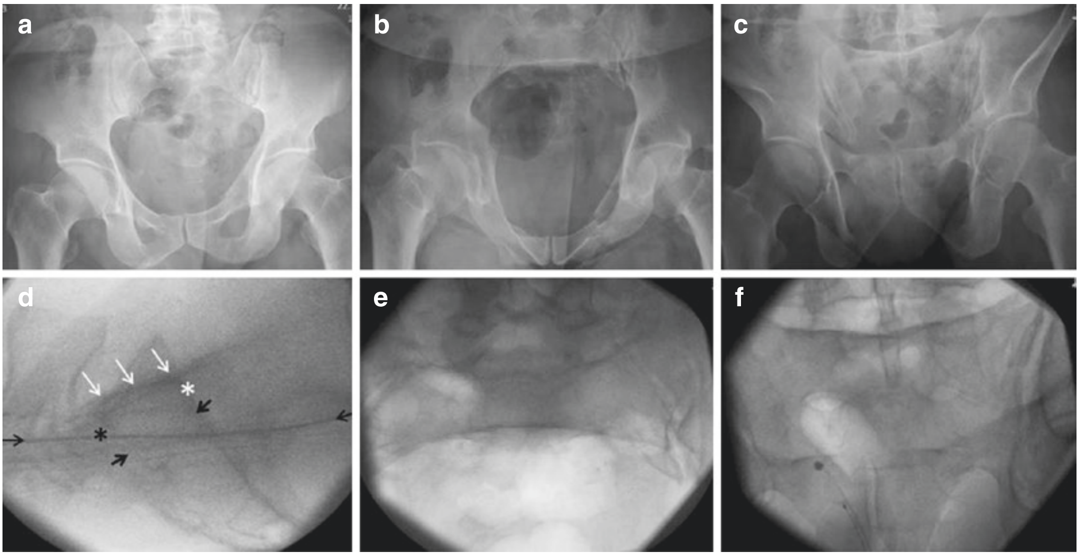

Fig. 11.11 Preoperative X-ray examinations and planning for iliosacral screw osteosynthesis. Sixty-seven year old male after domestic fall and immobilizing pain on the anterior and posterior left pelvis. (**a**) A.p. pelvic overview showing a left-sided superior and inferior pubic ramus fracture. There is an irregularity at the left sacroiliac joint. (**b**) Pelvic inlet view confirms the left pubic ramus fracture. An interruption of the anterior sacral cortex at the left sacral ala is visible. (**c**) Pelvic outlet view. There is no vertical displacement of the left anterior and posterior pelvic ring. (**d**) Lateral fluoroscopic view of the lumbosacral junction with the patient on the operation table in supine position. The horizontal line between the thin *black arrows* is the margin of the pillow on which the patient is positioned on the operation table. This line is not a projection of any bony landmark. The following landmarks are the margins of the area of S1: iliac cortical densities superiorly (*three white oblique arrows*), the anterior sacral cortex (*white asterisk*), the transition between the S1 and S2 sacral body inferiorly (between the *thick black arrows*) and the sacral canal posteriorly (*black asterisk*). (**e**) Fluoroscopic pelvic inlet view showing the same landmarks as the preoperative pelvic inlet view (Fig. 11.11b). (**f**) Fluoroscopic pelvic outlet view showing the same landmarks as the preoperative pelvic outlet view (Fig. 11.11c)

ized just posterior to the sacral canal [23]. A small horizontal skin incision is made with the tip of the drill in its middle. The drill is now turned into the horizontal plane and pushed through the skin incision into the gluteal muscles until its tip is placed at the ideal insertion point on the outer cortex of the posterior ilium. With a hammer blow or a short drilling, the drill tip perforates this outer cortex. The orientation of the drill is now adapted so that it points towards the sacral corridor (Fig. 11.12).

The fluoroscope is now turned back for a.p., inlet and outlet views. The orientation of the drill and position of the drill tip are identified in these projections. The drilling trajectory is projected as an imaginary line in continuity with the existing and visible drill orientation. In normomorphic sacra, the entry portal and horizontal trajectory points towards the center of the S1 sacral body in the inlet and outlet views. In dysmorphic sacra, the entry portal and trajectory are different. Carlson et al. localized the entry portal at the level of the posterior sacral cortex in the inlet view and being at the inferior S1 foramen in the outlet pelvic view in dysmorphic sacra [23]. The direction of the drill is now fine-tuned for ideal positioning of the iliosacral screw.

Subsequently, the drilling procedure is started. The drill tip consecutively perforates the inner cortex of the posterior ilium and the lateral cortex of the sacrum. This can be felt by the surgeon. In regular intervals, the position of the tip of the drill is controlled in relation to the visible landmarks of the anterior and posterior sacral cortex, the shoulder of the sacral ala and the neuroforamen of S1. Drilling is continued until the tip of the drill reaches the opposite sacral ala

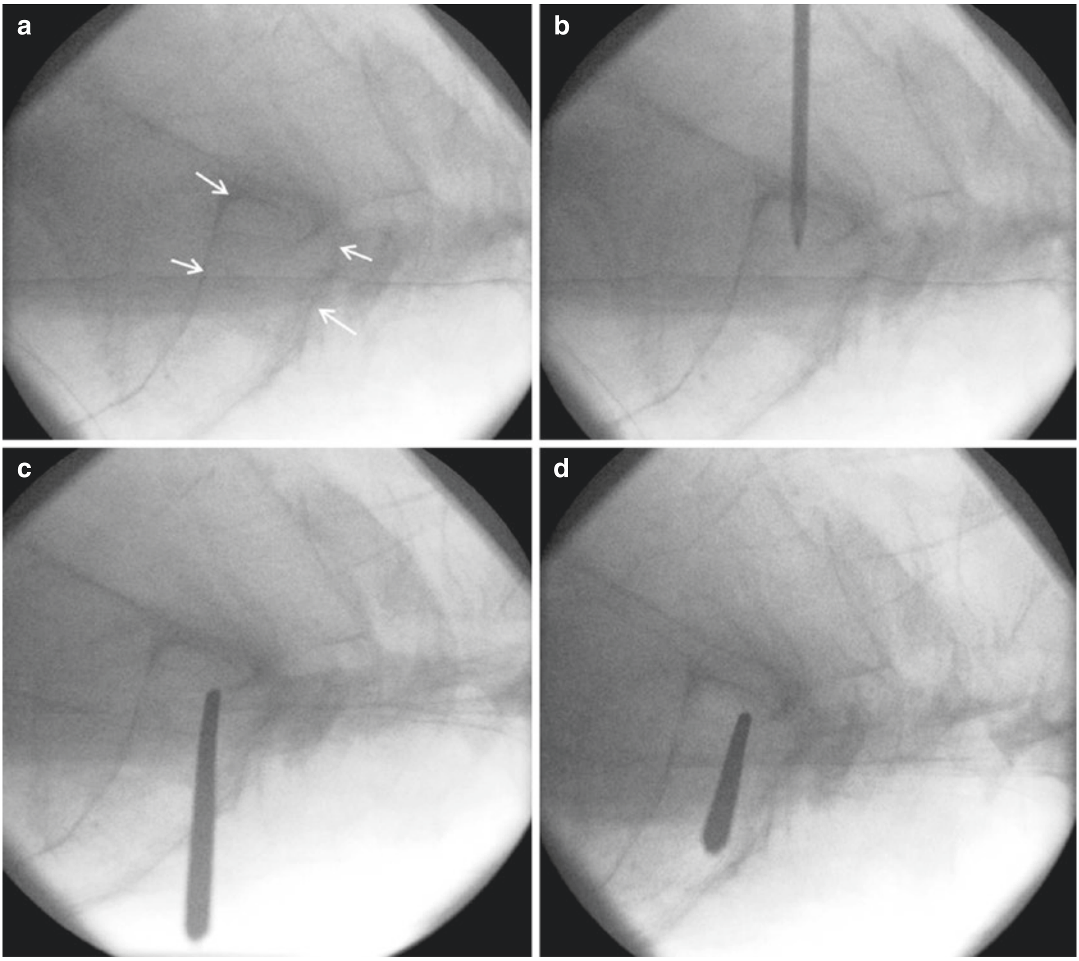

Fig. 11.12 Lateral fluoroscopic views of the lumbosacral junction of a 82-year old female with a FFP Type IIIc lesion (same patient as in Fig. 11.9). (**a**) The area between the *white arrows* is identified (see also Fig. 11.11d). (**b**) The tip of the drill, which is hold vertically near to the skin, points towards the center of S1. A horizontal skin incision is made with the drill tip in its middle. (**c**) The drill is now oriented horizontally and pushed through the skin incision and the gluteal muscles until it reaches the posterior ilium. (**d**) The direction of the drill is adapted so that it points towards the sacral corridor

(Figure 11.13a–d). In case the opposite sacral ala cannot be reached due to sacral dysmorphism, an as long trajectory as possible should be drilled. This ensures that the thread of the screw is situated in the sacral body, which has the highest trabecular density (Denis zone III) [5, 8]. With a depth gauge, the length of the drill inside the bone is measured. Three cortices (outer and inner cortex of the ilium and lateral cortex of the sacrum at the sacroiliac joint) are over-drilled with a cannulated 4.5 mm drill, which is glided over the 2.8 mm drill bit. Thread-cutting of the screw trajectory is not necessary in osteoporotic bone. A 7.3 mm or 8 mm cannulated screw of the same length is now inserted. When a washer is used, a screw with a length of 5 mm longer than measured with the depth gauge, is chosen to compensate for the height of the washer. The washer avoids penetration of the screw head through the near cortex. Tightening the screws with a long thread—and the thread being on the contralateral side of the fracture—puts compression on the fracture site. The surgeon feels increasing resistance when the screw head with

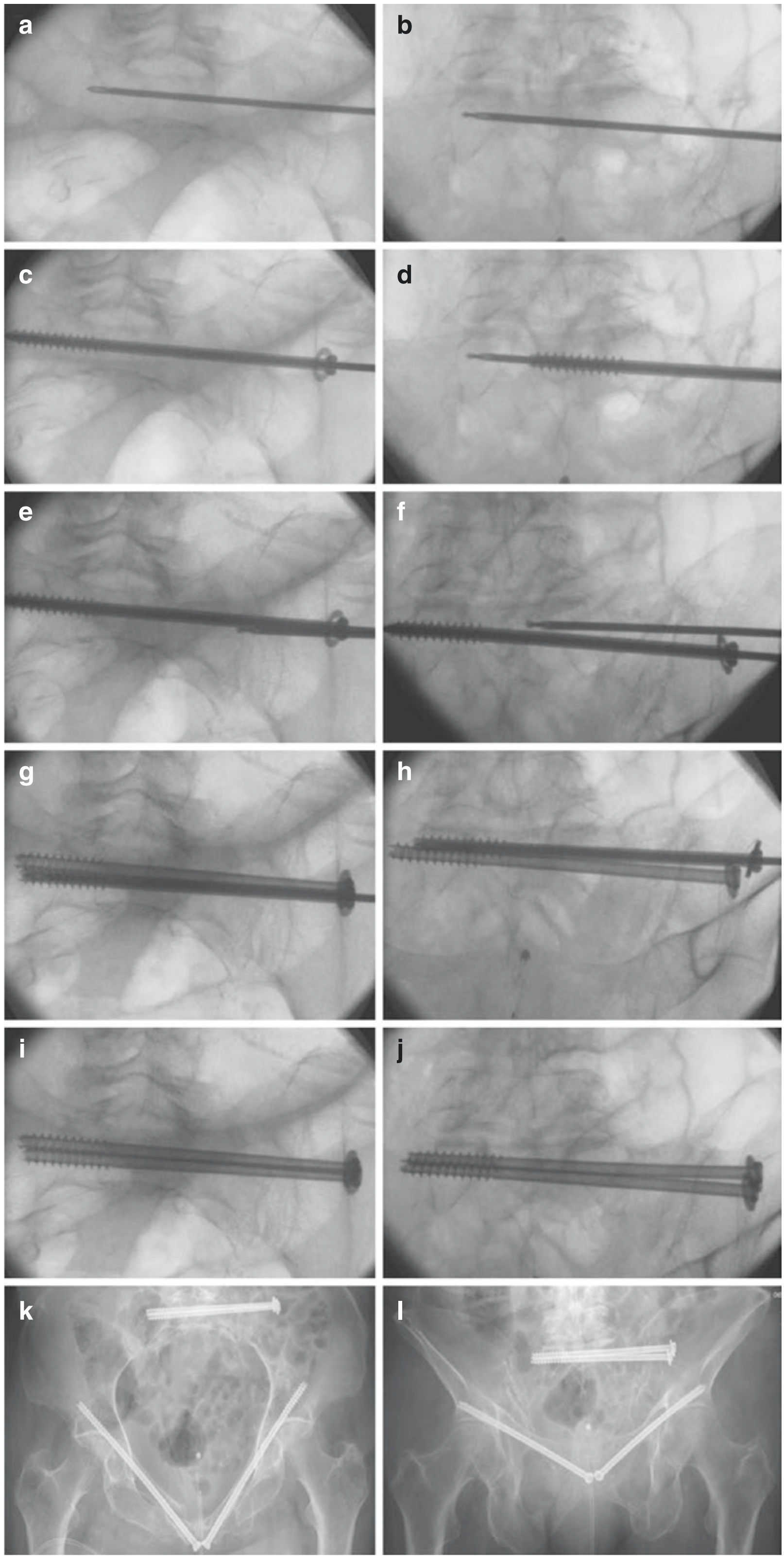

Fig. 11.13 Fluoroscopic pelvic inlet (*left*) and pelvic outlet (*right*) views of the same patient as in Fig. 11.9 and in Fig. 11.12. (**a, b**) The drill is located in the center of the S1 body and its tip reaches the opposite sacral ala. (**c, d**) A cannulated 7.3 mm cancellous screw with long thread is inserted over the drill. To prevent perforation of the screw head through the outer cortex of the posterior ilium, a washer is used. (**e, f**) Drilling of the trajectory of the second screw in S1, which is nearly parallel to the first screw in both the inlet and outlet views. (**g, h**) Insertion of the second screw with washer over the drill bit. (**i, j**) Final fluoroscopic control of the iliosacral screw positions in inlet and outlet view. The drill bits have been removed. The screws heads with washers have been tightened against the outer cortex of the posterior ilium. (**k, l**) Postoperative pelvic inlet and outlet views

washer presses directly on the lateral cortex of the posterior ilium. No compression is obtained when a screw with continuous thread is used; the screw has the function of a positioning screw. Depending on the diameter of the sacral corridor, insertion of one or two screws is possible. In case two screws are inserted in S1, their trajectories should be parallel or slightly converging in the inlet and outlet views to minimize danger of malposition (Fig. 11.13e–l) [23]. If the second screw is placed in the body of S2, the same steps of the procedure are repeated, taking into account that the dimensions of the sacral corridor of S2 are smaller than those of S1.

11.5.2 Prone Position

The prone position allows for direct access of the sacrum, sacroiliac joint and dorsal ilium and enables open reduction, when needed [28, 41]. The prone position has several other advantages. Due to gravity, the soft tissues of the buttocks will fall down, which makes access to the posterior ilium easier. The posterior iliac crests and the spinous processes of the sacrum can be felt easily through the skin. Especially in obese persons, the prone position is of major advantage.

The patient is placed prone on a radiolucent Table. A firm pillow is placed below the lumbosacral region. A large transverse skin area between the spinous processes of the lumbar spine and sacrum on the medial side, and reaching very anteriorly at the gluteal region at the lateral side, is disinfected and draped. This area gives the surgeon a good exposure of the surgical site and a good overview of the body axis of the patient on the table. The ipsilateral lower extremity must not be draped free, as reduction manoeuvers are not necessary. The technique of iliosacral screw osteosynthesis is the same as described for the supine position [17, 42].

11.6 Results

Numerous literature data are available on incidence of complications and on outcome of iliosacral screw osteosynthesis in high-energy pelvic trauma. Matta et al. already published 1989 a series of 29 patients, who were treated with internal fixation. The patients had better clinical results and higher union rates than those treated conservatively or with external fixation [11]. Routt et al. published 1995 the results of 68 patients treated with 103 percutaneous iliosacral screws. There were 5 screw-related problems, of which one was a screw malposition and another one was a transient L5 nerve root palsy. There were only three failures of fixation. There was no nonunion and no screw breakage [15]. Gardner et al. performed 106 iliosacral screw insertions in 68 patients without neurologic monitoring. There were no neurological complications. They concluded that iliosacral screw placement can safely be done without intraoperative neuro-monitoring [39]. Gras et al. evaluated screw malposition and functional outcome after iliosacral screw placement using a 2D navigation system. Out of 56 iliosacral screws, correct position in cancellous bone was present in 80%, screw position in contact with cortical bone in 14% and penetration of cortical bone in 6% [40]. Osterhoff et al. published 2011 data on 83 iliosacral screw insertions in 38 patients using conventional fluoroscopy. Secondary surgery due to malposition or loosening had to be performed in four patients. There was one non-union [17].

Pieske et al. published 2015 data on CT-guided 136 screw insertions. There were 132 correct placements (97.1%), 3 screws perforated up to 1.0 mm (2.2%) and one screw (0.7%) extended into a neuroforamen. No procedure-associated complication was observed and all injuries healed [41]. Zwingmann et al. performed a systematic review and meta-analysis on the malposition and revision rate after percutaneous screw fixation, depending on different imaging modalities. The malposition rate for the conventional technique was 2.6%, which was significantly higher than only 0.1% using CT-navigation. When 2D- and 3D–image-based navigation was used, the malposition rate was 1.3%. There was no significant difference between the conventional and the 2D- and 3D–image-based navigation techniques. Revision rates were 2.7% in the conventional group, 1.3% in the group of 2D and 3D image-based navigation and 0.8% using the

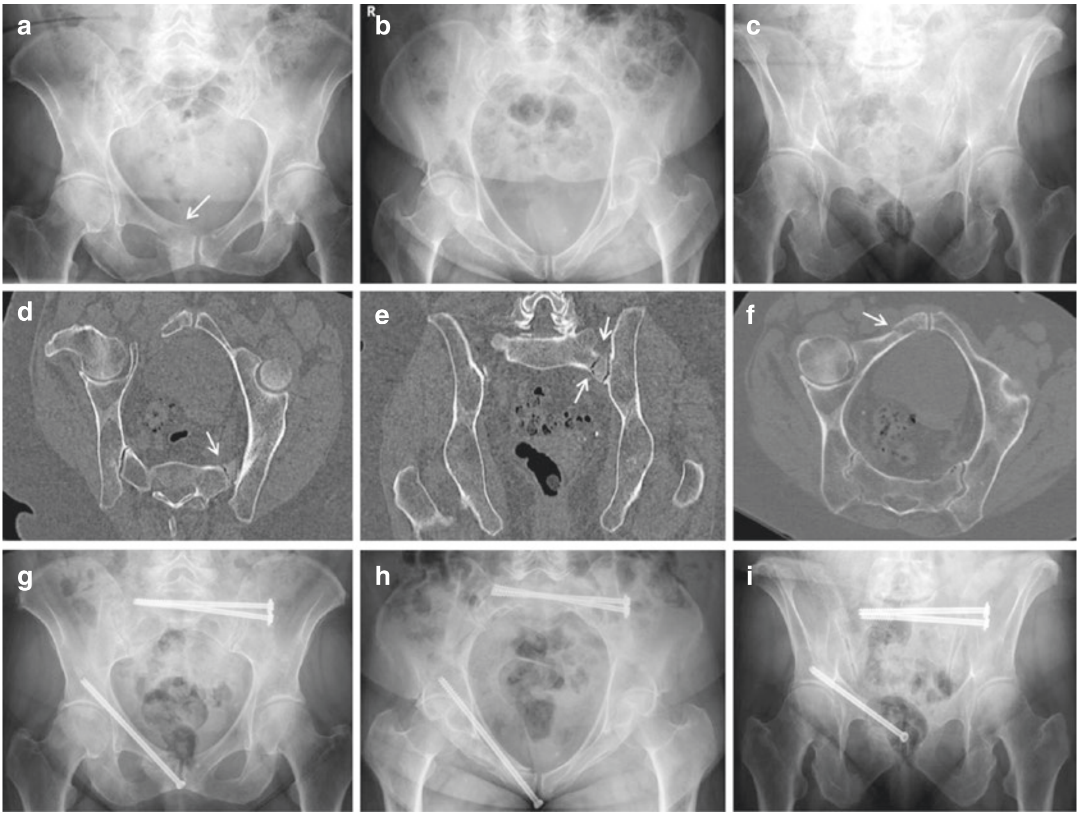

Fig. 11.14 Seventy-five-year-old female with a history of a domestic fall and disabling lower back pain. (**a**) A.p. pelvic overview reveals a right displaced pubic ramus fracture (*white arrow*). A lesion of the posterior pelvic ring is not detectable. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. (**d**) Oblique CT-reconstruction reveals a complete fracture of the left sacral ala (*white arrow*). (**e**) Coronal CT-cut confirms the complete left sacral ala lesion (*white arrows*). (**f**) Oblique CT-reconstruction of the pelvic ring showing the right pubic ramus fracture (*white arrow*). (**g**) Postoperative a.p. pelvic overview. After failed conservative treatment, two long iliosacral screws were placed in S1 on the left side and a retrograde transpubic screw on the right side. (**h**) Pelvic inlet view. (**i**) Pelvic outlet view. Complaints improved significantly after surgery

CT-navigation. These differences were not significant. Although most of these studies were done on patients with high-energy pelvic trauma, we assume that the technique is as safe in elderly patients with osteoporotic bone. Due to osteoporosis, the visibility of the bony structures may be reduced, but thorough preoperative analysis and CT- or 2D- or 3D–based navigation systems may enhance accuracy of screw insertion [42].

Hopf et al. treated 30 patients with an average age of 78.4 years with FFP using 58 iliosacral screws. There was one screw malposition with nerve irritation, which forced to revision surgery. There was one screw loosening. There was a favorable pain reduction in all patients. The authors concluded that conventional percutaneous iliosacral screw fixation is a successful operative treatment for elderly patients with persistent lower back pain after unstable posterior ring fractures of the pelvis [43] (Fig. 11.14).

Conclusion

Iliosacral screw fixation can be regarded as a valid and safe minimally invasive technique for stabilization of fractures of the sacrum and fracture-dislocations of the sacroiliac joint in FFP. Large series of iliosacral screw placement have shown adequate stability, significant reduction of pain, high healing rates and a low incidence of malposition and other complications. Although most literature data are derived from case series with high-energy pelvic trauma, they may be transferable to FFP. A thorough preoperative analysis of sacral morphology, fracture plane(s) and bone mineral density using conventional pelvic views and 2D–CT-reconstructions is indispensable for planning the correct position of the iliosacral screws. Screw direction ideally is perpendicular to the fracture plane and screw length as long as possible. Two screws should be inserted to stabilize one fracture, whenever possible. Due to reduced bone strength in elderly people, there is a risk of bad visibility of the anatomical landmarks of the posterior pelvic ring and low stability of the osteosynthesis. Computer navigated screw insertion and 2D- or 3D–based navigation may increase correct screw placement. In case of bilateral lesions or complex fracture morphology, an adjunct osteosynthesis of the posterior pelvic ring is recommended.

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12 Iliosacral Screw Fixation with Cement Augmentation

Michael Raschke and Thomas Fuchs

12.1 Introduction

Geriatric pelvic ring fractures cause prolonged pain, immobility and high mortality. They are the result of a low-energy trauma. Sometimes, no trauma is memorable. Particularly, elderly women are affected [1, 2]. Osteoporosis is the major co-morbidity and reduced implant anchorage in the sacrum is reported [3, 4]. To address this anchorage problem, several techniques using bone cement have recently been developed.

Sacroplasty as an attempt to treat sacral insufficiency fractures has first been described in 2002 [5]. Bone cement is injected into the fracture area. Pain relief is explained by fracture stabilization after cement hardening [6, 7]. However, vertical shear stress in the sacrum may cause early cement failure. In addition, cement leakage and impaired bone healing are reported as further drawbacks. In our opinion, sacroplasty remains subject to special indications [8, 9].

Cement injection following screw insertion has been used in selected cases only—broad clinical experience is lacking so far [4, 10]. Recent cadaver studies suggest similar stability of through-the-screw cement augmentation compared to augmentation prior to screw placement. It is assumed that augmentation prior to screw insertion causes more complications due to cement leakage. This remains subject to further research [11].

Iliosacral screw fixation is an effective method of treatment to reduce micro-motion at the fracture site of osteoporotic sacral fractures [12]. However, reduced bone mass, less bone-implant contact and little purchase of screws may impede implant anchorage. Augmentation using polymethylmethacrylate (PMMA) or tri-calcium phosphate bone cement is one method to increase primary implant stability [9, 13]. The exact technique of augmenting iliosacral screws has recently been described by our group [14].

Stable insufficiency fractures of the posterior pelvic ring should be treated conservatively. Indication for operative therapy is persisting immobilizing pain after 1–2 weeks of conservative treatment with adequate pain medication. If patient mobilization remains impossible, iliosacral screw fixation with cement augmentation may lead to immediate pain relief. More complex

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_12

Table 12.1 Advantages and disadvantages of iliosacral screw fixation with cement augmentation

Advantages	Disadvantages
• Minimally invasive surgery	• Demanding technique
• Intra-operative decision making possible	• Intraoperative 3 D imaging required
• Marginal extension of operation time	• Carbon table needed
• Increased strength of bone-implant construct	• Conventional X-ray imaging is impeded by low bone density, intestinal gases and abnormal anatomy
• Full weight-bearing possible	• No cement removal possible
• Early mobilization and less secondary complications such as thrombosis, pulmonary embolism, pneumonia, decubitus ulcer, obstipation and danger of fall	• Cement leakage, cement embolism

posterior pelvic ring instabilities such as displaced H-type fractures of the sacrum can be treated with triangular osteosynthesis or lumbopelvic fixation (see Chap. 16) in combination with augmented iliosacral screws.

In Table 12.1, advantages and disadvantages of iliosacral screw fixation with cement augmentation are summarized.

12.2 Surgical Technique

Iliosacral screw insertion with cement augmentation is similar to conventional screw insertion as described in Chap. 11. The patient is placed in supine position (Fig. 12.1). Skin disinfection, draping and WHO time-out are carried out.

The mobile fluoroscopy unit is used to verify the anatomical landmarks of the posterior pelvic ring in a.p., inlet and outlet projections. A strict lateral view is obtained, when both greater sciatic notches are superimposing. A 2.8 mm diameter drill bit is inserted into the first sacral body until it crosses three cortices. Particularly before cement augmentation, performing a 3D–CT scan is strongly recommended to confirm correct position of the drill bit in order to avoid later cement leakage. In case of severe osteoporosis and bad visibility of the osseous landmarks, we recommend using 3D–navigation for the insertion of the drill bit (Figs. 12.2, 12.3 and 12.4).

Once the drill bit has been placed in correct position, the adequate length and type of screw are chosen. After measuring the length of the 2.8 mm drill bit inside the bone and before screw implantation, a larger, cannulated drill bit of 5.0 mm diameter (DePuy Synthes, Umkirch, Germany) is used to over-drill the most lateral centimeters of the screw canal, including three cortices. The last centimeters must not be over-drilled in order to preserve trabecular architecture of the sacral body for the best possible screw anchorage. A cannulated, fully or partially threaded screw with side perforations near to the screw tip (Marquardt Medizintechnik, Spaichingen, Germany) and with washer (Fig. 12.5) is forwarded until a tight grip is achieved (Fig. 12.6).

Fig. 12.1 View of the patient on the operation table from cranial and left. The entire lateral hip is draped. For 3D–CT scanning, the carbon table has to be covered at its lower surface with a sterile drape as well

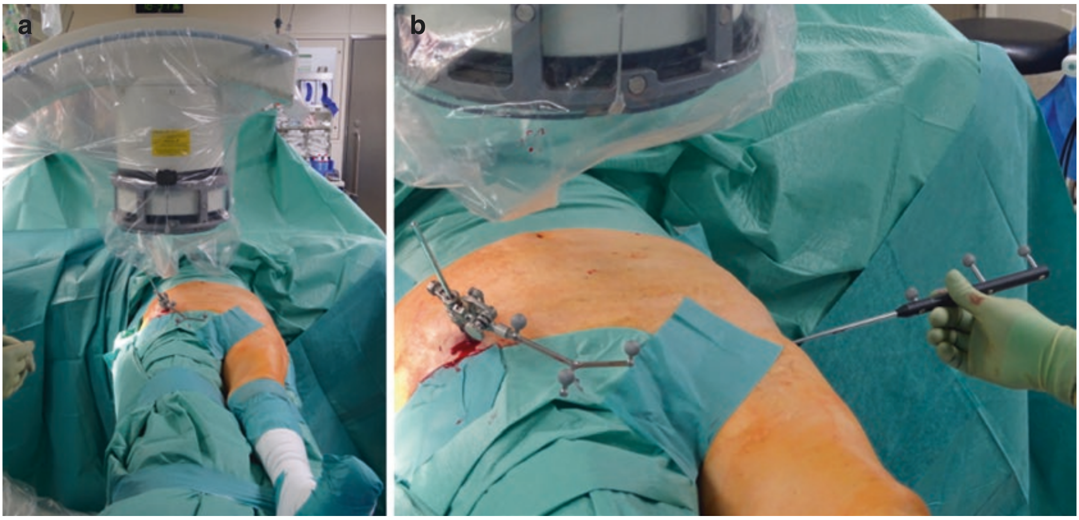

Fig. 12.2 3D–navigated implantation of an iliosacral screw. The reference arc is positioned at the iliac crest of the uninjured, contralateral side of the pelvis. (**a**) View of the patient from caudal. (**b**) Closer view of the operation field

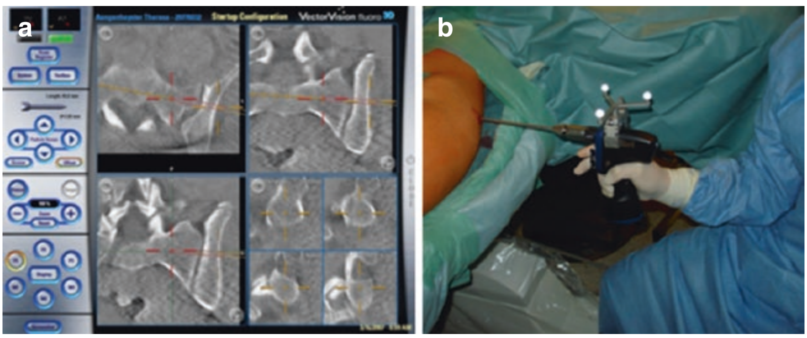

Fig. 12.3 A 2.8 mm drill bit with a length of 430 mm (Marquardt Medizintechnik, Spaichingen, Germany) is inserted. The insertion is guided with navigation. (**a**) Picture of the navigation monitor showing the position of the drill bit in different planes. (**b**) Intraoperative view of the navigated insertion of the drill bit

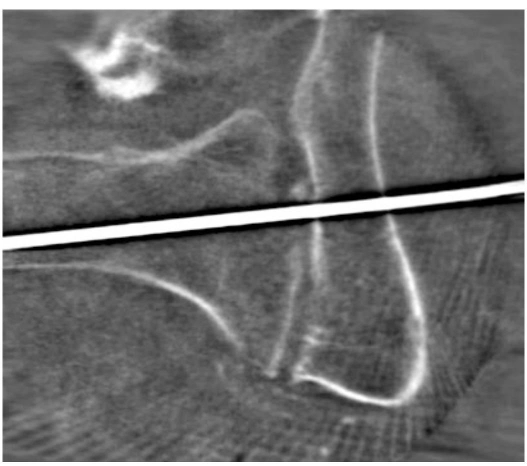

Fig. 12.4 Intraoperative 3D–scan showing the correct position of the drill bit

Fig. 12.5 Specifically designed cannulated, fully threaded screw with fixed washer. The tip of the screw is perforated laterally at different sites to achieve even cement distribution. For better anchorage in osteoporotic bone, the surface of the screw is roughened

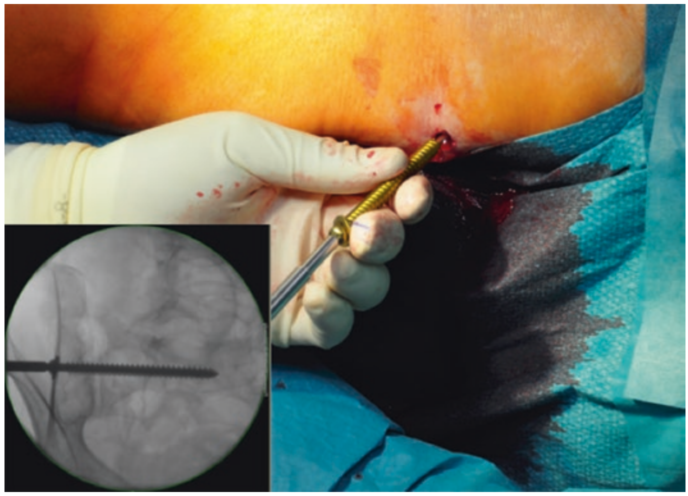

Fig. 12.6 Over-tightening of the screw should be avoided as torque moment and fixation are then reduced. Correct screw placement is confirmed under fluoroscopy

Fig. 12.7 Insertion of a Luer-lock cannula into the cannulated screw for application of contrast media and cement

During screw insertion, the surgeon has the choice to decide whether augmentation is required or not. For this purpose, rough assessment of the torque moment during screw insertion is helpful. If the surgeon decides to augment the sacral screw with cement, the K-wire is removed and a Luer-lock cannula is placed into the previously inserted screw (Fig. 12.7). Contrast medium is injected through the Luer-lock cannula to rule out pre-sacral or intra-spinal leakage (Fig. 12.8).

Augmentation is conducted using PMMA based bone cement (e.g. Traumacem™ V+; Fa. DePuy Synthes, Solothurn, Switzerland). During cement injection, the anesthesiologist should carefully observe respiratory parameters. Two to 3 mL cement are injected under permanent fluoroscopic control (Fig. 12.9). Additional cement, which remains in the Luer-lock injection cannula may be pushed into the sacral body with a cement pusher (Figs. 12.10 and 12.11). Screw augmentation is checked with final intraoperative fluoroscopic controls (Figs. 12.12 and 12.13).

In case of bilateral sacral fractures, the same procedure is repeated on the contra-lateral side. In case of anterior pelvic fractures, the surgery can be combined with a supra-acetabular external fixator (Fig. 12.13). Sufficient thrombosis

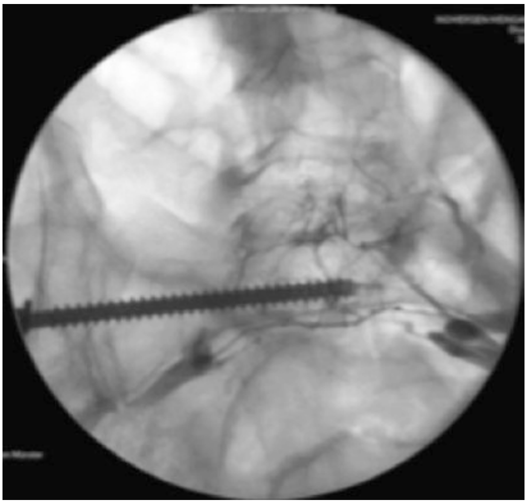

Fig. 12.8 Contrast medium is injected through the Luer-lock cannula. Regular drainage of the contrast medium through the pre-sacral venous plexus is shown in this inlet fluoroscopy projection. If there is a leakage through the fracture into pre-sacral, intraspinal or neuroforaminal area, cement augmentation should not be carried out

Fig. 12.9 Cement is injected into the first sacral vertebral body. Uniform cement distribution through the different side openings and the tip of the screw is achieved. If cement leakage is observed, cement injection should to be stopped

Fig. 12.10 Cement pusher

Fig. 12.11 Use of cement pusher for additional cement application

Fig. 12.12 Intraoperative pelvic outlet view to control cement distribution after iliosacral screw cement augmentation

prophylaxis and postoperative ultrasound control of the deep veins of the lower extremities is strongly recommended. The patient can start with full weight bearing immediately after surgery. Crutches, walking frames, thera-bands and bed pedal exercises can be used for quicker mobilization. During follow-up, a conventional pelvic view should be taken to confirm ongoing fracture healing and rule out screw loosening or secondary displacement.

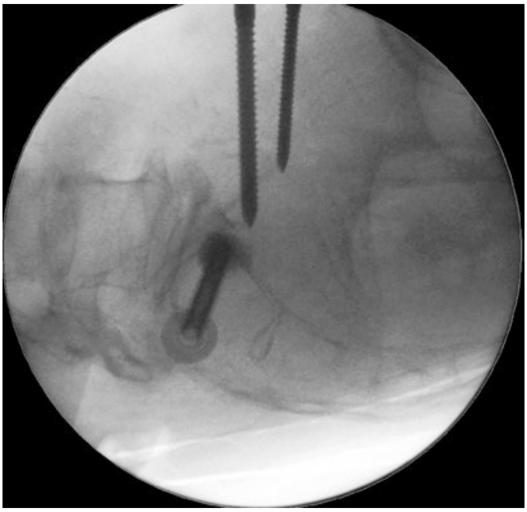

Fig. 12.13 Intraoperative lateral view of the sacrum to control cement distribution after iliosacral screw cement augmentation. The tips of the Schanz' screws of a supra-acetabular external fixator can be seen in this view

12.3 Results

In our first series of 12 female patients, there were no complications and patients had a mean pain reduction from 8.2 to 2.6 points on the visual analog scale [14]. Continued data collection of additional 39 patients showed similar results with two cases of screw loosening. Additionally, own unpublished *in vitro* data suggests that cement augmentation significantly increases the number of cycles to failure at the screw tip, but does not affect the overall construct stability.

Cement augmentation of iliosacral screws seems to be an effective, minimally invasive procedure, which efficiently reduces pain after sacral insufficiency fractures in a geriatric population [15]. However, extended, multi-center based clinical experience is lacking and implants are scarcely available. In order to proof our excellent experience, multicenter-based, large-scale studies are needed.

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13 Transsacral Bar Osteosynthesis

Alexander Hofmann and Pol Maria Rommens

13.1 Introduction

Unstable fragility fractures of the pelvis (FFP), involving the posterior pelvic ring (according to FFP-types III and IV [1]), represent potential indications for surgical stabilization. Anatomically, the sacrum connects the spine to the pelvis and is in a key position for translation forces from the body to the legs. Although the degree of instability in FFP is not comparable to traumatic pelvic fractures in younger adults, unstable mono- or bilateral sacral ala fractures in elderly persons (FFP Types IIIc, IVb-c [1]) may cause significant disability and result in non-union, if treated nonsurgically. Therefore, the aim of the surgical treatment is reducing the pain level and improving the functional outcome of the patient by stable fixation of the pelvic ring.

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Progress in methods for internal fracture fixation has generated a myriad of techniques for stabilization of the posterior pelvic ring. They all differ in terms of their surgical invasiveness, biomechanical stability, safety, and efficacy. However, each of these techniques has been supposed to provide clear benefits and better outcomes compared with non-operative treatment.

Percutaneous sacroiliac screw fixation is one of the most popular techniques for stabilization of traumatic sacral fractures and SI-dislocations in younger adults [2]. Potential indications for this method in the sacrum are the non-displaced Denis zone I and II sacral fractures [2, 3]. The surgical procedure can be performed with the patient in both the supine or prone position. In hands of an experienced surgeon, sacroiliac screw fixation may be safely and quickly applied for definitive fracture fixation even in a polytrauma scenario. Nevertheless, in osteoporotic bone, only moderate compression of the fracture can be achieved by tightening the screws even when washers below the screw heads are used. Besides quality of reduction and correct screw placement, the stability of SI-screw fixation is directly linked to the bone mineral density. Therefore, in osteoporotic bone this method is associated with a high rate of loosening and failure, as described in detail in Chap. 11. To prevent such complications, different techniques to improve the anchorage of the screws (cement augmentation [4]) or to reduce the overall instability of the fracture (additional

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_13

lumbopelvic fixation) have been proposed. This chapter summarizes the rationale and the surgical technique of the sacral positioning bar osteosynthesis, which provides the advantages of a minimally invasive approach yet reducing the risk of implant loosening.

13.2 Rationale and Development

The so called compressive ilio-iliac bar osteosynthesis has frequently been used in the past for fixation of unstable pelvic disruptions [5, 6]. This technique has been popularized by Marvin Tile [6] and proved to be effective in younger adults with good bone quality. In the original technique, the full-threaded 6 mm sacral bar was inserted under fluoroscopic control through the ipsilateral posterior ilium, advanced posterior to the sacrum to reach and perforate the opposite posterior ilium. Washers and nuts were placed on top of the sacral bar on both sides (Fig. 13.1a). The clinical experience with this implant, however, showed some disadvantages. The eccentric posterior position of the bar outside the fracture region was accountable for secondary fracture displacement and lack of stability of the construct (Fig. 13.1b, c) [7]. Especially in bilateral vertically unstable posterior injuries (Tile's Type C3) early loss of stability and dislocation of the SI-joint have been noticed with this technique. Because of the position of the bar posterior to the sacrum, wound complication rates were also reported to be high [7].

The disadvantages of this method have been addressed by changing the position of the bar as described by Vanderschot et al. [8–11] and Mehling et al. [12]. In this modified technique, a threaded 6 mm bar is inserted through the posterior part of the ilium and through the SI-joint and advanced through the center of the S1 vertebral body towards the opposite posterior ilium (Fig. 13.2a). Washers and nuts are placed and tightened on both ends of the bar providing compression of the vertical fracture planes in the sacrum (Fig. 13.2b). Thus, the stability of fixation does not depend on the bone mineral density of the sacrum itself. The advantage of this technique

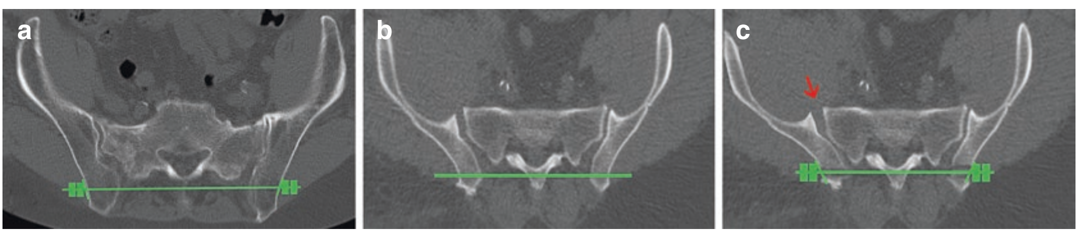

Fig. 13.1 (**a**) Anatomic position of the ilio-iliac sacral bar osteosynthesis posterior to the sacrum. In this method, washers and nuts are used to fix the posterior pelvis. (**b**) In unstable posterior pelvic disruptions, tightening of the nuts may cause loss of reduction due to eccentric position of the bar (**c**). Furthermore, in osteoporotic bone loosening of the bar may rapidly occur

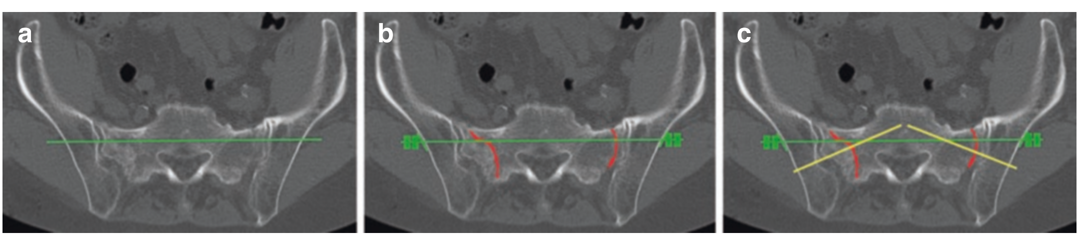

Fig. 13.2 (**a**) Anatomic position of the transsacral sacral bar within the center of the S1 vertebral body. (**b**) The implant is oriented almost perpendicular to the fracture plane. Tightening the nuts allows achieving compression in the fracture planes. (**c**) *Yellow lines* show the trajectories for optional sacroiliac screws

is the central position of the implant in the body of S1 crossing the fracture planes in almost 90° (Fig. 13.2b) as well as the reduced risk for pull-out and loosening due to blocking the nuts with counter-nuts. For selected indications like bilateral vertical sacral ala fractures (FFP IVb), the transsacral bar osteosynthesis provided promising results [8, 12, 13]. Additional use of iliosacral screws may be considered to increase the overall stability of the construct (Fig. 13.2c).

13.3 Preoperative Planning

The availability of the so-called transsacral corridor is a general prerequisite for performing the transsacral bar osteosynthesis (Fig. 13.3a). In the sacral body S1, this corridor is formed between the anterior cortex of the sacrum, the superior cortex of the sacral ala and vertebral disc plate of S1, the vertebral canal and the anterior cortices of the neural foramen S1. In contrast to SI-screws that can be placed oblique to the vertical axis of the sacrum, running from inferoposterior towards the center of the body of S1 (Fig. 13.2c), the transsacral corridor is much more limited in its anatomical diameter as shown by Mendel et al. [14, 15] and Wagner et al. [16]. Furthermore, the sacral anatomy is highly variable showing in up to 35% signs of dysmorphism [17]. Thus, space for placing transsacral implants may be very limited (Fig. 13.3b) at the level of S1. Although, the transsacral corridor is much more constantly present at the level of S2 [14, 16], indications for placement of transsacral implants through the body of S2 are limited to very few types of FFPs only. This is due to the fact that bilateral FFPs are usually connected through an additional horizontal fracture at the sub-S1 level (H-type and U-type fractures [18, 19]). Therefore, implants inserted through the body of S2 will not aid to stability of the unstable S1-fragment, which remains connected to the lumbar spine but has broken out the pelvic ring [20].

A thorough preoperative analysis of the fracture morphology and the morphology of the transsacral corridor is paramount. The width of the transsacral corridor is measured in both transverse and coronal multiplanar reconstructions of the CT-scan pictures (Fig. 13.4a–h). The corridor must provide enough space for placing at least a 6 mm threaded bar though the center of S1. In mono- and bilateral fractures without a horizontal component, the transsacral positioning bar provides sufficient stability for fracture compression and fixation as a standalone implant. In H- and U-type fractures, the S1-fragment may need additional fixation to neutralize rotational forces acting around the unstable S1-fragment. In such cases, placement of additional (augmented) sacroiliac screws may be considered (Fig. 13.4g, h).

13.4 Surgical Technique

13.4.1 General Remarks

In its present stage of development, the sacral bar is a not cannulated implant, since it has been developed as an ilio-iliac-implant originally (Fig. 13.5). For transsacral osteosynthesis, the surgeon must be familiar with the complex radiologic anatomy of the sacrum, because safe

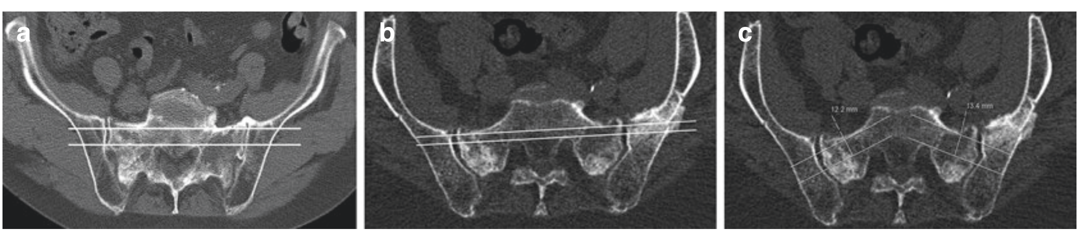

Fig. 13.3 Assessment of the transsacral corridor. (**a**) A transverse CT scan showing a sufficient width of the transsacral corridor for transsacral bar osteosynthesis. (**b**) Another example showing a very limited width of the transsacral corridor, where placement of the transsacral bar may be dangerous. (**c**) In such cases, there may be still enough place for osteosynthesis with iliosacral screws

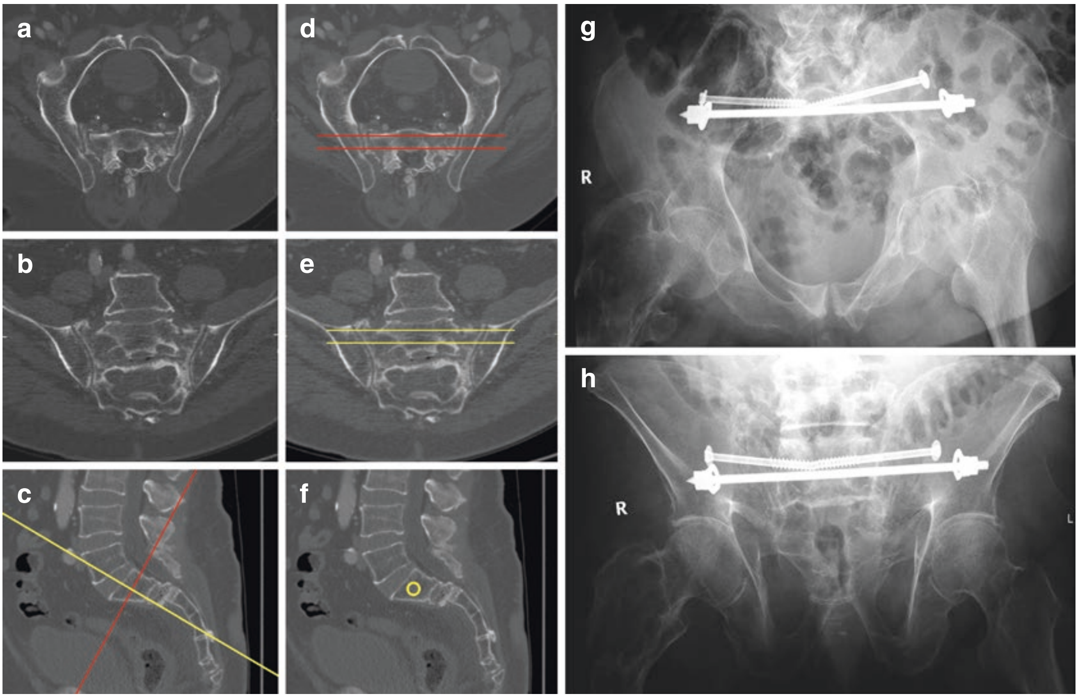

Fig. 13.4 Preoperative assessment of the transsacral corridor in a 73-year-old male patient, who developed a FFP Type IVb-lesion (H-type sacral fracture) of the posterior pelvic ring after irradiation of the pelvis due to prostate cancer. The patient presented 5 months after the onset of drug-resistant pain in the lower back. The transsacral corridor is analyzed using different multiplanar CT-reconstruction pictures including pelvic inlet (**a**, according to the *red line* in **c**) and pelvic outlet (**b**, according to the *yellow line* in **c**) planes. (**c**) Orientation of the respective planes in a sagittal CT-reconstruction. (**d**, **e**) The width of the transsacral corridor at the level of S1 vertebral body. (**f**) The sagittal CT-reconstruction shows the intended central position of the bar in the body of S1. In all CT-reconstruction pictures, displaced fractures are noticed in all three planes with the unstable fragment S1 remaining attached to the lumbar spine. Additionally, the horizontal fracture line at the sub-S1-level is clearly visible. Implants inserted at levels lower than S1 are, therefore, not suitable to fix the unstable S1-fragment in such kinds of injury. (**g**, **h**) corresponding postoperative inlet and outlet views, according to Fig. 13.4d, e

and adequate fixation may be difficult to achieve, due to reduced bone mass in the elderly and limited intra-operative visibility with fluoroscopy.

There is no specific device for cutting the bar to an appropriate length after the nuts have been placed and finally tightened. For this purpose, a large side cutter must be inserted as closely as possible to the nut, which requires an appropriate length of the skin incision (Fig. 13.5e). Due to this reason only, the patient must be positioned prone.

13.4.2 Patient Positioning

The patient is positioned prone on the radiolucent carbon table. Prior to surgery, the anatomical landmarks of the sacrum are identified in a.p., inlet and outlet views (Fig. 13.6). If possible, the patient is prepared for surgery with rectal washout the day before surgery to improve intraoperative visualization.

13.4.3 Surgical Steps

First, the sacrum is visualized in a lateral view [21] and the site of skin incision is tagged with a pincette or a wire (Fig. 13.6a). Alternatively, a computer navigation system may be used. The first skin incision should be long enough to allow for cutting the bar with a large side cutter later on. The fascia is incised and the gluteus muscles are bluntly spread with scissors. The tip of the 2.8 mm drill wire is placed in a central projection over S1 under

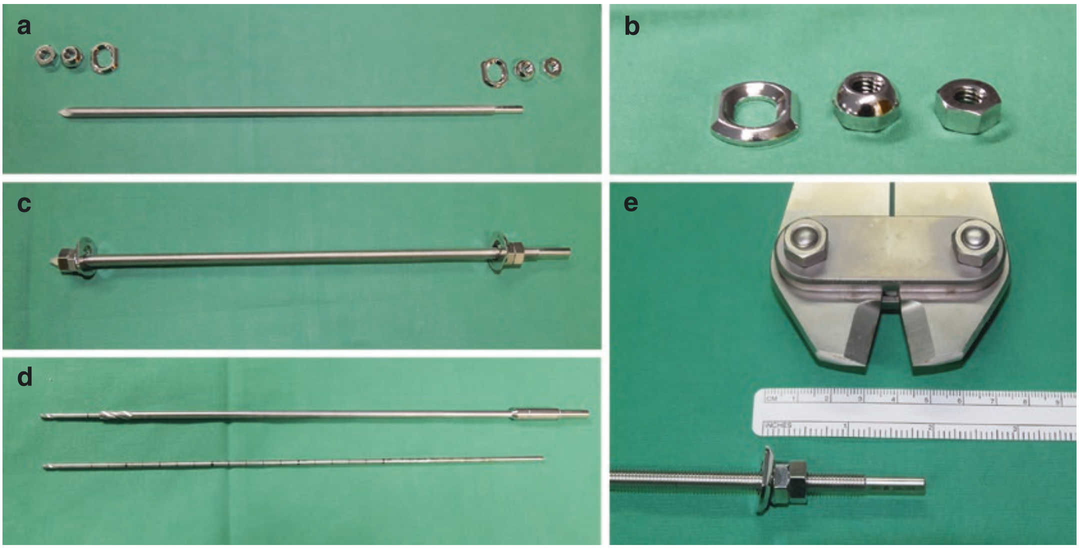

Fig. 13.5 (**a**) A fully threaded 6 mm bar is used for the transsacral bar osteosynthesis. (**b**) On both ends, a washer (*left*), a rounded nut (*middle*), and a hexagonal counter-nut (*right*) are used to achieve and maintain compression of the posterior pelvic ring. (**c**) The sacral bar in the assembled state is shown. (**d**) To prepare the drill hole for the insertion of the sacral bar, a 2.8 mm drill wire (*below*) and a 4.5 mm cannulated drill bit (*top*) are used. (**e**) A large side cutter is used to shorten the bar to the appropriate length

fluoroscopic control and the first cortex of the ilium is perforated after correct positioning of the wire with a slight hammer blow (Fig. 13.6a). The tip of the wire must always be located underneath the iliac cortical density to prevent accidental perforation of the antero-cranial cortex of the sacral ala and damage of the L5 root (Fig. 13.6a) [21].

The position of the wire is subsequently verified in a.p. (Fig. 13.6b), inlet (Fig. 13.6c, d) and outlet views (Fig. 13.6e, f) and the drill wire carefully advanced through the SI-joint, the sacral body and through the opposite SI-joint under fluoroscopic control (Fig. 13.7). The respective bone structures can be felt during the drilling procedure. A skin incision of 3–4 cm length is made on the contralateral side over the tip of the wire, which can be now palpated subcutaneously. The tip of the wire is exposed by blunt dissection and fixed with a clamp. The drill wire is now over-drilled with a 4.5 mm cannulated drill bit and removed thereafter. The 6 mm fully threaded sacral bar (Depuy-Synthes Company) is inserted through the drill hole under careful fluoroscopic control (Fig. 13.7). The first washer, the rounded nut and the hexagonal counter-nut are placed on the contralateral side. The tip of the bar should be a little bit longer than the counter-nut. From our experience, the sharp tip of the bar does not cause any problems because of its deep position under the gluteal muscles. The bar is turned back until the washer is in close contact with the outer cortex of the posterior ilium. The second washer and the second rounded nut are subsequently placed on the ipsilateral side and compression is applied by tightening the second rounded nut and holding the counter-nut on the contralateral side with a screw-wrench. Finally, the second counter-nut is used to block the second rounded nut. The protruding end of the bar is cut using a large side cutter. The both wounds are rinsed and closed in layers. The patient is turned back into supine position and the anterior pelvic pathology is addressed, if necessary.

13.4.4 Pitfalls

Cutting the bar with the side cutter will cause a plastic deformation of the bar end making removal of the nuts difficult (Fig. 13.8). Therefore, the bar should be cut on one side only, to allow removal of the bar later on, if necessary. For this purpose, the nuts are removed on the contralateral side and the

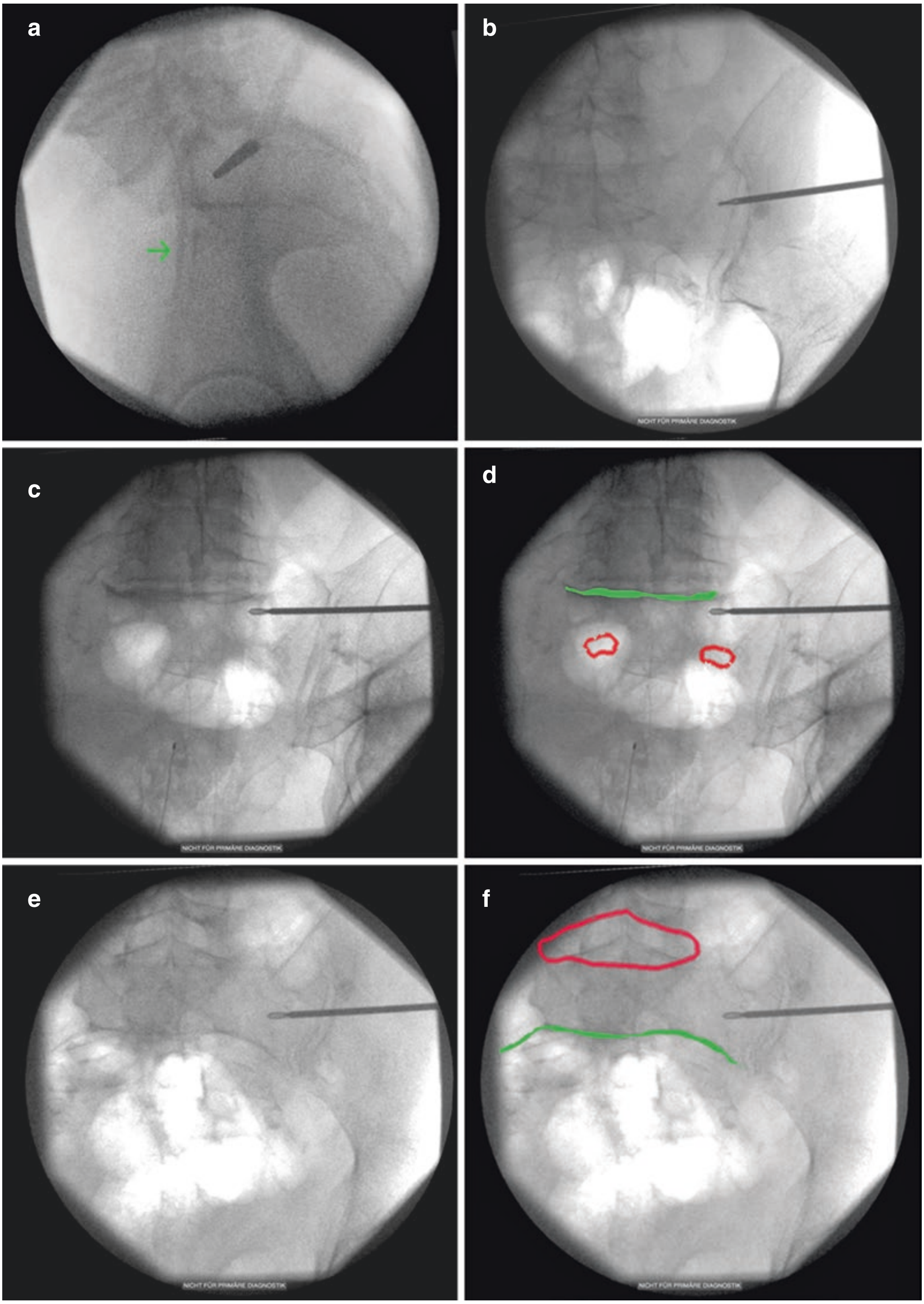

Fig. 13.6 Critical steps in placement of the transsacral drill wire. (**a**) In a lateral view, the center of the S1 body is identified and the tip of the drill wire placed in a central position. The insertion point for the transsacral osteosynthesis must be located underneath the iliac cortical density (*green arrow*) to prevent damage of the L5 nerve root. Subsequently, the position of the wire is checked in a.p. (**b**), pelvic outlet (**c**) and pelvic inlet (**e**) views. Following anatomical structures must be respected: (**d**) the neuroforamen S1 (*red*), the endplate of the sacral body S1 (*green*); (**f**) the spinal canal (*red*) and the anterior cortex of S1 (*green*)

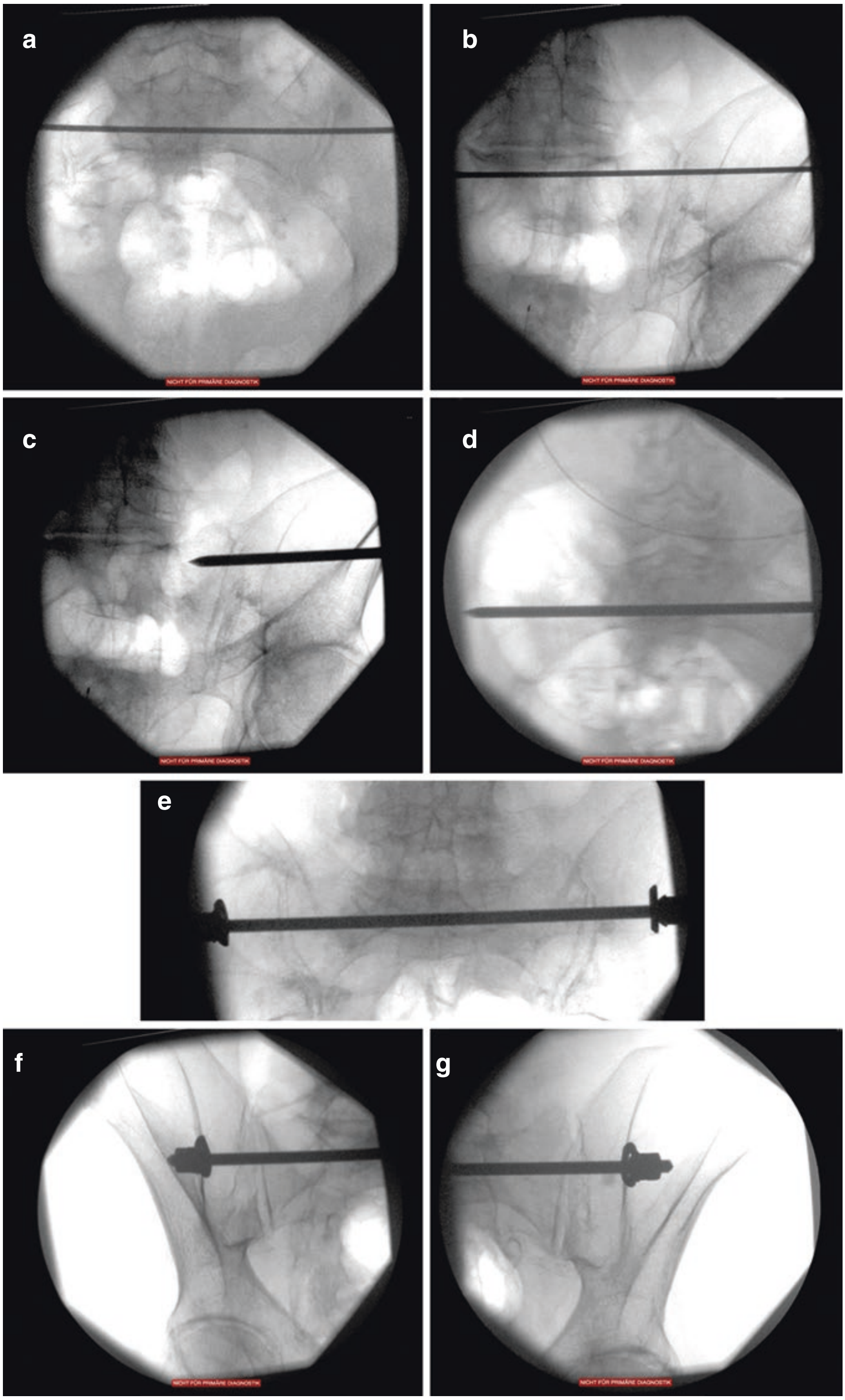

Fig. 13.7 Insertion of the transsacral bar. After placement of the drill wire (**a**: *inlet view*; **b**: *outlet view*), a canal is created using a 4.5 mm cannulated drill bit (not shown). Since the bar is not cannulated, the guide wire must be removed. The bar is inserted through the created drill hole under fluoroscopic control (**c, d**). Placement and tightening of the washers and the nuts is performed as described in the text (**e–g**)

bar removed by turning back the counter-nut on the ipsilateral side using a screw-wrench.

13.5 After-Treatment

After sacral bar fixation, the patients can usually be mobilized under full weight bearing. However, the decision about the after-treatment protocol is made individually according to the underlying pathology (Figs. 13.9, 13.10 and 13.11).

Fig. 13.8 Cutting the bar with the side cutter causes a plastic deformation of the bar end making removal of the bar later on difficult

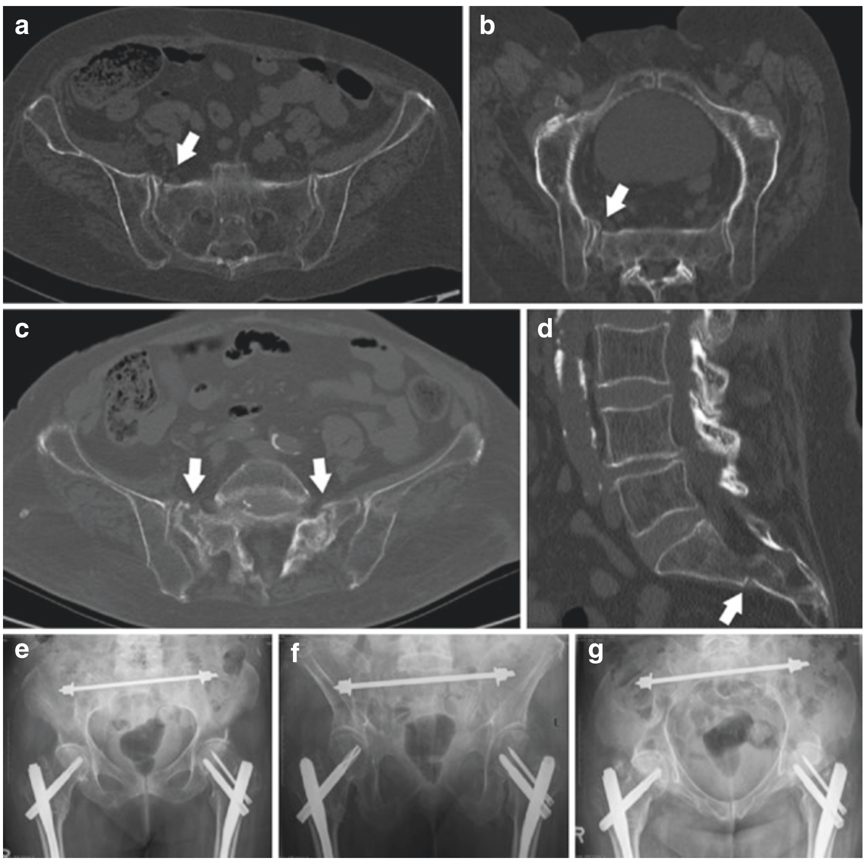

Fig. 13.9 An 87-year-old female patient suffered a non-displaced sacral ala fracture on the right after a low-energy domestic fall. (**a**) Transverse CT-reconstruction of the sacrum and (**b**) CT-reconstruction according to the pelvic inlet plane showing the non-displaced impaction of the sacral ala (*arrows*). Non-operative treatment was initiated. Due to persistent pain in the lower back, a follow-up including another CT scan was performed after 3 months. A progression of the pelvic ring collapse according to an FFP Type IVb lesion was noticed. (**c**) Transverse CT cut shows the bilateral fractures of the sacral alae (*arrows*). (**d**) Sagittal CT-reconstruction showing the horizontal component of the H-type fracture (*arrow*). There were no fractures in the anterior part of the pelvic ring. The fractures of the sacrum were fixed using a transsacral bar and the patient mobilized under full weight bearing. (**e**) A.p. pelvic overview, (**f**) Pelvic outlet, (**g**) Pelvic inlet views 1 year after surgery

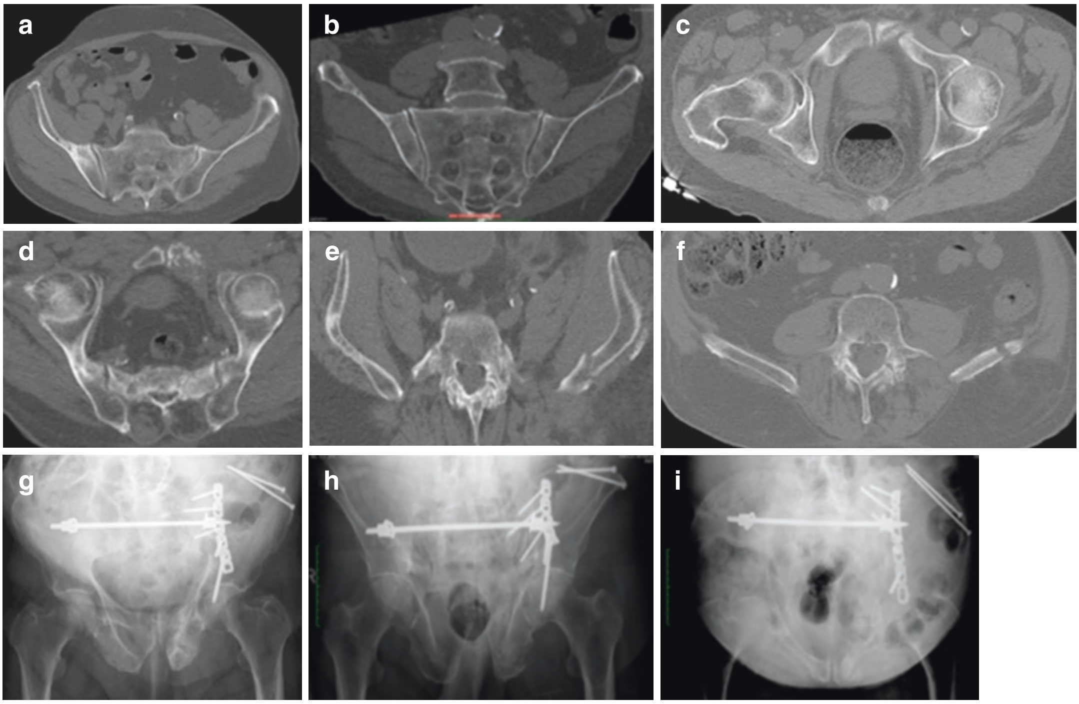

Fig. 13.10 A CT-scan was performed in an 87-year-old female patient for diagnostic reasons of lower back pain which was increasing in the last 6 weeks without any history of trauma. A non-displaced sacral ala fracture was found on the left according to a FFP IIb lesion. (**a**, **c**) Representative transverse CT-cuts and (**b**) coronal CT-reconstruction show a little impaction of the sacral ala and a fracture of the pubic bone on the left. Treatment was non-operative with pain medication and mobilization out of bed as tolerated. After 4 weeks, another CT-scan was performed because of increasing pain. Due to severe pain, the patient could not be mobilized out of bed anymore. (**d–f**) Representative transverse CT-cuts showing the progression of the pelvic ring collapse including fractures of the sacral alae on both sites and a fracture of the ilium on the left according to an FFP Type IVc lesion. Operative treatment was indicated because of progressing pelvic collapse. The sacral alae fractures were fixed using a transsacral bar. The fracture of the ilium was reduced and fixed using long lag screws and angular-stable buttress plate through the first window of the ilioinguinal approach. The anterior pelvis was not addressed because of bad skin conditions and dermatitis. The patient was mobilized under full weight bearing and regained the previous level of activities. (**g**) A.p. pelvic overview, (**h**) Pelvic outlet and (**i**) Pelvic inlet view taken 6 weeks after surgery

13.6 Outcomes

The transsacral bar osteosynthesis represents a simple and straightforward method for fixation of posterior pelvic ring lesions. However, there is still little evidence about its clinical use. Table 13.1 summarizes the results of the current literature on the use of the transsacral bar osteosynthesis in the elderly. These three studies showed a significant improvement in pain, need for analgesic medication, and function after early fixation of FFP. The complication rate seems to be low. However, further studies are needed to delineate the importance of this minimally invasive method for fixation of FFP.

Table 13.1 A thorough search of the medical literature databases revealed only three studies on the use of the transsacral bar osteosynthesis in the elderly

	n	Mean age (years)	Gender (f/m)	Follow-up	Complications	Outcomes (before surgery/at follow-up)
Sciubba et al. (2007) [22]	1	76	f	6 months	–	VAS: 6–8/10/1–2/10
Vanderschot et al. (2009) [8]	19	71.7	15/4	9 months (range: 3–24.5 months)	*n* = 2 hematoma	VAS (from 0 to 100mm): 67.8/100 mm/23.2/100mm
		range: 57–82				Narcotic analgesics:
						n = 15/*n* = 1
						NSAIDs: *n* = 2/*n* = 3
						Improvement in ADL after surgery at follow-up
Mehling et al. (2012) [12]	11	73	9/2	14 months (range: 3–43 months)	*n* = 1 temporary L5 root paresis	Rommens/Hessmann score [23]
		range: 54–86				*n* = 2 excellent
						n = 5 good
						n = 4 fair
						German Multicentre Pelvis Study Group-Score [24, 25]
						n = 2 excellent
						n = 5 good
						n = 4 fair
						– Fractures of the posterior pelvic ring healed in all cases

VAS visual analog scale for pain, *ADL* activity in daily living

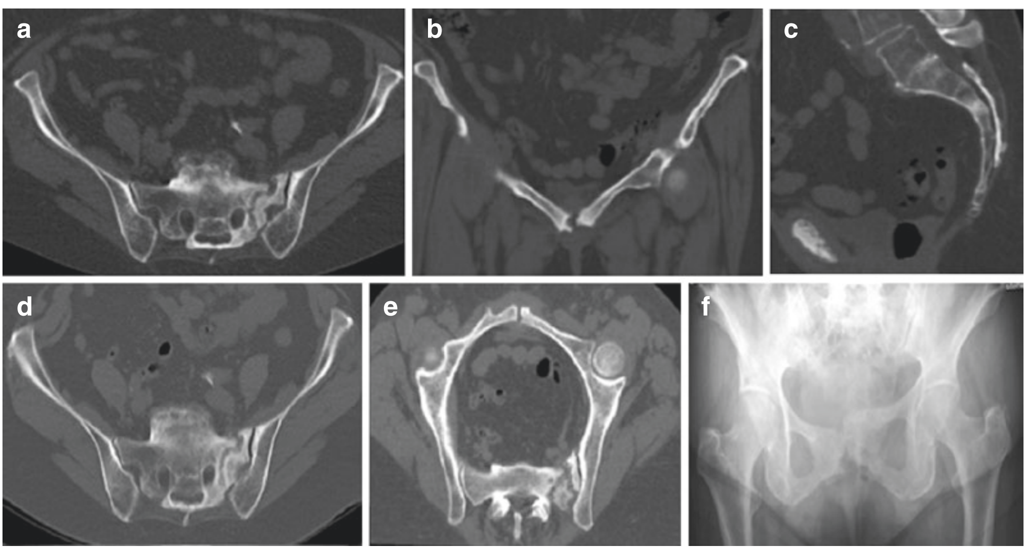

Fig. 13.11 Representative transverse (**a**), coronal (**b**) and sagittal (**c**) CT-reconstructions taken in a 77-year-old-female patient for diagnostic reasons of severe lower back pain without any history of trauma, showing a unilateral complete fracture of the sacral ala on the left (**a**) and radiological signs of symphyseal instability (**b**) according to an FFP Type IIC lesion. There was no transverse fracture of the sacrum (**c**). Although an indication for surgical fixation was seen in this case, the patient declined operative treatment. Three months later, the patient presented with increasing pain in the groin while walking. The respective transverse CT-cut of the sacrum (**d**) did not show any changes. However, CT-reconstruction in the pelvic inlet plane (**e**) showed additional new fracture lines in the sacrum. A one-leg-stance pelvic overview (**f**) demonstrated gross instability of the symphysis. The patient was treated with transsacral bar and IS-screw-fixation of the sacrum and a rigid, angular-stable double plate osteosynthesis of the pubic symphysis. (**g**) A.p. pelvic overview, (**h**) Pelvic outlet view, and (**i**) Pelvic inlet view taken 2 months after surgery

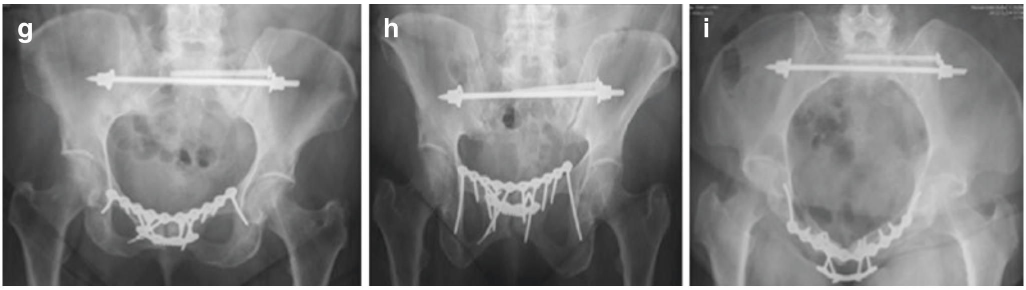

Fig. 13.11 (continued)

Conclusion

Transsacral bar osteosynthesis is a valuable alternative for rigid fixation of insufficiency fractures of the sacrum in FFP. An interfragmentary compression is created and the stability of the fixation does not depend on the mineral density of the cancellous bone. Thorough preoperative planning and analysis of the transsacral corridor is mandatory to prevent possible complications. This minimally invasive method seems to be safe and effective, if performed correctly.

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Bridging Plate Osteosynthesis

14

Thomas Hockertz

14.1 Introduction

Posterior bridging plate osteosynthesis is an established stabilization technique for high-energy posterior pelvic disruptions, which already has been described in the 1990s [1, 2]. In the original technique, a large-fragment reconstruction plate is bent around the posterior iliac crests near to the posterior iliac spines and lies posterior to the sacrum (Fig. 14.1). Thereafter, several modifications for plate insertion have been developed. In one modification, two tunnels in the posterior iliac wings near to the posterior iliac spines are pre-drilled. A pre-bent transiliac plate is placed behind the sacrum. Both ends of the plate are inserted through the tunnels and are in close contact to the posterior ilium. This prevents hardware disturbing the soft tissues below the skin in the gluteal region (Fig. 14.2) [1]. In a similar technique, osteotomies of the posterior superior iliac spines and the spinal process of the sacrum are performed and bone blocks with the width of the plate removed. Once the plate has been inserted, the bone blocks are re-inserted and fixed with small screws (Fig. 14.3a, b) [3]. The plate can also be inserted more distally at the notch below the posterior inferior iliac spine

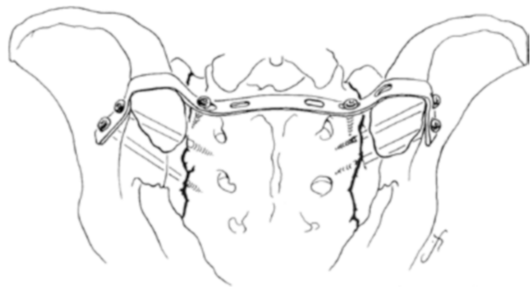

Fig. 14.1 Drawing of the posterior bridging plate osteosynthesis with the plate being bent around the posterior iliac crests. On each side, two longer screws perforate the iliosacral joints and end in the sacral ala. One additional screw is drilled directly into the sacral ala from posterior (from Kellam et al. [2])

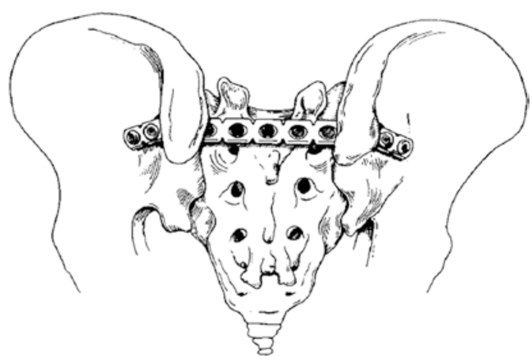

Fig. 14.2 Drawing of the posterior bridging plate osteosynthesis with both plate ends perforating tunnels through the posterior ilium near to the iliac crests. The pre-bent transiliac plate is placed behind and near to the sacrum. Both ends of the plate are in close contact to the posterior ilium (from Albert et al. [1])

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_14

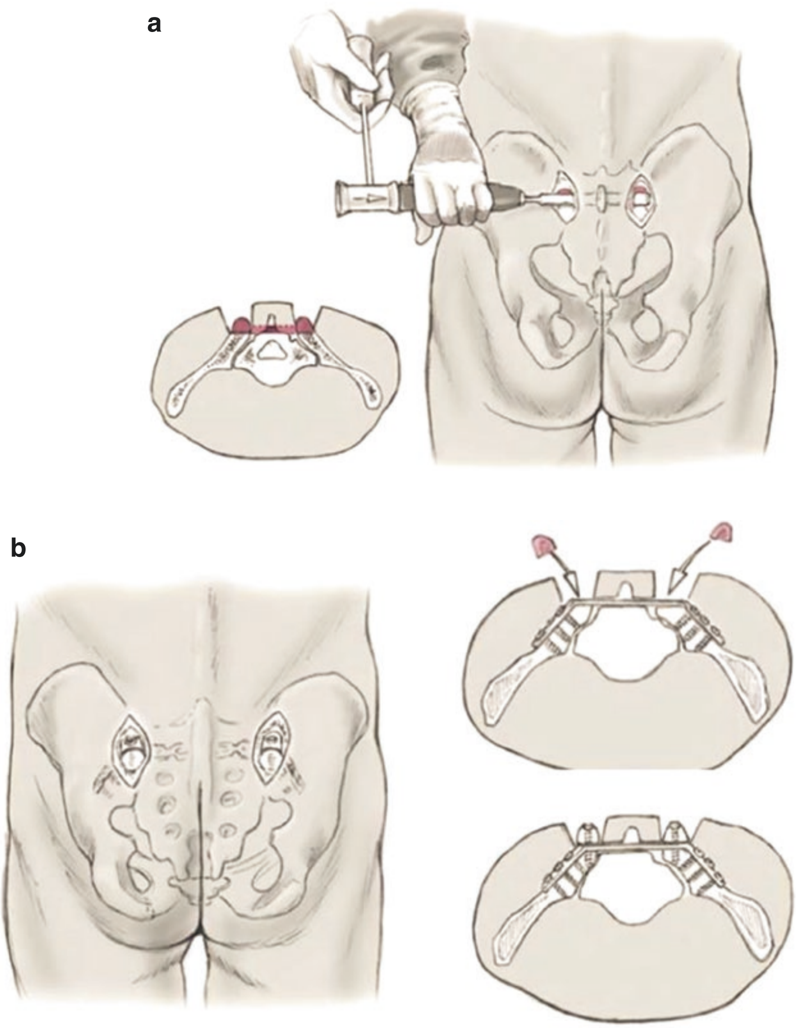

Fig. 14.3 (**a**) Drawing of the posterior bridging plate osteosynthesis. Preparation of a subcutaneous tunnel between both posterior iliac crests. Osteotomies of the posterior superior iliac spines and the spinal process of the sacrum are performed and bone blocks with the width of the plate removed from the iliac crests. (**b**) Insertion of a pre-bent plate, which is in close contact with the sacrum and the posterior ilium. After plate fixation, the osteotomized bone blocks of the iliac crests are re-inserted and fixed with small screws (from Dolati et al. [3])

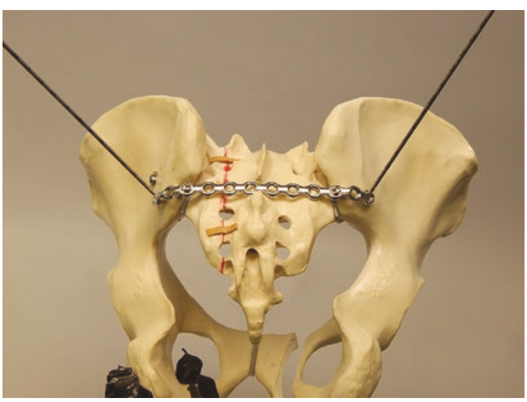

Fig. 14.4 Artificial model of disrupted pelvic ring with left-sided transforaminal fracture posteriorly and right-sided pubic bone fracture anteriorly. View from posterior. A bridging plate is placed behind the sacrum just below the posterior inferior iliac spines. Both edges of the plate are bent to optimally fit on the posterior ilium just above the greater sciatic notch

(Fig. 14.4). This distal plate location has the advantage of the implant being very near to the posterior cortex of the sacrum. Long screws can be inserted through the two marginal plate holes on each side. One screw goes in the anterior direction parallel to the sacroiliac joint, the other screw in the superior direction parallel to the iliac crest (Fig. 14.4). An angular-stable plate may also be used in the same position (Fig. 14.5) [4]. In a comparative biomechanical study, Albert et al. demonstrated that the strength of the transiliac plate fixation was equal to that of transiliac sacral bar fixation with one or two bars. If applied for fixation of a disrupted sacroiliac joint, the transiliac plate fixation restores sufficient stability, given that the anterior injury is reduced and fixed appropriately, as well [1]. More recently, angular stable pre-bent plates have been

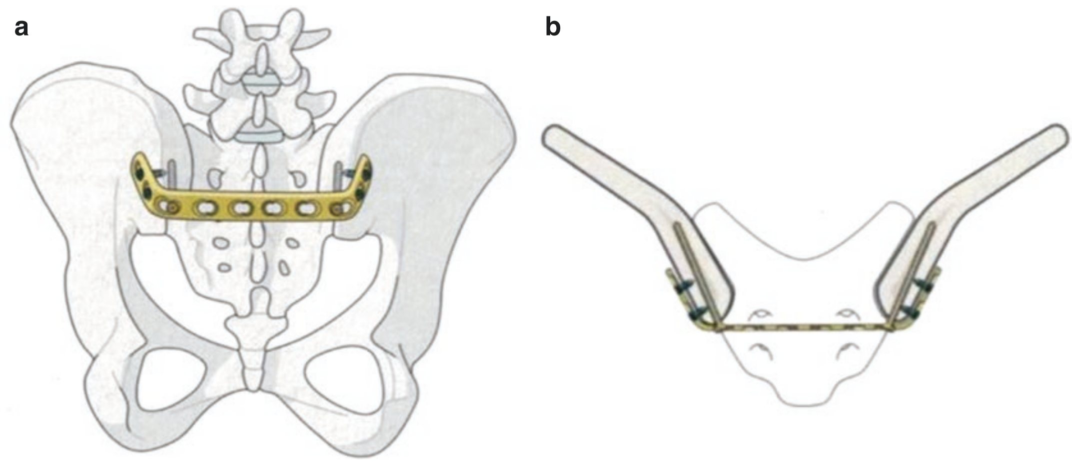

Fig. 14.5 (**a**) Angular-stable plate placed behind the sacrum just below the posterior inferior iliac spines. (**b**) Long screws can be used through the holes, positioned above the iliac crests (from Wagner and Frigg [4])

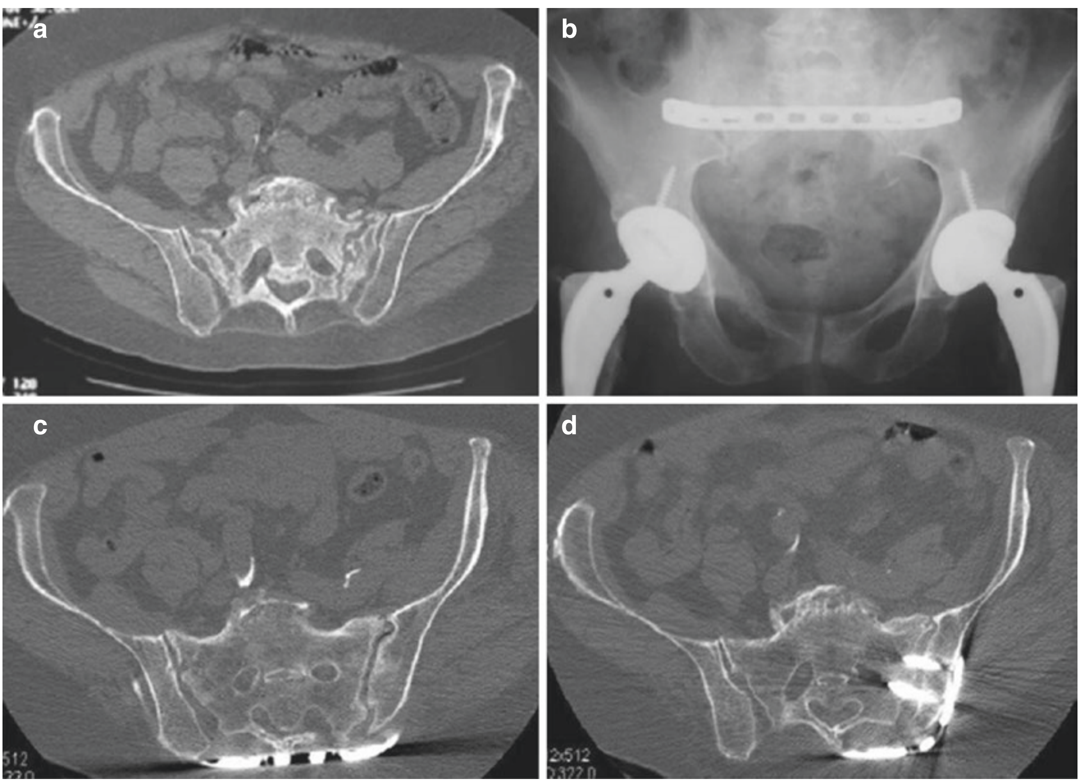

Fig. 14.6 Eighty-two year-old female patient with bilateral sacral ala fractures (FFP Type IVb). (**a**) transverse CT-reconstruction of the posterior pelvic ring showing bilateral sacral fractures with areas of bone resorption. (**b**) A.p. pelvic overview 1 year after surgical stabilization with posterior bridging plate osteosynthesis. The right-sided pubic ramus fracture, which was not treated surgically, is healed. (**c**, **d**) Transverse CT-reconstructions showing complete healing of both sacral ala fractures

used in elderly patients with FFP (Fig. 14.6) [5]. They create higher fixation stiffness in the posterior pelvic ring than non-angular stable plates [6]. In all techniques, less invasive approaches with two small incisions at the two posterior iliac spines are used (see Sect. 14.3).

14.2 Indications

Stabilization with a transiliac locked compression plate is indicated in mono- or bilateral sacral insufficiency fractures or impending insufficiency fractures with severe dorsal pain and bone edema in the MRI. Further indications represent trauma or painful non-unions of the dorsal and/or anterior pelvic ring. Usually, fractures with minor dislocation of the anterior pelvis are sufficiently stabilized with the dorsal plate osteosynthesis to achieve bony healing (Fig. 14.7). Indications for

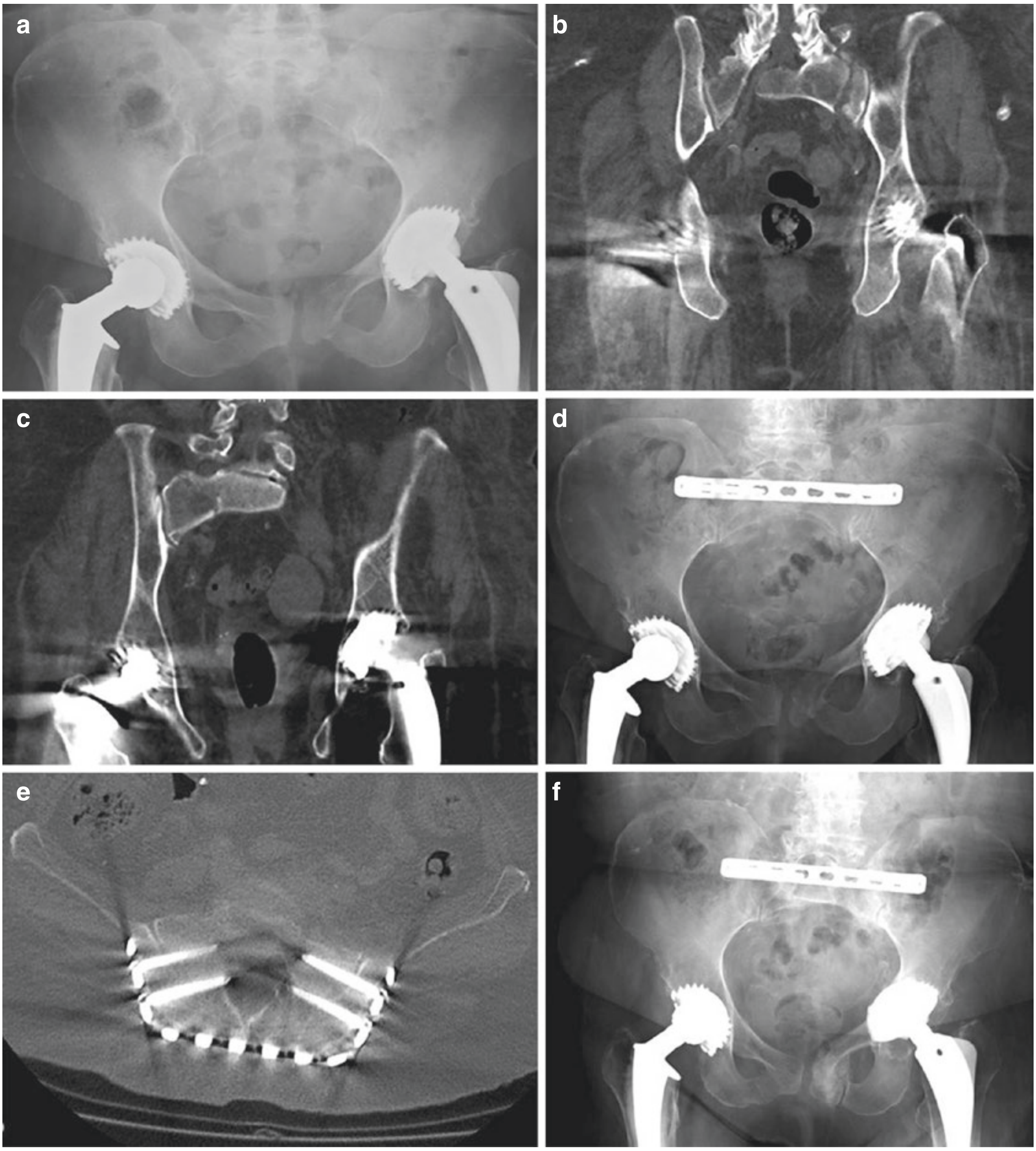

Fig. 14.7 Seventy-seven-year-old female with immobilizing pain 3 weeks after a domestic fall. She already had bilateral total hip endoprosthetic replacement. (**a**) The a.p. pelvic overview reveals a left-sided slightly displaced fracture of the pubic bone. (**b**, **c**) Coronal CT-reconstructions show left- and right-sided sacral ala fractures. (**d**) Surgical treatment with angular stable posterior bridging plate osteosynthesis. The fracture of the anterior pelvic ring is not addressed. (**e**) Transverse CT-cut through the posterior pelvic ring showing the close contact between the plate and the posterior cortical surface of the sacrum and the posterior ilium. On both sides, two longer screws perforate the iliosacral joint and end in the sacral ala. (**f**) A.p. pelvic overview one and a half year after surgical treatment. The fractures healed. The patient is symptom-free and independent for activities of daily life

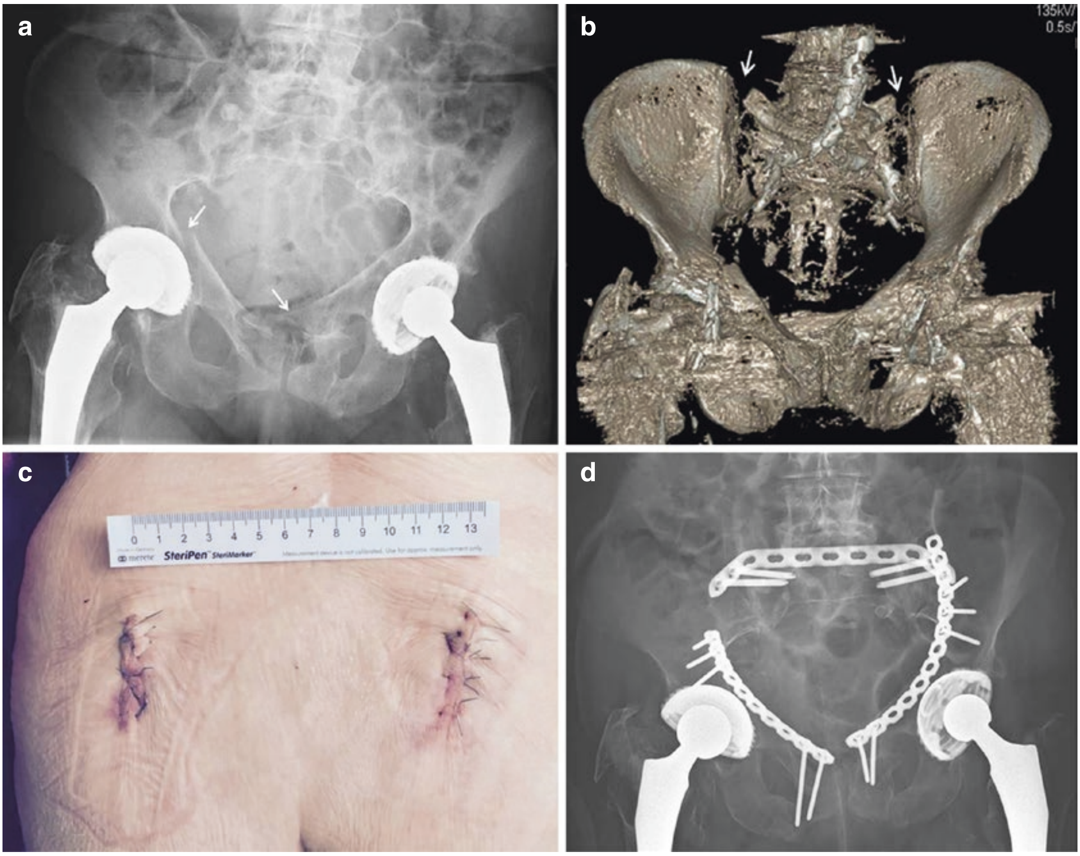

Fig. 14.8 Eighty-eight-year-old female, who was admitted after a fall in her nursing home. (**a**) A.p. pelvic overview reveals a periprosthetic acetabular fracture on the right and a displaced pubic bone fracture on the left (*white arrows*). The patient had bilateral total hip replacements. (**b**) 3D–CT-reconstruction of the pelvic ring reveals severe osteoporosis of the posterior pelvic ring with bilateral sacral ala fractures (*white arrows*). (**c**) The posterior and anterior instabilities were treated surgically. The posterior bridging plate could be inserted through two small incisions near to the posterior iliac crests. (**d**) A.p. pelvic overview 5 months after surgery. Posterior pelvic ring fixation with a bridging plate and 4 angular stable screws going into the sacral ala. Insertion of two reconstruction plates through a modified Stoppa approach for bilateral instabilities of the anterior pelvic ring. The patient is mobile and self-supporting

an additional anterior stabilization represent posterior pelvic injuries in combination with major anterior fracture dislocation or rupture of the pubic symphysis. In these cases, anterior plate stabilization is performed through a Pfannenstiel incision and Stoppa approach (Fig. 14.8).

14.3 Surgical Technique

The patient is placed in prone position on a radiolucent table, favorably carbon table. Before sterile draping, pelvic a.p., inlet and outlet views are made with the fluoroscope for control of image quality and identification of the most important landmarks (see Sect. 11.5). The complete area of the buttocks including the lower lumbar spine is draped.

Following single-shot antibiotic prophylaxis, two vertical skin incisions with a length of 4–5 cm lateral to the posterior superior iliac spines are made. After dissection of the subcutaneous tissue, the gluteus maximus muscle and the thoracolumbar fascia are visualized and sharply dissected off the bone. It is important to identify and secure the fascia in order to guarantee a subfascial insertion of the plate, which enables closure of the fascia above the implant at the end of the procedure. A chisel is used to dissect the muscles from the lateral aspect of the posterior iliac spine and posterior ilium, and to prepare a

Fig. 14.9 Insertion of the angular stable bridging plate. Two vertical incisions lateral to the posterior superior iliac spines have been made. A pre-bent plate is inserted in the tunnel, which has been developed below the fascia between the two incisions. The plate is then turned 180° around its longitudinal axis, giving a good fit of the plate ends to the posterior ilium

subfascial tunnel towards the contralateral side. In cachectic patients, the posterior iliac crest has to be partially removed with a rongeur to allow deeper insertion of the plate in order to avoid postsurgical soft tissue complications.

A small fragment locking compression plate (LCP, Depuy Synthes) with 10–12 holes is used and bent at both ends at the third plate hole approximately 55–60°. After bending, the LCP is slide-inserted through the tunnel and into the prepared grooves and turned axially by 180° (Fig. 14.9).

It is of major importance to verify the subfascial insertion of the plate. The plate positioning is now verified with the fluoroscope in the a.p., inlet and outlet views. The plate is fixed with 4.5 mm cortical screws of 65–85 mm of length in each posterior ilium (Fig. 14.5). The long screws push the plate tightly to the posterior ilium. Consecutively, locking screws are placed in the first and second screw hole on both bent ends of the plate. Therefore, an additional stab-incision may be required. Predrilling is performed through three cortices (inner and outer cortex of the posterior ilium and lateral sacrum). The already positioned cortical screws may hinder drilling. In this case, the plate is secured with monocortical locking screws. Subsequently, the cortical screws are removed, and the monocortical locking screw replaced by 45–60 mm locking screws. The length of the locking screws depends on whether the screws are supposed to end before or in the sacral ala.

Adequate soft tissue coverage is essential for the success of posterior bridging pelvic plate osteosynthesis. Therefore, the thoracolumbar fascia and the fascia of the gluteus muscle are closed tightly over the inserted plate followed by subcutaneous and cutaneous suturing.

Pain-adapted full weight-bearing is immediately possible; however medical prophylaxis against thromboembolism has to be administered until full mobilization. Implant removal is usually not required unless implant-associated discomfort is present.

14.4 Results and Personal Experience

Krappinger et al. described 2007 a series of 31 patients with high-energy type C injuries, who were treated with posterior non–angular stable bridging transiliac plate osteosynthesis with average follow-up of 20 months. There was a loss of reduction in 2 out of 23 patients (8.7%) [6].

Ayoub et al. published 2016 a series of 42 patients with high-energy type C pelvic ring injuries, who were treated with a standalone posterior transiliac bridging plating. Average follow-up was 22 months. There was an adequate stability and good control of reduction. The authors recommend the procedure as simple, with minimal incisions, short operation time, less radiological exposure and less iatrogenic injuries. No secondary dislocations have been reported [7].

There is little data about angular stable posterior bridging plate osteosynthesis in patients with FFP [5]. In an 8-year period (2007–2015), we treated 55 patients with a fragility fracture of the sacrum with a posterior bridging locked compression plate (Fig. 14.10). The patients had an average age of 76 years (60–99). Forty-nine patients were women, 6 were men, the female/male ratio being 8.2/1. There were no neurovascular complications. There was only one deep wound infection (1.8%). In this case we had to remove the implant. All other patients could be

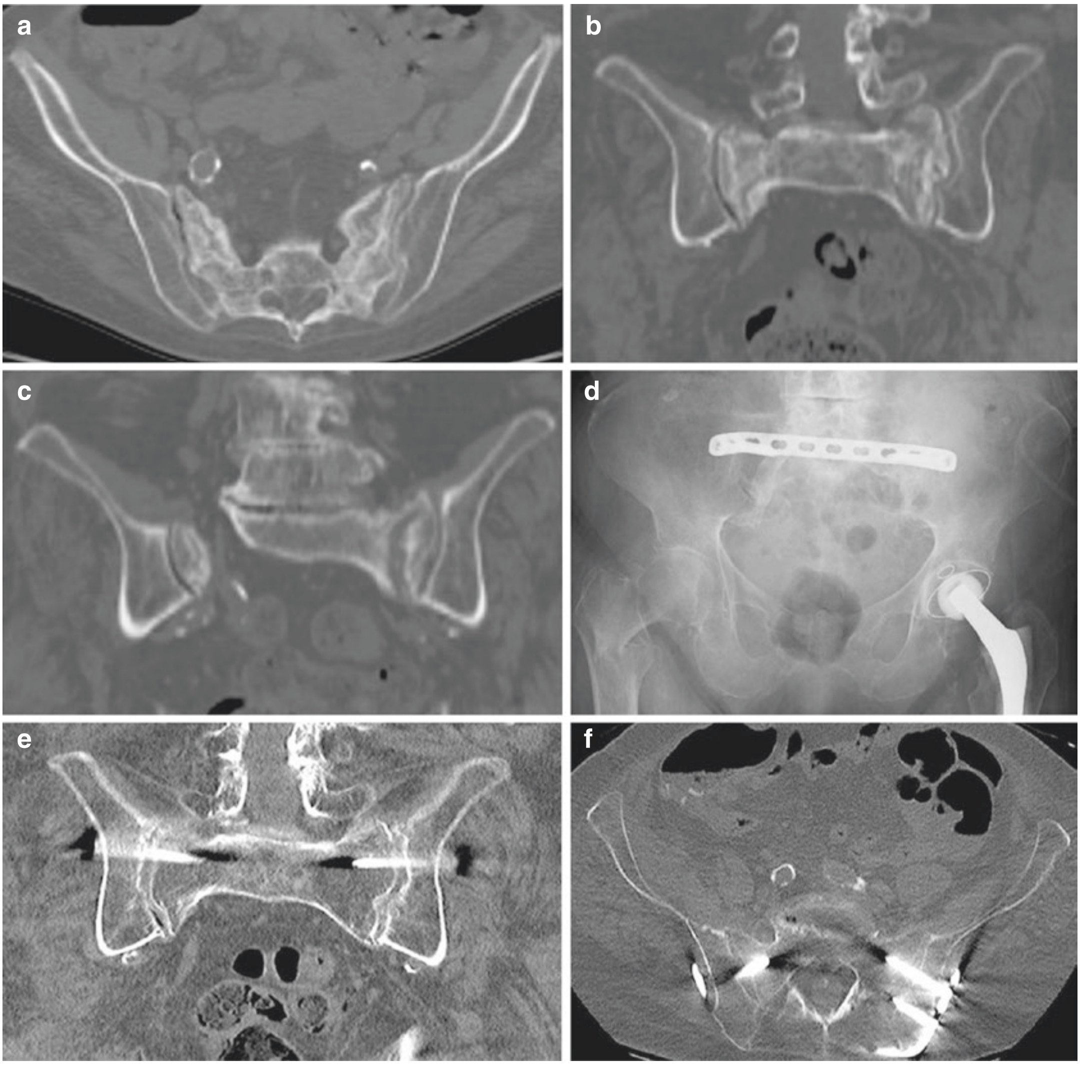

Fig. 14.10 Eighty-five-year-old female with history of a fall. No diagnostics were performed and low lumbar pain was treated with analgesics and limited mobilization. Later on, patient was admitted because of increasing pain intensity and frequency. (**a**) Transverse CT-reconstruction through the posterior pelvis reveals a chronic bilateral sacral ala fracture. (**b**, **c**) Coronal CT-reconstructions reveal a bilateral sacral ala fracture with areas of fracture widening and bone resorption indicating the presence of a chronic instability. (**d**) A posterior angular stable bridging plate had been inserted. A.p. pelvic overview taken 6 years after surgical treatment at the occasion of a new admission due to a right-sided pertrochanteric hip fracture. (**e**, **f**) Coronal and transverse CT-reconstructions through the posterior pelvic ring show a complete healing of the sacral ala fractures. The patient had been independently mobile until she suffered the pertrochanteric fracture

mobilized with pain adapted weigt-bearing immediately after surgery.

Conclusions

Posterior angular stable bridging plate osteosynthesis is a simple, safe, quick and reliable stabilization technique for patients with FFP. Special attention should be paid to subfascial insertion of the plate and adequate soft tissue coverage to avoid postoperative soft tissue disturbances. More clinical data are needed to assess advantages and drawbacks of this technique, when compared with alternative procedures, and to identify its optimal indications.

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15 Transiliac Internal Fixator

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15.1 Indications

The transiliac internal fixator is a posterior bridging stabilization device and an alternative to other posterior bridging techniques such as transsacral bar fixation (see Chap. 13) or posterior bridging plate osteosynthesis (see Chap. 14). Transiliac internal fixation is suitable for the treatment of simple unilateral osteoporotic sacral fractures in the central, transforaminal or alar region of the sacrum. This method is also useful in sacroiliac joint disruptions but not in transiliac injuries. In bilateral injuries, additional stabilization of the free-floating sacrum by either lumbopelvic fixation or additional iliosacral screw fixation is advisable. In cases of bone defect or severe comminution of the fracture, which is seldom in osteoporotic fractures, neutralization of vertical shear forces by lumbopelvic fixation may also be necessary in unilateral injuries.

15.2 Biomechanical Data

Dienstknecht et al. [1] compared the transiliac internal fixator to both posterior iliosacral screw fixation and anterior plate fixation of the sacroiliac joint in a biomechanical experiment. An AO type C1.2 injury with unilateral disruption of the sacroiliac joint and disruption of the pubic symphysis was created in fresh frozen human pelvises. The disruption of the pubic symphysis was fixed by an anterior plate and the sacroiliac joint injury by either the transiliac internal fixator using the USS fracture system (Depuy Synthes), anterior double plating of the sacroiliac joint with two 3-hole 4.5 mm dynamic compression plates (Depuy Synthes) or with two 6.5 mm cannulated iliosacral screws with partial 32 mm thread (Depuy Synthes). The biomechanical performance was tested in a single leg stance model and no significant differences between these three competitive options for treatment were detected.

Salášek et al. [2] investigated the stiffness of the posterior fixation of a transforaminal sacrum fracture by two sacroiliac screws compared to a transiliac internal fixator in a finite element analysis. In this computed model, the authors calculated higher stiffness and lower stress in the transiliac internal fixator model compared to the sacroiliac screws. They concluded that the transiliac internal fixator provides a lower risk of

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_15

over-compression and thus is the superior method for fixation of transforaminal sacrum fractures.

15.3 Surgical Technique

The patient is placed in prone position on a radiolucent table. Intraoperative fluoroscopic pelvic a.p. and inlet/outlet views are mandatory. Basically, any internal screw-rod system for posterior thoracolumbar spine fixation can be used. The use of a polyaxial system is probably more convenient than monoaxial systems, in which exact bending of the connecting transverse rod is necessary. Low-profile systems are more easily covered by the fascia, which is an important factor to avoid soft tissue problems. Cement augmentation is an option to increase primary stability of the bone implant interface.

The principle of this technique is to insert one pedicle screw in each ilium and connect them with a transverse rod. This provides angular stable fixation of the broken hemipelvis to the intact one. There are two different techniques concerning the insertion site of the screws in the ilium and for the screw direction.

15.3.1 The Transiliac Internal Fixator with Screws in Cranio-Caudal Direction

In the technique described by Füchtmeier et al. [3], pedicle screws are inserted in the posterior ilium 1–2 cm cranial to the superior posterior iliac spine parallel to the posterior gluteal line in a cranio-caudal direction (Fig. 15.1).

The contours of the superior posterior iliac spine and the posterior iliac crest are palpated and marked on the skin. A 3 cm longitudinal skin incision is made on each side 1 cm lateral to the superior posterior iliac spine. The insertion site for the pedicle screws is 1–2 cm cranial to the superior posterior iliac spine and is prepared by incision of the fascia. The iliac crest is perforated at the insertion site with an awl. Depending on the internal screw-rod system that is used, the canal for the screw is prepared with a conventional or a cannulated pedicle finder. If a cannulated system is used, a wire can be inserted via the cannulated pedicle finder. An intraoperative fluoroscopic control prior to screw implantation facilitates correct screw position.

In this technique, it is important to insert the screw in the sagittal plane as much horizontal as possible, which corresponds with an angle to the longitudinal axis of maximal 30° to avoid soft tissue irritation by a prominent implant. A connecting transverse rod is inserted between the both pedicle screws below the fascia. Compression or distraction and other reduction maneuvers can be performed before tightening the nuts that connect the rod to the pedicle screws. The implant position is verified by fluoroscopic control. If closed reduction has been carried out, the position should be controlled with anterior-posterior pelvis as well as inlet and outlet views. After correct implantation of the transiliac internal fixator, the fascia is sutured over the implants and the wound closed (Fig. 15.2).

For better biomechanical stability, the use of large diameter screws (e.g. 7 mm diameter) is advisable and cement augmentation in osteoporotic bone may be helpful. Due to anatomical limitations, the maximal screw length is, however, limited to about 60 mm. This may be a disadvantage in osteoporotic bone.

The advantage of this technique is the low risk for soft tissue complications. The insertion site and direction of the screws facilitate easy coverage of the implants by the fascia. Since the insertion site is cranial to the superior posterior iliac spine, the patient does not lie directly on the implant. This is especially important in very slim patients. (Fig. 15.3).

When bulky implants are used, pressure sores and skin break-down may happen and then discredit the method. In case of major posterior soft tissue damage such as Morell-Lavallée lesions open posterior fixation is not recommended.

15.3.2 The Transiliac Internal Fixator with Screws in Dorso-Ventral Oblique Direction

In the technique described by Schmitz et al. [4], a different insertion point and direction for the

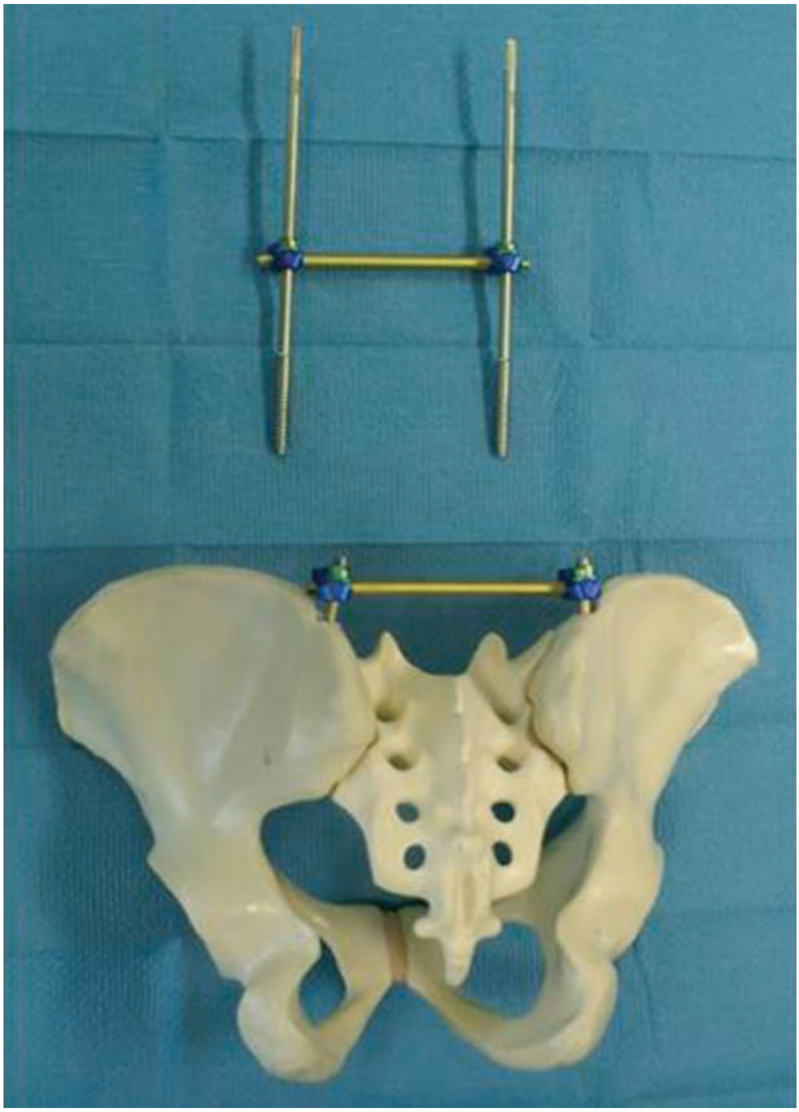

Fig. 15.1 Transiliac internal fixator with Schanz' screws placed in superior to inferior direction in a pelvic model

ilium screws are used. The screws are inserted from the superior posterior iliac spine and directed towards the anterior inferior iliac spine (Fig. 15.4). This bone corridor was suggested for lumbopelvic stabilization by Schildhauer et al. and allows screw lengths of up to 141 mm in male and 129 mm in female patients [5]. To take advantage of this possibility, either a pedicle screw system that offers such long screws or a Schanz' screw system should be used. We prefer a Schanz' screw system, because it allows a variable screw length. The Schanz' screw is inserted in the ilium until it provides good stability, which the surgeon can feel during insertion by the increasing torque. The use of screws with a blunt tip (not self-drilling) is recommended to avoid penetration of the ilium cortex and allow the screws to creep along the cortical walls within the corridor. Compared to long pedicle screws, the thread of Schanz' screws is shorter and the fixation in the bone may be weaker, but this on the other hand makes the stabilization less rigid with lower stress concentration on the implant outside the bone and, therefore, may reduce the risk of implant failure.

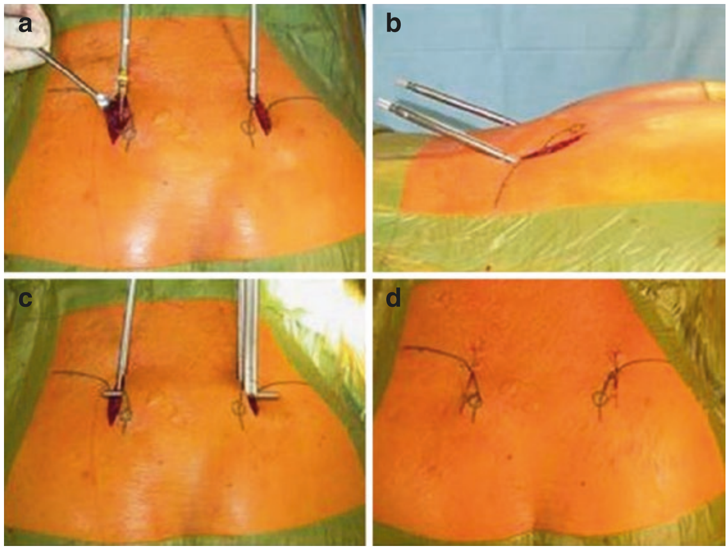

Fig. 15.2 Operative technique of transiliac internal fixation with ilium screws placed in superior to inferior direction. (**a**) A longitudinal skin incision of about 3 cm of length is made on each side 1 cm lateral to the superior posterior iliac spine. The screws are inserted in the sagittal plane. (**b**) The screws are directed as horizontal as possible, at an angle to the coronal plane of maximal 30°. (**c**) A connecting transverse rod is inserted between both pedicle screws below the fascia. (**d**) The fascia is sutured over the implants and the wound is closed (from Füchtmeier B et al. [3])

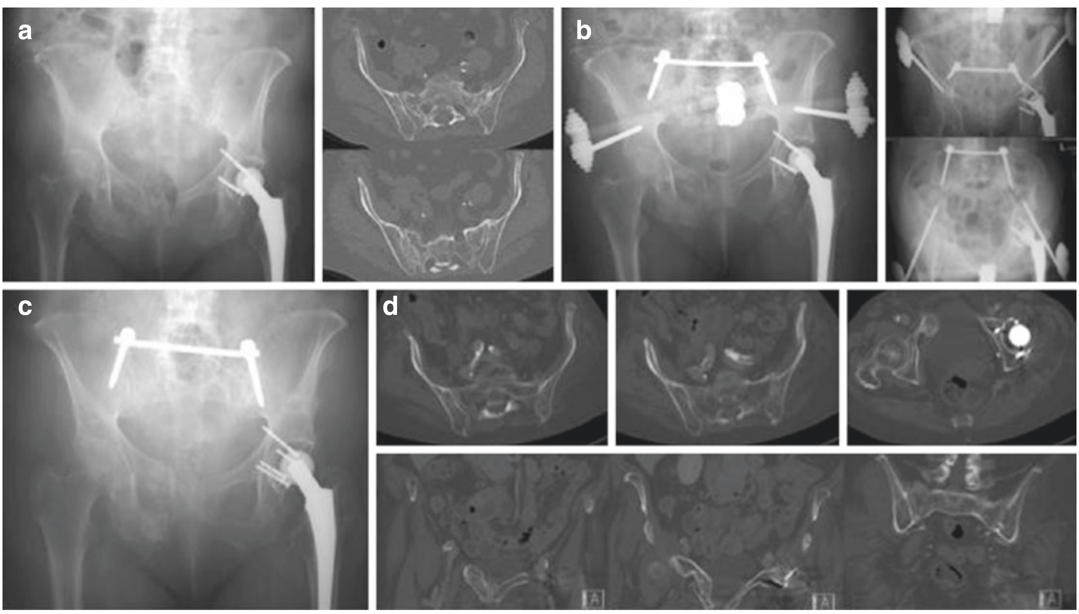

Fig. 15.3 (**a**) A.p. pelvic overview and transverse cuts through the posterior pelvis of a 73-year-old, polymorbid and cachectic female patient. A right-sided pubic ramus fracture (conventional pelvic overview) and bilateral sacral ala fractures (CT-cuts) are shown. The patient was treated for 3 months non-operatively resulting in increasing groin pain and severe lower back pain on the right. (**b**) Postoperative a.p., inlet and outlet pelvic overviews after transiliac internal fixation with the USS II system (Depuy Synthes) and a supraacetabular external fixator. The screws for the transiliac internal fixator were inserted in superior to inferior direction. (**c**) The a.p. pelvic overview 6 months after surgery shows healing of fractures. The external fixator was removed 6 weeks after surgery. The patient is almost free of pain. Loosening of the implants is noticed but expected after SI-joint transfixation. The transiliac internal fixator was removed because of discomfort. (**d**) Transverse and coronal CT cuts through the pelvic ring 4 years after surgery show healed fractures of the right pubic ramus and of the sacrum ala. The canals of the screws are still visible

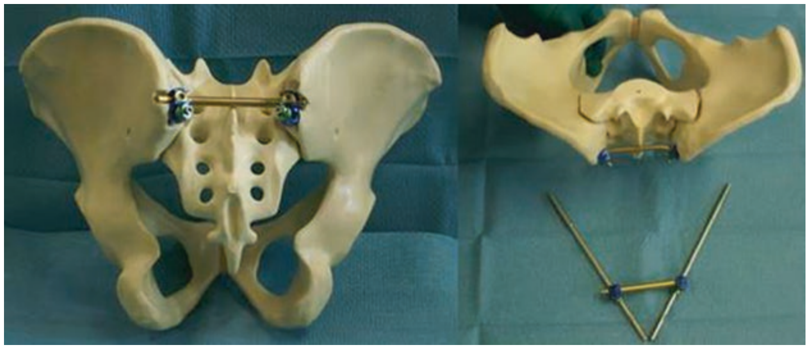

Fig. 15.4 Transiliac internal fixator in a pelvic model with Schanz' screws in posterior to anterior direction

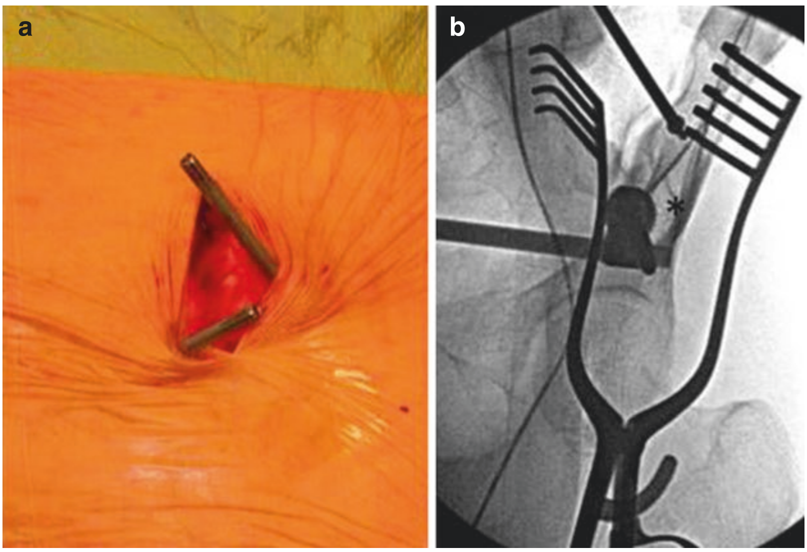

Fig. 15.5 (**a**) A midline incision is made between the superior posterior iliac spines. The spines are exposed by subcutaneous dissection. The insertion points of the Schanz' screws are identified under fluoroscopic obturator-outlet oblique views. (**b**) Intraoperative obturator-outlet oblique view. The *asterisk* (*) on the figure is located in the center of the teardrop-like figure representing the canal for screw insertion and the entry point for the screw. An anterior supraacetabular internal fixator is already in place

Although two separate short incisions or transverse incisions slightly cranial to the posterior superior iliac spines are possible, we prefer a longitudinal midline incision at the level L5/S1 to avoid having the incision at the conjunction of the iliac screws to the connecting transverse rod. After subcutaneous preparation towards the posterior superior iliac spines, a longitudinal incision of the fascia about 1 cm medial to the posterior superior iliac spine is carried out and the muscle insertions are mobilized from the bone. The next step is to define the entry point and direction of the Schanz' screws in the ilium. In an outlet-obturator view the supraacetabular bone canal is identified as a tear drop figure by fluoroscopy. We usually start with 30° obturator oblique and 20° outlet position of the C-arm and adjust the position until we have an axial view of the corridor. The entry point of the screw is situated in the center of this teardrop figure and the direction of insertion is parallel to the x-ray beam (Fig. 15.5).

When using a cannulated system, the cortex is penetrated with a cannulated pedicle finder and the guide wire inserted through this instrument and advanced into the ilium as far as possible. The depth of the wire and its position superior to the sciatic notch is verified fluoroscopically in iliac oblique view. The Schanz' screw is then inserted over the guide wire as deep as possible until a good purchase of the screw in the bone is reached. Removal of a small bone block at the posterior superior iliac spines is often necessary to countersink the connection rod deep enough, which facilitates closure of the fascia over the implant. This is especially important in thin patients. The transverse rod is inserted underneath the fascia from one to another side and connected to the iliac screws (Fig. 15.6). Bending of the transverse

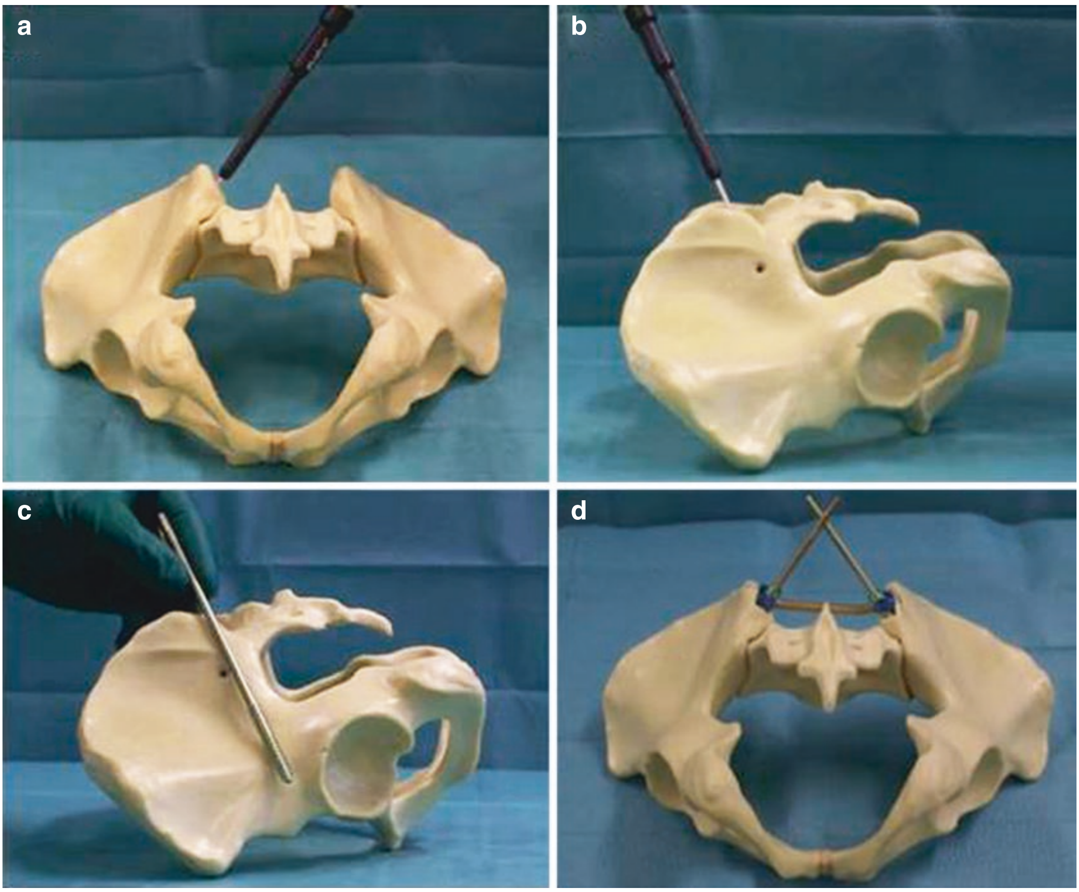

Fig. 15.6 Surgical technique of transiliac internal fixator with Schanz' screws oriented in posterior to anterior oblique direction. (**a**) Pelvic inlet view on the pelvic model. (**b**) Lateral view on the pelvic model. Preparation of the canal between the posterior superior and anterior inferior iliac spines with a cannulated pedicle finder. Consecutively, a guide wire is inserted through the cannulated pedicle finder and advanced in the bone as far as possible. A cannulated screw is inserted over the wire. (**c**) Lateral view on the pelvic model, showing direction and length of the Schanz' screw. (**d**) Pelvic inlet view of the pelvic model, showing the transiliac internal fixator before the Schanz' screws have been cut. The ends of the transverse rod are bent to facilitate fixation to the iliac screws without exceeding the maximum angulation of the system. A small bone block from the posterior superior iliac spine has been removed to allow closure of the fascia over the implant after cutting the screws

rod closely to its ends may be necessary to facilitate proper fixation of the rod to the iliac screws. The amount of bending depends on the maximum possible angulation within the internal fixator system used. Before tightening the clamps, reduction maneuvers or compression to the fracture can be applied using the Schanz' screws as joystick. In case of severe osteoporosis, cement augmentation at the tip of the Schanz' screws can improve implant fixation. Cement augmentation is done as last part of the procedure, after finishing the reduction maneuvers and after fixation of the transverse rod to the Schanz' screws. Applying cement after manipulation avoids loosening of the cement during manipulation. After cutting the Schanz' screws with a bolt cutter, the fascia is closed over the implants and the wound is closed in layers (Fig. 15.7).

15.4 Postoperative Care

Patients with unilateral fragility fracture of the pelvis that are treated with the transiliac internal fixator are mobilized with full weight bearing as tolerated. In case of a highly unstable unilateral injury, partial weight bearing of the injured side is recommended.

In geriatric patients, hardware removal is only carried out if mechanical irritation by the implant causes significant discomfort.

15.5 Results

In a prospective study including 31 patients and a clinical follow-up of 2 years, Füchtmeier et al. showed that none of the 62 pedicle screws inserted into the ilium in a cranio-caudal direction was positioned incorrectly [3]. Furthermore, no neuro-vascular lesions were caused by this procedure. Only one case of loosening of a pedicle screw and two superficial wound infections occurred. The time needed for the implantation of the transiliac internal fixator was 28.4 ± 6.1 min (interval: 20–45 min). The estimated intraoperative blood loss was less than 50 mL. The time for intraoperative fluoroscopy was 0.3 ± 0.2 min (confidence interval: 0.1–1.0 min).

In a retrospective study, Schmitz et al. analysed 15 patients with fragility fractures of the pelvis that needed surgical treatment [4]. In all patients, the Schanz' screws applied into the ilium were placed in an oblique dorso-ventral direction. A mean screw length of 100 ± 20 mm, (confidence interval: 70–135 mm) could be achieved. Twenty-two of the Schanz' screws have been augmented with bone cement. In four patients, the iliosacral joint was struck and in two patients a cement leakage into the soft tissue without necessity for revision occurred. In both previous studies, the clinical follow-up showed a sufficient mechanical stability of the fixations in all patients despite immediate weight bearing as tolerated. No loss of reduction or secondary dislocation occurred (Fig. 15.8).

Salášek detected one dislocation out of 27 patients treated with the transiliac internal fixator for unstable type C fractures caused by high energy trauma [6]. In a more recent study, Salášek compared the transiliac internal fixator to fixation using two sacroiliac screws in patients with AO type C1.3 fractures (unilateral transsacral fractures) [7]. Thirty-two patients were treated with iliosacral screws and 32 with a transiliac internal fixator. Comparing the entire population in this study, there were no significant differences in clinical and radiological outcomes but less complications were found in the internal fixator group. Analysis of the subgroups with unilateral transforaminal fractures revealed better clinical results in the internal fixator group. The authors concluded that in this subgroup, transiliac internal fixation is superior to iliosacral screws because of the lower risk for over-compression and iatrogenic nerve damage.

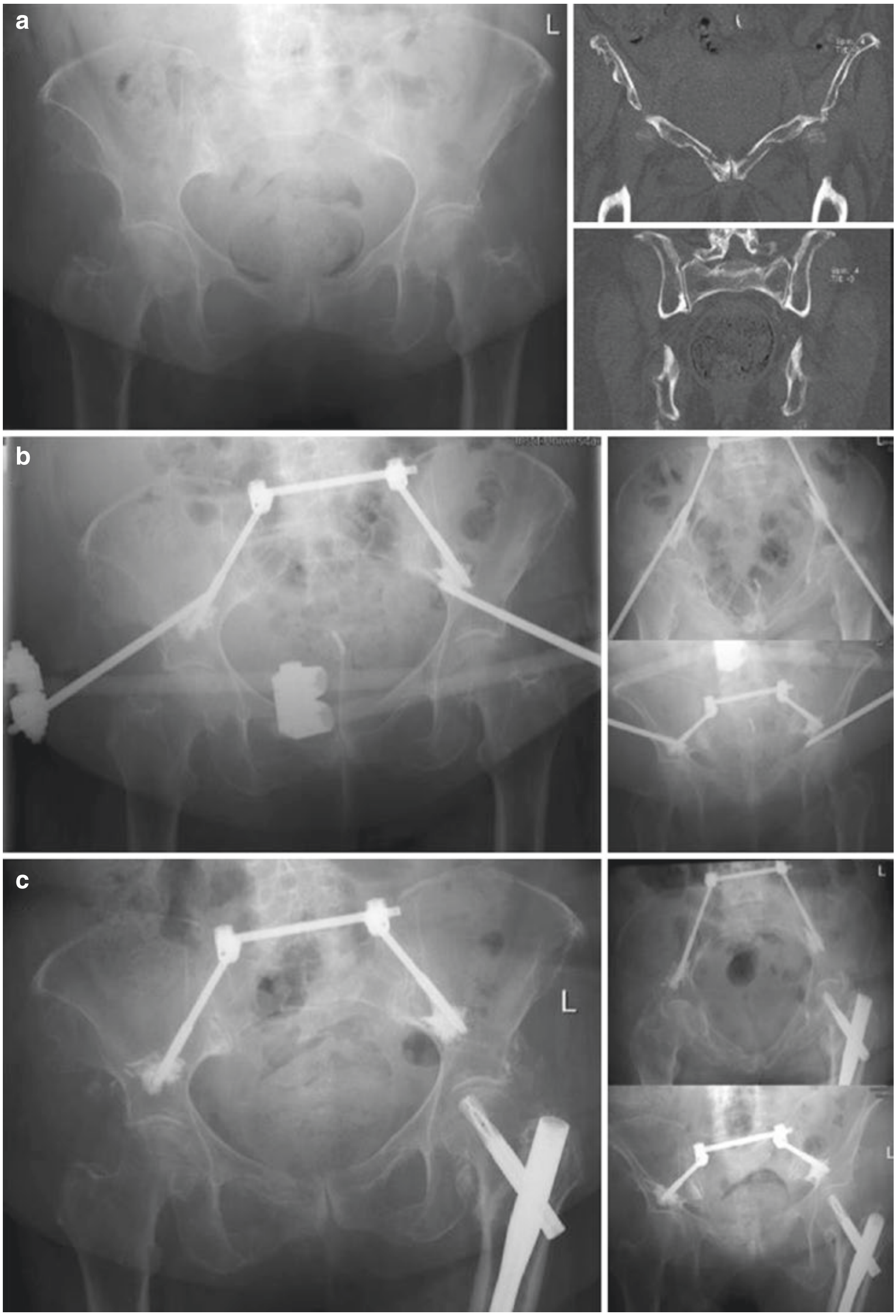

Fig. 15.7 Seventy-eight-year-old woman, suffers from immobilizing pain one week after a fall at home. (**a**) A.p. pelvic overview and coronal CT-cuts through the anterior and posterior pelvic ring show a bilateral transpubic fracture and a left central sacral fracture. (**b**) Pelvic a.p., inlet and outlet overviews after supraacetabular external fixation and cement-augmented transiliac internal fixation with Schanz' screws in posterior to anterior oblique direction. (**c**) Pelvic a.p., inlet and outlet overviews 6 months after trauma show no signs of implant loosening. The fractures are healed; the external fixator has been removed 6 weeks after surgery. The patient suffered a trochanteric fracture 3 months after the pelvic ring injury, which was fixed using a PFNA (DePuy Synthes)

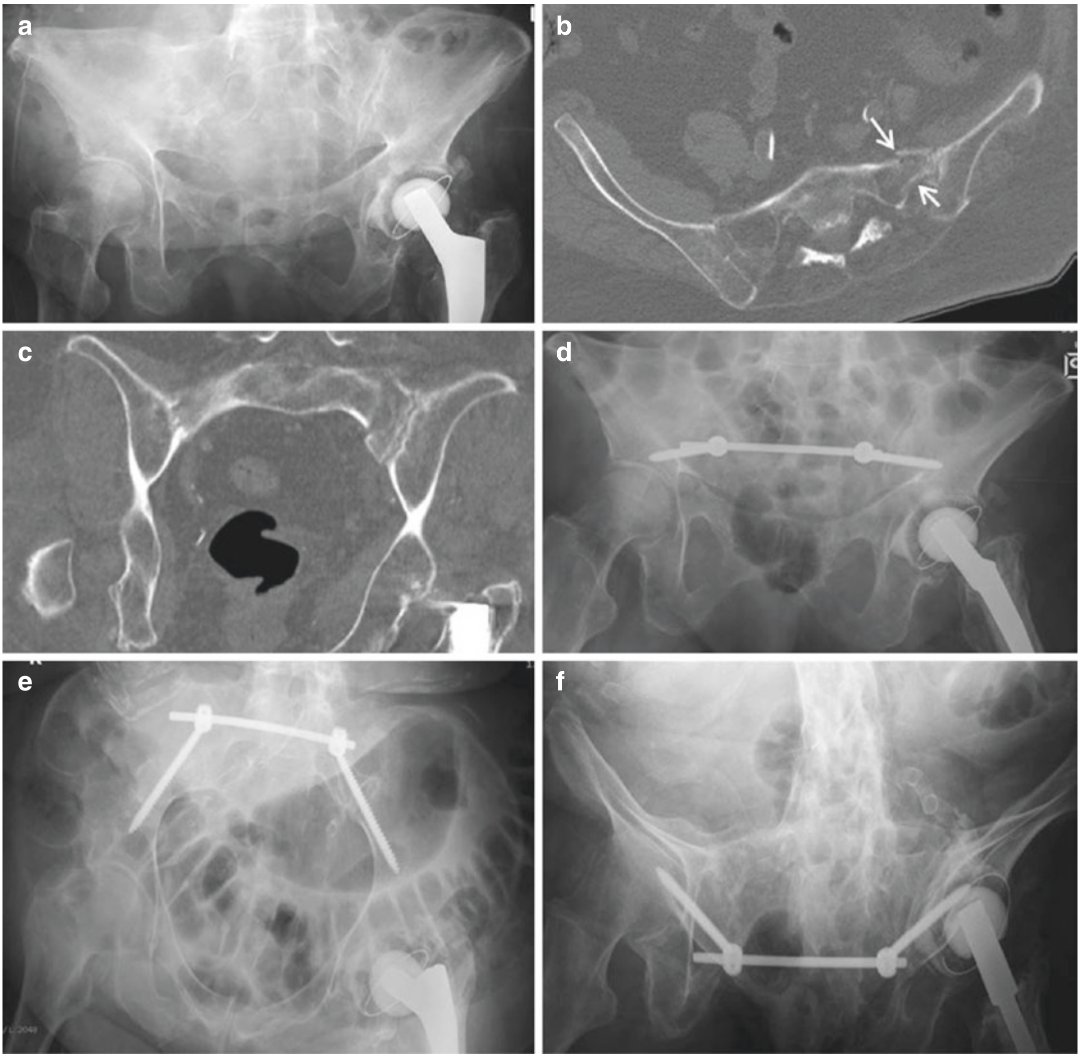

Fig. 15.8 Eighty-six-year-old woman with history of several falls and dorsal pelvic pain. (**a**) A.p. pelvic overview. A fracture of the anterior pelvic ring cannot be identified. (**b**) Transverse CT-cut through the sacrum reveals a complete fracture of the left sacral ala (*white arrows*). (**c**) Coronal CT-cut confirms the complete fracture of the left sacral ala. This lesion corresponds to a FFP Type IIa lesion. (**d**) Postoperative a.p. pelvic view. A transiliac internal fixator with pedicle screws in the dorsal to ventral oblique direction has been inserted. (**e**) Pelvic inlet view. (**f**) Pelvic outlet view. (Courtesy of Rommens PM et al., Mainz, Germany)

Conclusion

Transiliac internal fixation is a technically easy, less invasive and safe method for the fixation of unilateral fragility fractures of the sacrum. Angular stability and the possibility to use of up to 120 mm long screws as well as the option for cement augmentation provide good stability even in osteoporotic bone. A possible disadvantage of this method is the risk of soft tissue irritation by the implant. It can be reduced by choosing a different entry point or removal of a small block of bone at the entry point for deeper placement of the implants.

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Triangular Osteosynthesis and Lumbopelvic Fixation

16

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16.1 Introduction

Lumbopelvic fixation and triangular osteosynthesis of the posterior pelvic ring are elaborated fixation techniques, which create mechanical stability at the complex lumbopelvic junction by counteracting multidirectional forces [1, 2]. However, this technique is not intended to be a routine approach for any fracture of the posterior pelvic ring and lumbopelvic junction, but rather a reconstructive procedure for specific surgical indications [3]. Knowledge of their detailed technical application as well as advantages and disadvantages are prerequisite to avoid complications inherent to the complex anatomy, injury severity and fixation technique itself [4].

16.2 General Considerations

Lumbopelvic fixation and triangular osteosynthesis describe constructs that allow for restoration of multiplanar stability including the horizontal and vertical planes of the lumbosacral junction. It consists of a combination of a vertical fixation between the lower lumbar spine and the posterior ilium using modified pedicle-screw implant-systems on one hand, and a horizontal fixation with, for example, an iliosacral screw osteosynthesis on the other hand (Fig. 16.1). The concept is based on the fact, that severe and unstable posterior pelvic ring injuries are unstable in the horizontal and vertical direction and that

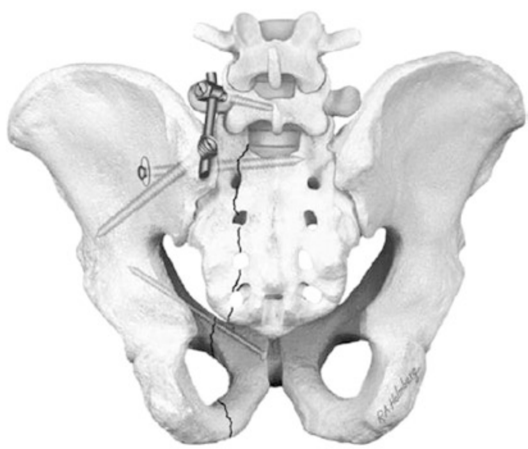

Fig. 16.1 Drawing of unilateral triangular osteosynthesis at the lumbosacral junction. One pedicle screw is inserted in the L5 pedicle; another pedicle screw is inserted at the posterior superior iliac spine in the posterior ilium and directed towards the anterior inferior iliac spine. A *vertical bar* connects the heads of both screws. Additionally, an iliosacral screw is inserted into the S1 sacral body. The construct creates a high stability in all planes

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_16

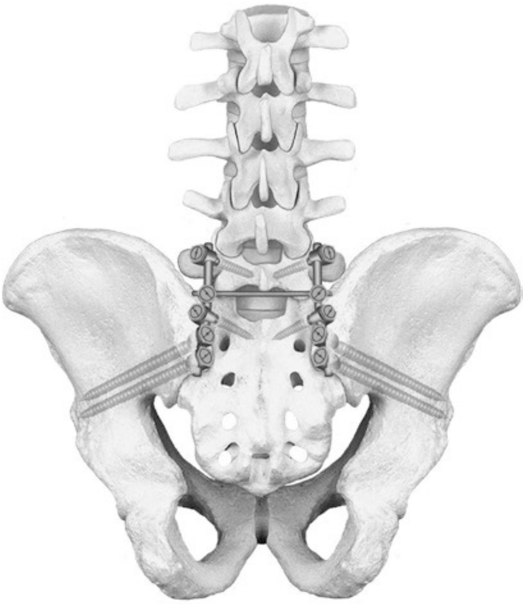

Fig. 16.2 Drawing of a bilateral lumbopelvic fixation. Two screws are inserted in the pedicles of L5 and two pedicle screws in the sacral body of S1. Two long parallel pedicle screws are inserted from the superior and inferior posterior iliac spines in the direction of the anterior superior and inferior iliac spines. On each side, the four pedicle screws are connected with a *vertical bar*, each of them with angular stability. Both *vertical bars* are connected with a smaller transverse crossing bar. There is no additional iliosacral screw fixation

conventional isolated osteosynthesis techniques may not sufficiently address all multiplanar instabilities in a conjoined matter when needed.

The term 'triangular fixation' or 'triangular osteosynthesis' describes a lumbopelvic fixation combined with an iliosacral screw in a unilateral application [5]. This construct addresses all three geometric planes and forms a triangle in conventional radiographs. The terms 'spinopelvic fixation' or 'lumbopelvic fixation' are used for any bilateral application of the triangular osteosynthesis concept, with combination of the above-mentioned vertical and horizontal fixation techniques (Fig. 16.2).

Posterior pelvic ring fracture patterns in the elderly population take many shapes owing to their preexistent comorbidities, body habitus, spinal alignment and underlying bone condition as well as—of course—their injury mechanism [6]. Radiographic manifestations often include crush zones and actual bony voids and may involve the bilateral sacrum and lumbosacral junction in form of U- and H-shaped fracture patterns. Significant displacement in the setting of very poor bone quality and neurologic deficits may be present as well. Increasingly, there is a history of previous lumbosacral spine instrumentation. The combination of fracture morphology and impaired bone quality poses a serious challenge to the surgeon, whose task is to realign and stabilize these injuries in patients who typically cannot follow long-term partial weight-bearing directions [7, 8].

Iliosacral screw fixation, transsacral bar osteosynthesis or dorsal bridging osteosynthesis all create a horizontal fixation of the posterior pelvic ring by exerting some amount of compression forces across various locations in the ilium and sacrum. Triangular osteosynthesis applied in cases of unilateral instability adds additional protection against cranial migration of the injured half of the pelvic ring by transferring vertical loads applied through the ilium to the lower lumbar spine. In doing so, the sacral fracture is partially protected from these loads and the horizontal component of the triangular fixation (e.g. iliosacral screw) can more effectively stabilize the fracture in the horizontal plane, therefore counteracting internal rotation as one mode of failure in these unilateral injuries [9]. In isolation, horizontal fixation may be insufficient to resist vertical shearing loads; similarly, lumbopelvic distraction spondylodesis alone cannot achieve rotational stability in the coronal plane, since a two-point vertical fixation still allows displacement of the posterior pelvic ring, e.g. splaying of the fracture under weight-bearing. Lumbopelvic fixation does not only counteract cephalad migration but also flexion of the injured hemipelvis when a long ilium screw is used. The long iliac and pedicle screws are both directed slightly obliquely from posterior to anterior, thereby creating a large moment opposing rotation of the hemipelvis in the sagittal plane (flexion). Another mechanical advantage of lumbopelvic fixation with long iliac screws is that the long iliac screw, which is ideally placed between the inner and outer table, has the benefit of bicortical purchase over a large extent of its screw tract. The screws of the lumbopelvic fixation, including the pedicle screw with its cortical purchase within the lumbar pedicle, are therefore, characterized by a higher ratio of effective cortical contact areas of their screw-bone interfaces with increased pull-out strength. This is an especially important factor for stability of osteosynthesis constructs in osteoporotic bone [9].

Unilateral triangular fixation constructs typically involve lumbopelvic fixation between L5 and the ilium combined with an iliosacral screw. However, in more displaced fractures, in a sacrum with minimal safe zones for iliosacral screws or in case of other sacral pathology, where iliosacral screws cannot be placed, it may be necessary to add an additional anchor screw in the lower lumbar spine by involving the level of L4. Also, in severely osteoporotic iliac bone, it may be advisable to add a second iliac screw to the construct with an attempt to achieve bicortical fixation by engaging the anterior iliac crest (see iliac screws in Fig. 16.2). It is important to understand, that a minimum of a three-point fixation is necessary for the triangular fixation construct, either reached by combined two-point lumbopelvic and horizontal iliosacral screw fixation, or by a minimum of three-point lumbopelvic fixation and anchorage [10].

Bilateral lumbopelvic fixation constructs address bilateral injuries and complex lumbopelvic dissociation pathologies and pseudarthroses. Basically this means that the triangular fixation concept is applied bilaterally. Either the bilateral two-point lumbopelvic fixation is combined with bilateral horizontal iliosacral screw fixation, or, the horizontal stabilization is gained by one or better two cross-connections between the vertical rods on each side, thereby counteracting horizontal rotational or splaying forces (Fig. 16.3). In

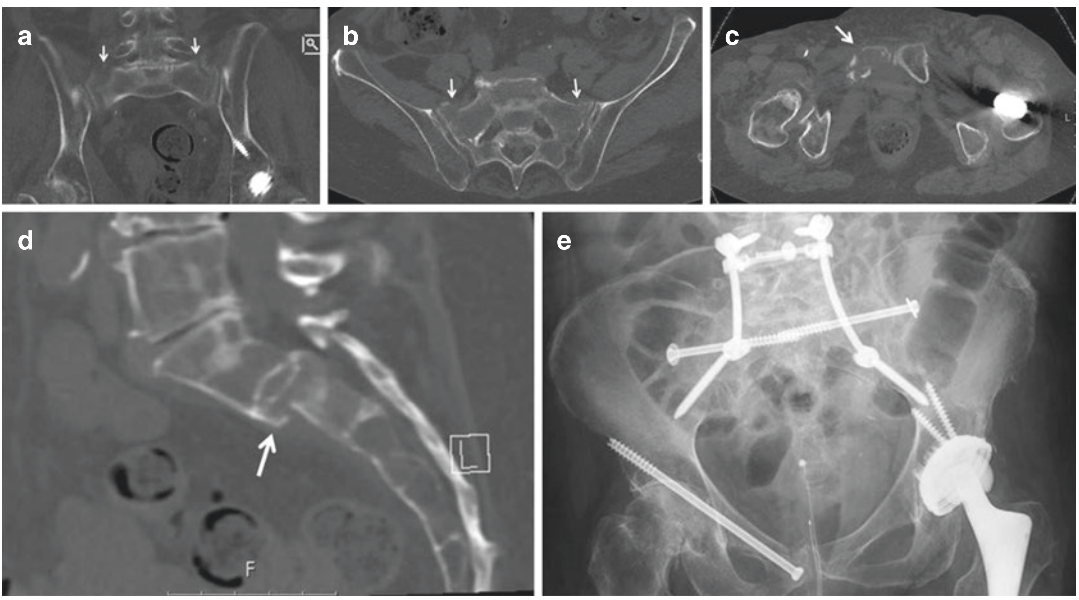

Fig. 16.3 (**a**) Coronal CT-cut through the sacrum of a 67-year-old female with chronic pain in the posterior pelvis. A trauma is not memorable. There are bilateral complete fractures of the sacral ala (*white arrows*). (**b**) Transverse CT-cut through the sacrum confirms the fractures in the sacral ala (*white arrows*). (**c**) Transverse CT-cut through the anterior pelvic ring shows a right-sided superior pubic ramus fracture (*white arrow*). (**d**) A sagittal CT-cut through the mid-sacrum reveals a horizontal sacral fracture between S1 and S2 with intrusion of the lumbosacral segment into the small pelvis (*white arrow*). There is an H-type fracture of the sacrum and a fracture of the anterior pelvic ring, which corresponds with an FFP Type IVb lesion. (**e**) The patient has been treated with bilateral lumbopelvic fixation between L4 and the posterior ilium. Additionally, an iliosacral screw was inserted in S1 on both sides. The fracture of the right pubic ramus was stabilized with a retrograde transpubic screw. A.p. view of the pelvis 3 months after surgery. (**f**) Pelvic inlet view. (**g**) Pelvic outlet view. (Courtesy of Rommens PM et al., Mainz, Germany)

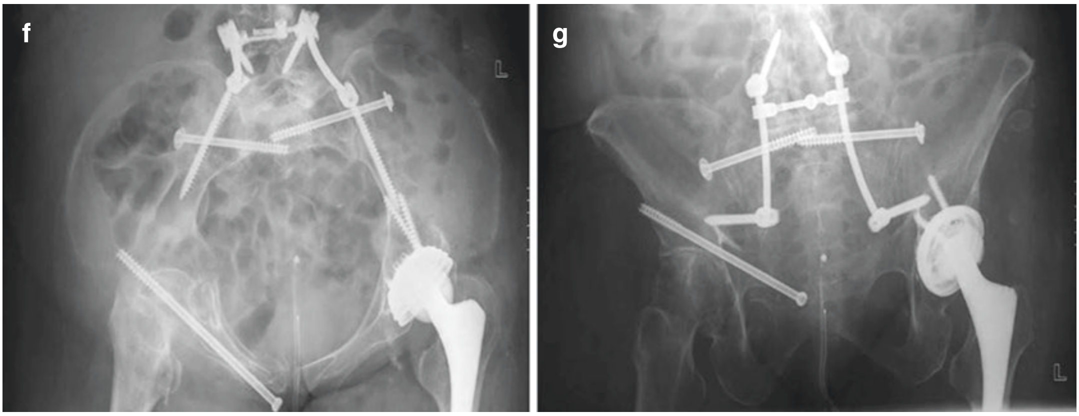

Fig. 16.3 (continued)

bilateral highly unstable situations at the lumbopelvic junction, it is recommended to also add an additional anchorage in the lumbar spine at the level of L4.

Timing of surgery is determined according to the optimal preparation of the patient and surgical environment. Although patients are thought to benefit from early mobilization/weight-bearing and decompression of compromised neural elements provided by early surgical intervention, these benefits must be weighed against the considerable risk factors associated with surgery, especially in an elderly population affected by a number of comorbidities. Whenever possible, modifiable comorbidities and medications have to be optimized in a ‘prehab’ process with intent to lower perioperative risks. However, in patients with deteriorating neurologic examination, progressive pain or impaired dorsal integument, more urgent operative intervention is recommended. Other than in cases requiring emergent intervention, the timing of surgical intervention is adapted to the patients’ physiologic status, and may take place between 48 h and 2 weeks after injury manifestation.

The condition of the dorsal soft tissues is of importance when open surgical techniques such as lumbopelvic fixation are considered. Open techniques at the posterior pelvic ring may result in wound healing problems of any kind. For this reason, percutaneous and minimal invasive surgical techniques may receive increased attention for elderly population with precarious dorsal integument. For open posterior lumbosacral procedures, soft tissue dissections and closures should pay attention to the precarious nature of this area in light of an increased wound breakdown and infection risk. Preexistent areas of soft tissue compromise such as decubital ulcers, should be sufficiently addressed with adjusted and modified incisions, local excisions, and, if necessary, with local rotational muscle flaps.

16.3 Indications

In acute osteoporotic, non-displaced or minimally displaced, unilateral posterior pelvic ring fractures or in bilateral fractures that fit into the category of lumbopelvic fractures (U-, H- and Y-fracture patterns), open lumbopelvic fixation is typically not necessary and percutaneous fixation may be preferred. However, highly unstable situations, such as displaced fractures, fractures with comminuted zones of osteoporotic bone, fractures with progressive displacement or secondary loss of reduction after percutaneous or other fixation techniques, may be good indications for unilateral or bilateral open lumbopelvic fixation.

Another indication may be the treatment of posterior pelvic ring pseudarthroses as they occur in neglected pelvic fragility fractures, after insufficient surgical therapy (Fig. 16.4) or caudal to previous lumbosacral fusions [11]. In these situations, a highly stable multidirectional bony fixation,

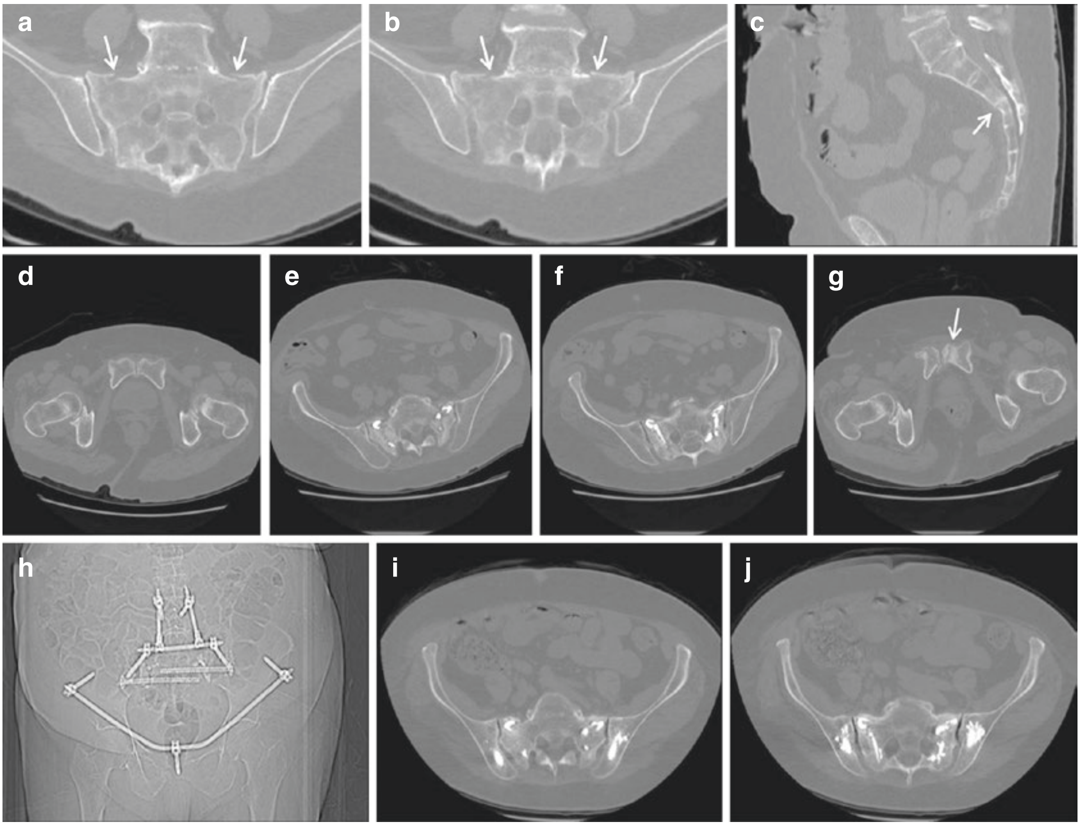

Fig. 16.4 Eighty-four-year-old woman with low back pain since 2 months (**a**) Coronal CT-reconstruction through the posterior pelvic ring reveals bilateral non-displaced sacral ala fractures (*white arrows*). No specific therapy was initiated. (**b**) Because of persisting pain, a new CT was performed after 2 more months to analyze the fracture situation. Coronal CT-cut through the posterior pelvic ring reveals the same bilateral sacral ala fractures (*white arrows*). (**c**) The midsagittal CT-reconstruction through the sacrum shows a slightly displaced horizontal fracture between S2 and S3 (*white arrow*). This fracture was not present 2 months earlier. (**d**) Transverse CT-cut through the anterior pelvis does not reveal a pubic ramus fracture. (**e** and **f**) A bilateral sacroplasty was carried out. Because of persisting and increasing pain, another CT-scan was performed 3 months later. Transverse CT-cuts through the posterior pelvic ring show bilateral cement application in the sacral ala. There is no healing of the sacral ala fractures. (**g**) Transverse CT-cut through the anterior pelvic ring shows a left-sided pubic bone fracture (*white arrow*), which was not present in the previous CT-examination. (**h**) The patient was treated with bilateral triangular osteosynthesis. The *vertical bars* are attached to a *horizontal bar* connecting the heads of the posterior ilium screws (trans-iliac internal fixator, see chapter 15). The anterior instability was treated with an anterior internal fixator. (**i** and **j**) CT-cuts 5 months later show complete healing of the sacral ala fractures. (Courtesy of Mayr E, Augsburg, Germany)

typically in conjunction with bone grafting, is necessary for bony healing, which may only be assured with triangular fixation applied in the vertical as well as horizontal direction.

For patients with an onset of neurologic symptoms consistent with cauda equina or lumbosacral plexus encroachment secondary to instability at the lumbopelvic junction and posterior pelvic ring, neural decompression is indicated. This typically includes sacral laminectomy as well as sacral foraminotomy, especially if bony fragments are impinging on sacral nerve roots at the anterior foraminae. Such neural decompression typically further reduces the already decreased stability of the osteoporotic posterior pelvic structures. Therefore, if neural decompression is indicated through an open approach to the posterior pelvic ring, then rigid lumbopelvic fixation may be indicated to avoid secondary displacement and maximize chances for neurologic recovery [12].

16.4 Patient Evaluation

Preoperative patient evaluation, with specific attention to the intended type of internal fixation, is an essential for successful surgery. In general, evaluation in regard to fracture type and soft tissue condition is similar in the younger and elderly population. However, in the elderly population with fragility fractures and posterior pelvic ring pseudarthroses, specific aspects have to be considered, which are important for the decision for or against an open surgical approach with lumbopelvic fixation.

Preoperative level of daily activities needs to be known in order to assess the necessity for an extensive open surgery. In patients who are wheelchair-bound or bedridden for other reasons, an extensive surgery with an openly performed lumbopelvic fixation may not be necessary, even in presence of a pseudarthrosis. Also, postoperatively, patients need to be aggressively mobilized to avoid wound healing problems or pressure sores at the posterior pelvic ring. Independently active patients can be expected to return to full and unrestricted activities under minimal use of protected weight-bearing accommodations.

It is desirable to assess patients for *comorbidities* preoperatively in order to optimize modifiable diseases wherever possible to minimize postoperative complications. In particular, preoperative anticoagulants have to be identified and plans made for a bridging protocol or temporary suspension of these medications to reduce intraoperative bleeding and to optimize early wound healing. Similarly, medications or toxins that can adversely affect healing are ideally modified preoperatively as soon as possible. Complete nicotine cessation and optimization of metabolic derangements, such as diabetes, are ideally accomplished prior to any surgical intervention in an area exposed to higher than usual risks of breakdown, such as the posterior pelvic ring.

Pain can be a helpful indicator of fracture instability. Typically patients who are reasonably comfortable when laying in a recumbent position but who experience significant worsening of low back pain when upright or ambulating, exhibit some degree of mechanical instability in this region. This important symptom may, however, not be as useful in elderly patients, who may present with preexistent deformities, surgery, impaired posture or chronic pain, all of which may distract from the sacral region as pain origin. Pain reporting may be altered for other reasons as well – such as extensive analgesic pain management, prolonged recumbence, general cachexia or deconditioning, altered mental status and other circumstances. Increasingly, complex sacral stress fractures have been reported following lumbosacral segmental fusion surgery. This patient population frequently presents with a secondary new onset of low back pain several weeks following an otherwise uneventful fusion surgery and commonly features a forward stooped posture and some vague radicular symptoms, commonly in a L5 distribution (Fig. 16.5). Lastly, chronic pain medication for any reason already prescribed and often longtime applied, may give doubts to patients' new pelvic pain unjustly.

Evaluation of the posterior *soft tissue condition* is a critical element of general clinical assessment. Although degloving injuries are rare in fragility fractures, decubital ulcers or impaired soft tissues with vulnerable skin, such as seen with chronic cortisone treatment, may make open dorsal approach surgery undesirable. Photographic posterior integument documentation placed into the chart may be helpful for longitudinal care documentation. Generally, targets of palpatory evaluation include assessing all bony prominences and looking for gluteal atrophy. Point tenderness can be an important tip-off for presence of an underlying fracture. Determination of hip and lumbar spine range of motion can help in understanding a patient's general mobility status and also allow drawing inferences to their ability to compensate for deformities. A simple but effective clinical test to assess for pain localization is a posterior percussion test of the bone prominence of the posterior lumbar spine and pelvis.

An important but commonly overlooked aspect of clinical assessment of any patient with a sacral fracture is a clearly documented *examination of the lumbosacral plexus and sacral roots*. Segmental lower extremity neurologic functional motor status; dermatomal sensory and reflex status according to the ASIA criteria are an essential foundation for functional status deter-

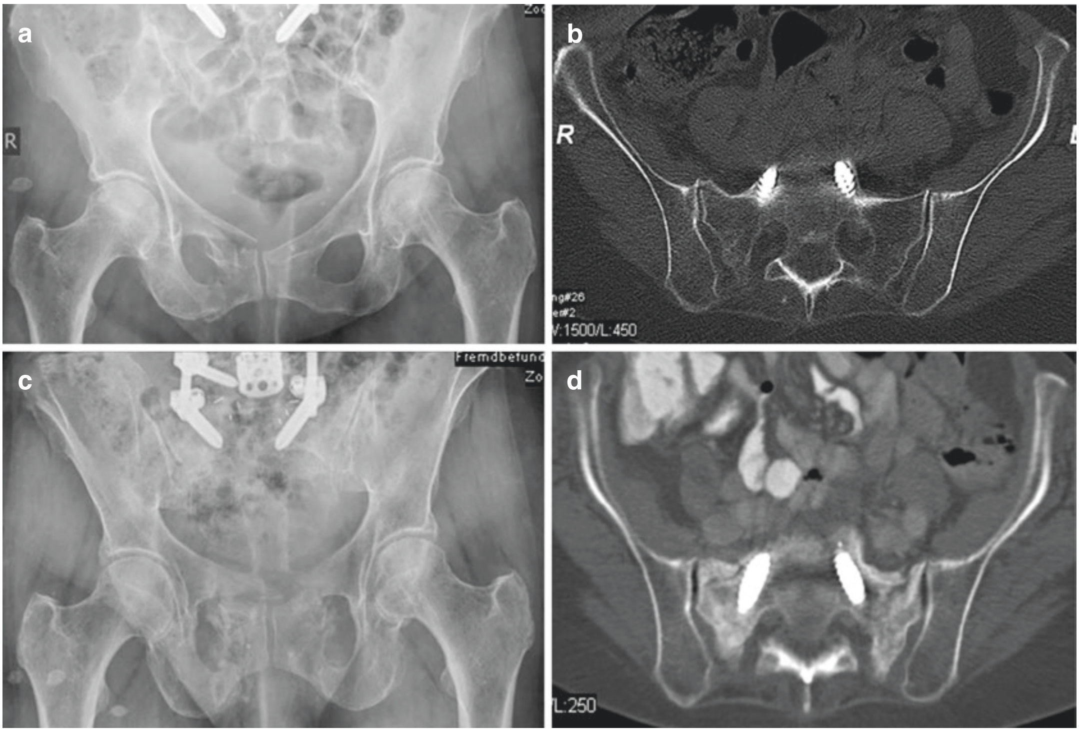

Fig. 16.5 (**a**) Pelvic a.p. overview of 72-year-old female with anterior and posterior intervertebral fusion between L4 and S1. After a fall in the rehabilitation hospital, she suffered a right-sided pubic ramus fracture. (**b**) Transverse CT-scan through the posterior pelvic ring does not show a sacral fracture. Therapy was non-operative. (**c**) After weeks of continuous pain, control radiographs and CT were performed. The a.p. pelvic overview shows bilateral, displaced fractures of the pubic rami with sclerotic margins, typical for a chronic instability. (**d**) Transverse CT-cut through the posterior pelvic ring shows bilateral sacral ala fractures. (Courtesy of Rommens PM et al., Mainz, Germany)

mination [13]. Sacral plexus evaluation requires digital rectal examination with determination of spontaneous and voluntary anal sphincter tone and maximum voluntary contractibility as well as evaluation for perianal sensation. Relevant sacral reflexes include identifying presence of a bulbocavernosus reflex and anal sphincter wink, aside from patella tendon and Achilles tendon reflexes. Nerve root traction signs, such as straight leg raising and femoral stretch testing may also help recognize lumbosacral root entrapment.

Neurologic deficits resultant to lumbosacral fractures or displacement may be hard to elicit in an impaired elderly patient population due to preexistent comorbidities such as chronic radiculopathies due to diabetes, vascular disease, neuropathies and lumbosacral disc disease or lumbar spinal stenosis or simple pelvic floor weakness with resultant bladder incontinence. In fact, all of these disorders may cause clinical symptoms that mimic elements of cauda equina or lumbosacral plexus impairment to the point where the fracture induced neurologic pathology is missed. Delay in diagnosis of worsening neurologic status is not uncommon in cases of progressive fracture displacement. If in doubt, electrophysiologic tests like pudendal somatosensory evoked potentials and anal sphincter EMG, or post void residual determination can be of help in distinguishing more recent onset neurologic pathology from an injury from more chronic deficits. The inference is that neurologic deficits resulting from a sacral fragility fracture may benefit from neural decompression with sacral laminectomy and foraminotomy with subsequent lumbopelvic fixation.

Aside from clinical evaluation of the patient, a clear understanding of the fracture type and its associated instability is required to plan for the appropriate osteosynthesis technique. For this purpose, prerequisite imaging includes computed tomography with coronal and sagittal reformats of the lumbopelvic junction preferably using 2 mm cuts. Magnetic Resonance Imaging (MRI) can be very helpful in early detection of stress fractures and for more detailed depiction of neural elements [14, 15]. Such imaging can also be valuable for differential diagnoses of neoplastic and infectious lesions. STIR images with ability to visualize perineural fluid can help show more chronic radiculopathies. Radionuclide studies such as technetium Tc99^{m} scans, especially when supplemented with single photon CT (SPECT) can help identify and localize pathologic or stress fractures in greater detail and also confirm fracture healing [16].

16.5 Surgical Management and Technical Aspects

Lumbopelvic fixation follows a different pathway, depending on the type of instability affecting the anterior and posterior pelvic ring as well as the lumbopelvic junction. For lumbopelvic fractures with minor displacement that involve the posterior pelvic ring only and not the anterior pelvis, as sometimes is the case in U-type sacral fragility fractures, sole posterior pelvic ring stabilization can be considered (Fig. 16.6). For fractures and instabilities involving the anterior and posterior pelvic ring and lumbopelvic junction, the anterior pelvis may need to be considered for open reduction and fixation as well. For anterior pelvic ring pseudarthroses and highly unstable situations, such as bilateral ramus fractures or significant anterior ring diastasis, osteosynthesis of the superior pubic ramus is typically performed first. Anterior pelvic ring fixation provides for indirect reduction of the posterior pelvic ring and partial pelvic stability. With the anterior pelvic ring stabilized first, any posterior pelvic ring reduction maneuver can be performed around a fixed center of rotation anteriorly, which avoids further secondary anterior pelvic ring displacement during the posteriorly performed levering on the injured hemipelvis.

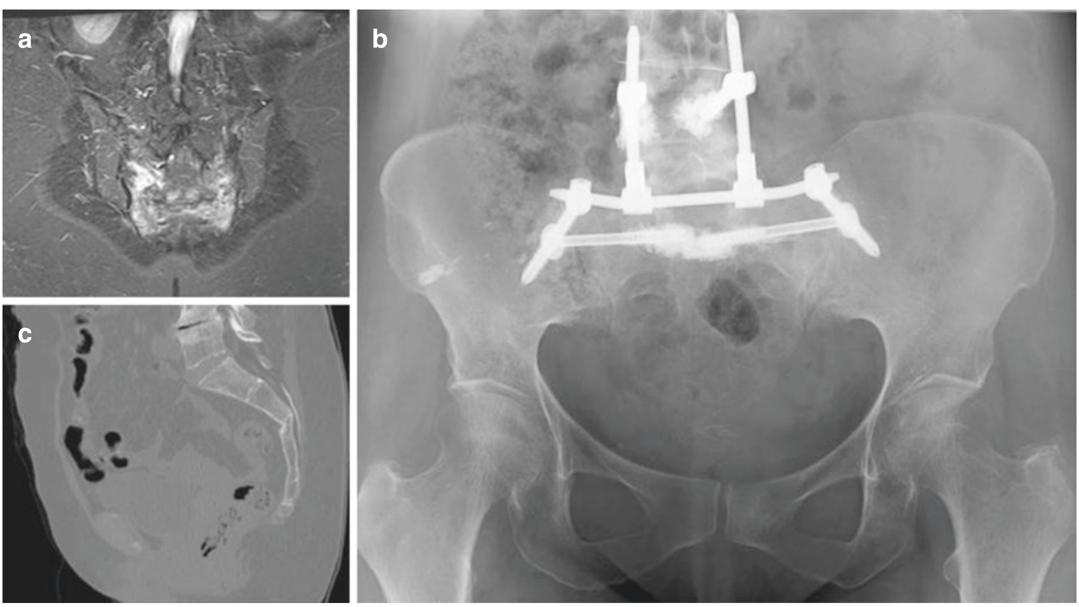

Fig. 16.6 Sixty-six-year-old woman with deep and immobilizing lumbar pain without history of trauma. (**a**) Coronal MRI-cut through the posterior pelvic ring showing intense bone bruise in both sacral ala, which is very suspicious for bilateral sacral ala fractures. (**b**) Midline sagittal CT-cut through the sacrum showing a horizontal fracture between S2 and S3. The patient has a FFP Type IVb lesion. (**c**) Surgical treatment with partially cement-augmented iliolumbar internal fixator and bilateral cement-augmented iliosacral screws. There is no fracture in the anterior pelvic ring. (Courtesy of Mayr E, Augsburg, Germany)

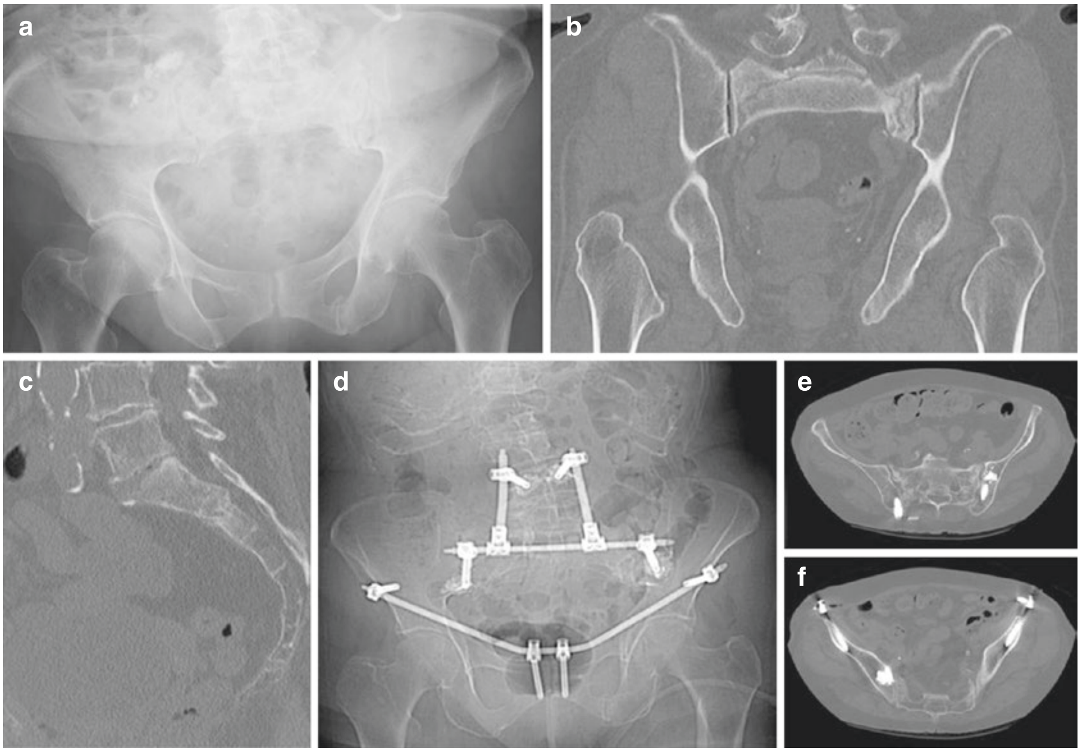

Fig. 16.7 An 84-year-old obese woman complains of heavy pain after a fall. (**a**) A.p. pelvic overview shows a left-sided pubic ramus fracture. (**b**) Coronal CT-reconstruction through the posterior pelvic ring reveals bilateral sacral ala fractures, non-displaced on the right side and with compression and displacement on the left side. (**c**) A midline sagittal CT-cut through the sacrum shows a horizontal fracture between S1 and S2. The CT scan also shows a non-displaced pubic ramus fracture on the right (not visible in this figure). The patient has a FFP Type IVb lesion. (**d**) The patient is treated with cement-augmented lumbopelvic fixation. An anterior internal fixator with screw anchorages in the anterior inferior iliac spines and in the pubic bones was inserted for stabilization of the anterior pelvic ring. (**e** and **f**) Transverse CT-cuts through the pelvic ring show healing of the sacral fractures and show the position of the posterior and anterior pedicle screws in the ilium. (Courtesy of Mayr E, Augsburg, Germany)

Typical pubic ramus fractures can be stabilized with large fragment retrograde transpubic screws. The screws allow minor rotation during posterior pelvic ring manipulation during any posterior reduction maneuver, while yet securing the reapproximation and overall reduction of the anterior pelvic ring. A plate osteosynthesis in the osteoporotic bone can be only recommended for parasymphyseal fractures, which do not allow sufficient intramedullary screw anchorage. In these situations, the plate should bridge the symphysis without attempting a fusion of this area. More recently, anterior internal fixators have been developed for bridging-fixation of the broken anterior pelvis (Fig. 16.7) [17, 18].

16.6 Surgical Technique

For lumbopelvic fixation, the patient is placed prone on a radiolucent operating table. Operating tables with metal sidebars may cause intraoperative C-arm visibility restrictions, especially in oblique views and should, therefore, be avoided. Preoperatively, the surgeon should make sure that acceptable oblique C-arm views can be obtained particularly for iliac screw placement. These include lateral and antero-posterior planes as well as iliac-oblique, obturator-oblique, and inlet and outlet trajectories.

Preoperatively, prophylactic broad-spectrum antibiotics are given. After thorough prepping and draping with soap and antiseptic agents, the skin is incised through a midline approach over the spinous processes of L4/5 down along the caudal end of the sacrum. Soft tissue handling is of paramount importance to avoid devascularization. The incision is continued through the fascia along the lumbosacral spinous processes and the multifidus muscles, which form the sole muscle coverage of the posterior sacrum to the lumbodorsal fascia, are elevated off and retracted subperiosteally out laterally from the posterior elements of L5 and the sacrum. Minimal diathermy dissection and avoidance of using electrocautery dissection into the posterior sacral foraminae is recommended to minimize injury to the cluneal nerves which arise out of these apertures. Upon reaching the posterior iliac crest, the muscles are elevated from the medial surface of the ilium to expose the posterior-inferior iliac crest. In case of complex deformities it can be helpful to elevate the hip abductors from the outer iliac table in order to enhance surgical orientation.

Alternatively, in situations where sacral laminectomy or neural element decompression is not indicated, subcutaneous dissection along the fascia laterally to the posterior inferior iliac spine (PSIS) may be an option to leave the multifidus muscles intact. The PSIS can then be approached through a separate fascial incision to allow placement of the iliac screw. Similarly, a separate fascial incision can be placed over the L5 pedicle insertion site for placement of the L5 pedicle screw. Later, a vertical connecting rod is placed subfascially through a muscular tunnel to connect the two screw heads.

Placement of the iliac and lumbar pedicle screws is usually addressed first before any neural decompression as these screws can be used as anchoring posts to help in reduction maneuvers and neural decompression.

Low profile pedicle screw systems are preferred to minimize soft tissue pressure and to diminish hardware prominence. Also, pedicle screw systems that allow for placement of rigid fixation posts on the screw head itself can be very helpful to facilitate reduction maneuvers. Polyaxial screw systems can be advantageous in case of multiple fixation points having to be connected.

The number of lumbosacral pedicle screws deserves some further consideration. In severely osteoporotic bone and more extensive bony defects in the sacral fracture zone or unstable pseudarthrosis, a bisegmental lumbar anchorage with pedicle screws in L4 and L5 may be advantageous. Fixation in the S1 segment can also be considered if that segment has remained intact and the transverse fracture zone is more caudally located. Lumbar pedicle screws are positioned in the standard technique under C-arm control in the lateral position. Pedicle screw size and trajectories are measured preoperatively on CT images with a goal of achieving maximum fixation while being mindful of the surrounding vascular and intraabdominal structures.

Screw application in the ilium is performed under C-arm visualization, primarily using the lateral sciatic notch pelvic view further enhanced by sequential obturator-oblique outlet and iliac oblique views. A starting point is established along the postero-medial aspect of the PSIS. Opening of the trabecular trajectory can be gained by taking of the tip of the PSIS using a large rongeur. A screw channel is cannulated in a lateral and downwards tilted direction between the inner and outer table of the ilium superior to the greater sciatic notch and the acetabulum, using a 3.5 mm drill or a blunt pedicle awl. Conceptually it can help to aim for the anterior inferior iliac spinous process, which is about 2–3 cm rostral to the acetabulum. On the lateral images the intraosseous trajectory should be within a region about 5 cm in height above the sciatic notch cortex. The iliac oblique view and the combined obturator-oblique outlet view with its typical teardrop figure may be useful in confirming appropriate intraosseous channel positioning and length (Fig. 16.8). Only after confirmation of desirable pilot hole trajectories using multiple C-arm views, the iliac screw can be placed. Typically, the iliac screw range in length from 80 to 130 mm with a thickness of 8 to 9 mm. Longer lengths with bicortical purchase—or close to such—provide solid iliac screw anchorage through their engagement within two intraosseous narrowings of the inner and outer iliac tables [19].

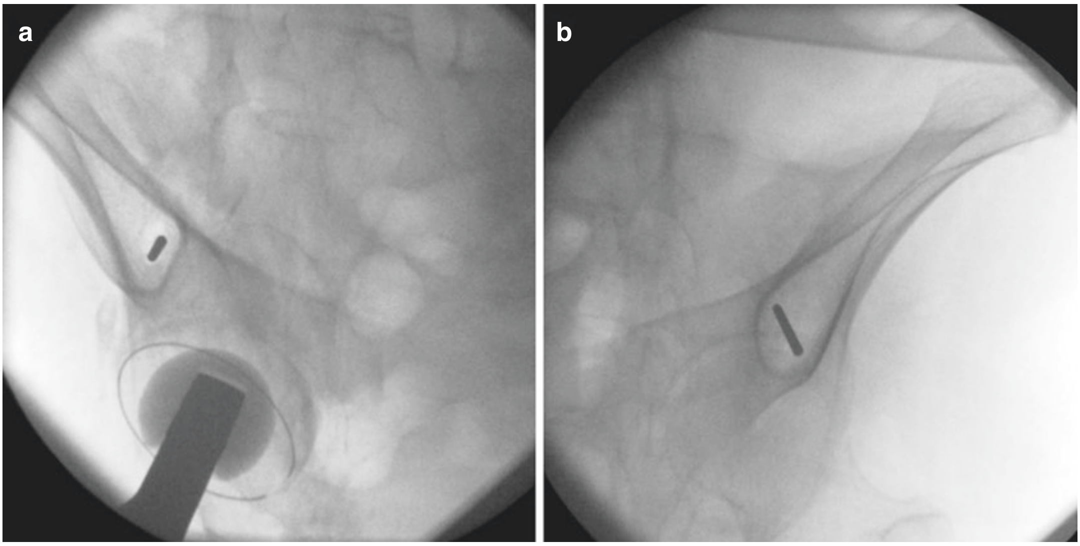

Fig. 16.8 The combined obturator-oblique outlet fluoroscopic view with its typical teardrop figure depicts the appropriate intraosseous channel for the pedicle screws of the ilium. (**a**) Right side with K-wire pointing towards the center of the teardrop. (**b**) Left side. (Courtesy of Rommens PM et al., Mainz, Germany)

Attention to detail in submerging iliac screw heads below the profile of the posterior iliac crest is necessary to minimize local pain and/or pressure sores (Fig. 16.9). Therefore, we recommend recessing these screw heads far into the PSIS. Bone at the PSIS can be removed for that, since the screws are not gaining their stability at the insertion site but at the described constrictions.

In severely osteoporotic bone, a second iliac screw may provide welcome enhancement of construct stability. Clinically, placement of a second iliac screw is easier after a prior good quality iliac screw placement has been confirmed by following the previous screw trajectory (Fig. 16.2).

Decompression of neural elements can be accomplished by several techniques. Indirect nerve root decompression may be accomplished through fracture reduction. This is usually easiest if done within 48 h of injury and becomes near impossible 3 weeks or more after fracture hematoma consolidation has occurred. As most patients with fragility fractures typically present on a delayed basis for surgical treatment, direct, open nerve decompression is usually warranted. Neural element decompression in the sacrum is usually accomplished through a laminectomy that starts from the L5-S1 interlaminar space and is laterally bound by the posterior sacral foraminae. A central laminectomy that extends beyond the transverse injury zone allows for each of the sacral roots to be traced out laterally until they have cleared the much larger anterior sacral foraminae. Ventral canal and foraminal decompression can be accomplished by freeing the sacral roots in the injury zone from their epidural venous cuff with bipolar cauterization and then proceeding with ventral sacral canal disimpaction or direct removal of protruding bone fragments. Placing an elevator into a transverse sacral fracture as a lever may facilitate ventral disimpaction. However, in severely osteoporotic bone, such a cantilever maneuver may lead to a larger sacral bone defect. Alternatively, a flat ended bony impactor can be used to directly disimpact the dorsal wall of the injured sacral vertebral body anteriorly thereby freeing up the sacral roots. In general, a moderately kyphotic midsacral deformity with anteriorly impacted sacral vertebral bodies is preferred over an improved reduction of the sacral alignment with resulting large bony midsacral defects without anterior support in these patients. Lateral C-arm imaging can be a valuable aid during sacral root decom-

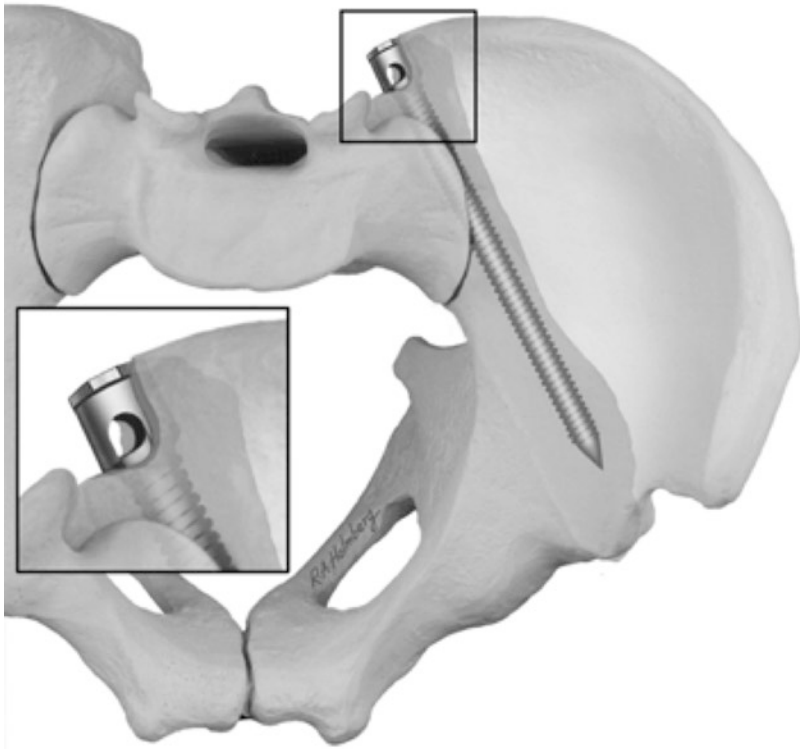

Fig. 16.9 The head of the iliac screw is submersed below the profile of the posterior iliac crest in order to minimize soft tissue irritation, local pain or pressure sores

pression surgery for orientation and assessment of sacral alignment and associated decompression of the sacral canal.

For unilateral posterior ring injuries, fracture reduction can be performed by direct manipulation on pedicle and iliac screw handles in multiplanar directions. If sufficient overall reduction is gained as seen on the dorsal aspects of the sacrum and confirmed by C-arm imaging under C-arm control, then a pointed large bone reduction clamp may initially secure the reduction by placing it on one spinous process medially and on the PSIS laterally. A longitudinal connecting rod is then contoured in the frontal and sagittal plane typically into an S-shaped form. It is applied to the screw heads and then fixed either cranially or caudally. With a distractor along the connecting rod and between the pedicle screw and the ilium screw or between the pedicle screw and a C-ring placed on the longitudinal rod, more detailed reduction in the vertical plane can be gained. Rotation of the longitudinal S-shaped rod with a rod holder, on the other hand, allows some further and detailed reduction in the horizontal plane.

Should the S1 vertebral body be intact and its sacral corridor large enough, then an iliosacral screw with washer can be placed in the typical technique securing stability in the horizontal plane. However, for reduction purposes, a distracting force has been applied along the longitudinal rod. Despite the reduced and stabilized sacral fracture, secondary distraction forces can still cause scoliotic and/or rotational deformity at the lumbosacral junction between L5 and S1, especially if the L5/S1 facet is injured as well. Therefore, lumbopelvic fixation can be considered to support an iliosacral screw. Prior to completion of any reduction of the lumbosacral junction, appropriate alignment of the L5/S1 junction can be assessed with C-arm imaging, with the longitudinal rod used to fine tune and then neutralize the injury reduction.

In bilateral sacral injuries and/or lumbopelvic dissociation injuries, such as U- or H-shaped sacral fracture patterns, handles on bilateral pedicle and iliac screws can help to reduce the overall alignment of the typically kyphotic deformity at the sacrum. Manipulation in multiplanar direction can thus be performed. Nevertheless, some kyphotic deformity at the mid sacrum can be accepted in osteoporotic and impacted bone at the cost of overall alignment, since bony defects in the sacrum after fracture reduction are a more important problem than remnant misalignment and bony instability. This remaining kyphotic deformity usually does not compromise the neural structures in the canal. Fracture reduction can as well be facilitated by rotating pre-contoured longitudinal rods in the above described manner. With a distracting force along these bilateral rods further reduction can be performed. Also, with 'in-situ' benders for longitudinal connecting rods, as they are supplied with some spinal implant systems, further reduction in the sagittal plane can be gained to correct kyphotic deformity.

In kyphotic deformity of the upper sacrum, as it occurs and may be tolerated in fragility fractures, associated horizontal fracture stabilization with iliosacral screws may not be possible and secure. In these situations, cross-connecting rods are required between the bilateral longitudinal rods. In highly unstable situations, two interconnecting rods create more stability in a rectangular fixation concept. However, the distal connecting rods may cause problems due to prominent hardware, if the implants at the PSIS are not recessed. Also, care should be taken to ensure that this horizontal compression does not compromise the sacral neuroforamina.

Controversy exists on the necessity to fuse the lumbosacral junction in association with lumbopelvic fixation. In our practice, we do not perform fusions for unilateral fractures and open reduction internal fixation of less displaced sacroiliac injuries. For patients with bilateral fixation of lumbopelvic dissociation injury patterns or pseudarthroses, local bone graft from the sacral laminectomy is applied to the decorticated posterolateral elements of the most rostral instrumented lumbar vertebra to the sacral ala. The pelvis and the posterior ilium, however, are not included in the arthrodesis, except in situations with fractures involving the iliosacral joint or in pseudarthrosis involving the lateral sacral ala. Additionally, in pseudarthrosis, as often observed in neglected fragility fractures, the pseudarthrotic zone is cleaned out of fibrous tissue posteriorly and the resected areas are filled with bone graft. If necessary, the autogenous bone graft is extended with bony allograft.

Wound closure is finally performed over two drains in a layered fashion.

16.7 Postoperative Treatment

Postoperatively, it is advisable to get an early CT scan to allow for assessment of neural element passage, lumbosacral alignment in three planes, and check on hardware placement, especially if intraoperative navigation has not been available.

Patients with pelvic ring fractures and osteosynthesis performed are at high risk for venous thromboembolism (VTE). Therefore, in every patient, a postoperative duplex ultrasonography is recommended to allow early diagnosis of VTE. Irrespective of that, proper thromboembolism prophylaxis with drugs should be initiated early postoperatively. Chemical thromboembolism prophylaxis will obviously have to take consideration of patients' comorbidities and preexisting anticoagulation requirements and medications.

Triangular osteosynthesis and lumbopelvic fixation promise a stable fixation at the lumbopelvic junction, which allows for immediate patient mobilization with full weight-bearing. In the elderly population, which typically cannot follow partial weight-bearing directions, this is of eminent importance (Fig. 16.10) [20]. Mobilization should also be encouraged in bed with frequent posture changes to avoid local pressure and decubital ulcer on the posterior pelvic prominences and possibly prominent implants at the PSIS. Prone positioning will allow for incision decompression and minimize the risk of fecal contamination, but is not well tolerated by many patients. Especially in acute fractures with associated soft tissue impairment, wound healing problems or pressure related decubital ulcer may occur otherwise [4, 21].

Hardware removal after fracture healing is usually not indicated. However, prominent implant screw heads, especially at the PSIS,

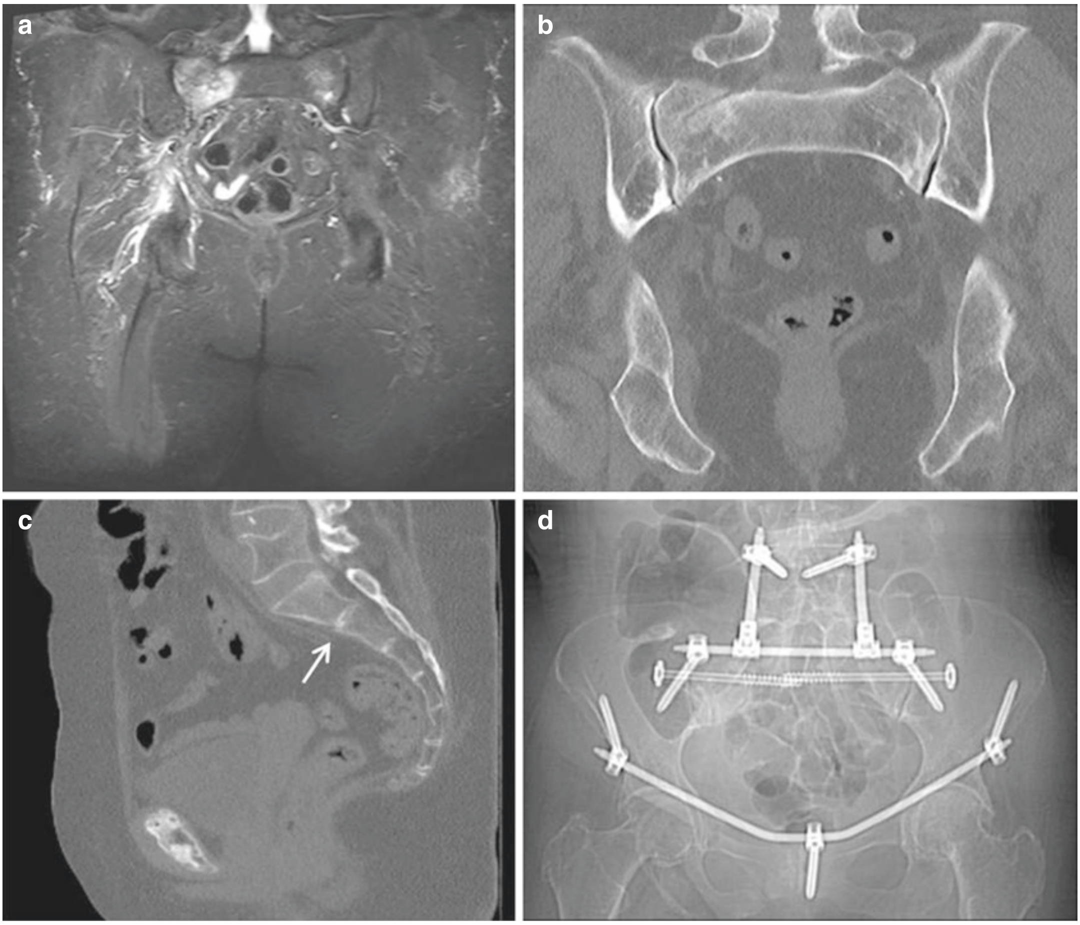

Fig. 16.10 Seventy-five-year-old female with low back pain without history of trauma. Hospital admission due to increasing and immobilizing pain. (**a**) Coronal MRI-cut through the posterior pelvic ring reveals bilateral edema in the sacral ala, more pronounced on the right side. (**b**) Coronal CT-cut through the posterior pelvic ring shows a complete fracture of the right sacral ala and an incomplete fracture of the left sacral ala. (**c**) Sagittal CT-reconstruction through the midline of the sacral body shows a horizontal fracture line without displacement between S1 and S2 (*white arrow*). There were bilateral slightly displaced pubic ramus fractures (not visible in the figures **a**–**c**). (**d**) Stabilization with iliolumbar fixation with screws in the L4 pedicles and in the posterior ilium. Additional fixation with one iliosacral screw in S1 on both sides. The anterior instabilities are bridged with an anterior internal fixator, connecting screws in the left and right anterior superior iliac spine and in the left pubic bone. Immediate mobilization with full weight-bearing can be allowed. (Courtesy of Mayr E, Augsburg, Germany)

may be uncomfortable and may, therefore, lead to the need of hardware removal.

Micromotion at the sacroiliac joints, which are bridged by the lumbopelvic fixation, may result in failure of the longitudinal connection rods between the pedicle and iliac screws. This hardware failure is not a result of a pseudarthrosis at the fracture site, but a result of constant cyclic loading caused by physiologic motion of the sacroiliac joint and the lumbopelvic junction. Hardware removal of the lumbopelvic fixation can prevent this hardware failure. Some authors therefore have recommended hardware removal after fracture healing between 6 and 12 months postoperatively. Another alternative is to simply allow the hardware breakage to occur and to proceed with removal only if clinically indicated, as the rod breakage is often asymptomatic. This policy may avoid the need for an additional surgical intervention.

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Plate and Screw Fixation of the Ilium

17

Martin H. Hessmann

17.1 Introduction

In the context of fragility fractures of the pelvic ring (FFP), fractures of the ilium are seldom. Fractures of the sacrum are much more frequent and most typical. Epidemiological data suggests that ilium fractures are more common in younger (13% of all pelvic ring fractures) than in older patients (7% in octogenarians), and that local and systemic complication rates are increasing with age [1, 2]. Fractures of the ilium compromise pelvic ring integrity due to partial or complete posterior instability. Consequently, they represent an important pathology, which may have considerable impact on clinical function [3].

Complete fractures of the posterior ilium belong to the B- or C-type pelvic fracture pattern of the AO/OTA-classification [4, 5]. However, the clinical presentation of patients with FFP does not correspond with this of high-energy pelvic ring lesions. To address the specific morphologies and characteristics of FFP, a new, comprehensive classification has been developed by Rommens and Hofmann [6]. Unilateral fragility fractures of the ilium are classified as FFP type IIc injuries, if they are non-displaced. They are part of FFP type IIIa injuries in case of displacement. Bilateral fragility fractures of the ilium are part of FFP type IVa lesions. The last are very seldom. Unilateral fractures of the ilium may be accompanied by a fracture of the sacrum on the opposite side. Associated uni- or bilateral anterior pelvic ring fractures are common (see Sect. 17.3).

Fragility fractures of the pelvic ring sometimes reflect an ongoing pathology, resulting in progressive biomechanical instability. In these cases, fractures are incomplete initially, and progress consecutively to a complete uni- or bilateral pelvic ring discontinuity. Fragility fractures of the ilium typically start at the pelvic brim near to the sacroiliac joint, sometimes involving a part of the joint, and continue cranially and laterally to reach the iliac crest at its most proximal point. It remains unclear how this fracture occurs, there may or there may not be a history of low-energy trauma.

Some patients have a history of an intrapelvic malignant disease (colon, prostate, gynecological organs) treated with irradiation [7–9]. In this case, local bone biology and viability may be significantly decreased or even completely absent. Fractures may not heal despite adequate surgical stabilization. Also long-term bisphosphonate intake decreases metabolic bone turnover. Evidence suggests that bisphosphonates negatively influence fracture healing [10]. Strong implants should be chosen and configured for stabilization, in order to reduce the risk of hardware failure due to delayed or non-healing.

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_17

17.2 Anatomical Considerations

The innominate bone consists of the ilium, the ischium and the pubis. The widest and largest of these three bones is the ilium. The pubis and the ischium anatomically belong to the anterior pelvic ring; treatment of fractures of these bones will be addressed in Sect. 17.6. The ilium articulates with the sacrum posteriorly and fuses with the ischium and the pubis at the lower aspect of the acetabulum. Fractures of the acetabulum represent a separate pathology that will not be discussed here.

The ilium is an essential part of the posterior pelvic ring and plays a pivotal role in transmitting forces from the vertebral column to the lower extremities. It also is a structure from which the gluteal muscles originate externally and the iliac muscle internally. Complete fractures of the ilium run from the pelvic brim to the iliac crest. They disrupt the continuity of the pelvic ring. These fractures are biomechanically unstable [6] and will not heal without surgical treatment. Iliac wing fractures are incomplete ilium fractures. They do not affect the stability of the pelvic ring. Iliac wing fractures, however, may be painful and impair adequate patient mobilization.

17.3 Clinical Presentation and Diagnostic Evaluation

In patients with history of low-energy trauma, at least a pelvic overview in the antero-posterior plane will be taken. Additional inlet and outlet views are required, in case a fracture of the pelvic ring is suspected or detected. Anterior pelvic ring fractures with or even without posterior pain are very suspicious for a posterior pelvic ring fracture [11, 12]. More detailed information will be provided by CT-scans with multiplanar and 3D–reconstructions [13–15]. MRI is not indicated as a routine. However, occult fractures may be detected with MRI in these symptomatic patients, where a fracture is not visible on conventional x-rays and CT [16, 17].

A large number of patients has no history of a recent trauma. Pain around the pelvis, the hip or lower back during weight-bearing is an indicator for a potential FFP. Pain complaints often cannot be localized very specifically, but ongoing or progressive discomfort during ambulation must raise suspicion, if no other pathology that reasonably explains this pain is detected.

A number of patients with fractures of the ilium have pain, which exists since several months already. Some of them even had recent spinal surgery for this reason, but this intervention, however, was not successful in substantially palliating pain. Chronic fractures may show some amount of callus formation on pelvic CT evaluation. The patient's clinical presentation in such a situation is an important indicator for the surgeon in order to differentiate between ongoing fracture healing and delayed union or nonunion.

17.4 Indications for Surgery

Fractures of the ilium may be stable, and partially or completely unstable. Incomplete fractures are stable or partially unstable. They neither disrupt the continuity of the pelvic ring nor compromise the biomechanical load transfer to the lower extremities. Avulsions of the iliac spine and fractures of the iliac wing are typical examples. They, however, are uncommon in the geriatric population. Those injuries will be treated conservatively. Displaced large iliac wing fragments, which involve the anterior superior iliac spine, being the insertion of the inguinal ligament and the sartorius muscle, are a relative indication for surgery.

Incomplete fractures of the ilium may also be treated non-operatively. Conservative treatment with partial weight-bearing has a reasonable chance to lead to fracture consolidation. It however should be kept in mind that frail patients will not be able to avoid weight-bearing. Continued loading may compromise fracture healing and the incomplete fracture may become complete. Moreover, fractures in geriatric patients often heal slower than in the younger population due to metabolic bone disturbances like low vitamin D- or Ca++ levels or a long history of bisphosphonate intake. Due to inadequate and aggressive rehabilitation, incomplete fractures may become

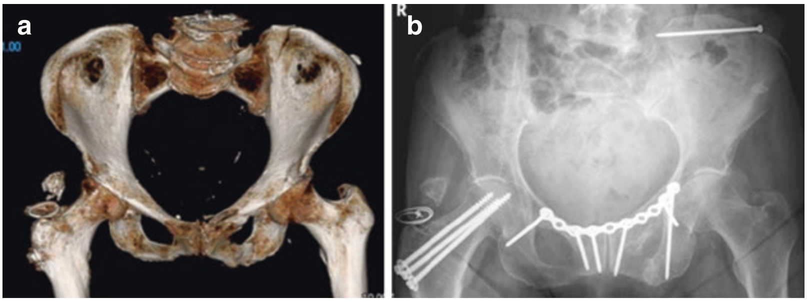


Fig. 17.1 (**a**) Fragility fracture of the pelvis with incomplete fracture of the left ilium. The fracture starts high at the level of the iliac crest. The fracture may progress and become complete with time if mobilization and unrestricted weight-bearing is continued. (**b**) The incomplete fracture at the iliac crest has been fixed with a 100 mm screw, which runs parallel to the crest and is inserted between the inner and outer cortex. The pubic bone fracture has been stabilized with a plate and screws. See also Fig. 25.1

complete and unstable over time. Careful patient follow-up therefore is necessary. In some instances, surgical fracture fixation therefore may be considered as a measure to avoid fracture progression (Fig. 17.1). Ongoing or increasing pain during mobilization must be interpreted as a potential sign of progressive instability.

Complete fractures lead—even when they are non-displaced—to a uni- or bilateral disruption of the pelvic ring. These fractures therefore require internal fracture fixation since spontaneous fracture healing cannot be expected. Associated anterior pelvic ring fractures are not obligatory but common. The author prefers to stabilize both the anterior and posterior lesions in order to achieve maximum stability in the whole pelvic ring, which is a prerequisite for proper fracture healing and early ambulation.

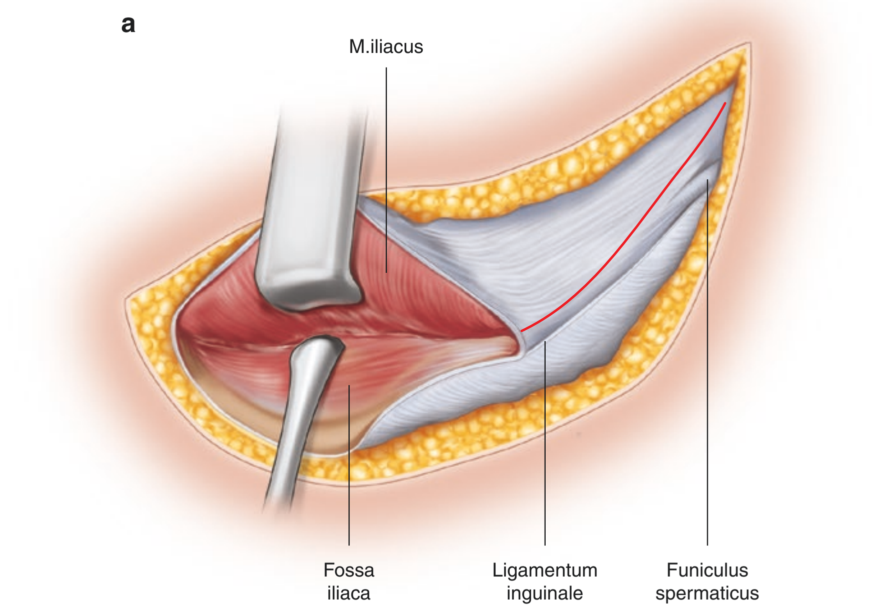
17.5 Preparation for Surgery and Surgical Approach

Patients are positioned supine on a radiolucent table. If no radiolucent table is available, it must be ensured preoperatively that appropriate image intensification in the antero-posterior, inlet and outlet views is possible. The ipsilateral leg is draped free and mobile. Prophylactic single-dose antibiotics are administered preoperatively.

The anterolateral approach gives a surgical access to the iliac fossa as far as the pelvic brim. The approach is simple, safe, soft-tissue friendly and well tolerated even by geriatric patients. It corresponds with the lateral or first window of the ilioinguinal approach to the acetabulum according to Letournel (Fig. 17.2a) [18, 19].

As an alternative, the external surface of the ilium can be exposed through the same incision with the patient in lateral decubitus position. Releasing the abductor muscles from the external surface, however, requires a more extensive surgical preparation. This surgical exposure is more invasive and may be associated with complications such as relevant blood loss, damage to the superior gluteal neurovascular bundle, muscle weakness and heterotopic ossifications. It therefore is generally not recommended, although exceptionally indicated as in iliosacral fracture-dislocations that involve the posterior ilium [20].

For the anterolateral approach, the skin incision starts at the level of the anterior superior iliac spine, which easily can be palpated even in obese patients. The incision is continued for at least 10–12 cm along the iliac crest towards posterior and proximal. Subsequent to preparation of the subcutaneous tissues, the abdominal wall muscles are released directly from the ilium. Since the external oblique abdominal muscle overlaps the iliac crest, slight retraction towards proximal and medial is necessary to expose its tendinous insertion on the bone. Release of the insertion of the abdominal wall muscles starts on the lateral edge of the iliac crest and progresses towards its medial edge. A transmuscular approach should be strictly avoided. On the



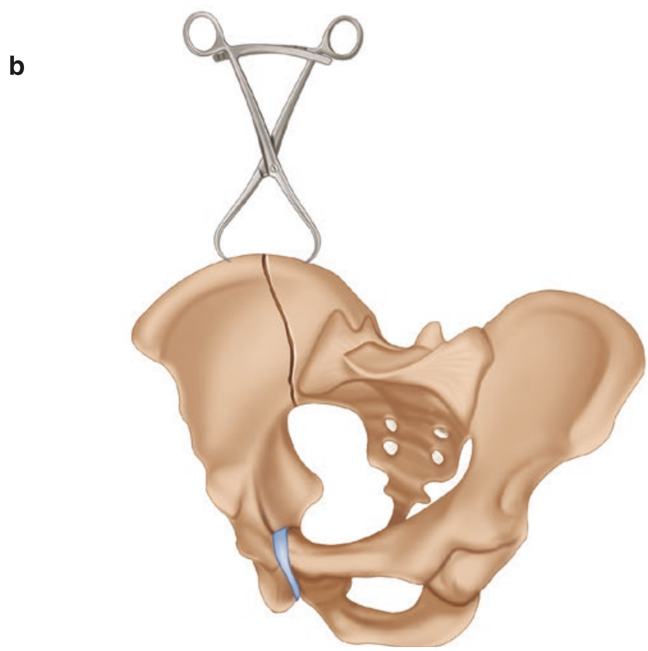


Fig. 17.2 (**a**) Surgical approach to the iliac fossa. The iliacus muscle is released from the internal surface of the iliac fossa as deep as the pelvic brim. Release of the inguinal ligament and the origin of the sartorius muscle from the anterior superior iliac spine is not done routinely. If needed, these structures can however be mobilized for better exposure of the internal iliac fossa and the supra-acetabular ilium body (Figure from: Tscherne Unfallchirurgie. Becken und Acetabulum. Tscherne H, Pohlemann T (eds), Springer Berlin Heidelberg 1998). (**b**) Reduction and provisional fixation of the fracture at the iliac crest with a pointed reduction forceps

medial edge of the iliac crest, the continuity between the tendinous part of the abdominal wall muscles and the periosteum of the ilium is preserved. The iliac muscle on the inner surface of the ilium is released subperiosteally with a sharp periosteal elevator (Fig. 17.2a). Strict subperiostal preparation avoids damaging the obturator nerve that runs between the iliacus and the psoas muscle and decreases bleeding. Flexing the hip and knee joint reduces muscular tension, reduces the risk of muscular damage due to traction and facilitates exposure. It is usually not necessary to release the origin of the sartorius muscle and the inguinal ligament from the anterior superior iliac spine. However, release of these structures will increase exposure and improve overview. Care must be taken not to harm the lateral subcutaneous femoral nerve that—with many anatomic variations—runs closely medial to the anterior superior iliac spine.

Subperiostal surgical dissection subsequently is continued medially to the sacroiliac joint, which mostly is well palpable, and to the sacrum. A Hohmann retractor, inserted with its tip in the lateral part of the sacrum, retracts the soft tissues and exposes the iliac fossa. Care must be taken not to harm the L5 nerve root, which runs parallel with and 10–15 mm medial to the sacroiliac joint. A second, blunt Hohmann retractor, which tip is inserted over the brim, improves visualization additionally.

The anterolateral approach gives an excellent overview of the internal surface of the ilium and allows perfect fracture reduction and fixation. Wound closure is simple and complication rates are low. If necessary, the approach can be extended towards proximal or distal. When long plates are used, e.g. for the stabilization of a combined fracture of the ilium and superior pubic ramus, extension to an ilioinguinal approach is possible. As an alternative, the anterolateral approach can be combined with a small suprapubic incision. The last will give access to the retropubic space, the third window of the ilioinguinal approach. Blunt, digital release of the iliopectineal fascia allows insertion of a long curved plate from the first to the third window along the pelvic brim, without opening the second window.

17.6 Fracture Reduction and Internal Fixation

Fracture reduction is performed under direct view. Fractures are less complex but less mobile than in acute high-energy injuries. The typical injury pattern of a fragility fracture of the ilium is a simple oblique fracture line or a Y-shaped fracture that starts at the pelvic brim and runs towards proximal and lateral to finish at the iliac crest. Additional fracture lines are possible but seldom. Fractures can be incomplete proximally (Fig. 17.1). In case of a complete ilium fracture, displacement occurs in the vertical direction with or without an additional rotational component.

Subacute and chronic fractures require resection of scar and callus tissue in order to mobilize the fragments as a prerequisite for reduction. Tight adhesions are divided with a chisel. Longitudinal traction on the limb helps correcting vertical displacement, if fracture fragments are sufficiently mobile. Anatomic reduction is not the ultimate goal of treatment, restoration of stability is more important in this patient group.

The anterior fragment is reduced against the posterior fragment, which is still attached to the sacrum by the intact sacroiliac ligaments. Similar as in high-energy fractures of the anterior column of the acetabulum, reduction starts proximally at the level of the iliac crest. Direct fracture fragment manipulation is achieved with a Schanz´ screw and a T-handle as a joystick. The Schanz' screw is inserted in the supra-acetabular iliac body at the level of the anterior inferior iliac spine. The strong cortical and trabecular bone in this area provides good holding power to the screw. The supra-acetabular position of the Schanz´ screw is clearly preferred over a screw inserted into the weaker bone of the iliac crest, since loss of fixation during manipulation occurs very early with the screw in the latter position.

A Faraboeuf clamp, placed directly over the iliac crest, is an excellent reduction tool as well. The clamp allows for direct manipulation of the mobile fragment in all planes. Fracture gaps and small steps at the level of the iliac crest may also be closed and temporarily fixed with a pointed

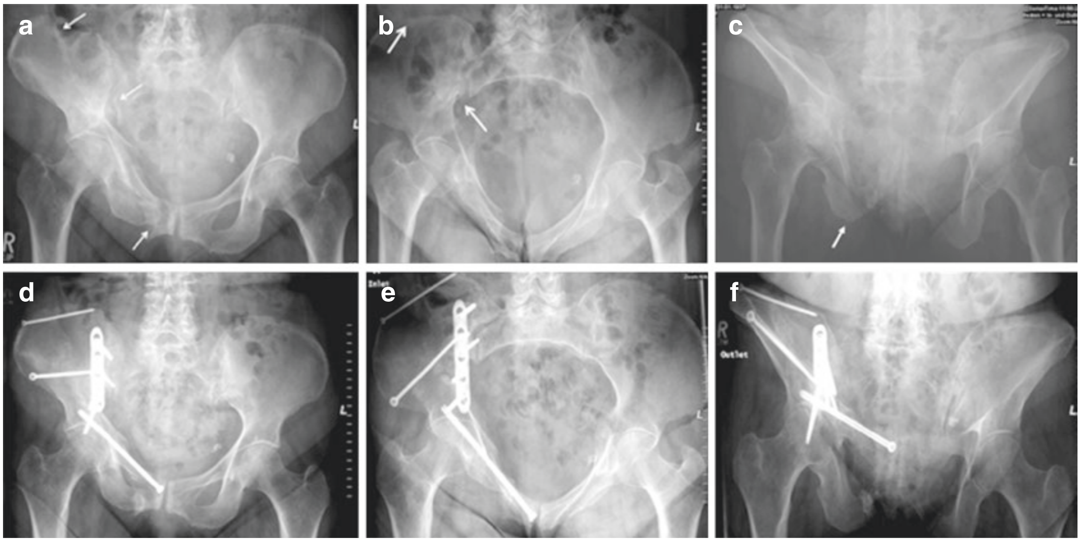


Fig. 17.3 Seventy-four-year-old female with FFP IIIa fracture. (**a**) Pelvic a.p. view shows transiliac and transpubic instability on the right side. There is a slight vertical displacement of the right hemipelvis. (**b**) Pelvic inlet view after trauma. (**c**) Pelvic outlet view after trauma is confirming the vertical displacement (*white arrows* in **a**–**c**). (**d**) Postoperative pelvic a.p. view. An angular stable plate has been used after open reduction of the right ilium fracture. The proximal screws of the plate are placed in posteromedial direction, parallel to the sacroiliac joint. The distal screws are placed in posterolateral direction. A small fragment screw controls the fracture at the right iliac crest. A large fragment screw is inserted from the anterior inferior iliac spine. A cannulated large fragment retrograde transpubic screw is used for fixation of the transpubic instability. (**e**) Postoperative pelvic inlet view. (**f**) Postoperative pelvic outlet view

reduction forceps (Weber clamp) placed across the fracture line (Fig. 17.2b). A pointed reduction clamp is preferred over a Faraboeuf clamp since the screws needed to attach the Faraboeuf clamp to the crest may interfere with subsequent definitive fracture fixation.

Definitive fixation at the level of the iliac crest is obtained with one or two screws. They are inserted between the inner and outer cortex perpendicular to the fracture plane and parallel to the iliac crest (Fig. 17.3). The exact position depends on the specific fracture morphology. Usually, screws with a length between 70 and 120 mm are used. Alternatively, a short one-third tubular plate can be placed on top of the iliac crest. The screws run parallel to the fracture plane and do not provide compression in the fracture. Screw fixation is therefore preferred above plate fixation.

After reduction and screw fixation of the fracture at the iliac crest, a malalignment may persist due to rotation of the innominate bone. This is corrected by direct pressure on the ilium body with a straight pointed ball spike. Also the plate used for fracture fixation can be used as a reduction tool. Plates applied on the pelvic brim are first fixed to the posterior ilium above the fracture line with one or two screws. Tightening these screws brings the plate down to the bone and closes the remaining fracture gap.

At the pelvic brim, the fracture is stabilized with plate and screws. Whereas small-fragment 3.5 mm pre-contoured reconstruction plates are typically used in the younger population, 4.5 mm implants may be considered in the elderly because of their higher stiffness. Rommens et al. recommended the use of angular stable plates (Figs. 17.4, 17.5 and 17.6) [21]. Locked plates better resist pull-out forces and there is a lower risk of loosening [22].

The exact position of the plate depends on the morphology and localization of the fracture. Screws should be inserted in those parts of the

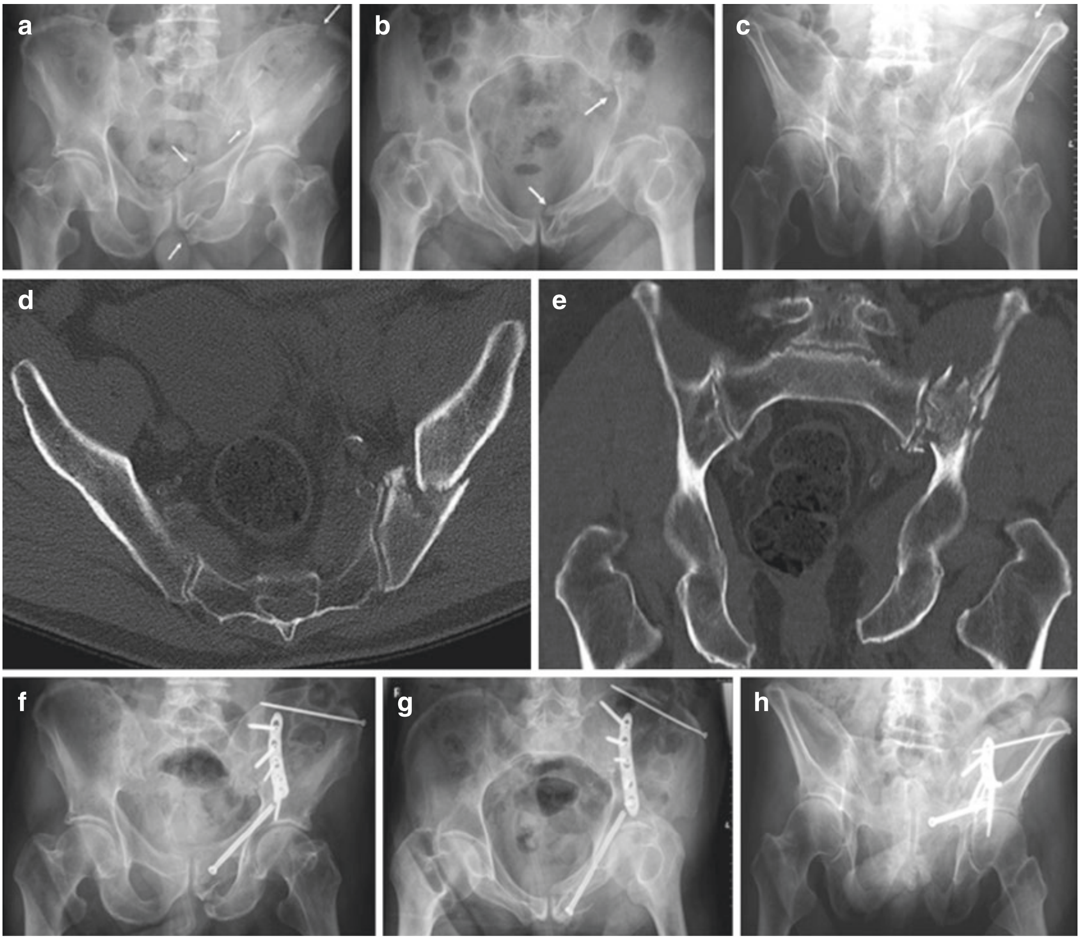
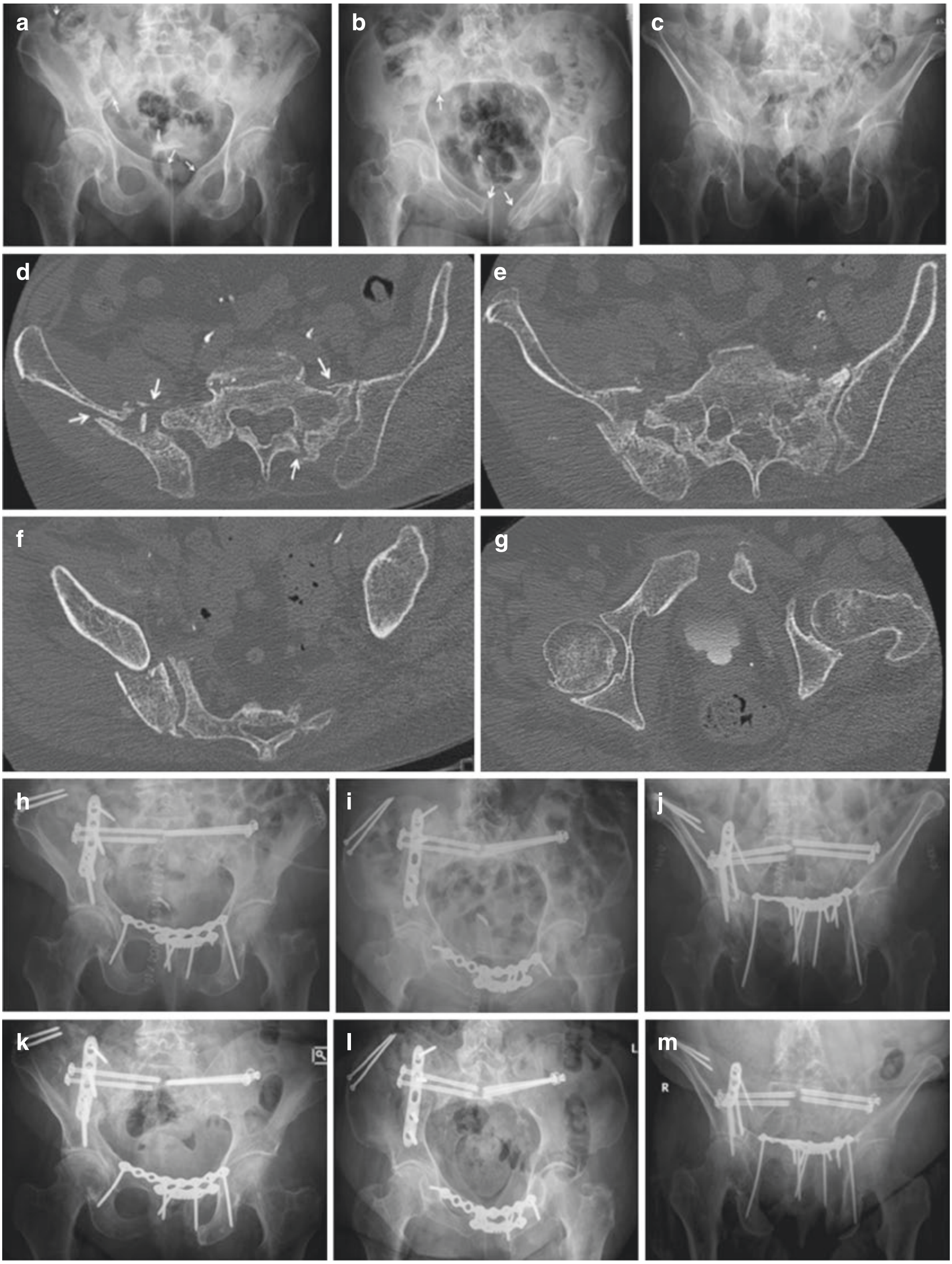


Fig. 17.4 (**a**) Seventy-eight-year old male with Alzheimer's disease and recurrent falls at home. The pelvic a.p. view reveals transiliac and transpubic instability on the left side (*white arrows*). There is vertical displacement of the left hemipelvis. (**b**) Pelvic inlet overview after trauma. (**c**) Pelvic outlet overview after trauma is confirming the fracture at the iliac crest (*white arrow*) and vertical displacement. (**d**) Axial CT-cut through the ilium is showing transiliac instability starting very near to the sacroiliac joint. (**e**) Coronal CT-cut is showing impaction of the fracture parts near to the sacroiliac joint. (**f**) Postoperative pelvic a.p. view. An angular stable plate has been used after open reduction of the left ilium fracture. An additional small fragment screw controls the fracture at the left iliac crest. A large fragment retrograde transpubic screw is used for fixation of the transpubic instability. (**g**) Postoperative pelvic inlet view. (**h**) Postoperative pelvic outlet view

pelvic ring, where the bone quality is best and pull-out strength highest [23, 24]. Stable osseous structures are the posterior ilium and the supra-acetabular bone. Plates generally are applied on the iliopectineal line. They are pre-shaped in order to match the contour of the innominate bone as good as possible. The proximal screws are inserted into the posterior ilium parallel to the sacroiliac joint. The trajectory of the screws should be as long as possible. Distal screws are inserted into the supra-acetabular bone. Perforation of screw tips into the hip joint must be excluded intraoperatively by fluoroscopy.

Bilateral fractures of the innominate bone are stabilized by bilateral plate fixation according to the technique described above. A contralateral fracture of the sacrum can be stabilized with a sacroiliac screw or transsacral bar (Figs. 17.5 and 17.6) [25]. In such a situation, the transsacral bar is inserted first as its trajectory might be blocked by the screws of the plate on the opposite site. From the technical perspective, it is easier to insert screws around the bar than vice versa.



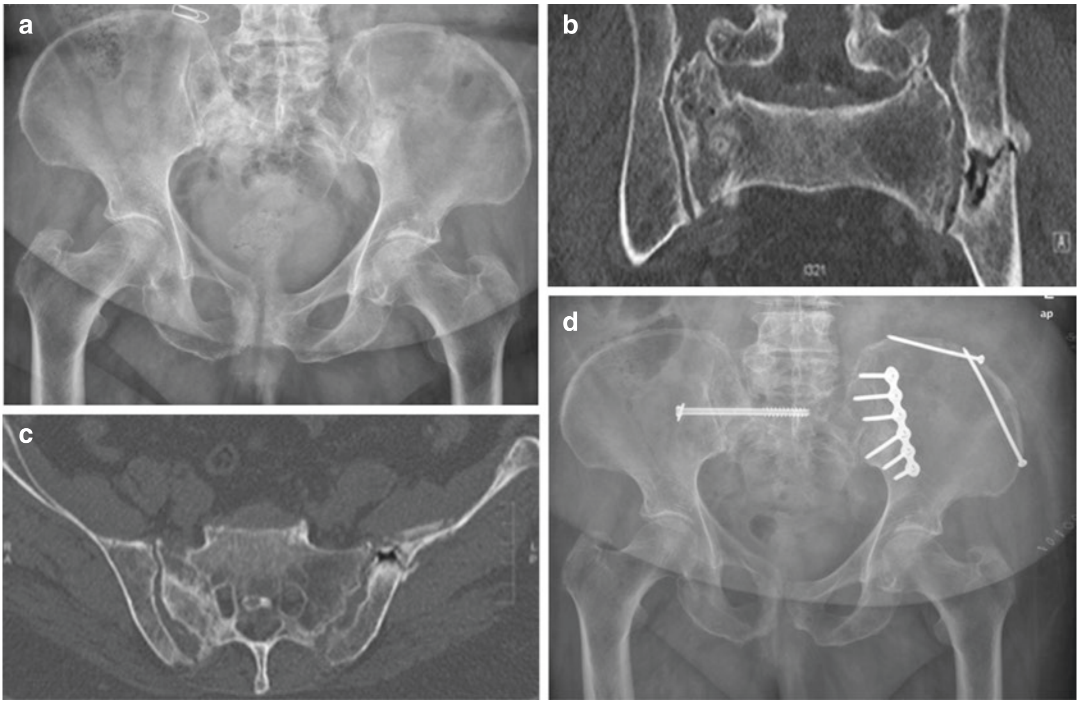


Fig. 17.6 (**a**) Pelvic a.p. view of a 82-year-old female patient with history of increasing pain since 7 months. There is no trauma history. Conservative treatment including repeated facet joint infiltrations was unsuccessful. A Y-shaped left-sided fracture of the ilium with callus formation is visible. (**b**, **c**) Coronal and axial CT-cuts through the posterior pelvic ring demonstrate a non-union of the posterior ilium involving the sacroiliac joint on the left side. A sacral ala fracture is visible on the right side. (**d**) Postoperative a.p. pelvic view. Percutaneous iliosacral screw fixation on the right side and plate and screw fixation of the ilium fracture on the left side have been performed

Fig. 17.5 (**a**) Seventy-five-year old female with history of fall 1 year ago. A left-sided pubic bone fracture very near to the symphysis pubis was treated conservatively. Months later, the patient was admitted in the neurosurgical unit because of severe low back pain with the diagnosis of lumbar stenosis. Pelvic a.p. view. Reveals a complete ilium fracture on the right side and diastasis of the pubic symphysis with pubic bone loss on the left (*white arrows*). (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. (**d**, **e**, **f**, **g**): CT-cuts through the pelvic ring are showing severe osteoporosis. The ilium fracture on the right starts at the sacroiliac joint and runs towards proximal and lateral to reach the iliac crest at its most proximal point (*white arrows*). Sacral dysmorphism is noticed in (**d**) and (**e**). Diastasis of the pubic symphysis and left-sided bone loss of the pubic bone are visible. (**h**) Postoperative pelvic a.p. view. Transiliac instability was mobilized through the first window of the ilioinguinal approach. The fracture was fixed with an angular stable plate with two screws above the fracture parallel to the sacroiliac joint and two screws distal to the fracture in posterolateral direction. At the iliac crest, the fracture was fixed with two lag screws. The sacral instabilities were fixed with iliosacral screws while the insertion of a sacral bar was impossible because of sacral dysmorphism. Diastasis of the pubic symphysis was reduced and fixed with a double plate. (**i**) Postoperative pelvic inlet view. (**j**) Postoperative pelvic outlet view. The long screw trajectories through the infra-acetabular corridor are shown. (**k**) Pelvic a.p. overview 1 month postoperative. One iliosacral screw shows slight loosening. (**l**) Pelvic inlet view 1 month after surgery. (**m**) Pelvic outlet view 1 month after surgery. The patient is standing and walking short distances in her room

17.7 After Treatment

Geriatric patients will not able to ambulate with partial weight-bearing. The individual decision whether to allow full weight-bearing or not depends on the estimated stability of the bone-implant construct. Whenever possible, early mobilization with weight-bearing is allowed, preventing muscle weakness and typical other complications of immobilization. Low-molecular-weight heparin is administered for at least 6 weeks to prevent thromboembolic complications. Medical treatment additionally includes work-up of bone metabolism and osteoporosis treatment if required.

Treating patients in a setting of a structured ortho-geriatric care unit with standardized protocols for pain management, prevention of delirium, management of malnourishment has proven to diminish hospital length of stay, morbidity and mortality [13, 26, 27].

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Part VI

Stabilization Techniques for the Anterior Pelvic Ring

18 External Fixation

Steven C. Herath and Tim Pohlemann

18.1 Biomechanical Considerations

Whenever considering the use of an external fixator, the surgeon must be aware of the biomechanical capabilities of this relatively easy applicable device. In the past, numerous studies have analyzed the mechanical characteristics of external fixation and have demonstrated that the supraacetabular external fixator does not provide a sufficient stability and retention for fractures of the posterior pelvic ring. When compared to an internal fixation of the posterior pelvic ring, the external fixator provides a 10–20 times lower stability in this region [1–7]. The earlier described combination of a ventral and a dorsal external fixator has been shown to partly settle this disadvantage, but leads to an inacceptable loss of comfort for the patient and an immense complexity of nursing care [8]. A recent study introduced a modified design for an external fixator that provides a significantly higher compression in the posterior pelvic ring. However, due to its design, this device seems only suitable for the emergency stabilization of life-threatening injuries [9].

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18.2 Indications for External Fixation

The supra-acetabular external fixator is a well-established tool for the emergency treatment of pelvic ring fractures in patients with a normal bone stock. Under certain circumstances, it can also be used for definitive treatment of transpubic fractures [10]. Isolated fragility fractures of the anterior pelvic ring (FFP Type I) should initially be treated conservatively with a few days of bed rest and sufficient analgesic medication, followed by mobilization under assistance of physiotherapists with weight bearing as tolerated by the patient [11, 12]. When no significant pain relief can be achieved with the abovementioned treatment, surgical treatment should be taken into account. For those patients, a supraacetabular fixator is a minimally invasive option that leads to a fast reduction of symptoms [12]. In fragility fractures that involve both the posterior and the anterior pelvic ring, an external fixator can be applied as a supplement to a posterior osteosynthesis in order to increase the overall stability of the pelvic ring (Fig. 18.1). If, for any reason, a posterior stabilization of the pelvic ring is not feasible, the sole application of a supra-acetabular fixator can be considered in order to achieve pain reduction (Fig. 18.2) [13].

The use of external fixators for the treatment of fragility fractures is discussed controversially. On the one hand, they are easy and fast to apply.

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_18

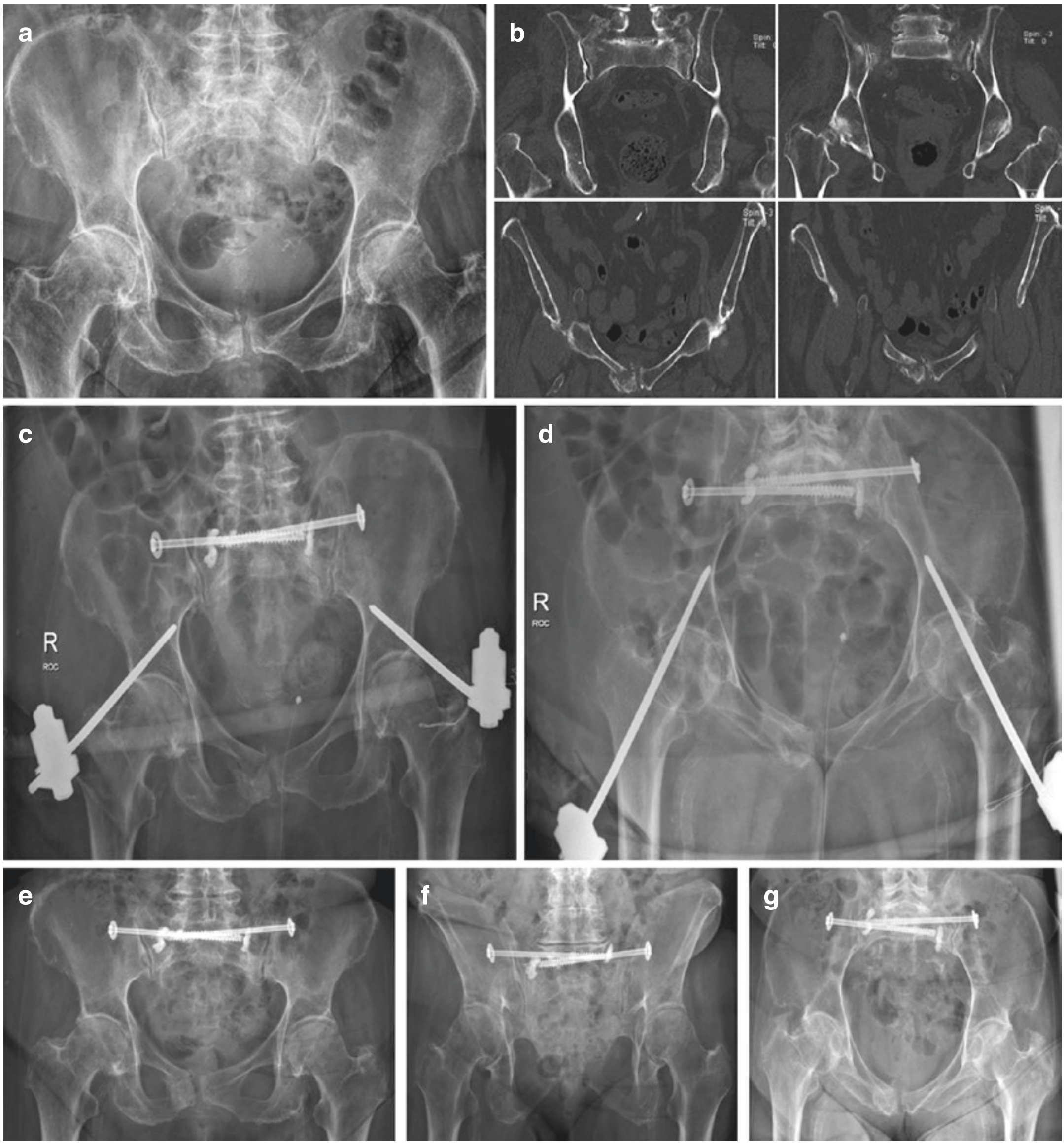

Fig. 18.1 An 83-year-old female suffered a fall in the garden. (**a**) An a.p. pelvic overview reveals a right-sided pubic bone fracture. (**b**) Coronal CT-cuts through the anterior and posterior pelvic ring show bilateral sacral ala fractures and confirm the right-sided pubic bone fracture. It concerns a FFP Type IVb. (**c**) Postoperative a.p. pelvic overview. The posterior pelvic ring was stabilized with two cement-augmented IS screws. The anterior pelvic ring was bridged with a supraacetabular external fixator. (**d**) Postoperative pelvic inlet view. (**e**, **f**, **g**) The external fixator was removed after 6 weeks. The a.p., inlet and outlet pelvic overviews were taken 3 months after surgery. The patient walked with full weight bearing without relevant pain

On the other hand, they cause significant patient discomfort. In osteoporotic bone, the risk of pin loosening is increased. Furthermore, pin track infection rates of up to 30% have been reported [14]. For non-displaced fractures of the pubic rami, a retrogradely inserted lag screw is an alternative procedure, which can be carried out minimally invasive via a small skin incision (see

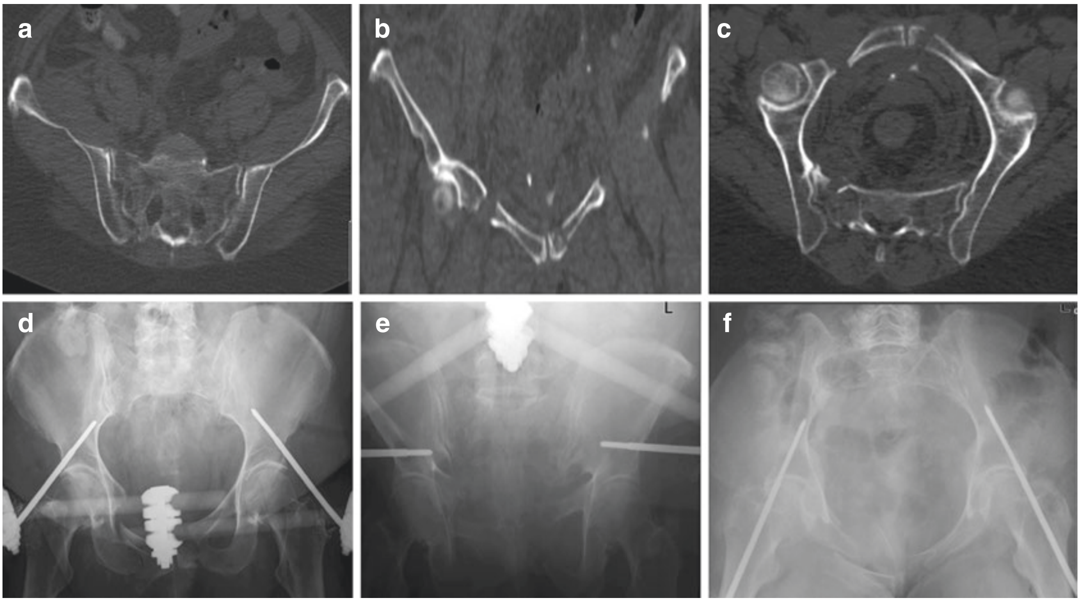

Fig. 18.2 A 76-year-old female patient suffered a fall in her nursing home. (**a**) Transverse CT-cut through the posterior pelvis reveals a right-sided sacral ala fracture. (**b**) coronal CT-cut through the anterior pelvis showing bilateral pubic rami fractures. (**c**) CT-reconstruction through the pelvic inlet plane showing the unilateral posterior and bilateral anterior fractures. (**d**) The pelvic ring was stabilized with an external fixator. A posterior internal fixation was impossible due to compromised soft tissue conditions. (**d**, **e**, **f**) Postoperative a.p. (**d**), pelvic outlet (**e**) and inlet views (**f**) demonstrate the supra-acetabular position and orientation of the Schanz' screws

Chapter 19). However, in contrast to any other osteosynthesis of the anterior pelvic ring, an external fixator can easily be removed. The fact that no anesthesia is needed for the removal of an external fixator is a big advantage especially in multimorbid patients. Therefore, in our opinion, the supra-acetabular fixator is still a powerful and important tool for the temporary stabilization of the anterior pelvic ring.

18.3 Surgical Technique

With the patient in a supine position, a 2 cm long incision is made approximately 3 cm caudally and 3 cm medially of the anterior superior iliac spine (Fig. 18.3). After blunt dissection of the soft tissues, the anterior inferior iliac spine is palpated. The entry point is identified and a trocar is inserted in the planned direction of the Schanz' screw. The correct position is controlled with image intensifier. To prevent a cutting out of the pin, the bone should only be drilled for a few centimeters, so that the Schanz' screw can find its way between the inner and outer cortex of the ilium by itself. The drill bit should be tilted to point approximately 20° cranially and 30° medially (Fig. 18.4). But the drill can easily slide off the anterior inferior iliac spine in this orientation. It therefore is recommended to center-punch the bone by a slight stroke with a hammer onto the trocar prior to drilling. It is also possible to perforate the cortex with the drill in an orientation perpendicular to the bone surface before tilting the drill as mentioned above. The Schanz' screw should be inserted as far as possible to achieve a maximum of stability. After both Schanz' screws have been inserted, connecting the pins completes the fixator. The use of a curved carbon rod minimizes the impairment for the patient and facilitates radiological examinations (Figs. 18.5 and 18.6). Alternatively, two

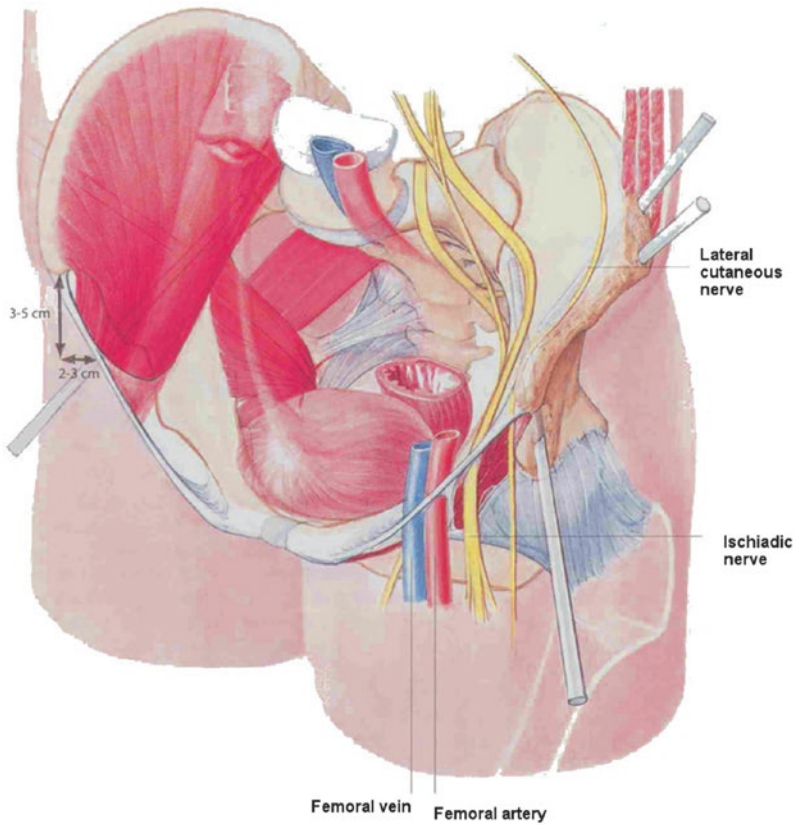

Fig. 18.3 Drawing of the soft tissue structures around the innominate bone and of the position of supraacetabular Schanz' screws on the left and right side. As the Schanz' screw is inserted very near to the lateral femoral cutaneous nerve, damage to this nerve should be avoided by using a trocar before and during drilling

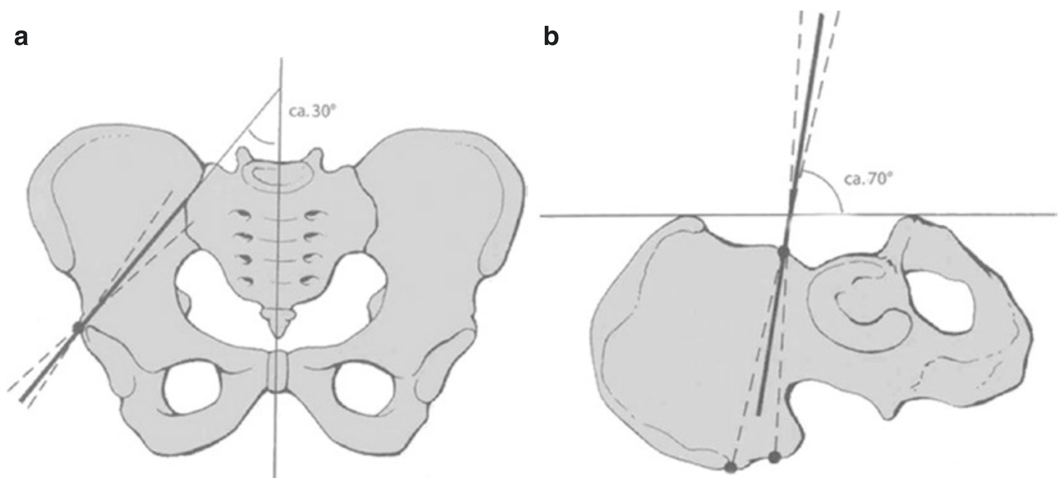

Fig. 18.4 Drawings of the corridor for screw insertion with the anterior inferior iliac spine as entry portal. (**a**) A.p.-view. (**b**) lateral view of the pelvis. Perforation of the hip joint, of the greater sciatic notch and of the sacroiliac joint must be avoided by correct orientation of the Schanz' screw

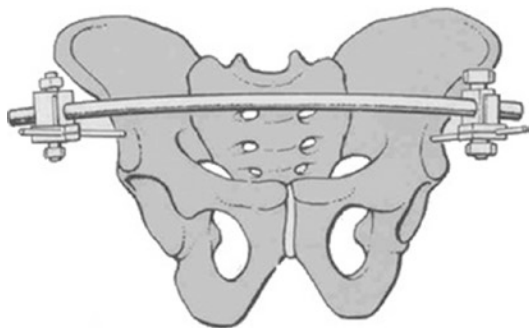

Fig. 18.5 Drawing of the supraacetabular external fixator. After both Schanz' screws have been inserted in the body of the left and right ilium, a curved carbon rod is connected to the Schanz' screws with ball joints

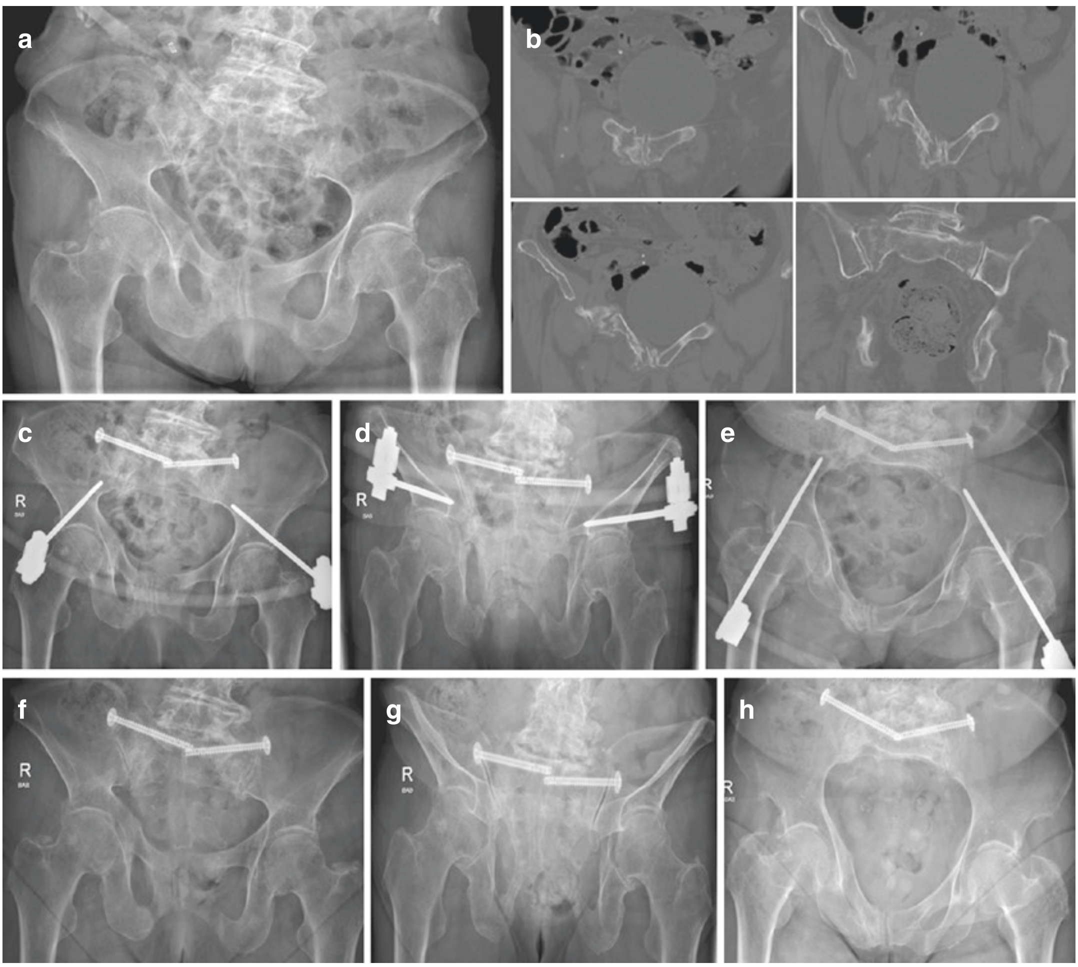

Fig. 18.6 An 86-year-old female suffered a fall on her way to the toilet. She first presented in the outpatient department 6 weeks after the accident. (**a**) An a.p. pelvic overview reveals a right-sided superior pubic ramus fracture. (**b**) Coronal CT-cuts through the anterior and posterior pelvic ring show bilateral sacral ala fractures and confirm the right-sided superior pubic ramus fracture. It concerns a FFP Type IVb. (**c**, **d**, **e**) Postoperative a.p., outlet and inlet pelvic overviews. The posterior pelvic ring was stabilized with two IS screws. The anterior pelvic ring was bridged with a supraacetabular external fixator, using a curved carbon rod. (**f**, **g**, **h**) The external fixator was removed after 4 weeks. The a.p., outlet and inlet pelvic overviews were taken 6 months after surgery and show complete healing of the anterior pelvic ring. The patient walked with full weight bearing, complaining pain when climbing stairs only

straight carbon rods connected with a ball joint may be used (Fig. 18.2). Skin closure is only necessary for longer incisions being made. In any case, the unhindered passage of the Schanz' screws through the skin must be assured before finishing the procedure. The skin incision must eventually be adapted to prevent direct pressure of the screws on the skin margin. The latest may provoke skin breakdown followed by pin track infection.

18.4 Aftercare and Removal

A meticulous care of the pin tracks is of utmost importance to avoid soft tissue problems and infection. Daily wound care including changing dressings is mandatory. Direct pressure of the fixator frame on the skin must be avoided in order to prevent pain, skin breakdown and necrosis.

Patients are allowed to mobilize out of the bed with weight bearing as tolerated. A sitting position with the hips flexed up to 90° is permitted. However, in obese patients, there may be a mechanical conflict between the fixator rods and the abdominal wall or the upper thighs. A less than 90° of hip flexion must then be respected.

Removal of the fixator can be done without anesthesia. The time-point of removal is depending on the characteristics of the anterior pelvic ring fracture. Bilateral and displaced fractures need a longer healing time than unilateral or non-displaced and therefore need longer immobilization with the external fixator. Before definitive removal, the connecting rod is loosened and pain intensity assessed during walking under full weight-bearing. If walking is possible painlessly, the Schanz' screws are removed. In case of persisting pain, the fixator is reconnected and the same examination repeated some weeks later. In case of clinical or radiological signs of screw loosening, removal is inevitable at any time.

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19 Retrograde Transpubic Screw Fixation

Pol Maria Rommens, Daniel Wagner, and Alexander Hofmann

19.1 Introduction

The main goals in treating fragility fractures of the pelvis (FFP) are reduction of pain and restoration of stability of the pelvic ring, allowing early mobilization to prevent immobilization-associated complications. The pelvic ring is a circular structure; fractures of the anterior pelvic ring are very often combined with fractures of the posterior pelvis. Scheyerer et al. conducted a retrospective study to evaluate the posterior pelvic ring in patients with pubic ramus fractures [1]. One hundred and seventy-seven patients with complete diagnostics, including a CT scan, were reviewed. In patients with no obvious other injury than the pubic ramus fractures in the a.p. radiograph, an injury of the posterior pelvic ring was found in 96.8% in CT. The study included high-energy as well as low-energy pelvic ring injuries [1]. Alnaib et al. conducted a prospective study on 67 patients with fragility fractures of the pelvis [2]. Fifty-four female and thirteen male patients with an average age of 87.5 years were included. Isolated sacral fractures were only present in 9%. Fifty-four percent of the patients with a single pubic ramus fracture had an associated sacral fracture. Sixty-one percent of the patients with two pubic ramus fractures had an associated sacral fracture [2]. In the study of Lau et al. including 37 patients above 65 years of age with a pubic ramus fracture, a posterior pelvic ring lesion was detected in 59% [3]. In our retrospective study of 245 patients above the age of 65 with FFP, only 44 patients (18%) had an isolated anterior pelvic ring fracture and 3 (1.2%) an isolated posterior pelvic ring fracture. The remaining 198 patients (80.8%) had a combination of anterior and posterior pelvic ring fractures [4]. We conclude that posterior and anterior pelvic ring injuries are combined in the vast majority of patients.

Anterior pelvic ring fractures or disruptions are located at the pubic symphysis, in the pubic bone near to the symphysis, at the superior and inferior pubic ramus involving the obturator foramen; and at the anterior lip of the acetabulum. In our retrospective study, we observed that most of the anterior pelvic ring fractures in elderly are pubic ramus fractures. Less frequent are pubic bone and anterior lip fractures. Instabilities of the pubic symphysis are the least frequent [4]. In a retrospective

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_19

study of Starr et al. on 145 anterior pelvic ring fractures operatively treated with percutaneous screw fixation, 22 were located medial to the obturator foramen, 100 above and 23 lateral to the obturator foramen [5]. The low number of symphyseal disruptions in the elderly may be due to the fragile cortical and trabecular bone [6], while ligaments become stiffer [7], but there are no biomechanical studies, which confirm this hypothesis. Fractures and dislocations are situated at areas of highest strain and lowest stiffness, i.e. in the sacral ala, the sciatic notch with the adjacent ilium, the supra-acetabular region, the quadrilateral surface, and the pubic rami [8]. This leads to consistent fracture patterns in the posterior pelvic ring [9, 10]. Similarly, the anterior pelvic ring breaks at its weakest point, which is the pubic ramus. Sometimes, instabilities of the pubic symphysis and bone defects near to it have been observed in chronic FFP (Fig. 19.1). In these cases, we suppose that the primary instability was located in the pubic bone. Subsequently and due to continuous and repetitive movements, bone resorption occurs and finally involves the nearby joint [11].

Different fixation techniques have been developed for stabilization of the anterior pelvic ring in high-energy pelvic disruptions. External fixation and open reduction and plate fixation (ORIF) are the most frequently used. These techniques are also valid for fixation of anterior pelvic ring fractures in FFP. More recently, the anterior subcutaneous pelvic internal fixator has been introduced as a less-invasive technique [12]. Retrograde medullary superior pubic ramus screw fixation is another minimal invasive technique. The technique has been described several decades ago but never gained wide acceptance [13, 14]. The popularity of retrograde screw insertion is increasing now due to the increasing number of FFP, the minimal invasiveness of the procedure and the high stability of the fixation [15].

Fig. 19.1 Seventy-four-year-old female with long history of rheumatoid arthritis. The patient already had bilateral total hip replacements. She has a limited walking distance due to chronic pain in the lower lumbar spine and at the pubic symphysis. A.p. pelvic overview reveals a bone defect of the left pubic bone with widening of the pubic symphysis and cortical reaction. Irregularities of the bone structure can also be seen at the right sacral ala

19.2 Rationale

Fractures of the anterior or posterior pelvic ring involve an interruption of the ring structure with loss of pelvic stability. Biomechanical studies by Tile et al. showed that stability of a cadaveric pelvic ring is diminished by 30% when the anterior pelvis is ruptured [16]. Nevertheless, when only the anterior pelvic ring is broken and diastasis between the fracture fragments not large, non-operative treatment will be the first choice. This choice of treatment is valid for fractures in adults and in elderly with FFP Type I. Analgesic therapy, bed rest and careful mobilization will lead to fracture healing and good functional recovery in the great majority of patients [17, 18].

In FFP, isolated anterior pelvic fractures account for merely 18%. More than 80% of patients with FFP have a combination of anterior with posterior pelvic ring instability. These are FFP Type II (except of FFP Type IIa), FFP Type III and FFP Type IV in the classification of Rommens and Hofmann [4]. In these fracture types, loss of stability is much higher than 30%, when compared with the intact pelvis. Consequently, non-operative therapy is challenging in some patients with FFP Type II and in most patients with FFP Type III and IV. Cumbersome management due to longer periods of immobilization and severe pain leads to prolonged recovery time and higher complication rates. Operative therapy is, therefore, recommended in all FFP

Type III and FFP Type IV. When conservative treatment is not successful after 1 week, operative therapy is also recommended in FFP Type II [19].

The surgical intervention should be as minimal invasive as possible. Prolonged surgeries may provoke additional pain, increased blood loss, higher risk of infection and endanger the limited physiological reserves of the patient. Minimally invasive fixation of pubic rami fractures is feasible with a retrograde transpubic screw through the "anterior column corridor". It can be done through an incision of a few centimeters near to the pubic symphysis. While splinting the fracture of the superior pubic ramus, the stability of the anterior pelvic ring is restored. This reduces pain immediately. However, retrograde transpubic screw fixation must be regarded as additional fixation to posterior pelvic ring fixation. If done as only procedure in patients with combined anterior and posterior fractures of the pelvic ring, there will be a higher risk of screw loosening, delayed union and nonunion of the pubic ramus fractures due to remaining posterior pelvic instability [5].

19.3 The Anterior Column Corridor

The superior pubic ramus is part of the anterior column of the acetabulum. Judet et al. described the innominate bone as an inversed Y structure, with the acetabular cavity hanged up between and being part of the two columns [20]. They distinguished the ilio-pubic as the anterior and the ilio-ischial as the posterior column. The anterior column comprises the iliac wing, anterior part of the ilium body, the anterior lip of the acetabulum, the superior pubic ramus and the pubic bone. In all patients, there exists a straight corridor between the anterior cortex of the superior pubic ramus near to the pubic tubercle and the external cortex of the ilium above the acetabulum [21]. The "anterior column corridor" lies inside the superior pubic ramus and passes medially and cranially of the acetabular cavity without penetrating it (Fig. 19.2). Its anterior and posterior entry portal, its anatomical landmarks, its dimension and orientation has recently been the subject of several anatomical and radiological studies.

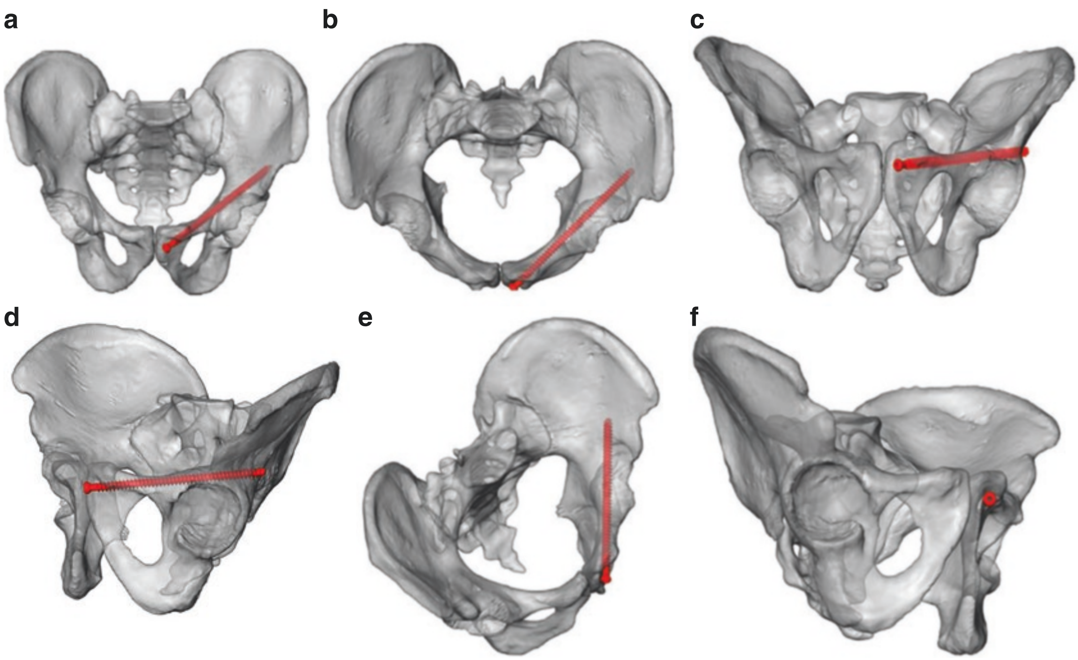

Fig. 19.2 Different 3D–projections of an intact pelvic ring. A retrograde transpubic screw is inserted through the left anterior column corridor. (**a**) a.p. pelvic view. (**b**) pelvic inlet view. (**c**) pelvic outlet view. (**d**) obturator-outlet view (**e**) iliac inlet view (**f**) axial projection of the anterior column corridor

Routt et al. 1995 published the technique and first results of retrograde transpubic screw placement in 24 patients. They identified an ideal starting point just inferior to the pubic tubercle and lateral to the pubic symphysis [13]. Suzuki et al. studied the anatomy of the pubic ramus and adjacent soft tissue structures in 160 Japanese (80 men and 80 women) using 3D reconstructions of pelvic CT scans. The minimal canal diameter (=maximum diameter of any implant) was on average 13.5 mm for men and 10.7 mm for women. The authors found a positive correlation between the canal diameters at the base of the corridor (para-symphyseal region) to body weight in both men and women. In women, the canal diameters at the base were also correlated to height. The canal diameters at the acetabulum were not correlated to height or weight. The mean length of the corridor was 124.6 mm in men and 123.8 mm in women. The minimum distances from the pubis to the bladder/iliac artery/iliac vein were 0 and 0 mm/4.9 and 4.6 mm/ 0.8 and 0.2 mm in men and women, respectively. The central axis of the anterior column corridor in supine position runs at a mean of 66° and 67° cephalad and 54.1° and 55.9° laterally for men and women, respectively [21]. Chen et al. created virtual cylindrical tubes, which were placed within 164 anterior column corridors obtained from CT data of 82 Chinese adults without pelvic bone pathology [22]. The mean maximum diameter of the cylindrical implant was 8.16 mm with a length of 109.4 mm. The spatial orientation of the cylinder was 39.7°, 20.8° and 42.7° to the transverse, coronal and sagittal planes, respectively. The anterior insertion point was localized in average 18.4 mm laterally to the pubic symphysis and 17.8 mm caudally to the rim of the superior pubic ramus. The length and diameter was larger in males, with the distance to the symphysis being shorter [22]. Puchwein et al. obtained 3D reconstructions of pelvic CT data of 50 polytraumatized patients (35 males and 15 females with a mean age of 41.3 years) without pelvic injury. Virtual bolts were placed in the anterior column without perforating any cortical layer or penetrating the hip joint. The length between the entry point and exit point was measured; and the areas with the smallest cortex-bolt distance were identified. The shortest distance between the bolt and the hip joint was also measured. The average length of the bolt was 127.2 mm, the narrowest diameter 14.6 mm. Consequentially, the insertion of a 7.3 mm screw should be possible in all patients. The average distance between the bolt and the hip was 3.9 mm. The bolt was oriented with an average of 39° in the sagittal plane and 15° in the coronal plane (Fig. 19.3) [23].

Dienstknecht et al. measured the distance from the entry point at the anterior cortex of the superior pubic ramus to different landmarks, which easily can be recognized intra-operatively in anteroposterior and oblique fluoroscopic pelvic views [24]. The following landmarks were identified within a 2.5 cm range in all specimens: pubic tubercle, iliopectineal eminence, the superior rim of the superior pubic ramus, and the anterior inferior iliac spine. The authors found that there was little gender difference, except a smaller distance to the cranial rim of the superior pubic ramus in females. They stressed the significance of anatomical landmarks in percutaneous fixation of anterior pelvic ring fractures. When relying on these landmarks, screw placement can be performed safely [24].

We learn from these studies that the anterior column corridor exists in all adult humans. The length of the corridor differs between Asians and Europeans. Chinese adults have the shortest corridor (±110 mm) whereas corridors of Japanese and Europeans have similar lengths (±130 mm). The maximal diameter of a virtual cylinder filling-up the anterior column corridor was smaller in Chinese than in Japanese or Europeans. Consequently, the screw diameter should be adapted individually. Women will need smaller diameter screws than men. It therefore is recommended to analyze the CT data in different reconstructions before surgery. Data on the spatial orientation of the corridor can hardly be compared. Striking is that the angle to the sagittal plane (direction towards lateral) was comparable in the studies of Suzuki [21] (±55°), Chen [22] (±43°) and Puchwein [23] (±39.0°) and did not differ between men and women. The values of the angle to the coronal plane (direction towards cranial) were more differing. This value certainly is depending on the inclination of the pelvic ring of the supine patient. We therefore recommend holding the drill bit in a 45°-45° position to the

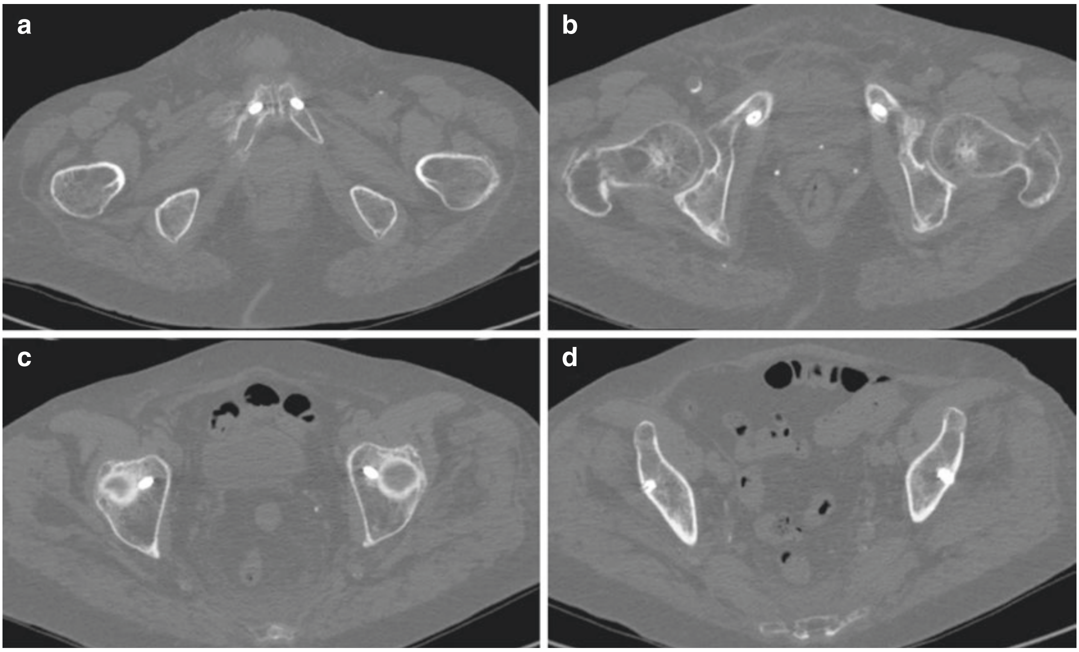

Fig. 19.3 Postoperative transverse CT cuts through the pelvis of the 82-year old female depicted in Figs. 11.9, 11.12 and 11.13. (**a**) CT-cut through the pubic symphysis (**b**) CT-cut through the pubic rami. (**c**) CT-cut through the roof of the acetabulum. (**d**) CT-cut though the ilium superior to the acetabulum. The screws run completely within the bony corridor and reach the lateral cortex of the ilium above the acetabulum

transverse and sagittal planes with the tip of the drill at the ideal entry portal before starting the drilling procedure (see Sect. 19.5).

19.4 Biomechanical Studies

Simonian et al. demonstrated that fixation of the anterior pelvic ring with a retrograde transpubic 4.5 mm screw obtains the same stability as with conventional 3.5 mm plating [25]. An anteroposterior compression type II (APC-II) unstable pelvic ring injury was created in cadavers. Under physiological loading, the stability of the construct with a contoured ten-hole 3.5 mm reconstruction plate fixed with four resp. six cortical screws or with a retrograde screw with a length of 80 mm resp. 130 mm was not significantly different. These techniques were tested on the same cadaveric pelvis in a random sequence. Solid large fragment 4.5 mm stainless steel screws were used for retrograde transpubic screw insertion. The authors concluded that retrograde screw fixation is a valid alternative to plate fixation of pubic ramus fractures [25].

Gras et al. compared different screw types with standard plate fixation of anterior column fractures [26]. They tested anterior column plate fixation versus infra- and supraacetabular titanium, stainless steel, or biodegradable Poly-L-Lactid screws. The fixation strength of plate osteosynthesis and titanium screws was similar; strength of stainless steel and Poly-L-Lactid screws was inferior to the abovementioned [26].

In a more recent study, Acklin et al. found a lower stability for retrograde screw fixation than for plate fixation of pubic ramus fractures [27]. A ten-hole plate with six cortical screws was tested against an 80 mm long 7.3 mm partially threated cannulated screw. Displacement and gap angle were significantly higher for the retrograde screw during cyclic loading. The screw osteosynthesis failed due to screw cutting through the cancellous bone. The plate construct failed under higher loads due to bending [27].

From a biomechanical point of view, retrograde medullary superior pubic ramus fixation can be regarded as a valid alternative to plate fixation. To avoid cutting through the cancellous bone, as described by Acklin et al. [27], we recommend using long screws, which perforate the lateral cortex of the ilium above the acetabulum. Thanks to the firm attachment of the screw tip in cortical bone, the screw is anchored in the cortical bone, despite its cancellous profile. In contrast to what the results of the biomechanical study of Simonian et al. suggest [25], we recommend the use of large diameter screws (e.g. 7.3 mm) (Fig. 19.4).

19.5 Surgical Technique

The patient is placed supine and eccentrically on a radiolucent operation table, with his/her feet at the end of the radiolucent carbon table. This enables free movement of the C-arm for intraoperative pelvic inlet and outlet views. The lumbosacral spine is supported with a blanket, giving more stability to the pelvic ring during drilling [13]. Before draping, the area of interest is analyzed in different fluoroscopic views and the ideal inclination of the C-arm for the iliac-inlet (I-I) and obturator-outlet (O-O) oblique projections registered and marked on the machine. Due

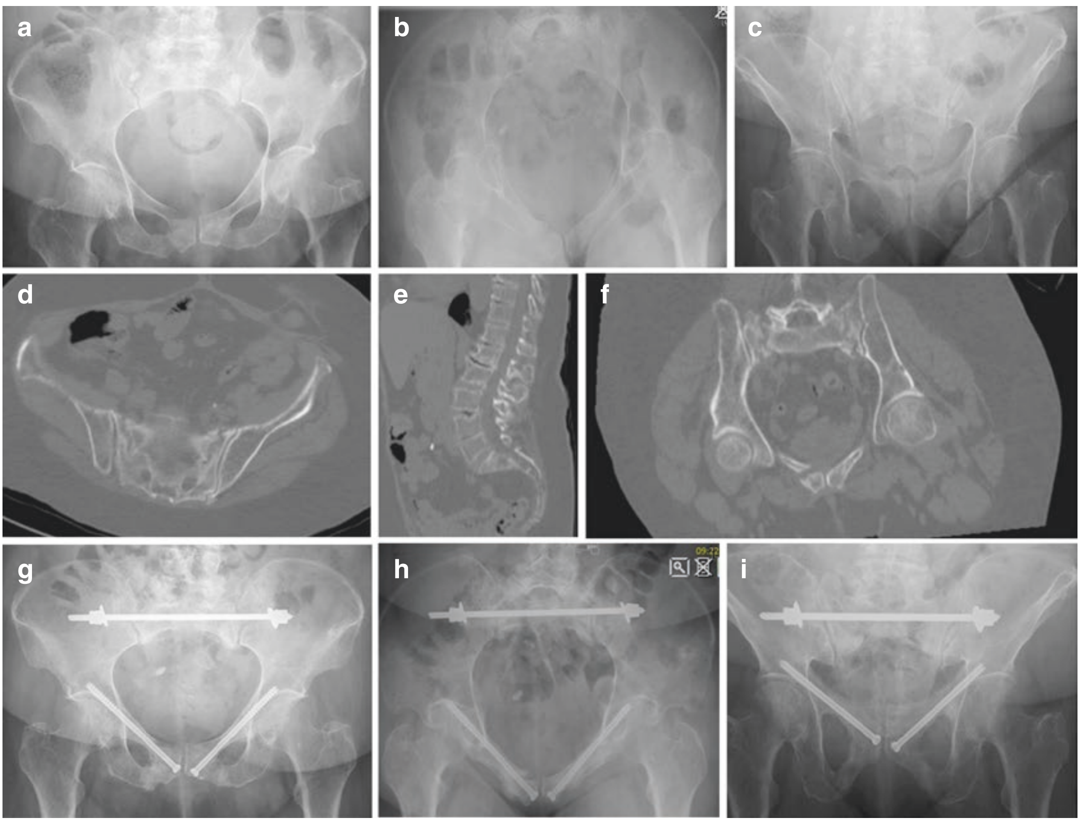

Fig. 19.4 Seventy-four-year-old female with spontaneous pain in the right groin. Initially, no specific therapy was given. Admission 3 months later due to continuous and immobilizing pain. (**a**) A.p. pelvic overview reveals a right-sided pubic ramus fracture. (**b**) Pelvic inlet view shows a non-displaced left-sided pubic ramus fracture. (**c**) Pelvic outlet view excludes any vertical displacement. The bone structure of the left and right sacral ala is irregular. (**d**) Transverse CT-cut through the posterior pelvis shows bilateral sacral ala fractures with slight widening of the fracture gap, which is typical for chronic instability. (**e**) Sagittal CT-reconstruction through the midline of the sacrum shows a slightly displaced horizontal fracture between S1 and S2. (**f**) Oblique CT-reconstruction through the small pelvis. The bilateral sacral ala fracture and the right-sided pubic ramus fracture are seen. The patient has a FFP Type IVb lesion. (**g**) Pelvic a.p. overview 5 months after surgery. Minimal-invasive surgical stabilization was done. The posterior instabilities have been treated with a transsacral bar, the anterior instabilities with two retrograde transpubic screws. (**h**) Pelvic inlet view. (**i**) Pelvic outlet view. The patient is free of complaints and independent for activities of daily life

to anatomical variations and different pelvic incidences, these values may vary from patient to patient [28]. The skin area around the pubic symphysis must be free; draping is done appropriately to enable free access to the ideal entry point of the screw through the skin. It is also recommended leaving the umbilicus free for better orientation of the midline longitudinal axis of the patient's body. Anatomical landmarks are palpated and marked on the skin. The surgeon stands opposite to the side of the pubic ramus fracture. The C-arm is placed at the side of the injury, the monitor besides the C-arm more cranial to it. The screen should be located in the working field of the surgeon. To facilitate orientation, the image seen on the screen is orientated identically to the surgeon's view of the operative site. Horizontal on the table must be horizontal on the screen, anterior on the table in the upper part of the screen, posterior in the lower part of the screen. On the broken side, the whole anterior pelvic ring should be visible in a.-p. and oblique views to facilitate localization of the entry portal, and adequate orientation of the drill before and during the drilling procedure [14].

Before skin incision, a long drill bit is placed on the skin of the lower abdomen and adjusted along the anterior column corridor using the a.p. view (Fig. 19.5a–e). This pathway is marked on the skin. A small skin incision is made in line with the corridor. The incision is situated in the midline just below the pubic symphysis or slightly lateral, on the opposite side of the fracture. A trajectory to the anterior pubic bone is prepared using blunt scissors. A 2.8 mm drill bit, protected by a sleeve or drill guide, is placed above the entry point of the bone. As shown in several studies, the entry point is situated approximately 20 mm lateral to the pubic symphysis and approximately 20 mm below the superior rim of the superior pubic ramus [22, 24]. At first, the drill bit is hold in 45°-45° inclinations to the frontal and sagittal planes. Under image intensifier control, the location of the drill tip is adjusted until it lies precisely in line with the optimal trajectory of the screw. For

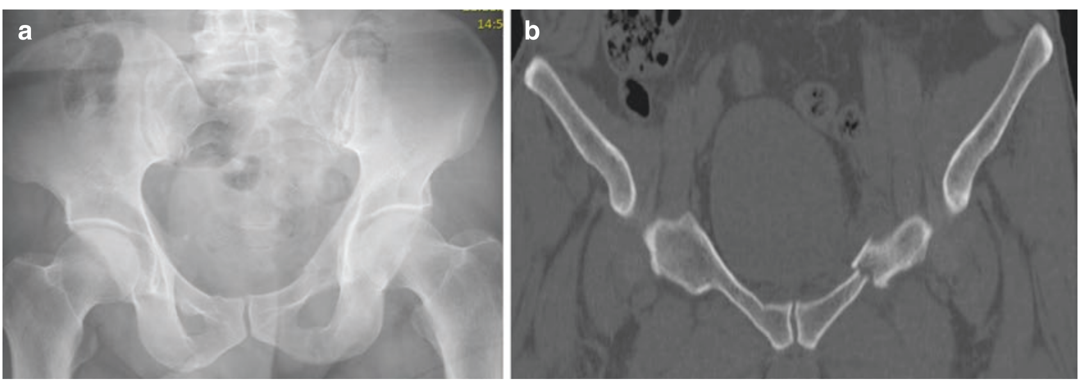

Fig. 19.5 Technique of retrograde medullary superior pubic ramus screw fixation. Sixty-five year old male with left-sided sacral ala fracture and bilateral pubic ramus fractures after a fall with his bicycle. (**a**) A.p. pelvic overview. (**b**) Coronal CT-cut through the anterior pelvic ring shows complete fracture of the left superior pubic ramus and incomplete fracture of the right superior pubic ramus. (**c**) A.p. fluoroscopic view of the left anterior pelvic ring and hip joint. (**d**) The drill bit is placed over the abdomen so that it superimposes the anterior column corridor. (**e**) A.p. fluoroscopic view with the drill bit on the abdomen. (**f**) Pelvic outlet view after insertion of the drill bit through the entry portal lateral to the pubic symphysis and below the superior ridge of the pubic ramus. (**g**) Iliac-inlet view of the left anterior pelvic ring with the tip of the drill bit inside the superior pubic ramus reaching the fracture. (**h**) Obturator-outlet view with the drill bit passing the roof of the left acetabulum. (**i**) iliac-inlet view with the drill bit inside the anterior column corridor and its tip perforating the lateral cortex of the ilium above the acetabulum. The *white arrows* show the inner cortex of the superior pubic ramus. (**j** and **k**) Obturator-outlet view of the left anterior pelvic ring after insertion of the screw. Position of the fluoroscope (view from the foot end of the patient) (**j**) and fluoroscopic view (**k**). (**l** and **m**) Iliac-inlet view of the left anterior pelvic ring after insertion of the screw. Position of the fluoroscope (view from the foot end of the patient) (**l**) and fluoroscopic view (**m**). (**n**) Postoperative pelvic inlet view. (**o**) Postoperative pelvic outlet view

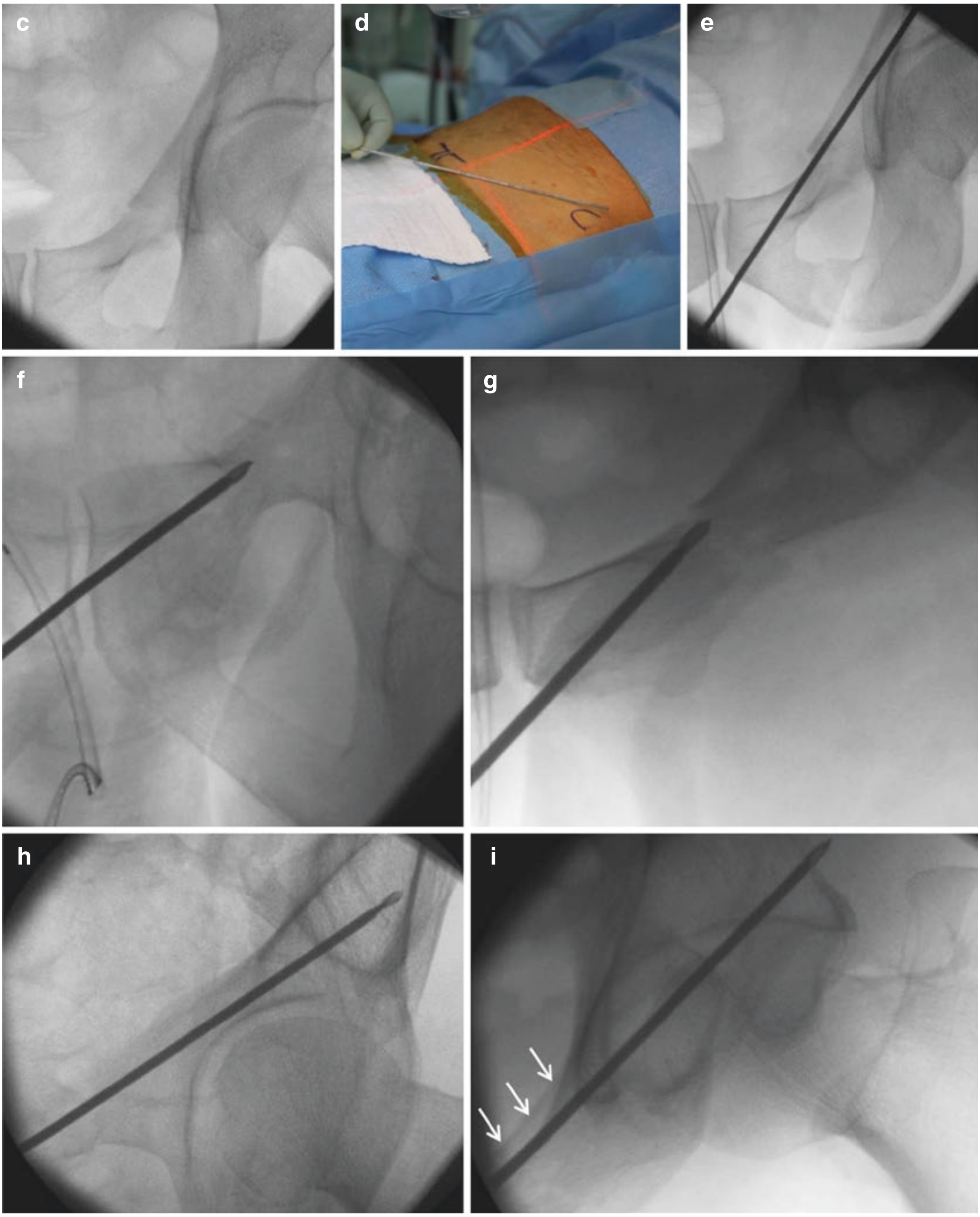

Fig. 19.5 (continued)

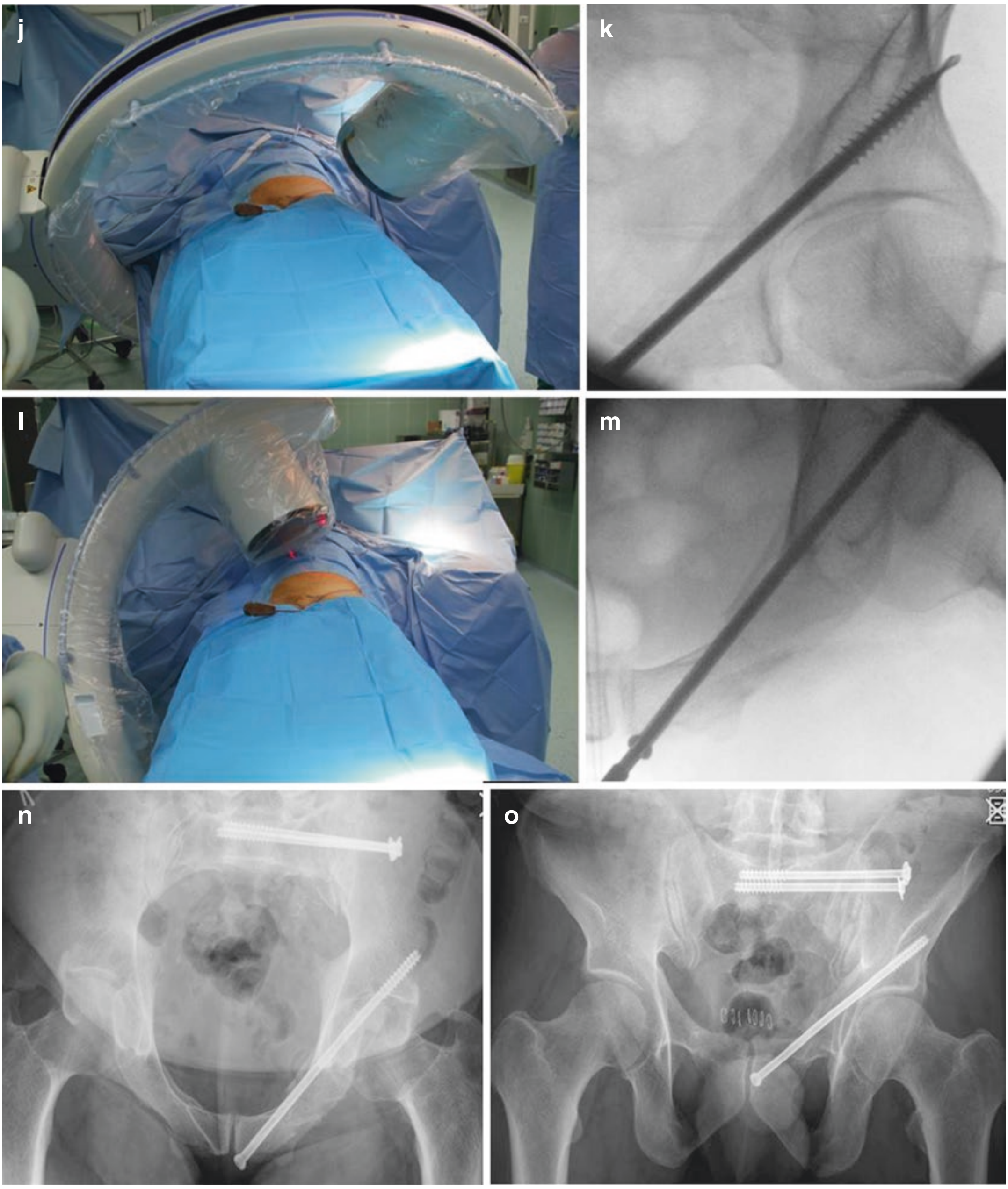

Fig. 19.5 (continued)

this, the image intensifier is inclined into I-I and O-O positions, consecutively. While the drill bit enters the canal, it moves cranially and laterally through the superior pubic ramus. A.p., I-I and O-O views are repeated during the drilling procedure to secure correct position of the drill bit. Special attention is paid to avoid penetration into the hip joint. The drilling procedure is continued until the tip of the drill bit reaches and perforates the lateral cortex of the ilium above the acetabulum (Fig. 19.5f–i) [29]. Especially in osteoporotic bone, repetitive careful hammer blows can be used to push the drill forward into the anterior column corridor. As shown by several authors, the length of the trajectory in the bone may reach 130 mm [18, 21, 23]. The most medial-anterior part of the trajectory is overdilled with a drill bit of 4.5 mm. A 7.3 mm cannulated screw of appropriate length is inserted over the 2.8 mm drill bit. The use of a washer is not necessary. The screw head lies in the thick tendinous attachment of the adductor muscles at the pubic bone (Fig. 19.5j–o). The screw primarily splints the superior pubic ramus fracture; it does not realize strong compression. When the drill bit cannot pass the acetabulum without perforating the joint, a shorter screw must be chosen.

Fracture reduction must be obtained before or during the drilling procedure. When both fracture fragments are displaced, but still in line with the anterior column corridor, reduction can easily be obtained with closed manipulation: careful pulling (external rotation) or pushing (internal rotation) on the ipsilateral iliac wing will close the fracture gap. If closed manipulation does not reduce the fracture adequately, minimally invasive techniques may be used. A small-size periosteal elevator or a bone hook is placed directly on the medial fracture fragment. Therefore, a small incision is made through the rectus abdominis muscle just above the fracture gap, alternatively through the linea alba. With the instrument in place and under image intensifier control, the medial fragment is brought in line with the lateral. When this maneuver also fails, the incision through the linea alba is enlarged and direct manipulation with the surgeon's fingers is carried out [5]. As an alternative, the drill bit and cannulated screw are inserted in the medial-anterior fragment first and this fragment aligned to the proximal through direct manipulation with the screw. Once aligned, the drill bit is forwarded and the screw inserted in the proximal fragment [29].

19.6 Results

There is only little evidence available for intraoperative complications and outcomes of retrograde superior pubic ramus fixation in pelvic ring fractures. Winkelhagen et al. used retrograde superior pubic ramus screw fixation in isolated pubic ramus fractures in six elderly patients without posterior pelvic ring pathology in conventional radiographs [30]. The mean age of the six female patients was 81 years. The surgery was performed because of severe and immobilizing pain despite pain therapy. There were no intraoperative complications. There was no screw breakage or loosening. After 1 year, four patients had returned to their preoperative functional status, one patient died and one patient suffered from ipsilateral arthritis of the hip, which prevented evaluation of outcome of pubic ramus screw fixation [30].

Starr et al. published a unique and large series of retrograde transpubic screw fixations in anterior pelvic ring instabilities [5]. Eighty-two patients, who underwent 108 screw fixation procedures, were followed until fracture healing, which averaged 9 months (range 2–52 months). The average age of the patients was 35 years (range 14–85 years). This patient population was not comparable with those having a fragility fracture of the pelvis. Only nine patients (11%) suffered a fall, the other patients were victims of traffic accidents. There were 68 retrograde and 40 antegrade screw fixations. There were no intra-operative neurologic, vascular or urologic complications. There was an average blood loss of 34 cc and fluoroscopy time of 7 min. There were 16% failures of fixation (11/68). The average age of the patients with failure of fixation was 55 years. Patients aged ≥60 years failed significantly more often. Ten of the eleven patients were female, six were older than 60 years. In all but one patient, there was an internal rotation deformity (lateral compression injury) with a partial recurrence of the internal rotation defor-

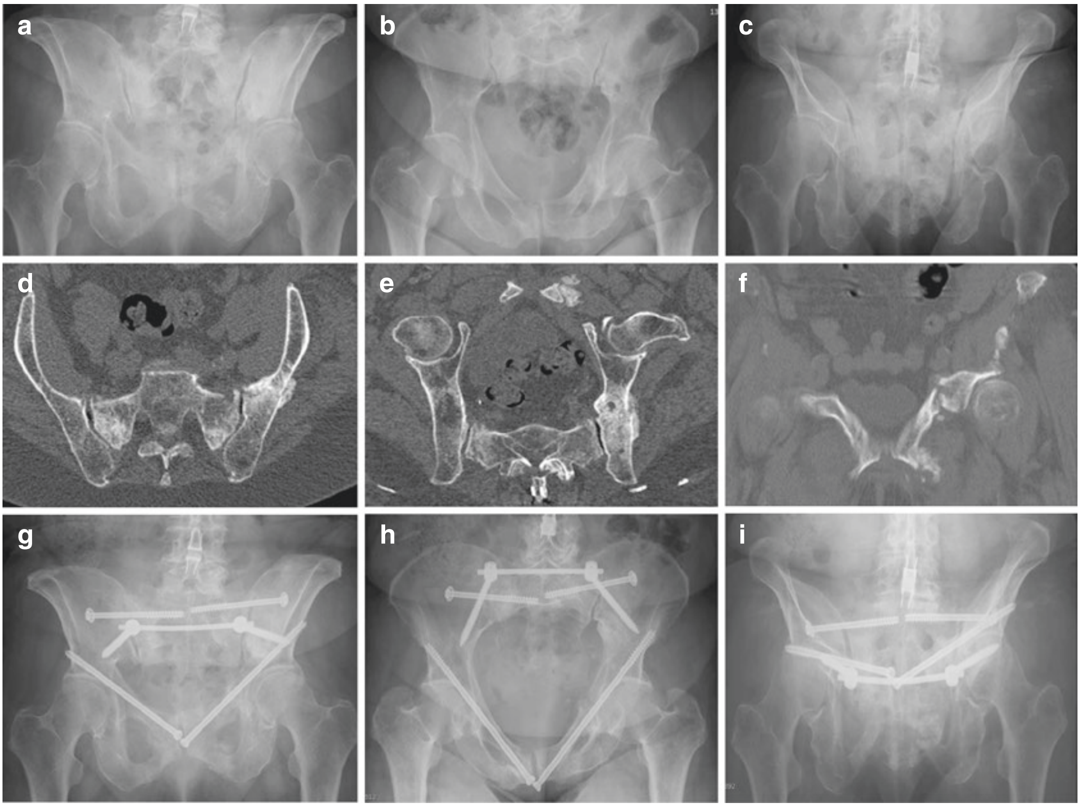

Fig. 19.6 A 73-year-old female with history of chronic pain after a fall. There has been a pain therapy with mobilization. (**a**) Pelvic a.p. overview 6 months after the fall reveals bilateral anterior pubic rami fractures with callus formation but without healing. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. (**d**) Axial CT-cut through the posterior pelvis reveals a left-sided ilium fracture with bridging callus, and bilateral sacral ala instabilities. (**e**) Multiplanar reconstruction of the pelvic ring showing anterior and posterior instabilities. The sacral corridor is too small for a safe transsacral bar placement. (**f**) Coronal CT-cut shows bilateral anterior instabilities. (**g**) Postoperative pelvic a.p. overview. The anterior instabilities were transfixed with two retrograde transpubic screws. The tip of both screws perforates the lateral cortex of the ilium, realizing the highest possible stability. The posterior instabilities were fixed with a transiliac internal fixator and two iliosacral screws. (**h**) Postoperative pelvic inlet view. (**i**) Postoperative pelvic outlet view (courtesy from Rommens et al. [31])

mity after failure. There was a higher rate of failure in the patients with a short medial-anterior fragment, when the fracture was localized near to the pubic symphysis. Only two patients underwent revision surgery [5].

The study by Starr et al., although retrospective, suggests that age and gender are risk factors for failure of fixation. Failure ratio might be higher in FFP than in the abovementioned series. A possible reason is the lower holding power of the retrograde screw in the osteoporotic bone, especially when the screw tip ends in the cancellous bone of the ilium. We, therefore, recommend using the maximum length of the anterior column corridor. When the screw tip perforates the outer cortex of the ilium, it has a stronger hold in the cortical bone and there is a lower risk of loosening (Fig. 19.6). Fractures near to the pubic symphysis with a short medial-anterior fracture fragment are less appropriate for retrograde screw fixation. There is low stability because the screw does not find good anchorage in the short medial-anterior fragment. For these types of fractures, we recommend a plate osteosynthesis.

Conclusion

The large majority of fragility fractures of the pelvis is characterized by a combination of a fracture of the anterior and the posterior pelvic ring. When treating the posterior pelvic ring operatively, surgical fixation of the anterior pelvic ring should also be considered. Minimally-invasive approaches have the advantage of being less aggressive with short operation time, minimal soft tissue damage and minimal blood loss [31]. Retrograde transpubic screw fixation is a valid alternative to other fixation techniques. When performed carefully under intra-operative image intensification monitoring, the procedure is safe. Stability is comparable to plate osteosynthesis. There is a higher risk of loosening or implant failure when the whole length of the anterior column corridor is not used and the screw tip ends in cancellous bone. Failure of fixation has been reported to be around 15% in a large series of pelvic ring fractures. Bone healing is the rule, although it may take a long period of time.

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20 Plate Osteosynthesis, Subcutaneous Internal Fixation and Anterior Pelvic Bridge Fixation

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20.1 General Considerations

Surgical treatment of anterior pelvic fragility fractures is indicated to improve stability of the pelvic ring after fixation of the posterior pelvis in unstable fracture variants. The purpose of fixation is to mitigate incapacitating pain, facilitate mobilization and rehabilitation, and prevent functionally significant pelvic malunions and nonunions. It is well accepted that long periods of recumbancy, particularly in the elderly, increase the risk of complications such as pressure sores, deep vein thrombosis, pneumonia and delirium [1–5].

The Rommens and Hofmann classification describes four classes of pelvic fragility fractures, of which Group III and IV are unstable. These fractures are distinguished by combination of anterior and posterior injuries which lead to greater instability. As "a rule of thumb", posterior fractures should be addressed first, and when additional stability is desired, anterior fixation is used to augment posterior fixation [6–13]. It is highly unusual for anterior or posterior pelvic fractures to occur in isolation, and most often the analogy of "a pretzel breaks in at least two places" applies to the pelvic osteoligamentous ring.

Anterior pelvic ring fragility fractures can be classified as ligamentous (pubic symphysis dislocations), osseous (pubic rami fractures) or osteoligamentous (combination injuries). Pure osseous injuries are more common in the elderly, because the bone quality is poor relative to the ligamentous integrity, and therefore tends to yield first. Even though there share similarities with high-energy fractures in younger individuals, there are substantial differences between these two patient populations, which necessitate special considerations when planning internal fixation. These differences can be broken down into *local* (metabolic problems of the bone and soft tissue quality) and *systemic* (related to poor general health) subgroups [4, 14–17].

Due to decreased strength of the osteoporotic bone, thinned cortices and patulous intraosseous spaces of the pubic rami, strength of fixation of each screw is diminished, which can lead to increased interfragmentary motion, screw pull out and ultimately failure of the construct with loss of reduction and resultant complications (Fig. 20.1) [18–21].

Local soft tissues of the anterior abdominal region of an elderly individual are fragile and do not tolerate aggressive dissection and retraction, resulting in frequent postoperative skin edge necrosis and wound breakdown. Physical exami-

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_20

nation and evaluation of computed tomography studies should be rigorous, assessing for hernias of the abdominal wall, previous scars related to abdominal or pelvic surgery, abdominal panniculus, and calcified iliac arteries (Fig. 20.2). Additionally, abdominal ileus is common, as well as the constipated patient which manifests with bowel distension and bladder retention which also can manifest in distended hollow viscus, thus interfering with surgical access.

From a broad medical perspective, a fragility fracture reflects general metabolic problems,

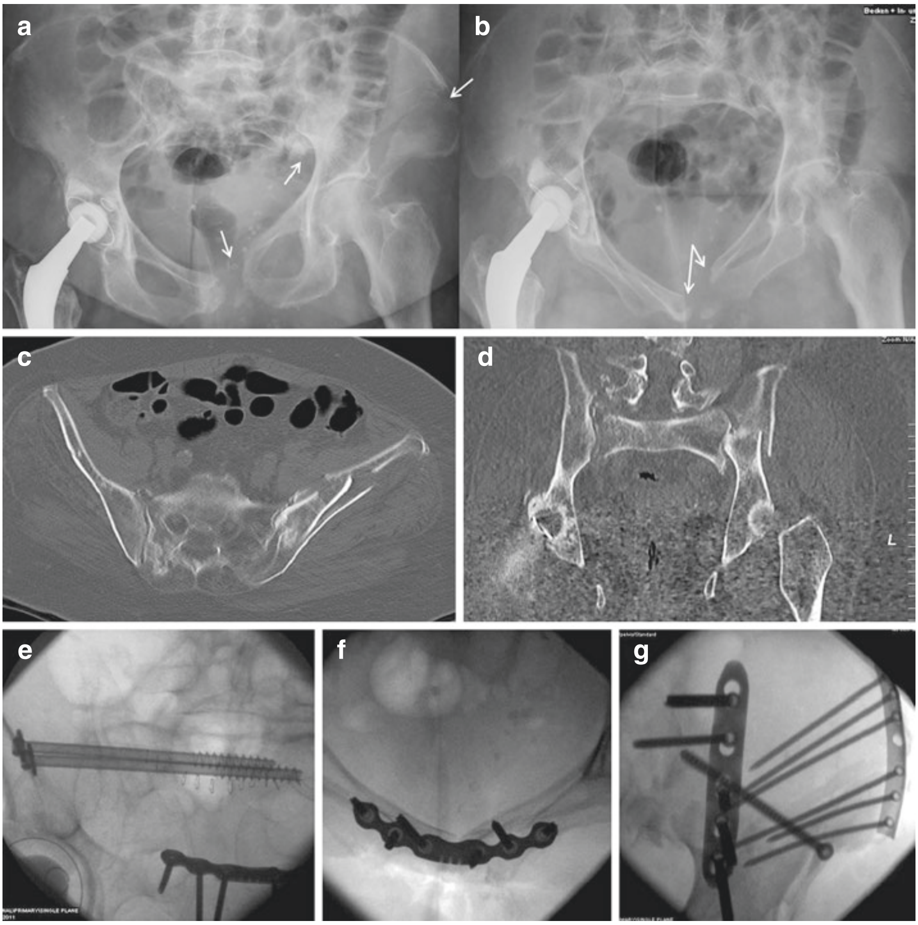

Fig. 20.1 Eighty-years-old morbid obese female patient after a fall at her nursing home. The patient already suffered from chronic pain in the anterior and posterior pelvic ring. (**a**) The a.p. pelvic overview shows a diastasis and bone defect at the pubic symphysis, a left-sided iliac wing fracture and a fracture of the left posterior ilium near to the iliosacral joint with vertical displacement (*white arrows*). (**b**) Pelvic inlet view showing the diastasis and bone defect of the left pubic bone (*white arrows*). (**c**) Transverse CT-cut through the posterior pelvic ring reveals a fracture of the right sacral ala and a fracture of the left posterior ilium. (**d**) Coronal CT-cut through the posterior pelvic ring shows the right-sided sacral ala fracture and a left-sided posterior ilium fracture with intrusion of the fracture fragments. The pelvic ring is highly unstable. The patient suffers a FFP Type IVc lesion. (**e**, **f** and **g**) Intraoperative fluoroscopic views showing stabilization of all fractures: iliosacral screws for the right sacral ala fracture, six-hole angular stable plate for the pubic symphysis diastasis, large-fragment angular-stable plate osteosynthesis for the posterior ilium fracture and non-angular stable small-fragment bridging plate with long screws for the iliac crest fracture. (**h** and **i**) Two weeks after surgery, the plate osteosynthesis of the pubic symphysis failed. Pelvic a.p. and outlet view. (**j** and **k**) The plate osteosynthesis of the pubic symphysis was revised. A longer plate with two long infra-acetabular screws, going into the posterior column towards the ischial tuberosity, has been inserted. Pelvic a.p. and outlet view. Although functional recovery of this patient was not satisfactory, pain level importantly diminished and implant-related problems did not occur. (courtesy of Rommens et al., Mainz, Germany)

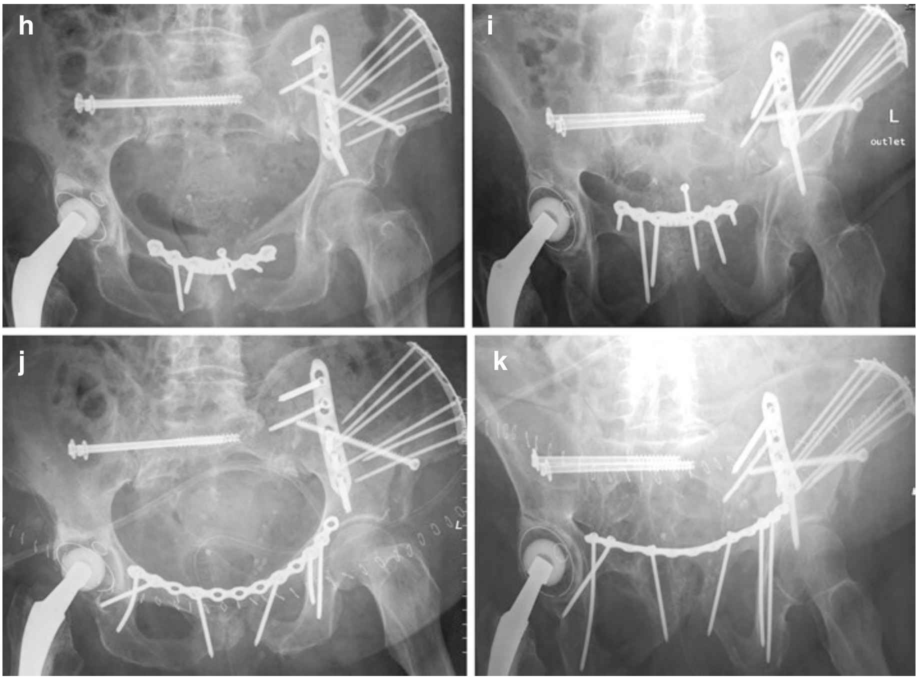

Fig. 20.1 (continued)

Fig. 20.2 Coronal CT-scan demonstrating left superior ramus fracture, aorto-iliac bypass graft, right femoral artery atherosclerosis, and descending colon diverticulae. Atherosclerotic arteries in the pelvis can be susceptible to damage and may result in bleeding in pelvis fractures

systemic illness or possibly malignancy. These individuals are all the more vulnerable, and poorly tolerate bed rest. Early and aggressive mobilization must be seen as an important goal for these patients; however, due to compromised mental capacity as well as poor balance and coordination, they are often unable to follow weight-bearing precautions. This limitation may create unfavorable forces across the fracture and interfragmentary motion endangering integrity of the fixation.

Additionally, regarding the patients' general health, their comorbidities, such as cardiac and vascular disease, coagulopathy and temperature regulation, make them more vulnerable to prolonged procedures and extensive blood loss. The latter may result in increased frequency of surgical site hematomas and infection.

Consequentially, patients with fragility fractures of the anterior pelvic ring should not be treated in the same manner as younger individuals with better metabolic reserves, who sustain high-energy injuries. Surgical techniques and strategies should therefore be planned to minimize perioperative morbidity while providing adequate and rigid fixation to facilitate immediate mobilization [3, 4, 16, 18, 22–25].

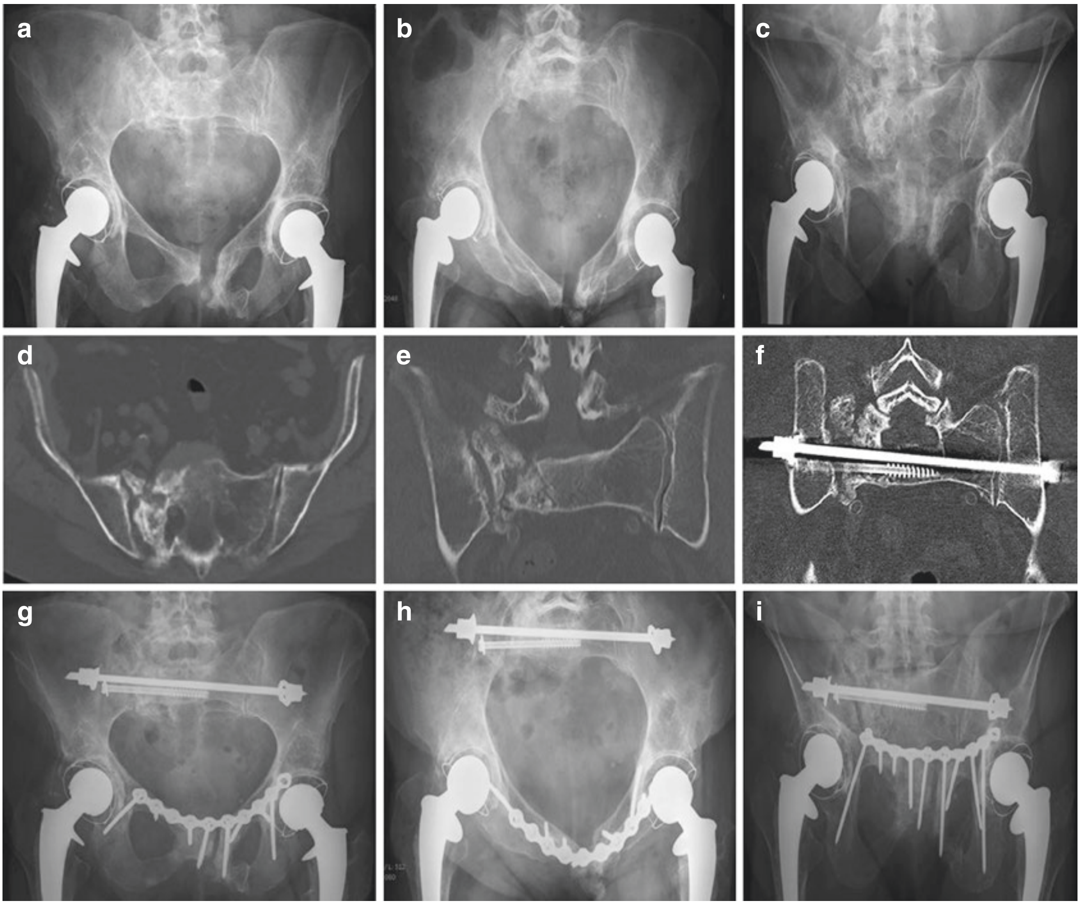

Fig. 20.3 A 75-year-old female with long history of rheumatoid arthritis complains of increasing and immobilizing pain at the pubic region and the right posterior pelvis. (**a**) The a.p. pelvic view shows bone resorption, bone defect and instability of the pubic symphysis. An irregular bone architecture is visible at the right sacral ala. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. (**d**) Transverse CT-cut through the sacrum shows a complete fracture of the right sacral ala with bone defect and involvement of the sacroiliac joint. (**e**) Coronal CT-cut shows the irregular sacral ala fracture with callus formation at the anterior sacral cortex. The bone defect at the pubic symphysis and the callus formation at the sacral ala point towards chronic instability. (**f**) Postoperative coronal CT-cut through the sacrum. The posterior pelvic ring fracture has been fixed with a transsacral bar and an additional iliosacral screw in the right sacral ala. (**g**) The instability of the pubic symphysis has been stabilized after debridement of the joint with a long curved plate. The marginal screws use the infra-acetabular corridor. All other screws use the longest bone trajectory possible. (**h**) Pelvic inlet view. (**i**) Pelvic outlet view 3 months after surgery. (courtesy of Rommens et al., Mainz, Germany)

In order to achieve durable fixation in weakened bone, implants should allow for greater anchoring options as well as improved load distribution and transfer. It is important to maximize fixation, perhaps with more points of fixation, with bicortical purchase, longer implant working lengths, or locking plate-screw constructs (Fig. 20.3). Additionally, screw purchase can be enhanced by augmentation modalities such as PMMA cement or bone substitutes [18, 19, 21, 26].

20.2 Plate Osteosynthesis

Plates provide the strongest mechanical fixation for the pelvic bone. They can be used to address virtually any type of anterior pelvic ring injury; however, there are two situations where plating is considered the modality of choice. They include, pure ligamentous disruptions of the pubic symphysis, and parasymphyseal fractures outside of mechanical protection by an ipsilateral inguinal

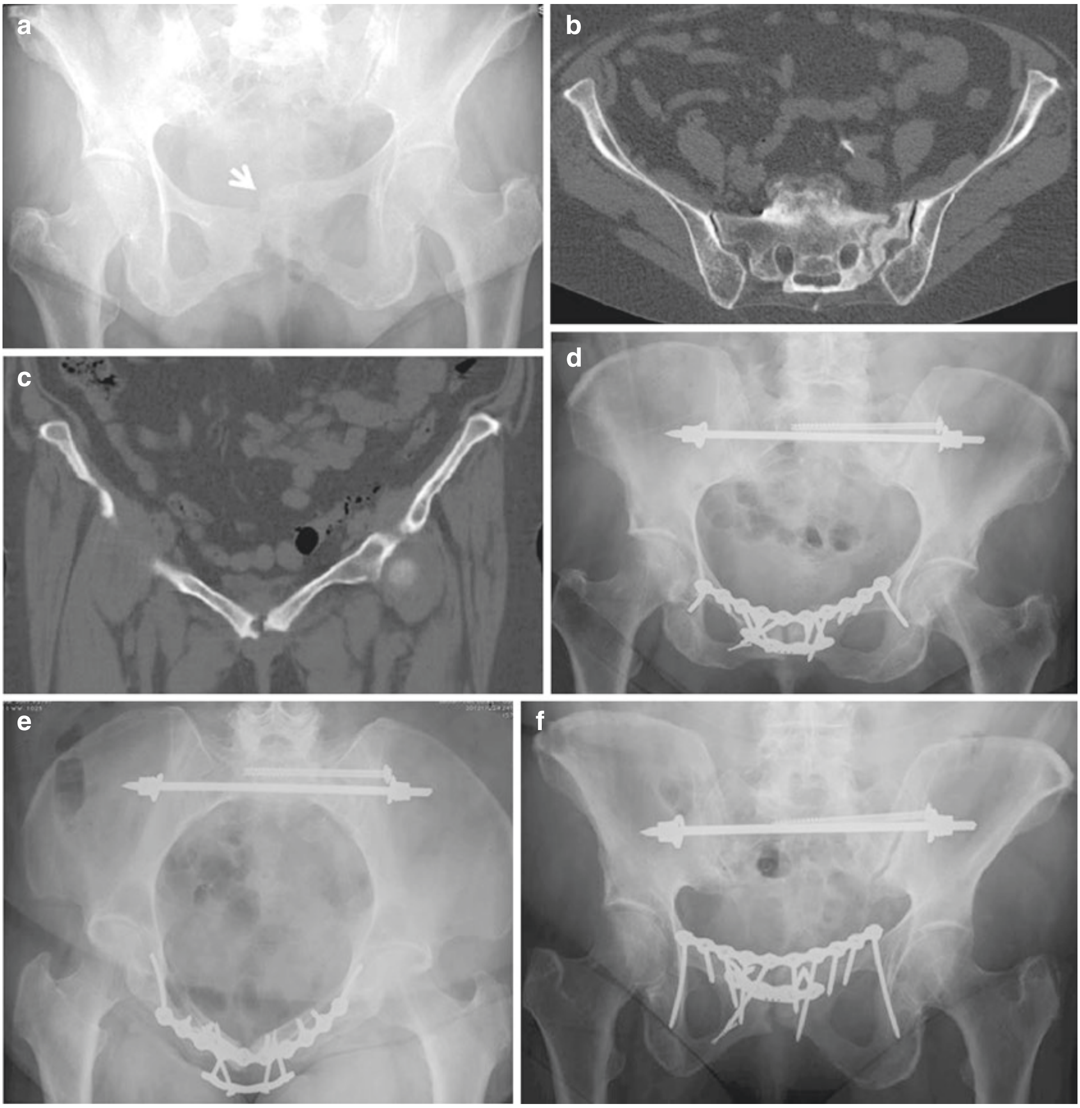

Fig. 20.4 (**a**) A.p. pelvic view in one-legged-stance of 77-year-old woman with long history of cortisone intake. The instability of the pubic symphysis is visible due to the vertical displacement of the left pubic bone. (**b**) Transverse CT-cut through the sacrum shows a complete and older left sacral ala fracture. (**c**) Coronal CT-cut through the pubic symphysis shows a small bone defect and irregular margins. (**d**) Postoperative a.p. pelvic view. The posterior instability has been treated with a transsacral bar and an additional iliosacral screw. The anterior pubic instability has been treated with pubic debridement, tri-cortical bone grafting and double plate osteosynthesis, as bony fusion of the pubic symphysis was the therapeutic goal and a longer healing time could be expected. (**e**) Pelvic inlet view. (**f**) Pelvic outlet view. The long marginal screws of the superior plate use the infra-acetabular corridor into the ischium. The second, anterior plate is angular-stable. The postoperative views have been taken 3 months postoperatively. (courtesy Rommens et al., Mainz, Germany)

ligament. These injuries require especially strong fixation that other constructs cannot provide (Fig. 20.4). Open plating is relatively contraindicated when the surgical field has been contaminated by bowel excrement or infected urine due to visceral injuries or open abdominal procedures after which the abdomen requires open packing, or perhaps in the scenario of transcutaneous urinary catheter placement in the surgical field [27–32].

Advantages of plating also include minimal interferences with patient's rehabilitation relative to external fixation, and no need for removal of the instrumentation in the future. Disadvantages include requirement for extensile and lengthy surgical dissection around vital neurovascular and visceral structures that in turn may lead to significant perioperative morbidity.

From a general standpoint, in order to provide additional points of fixation in osteoporotic bone, pelvic reconstruction plates should be long enough, allow placement of the longest possible screws through the plate, meticulously precontoured to match curvatures of the innominate bone. When appropriate, the plate may span both hemipelvices in a bridging mode [6–12, 19, 20, 25, 26]. Another principle in surgical fixation of fragility fractures, is to double the fixation that would be considered adequate for a patient with healthy bone.

Pubic symphysis disruptions require application of a six-hole, angle-stable, anatomically precontoured plate. In cases when additional strength of fixation is required, such as obesity, critically unstable posterior injuries (comminuted transforaminal sacral fractures), chronic symphyseal dislocations or nonunions, a double-plate ("90–90"or "box-type" construct) can be employed. In these cases, plates are placed perpendicular to each other on the cephalad and anterior surfaces of the symphysis (Fig. 20.5). In order to improve rigidity of fixation, hemipelvices should be compressed against each other through the symphysis before plate application.

Rami fractures, located in the projection of the obturator foramen or lateral to it, can be fixed with long, meticulously precontoured pelvic reconstruction plates allowing placement of the longest screws.

20.2.1 Surgical Technique

The patient is placed supine on the flat top radiolucent table to ensure radiographic control during the case. Both legs are strapped together just above the ankles if internal rotation is necessary to help effect the reduction of the pelvic ring. Likewise, inline femoral pin traction may be applied to the side of hemipelvic displacement, which is cephalad and/or posterior. The amount and vector of the traction depends on the force needed to help complete the closed reduction. The whole abdomen along with upper part of both thighs are included in a surgical field and protected with sterile drapes. A standard surgical approach to the symphysis and rami is carried through a transverse suprapubic Pfannenstiel incision, located 2.5 cm above the pubic symphysis. Bilateral external inguinal rings should be identified and protected. After longitudinal midline split of abdominal aponeurosis, the dissection is extended down to the pubic symphysis. The Space of Retzius is bluntly dissected and the bladder is protected with a large malleable retractor. Careful subperiosteal dissection is carried out laterally along the superior, anterior and posterior aspects of the pubic bodies until medial borders of both obturator formina are identified. At this point, a Farabeuf or Jungbluth forceps can facilitate reduction and compression across the symphysis (Fig. 20.6). The forceps is usually attached to two 3.5 or 4.5 mm cortical screws provisionally placed in the sagittal plane at the level of pubic tubercles.

In case of an acute pubic disruption, a six-hole angular-stable, precontoured plate is applied on top of the symphysis and fixed with long locking screws through the pubic bodies and inferior pubic rami. If maximal stability of the construct is desired or in case of a parasymphyseal rami fracture, fixation can be extended more laterally on both sides. In order to achieve it, the plate is slid underneath iliac vessels towards the root of the superior pubic ramus and fixed with long screws inserted into the posterior column through the infra-acetabular corridor bilaterally (see Fig. 20.3) [33, 34]. In case of the extremely lateral rami fractures, the modified Stoppa approach can be performed through the same incision. The plate can be extended posterior to the acetabulum along the pelvic brim and extra-acetabular fixation into the posterior column or sciatic buttress can be obtained [6–12, 19, 20, 25, 26, 35].

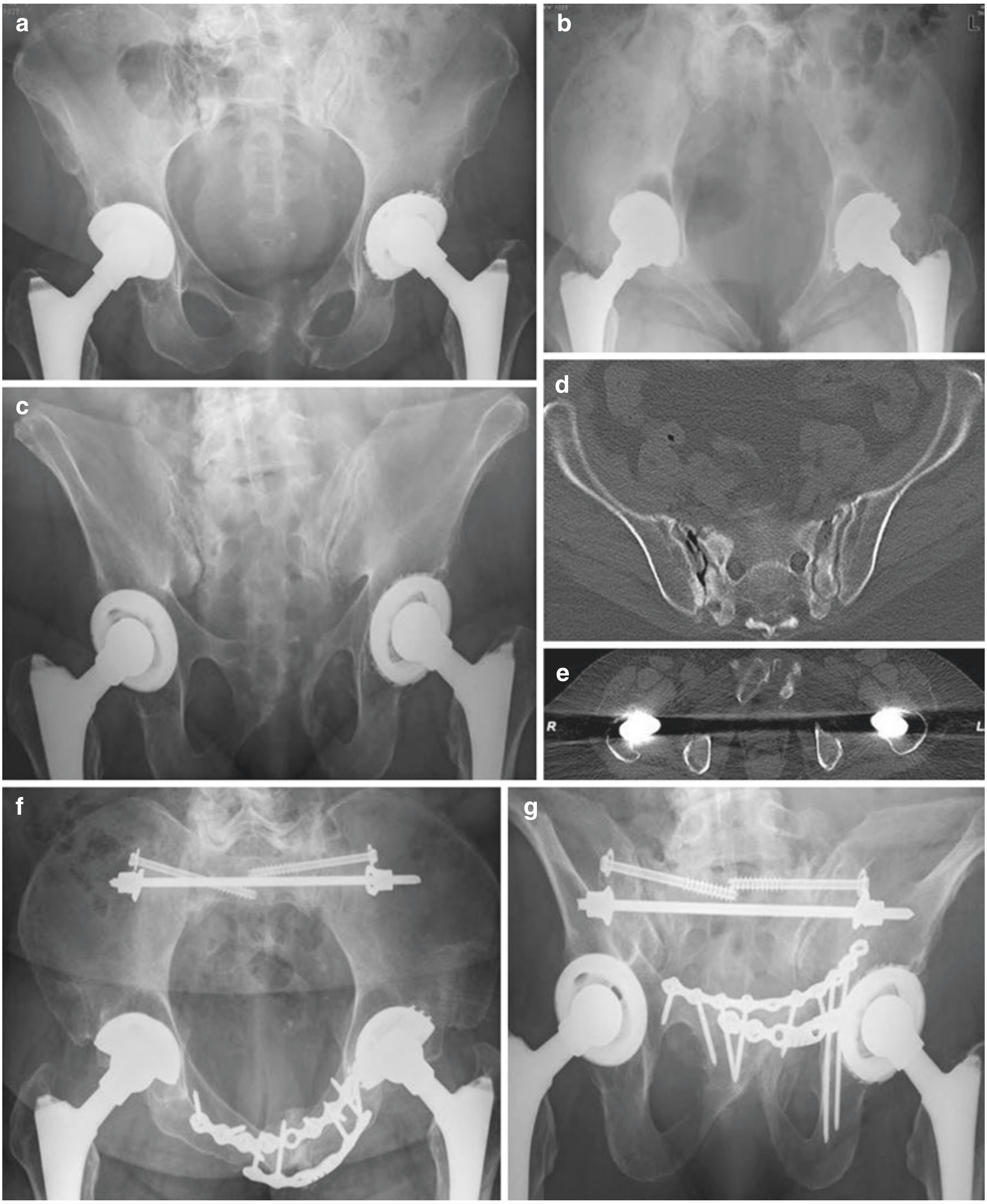

Fig. 20.5 Sixty-seven-year-old female with morbid obesity and chronic pain of more than a year after a fall. (**a**) A.p. pelvic overview reveals an instability with bone defect at the pubic symphysis and irregularities in both sacral ala. (**b**) Pelvic inlet view. The bone defect at the pubic symphysis is best visible. (**c**) Pelvic outlet view additionally shows the lesions of the right and left sacral ala. (**d**) Transverse CT-cut through the posterior pelvic ring shows bilateral complete sacral ala fractures with radiologic signs of chronic instability. (**e**) Transverse CT-cut through the pubic symphysis shows the bone defect very near to the symphysis. (**f**) Surgical treatment consisted in transsacral bar osteosynthesis through the corridor of S1 and bilateral S1 iliosacral screw osteosynthesis for the sacral ala fractures. The anterior bone defect was filled with a tricortical bone graft from the ilium and stabilized with double plate osteosynthesis. Two long screws were placed through the infra-acetabular corridor into the left posterior column. (**g**) Pelvic outlet view after 3 years. There was an excellent outcome. (courtesy Rommens et al., Mainz, Germany)

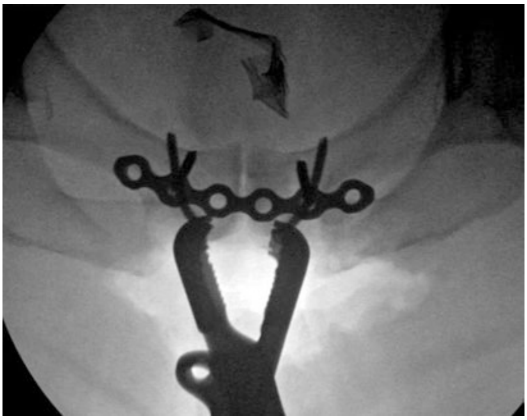

Fig. 20.6 Intraoperative fluoroscopy view demonstrating compression across the pubic symphysis utilizing a Farabeuf clamp

20.2.2 Results

There is a paucity of scientific data on plate osteosynthesis of the anterior pelvic ring in FFP in the contemporary English literature—all current recommendations are based on expert opinions. No results of clinical series of any higher level of evidence have been published to date.

20.3 Subcutaneous Internal Fixation

20.3.1 General Description

A spanning plate construct named the Pelvic Bridge and a subcutaneous pedicle screw-rod crossover fixator called INFIX belong to a modern subset of internal fixators that can be very useful in the settings of fragility fractures. Both Pelvic Bridge and INFIX are meant to combine advantages of plates, but avoid their disadvantages. Their advantages include relative ease of application, decreased perioperative morbidity due to shorter surgical time, minimal soft tissue dissection, associated blood loss and postoperative pain, subcutaneous location which on one hand protects important visceral and neurovascular structures, and on the other hand helps to diminish risk of deep surgical site infection, facilitate nursing care and minimally interfere with patient's rehabilitation and activities of daily living. Their disadvantages may include lower mechanical strength of fixation, compared to conventional plating, need for fluoroscopic monitoring during surgery, and possible need for removal of the construct. The possibility of compression of intraabdominal contents and femoral neurovascular structures due to technical errors have been discussed as a complication of the INFIX [36].

Both Pelvic Bridge and INFIX techniques utilize devices already tested in other fields of orthopedic surgery. They are placed subcutaneously in the lower abdominal region through small incisions and span damaged areas of the anterior pelvic ring by interconnecting the two hemipelvices.

Indications for INFIX and Pelvic Bridge include unstable unilateral or bilateral pubic rami fractures, isolated or in combination with posterior lesions where load-bearing stability is required for ambulatory rehabilitation. Subcutaneous internal fixators are especially useful in situations where local and general medical situations are extremely unfavorable, such as anterior abdominal wall soft tissue injuries or local infection, morbid obesity and coagulopathy, because both techniques require minimal surgical dissection and result in little intraoperative bleeding. Both the Pelvic Bridge and INFIX are contraindicated in cases of pure ligamentous dislocation of the pubic symphysis and in acute situations, requiring emergent stabilization of the pelvic ring [26, 37, 38].

20.3.2 INFIX: Anterior Subcutaneous Crossover Internal Pelvic Fixator

Anterior subcutaneous cross-over internal pelvic fixator consist of two large diameter (7–8 mm), long (75–110 mm) pedicle screws inserted into bilateral supraacetabular areae and interconnected by a 5–6 mm curved, titanium or stainless steel rod (Fig. 20.7) [39–41]. The original description of the fixator belongs to Kuttner et al. who published an explanation of the surgical technique and mid-term clinical results in German literature in 2009 [40]. Vaidya et al.

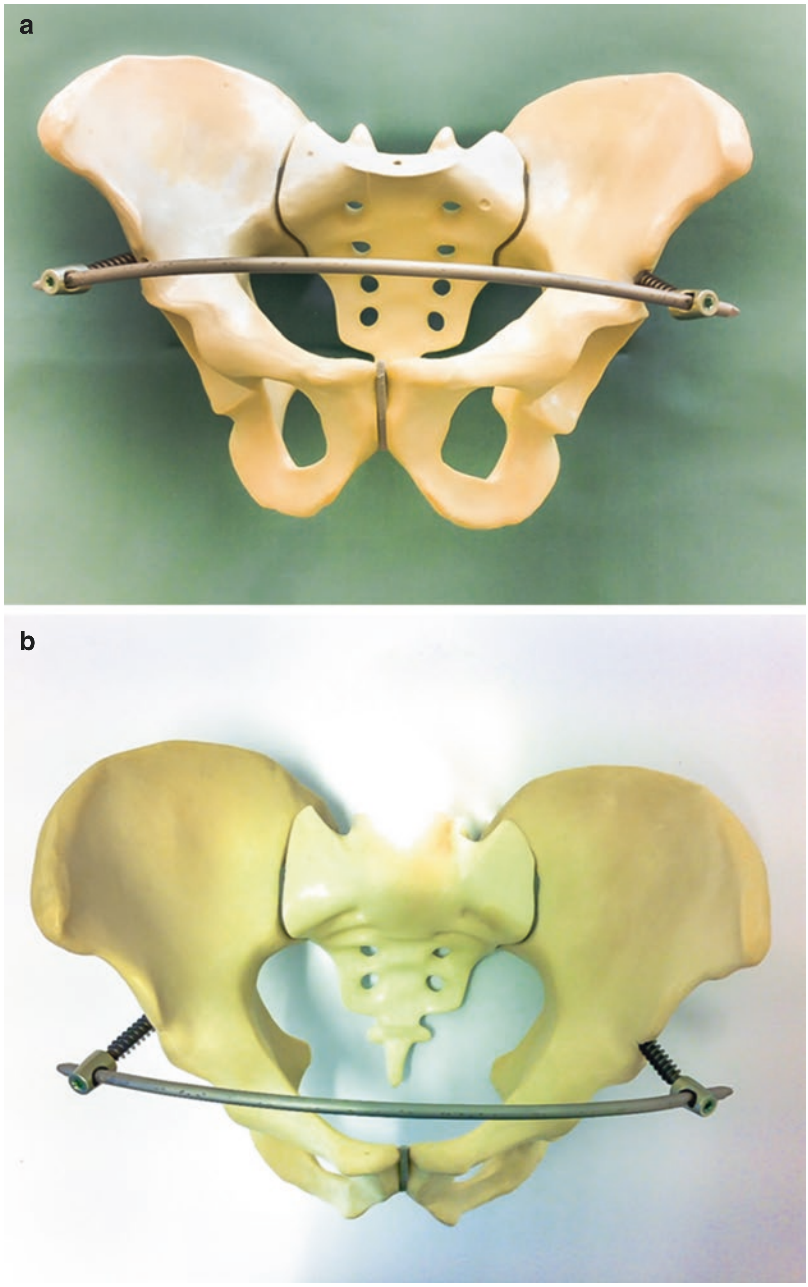

Fig. 20.7 Artificial model of pelvic ring with the INFIX in place: (**a**) A.p. view. (**b**) Pelvic inlet view. The long distance between the screw heads and the anterior inferior iliac spine is well visible

described the modified method and coined the nickname "INFIX" in the English literature in 2012 [41].

20.3.2.1 Surgical Technique

The surgery requires general anesthesia and intraoperative fluoroscopic verification. Two small incisions are made in the inguinal area at the projection of anterior inferior iliac spine (AIIS) bilaterally. Sharp and blunt dissection is carried down to bone in the interval between sartorius and tensor fasciae latae muscles. A series of dilation trocars from minimally invasive spinal set can be utilized for this part of the procedure [42]. A pedicle screw is inserted into the supraacetabular region of each ilium in a corridor of dense bone in

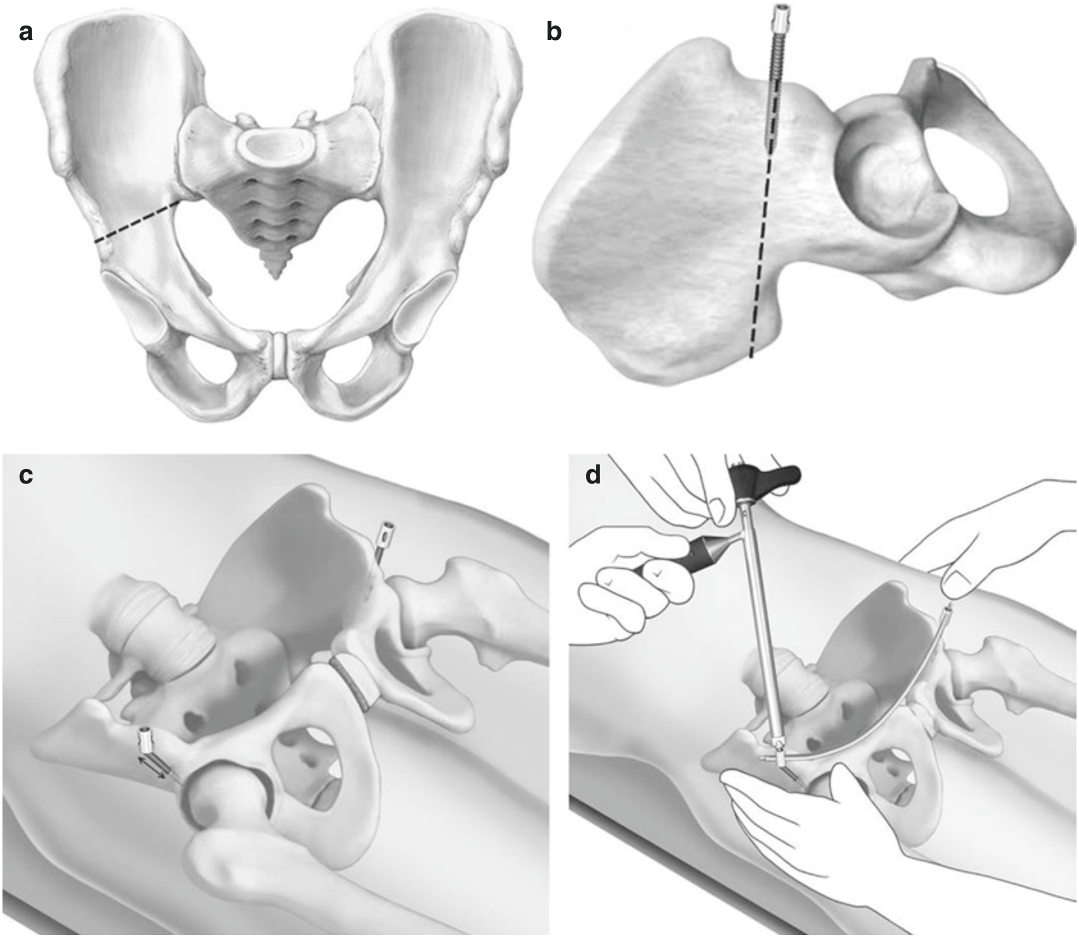

Fig. 20.8 Surgical technique for application of INFIX. (**a**) A pedicle screw is inserted into the supraacetabular region in a corridor of dense bone between the inner and outer cortex of the ilium. The entry portal is situated at the anterior inferior iliac spine, the screw is directed towards the posterior inferior iliac spine above the greater sciatic notch. A.p. pelvic view showing the screw trajectory in the right ilium. (**b**) Lateral view on the right innominate bone showing the same trajectory. (**c**) It is important to leave the screw heads at distance of the bony surface to ensure that these screw heads remain epifascial. (**d**) A curved metal rod is passed below the skin and connected to the heads of the pedicle screws. (From Scheyerer et al. [41])

between the inner and outer tables of the ilium, staying above the hip joint and the superior border of the greater sciatic notch. At least 50–60 mm of the screw length must be introduced into bone for adequate fixation. It is of utmost importance to leave the screw heads 15–50 mm proud off the bony starting point to ensure epifascial location of the head. A curved metal rod is passed below the skin and connected to the heads of the pedicle screws (Fig. 20.8). Manipulative multiplanar reduction of the displaced hemipelvices can be achieved before securing the rod to the screw heads. Though polyaxial screws provide better maneuverability to surgeon, monoaxial screws demonstrate stronger fixation in distraction settings [43]. Skin incisions are closed and dressed. Postoperative rehabilitation protocol may include protected weight bearing on the affected side but depends on the injury and stability rendered by internal fixation.

In vitro, the INFIX demonstrated superior stability at the pubic symphysis compared to the external fixator [37, 38, 44]. There is also evidence that the anterior internal fixator can

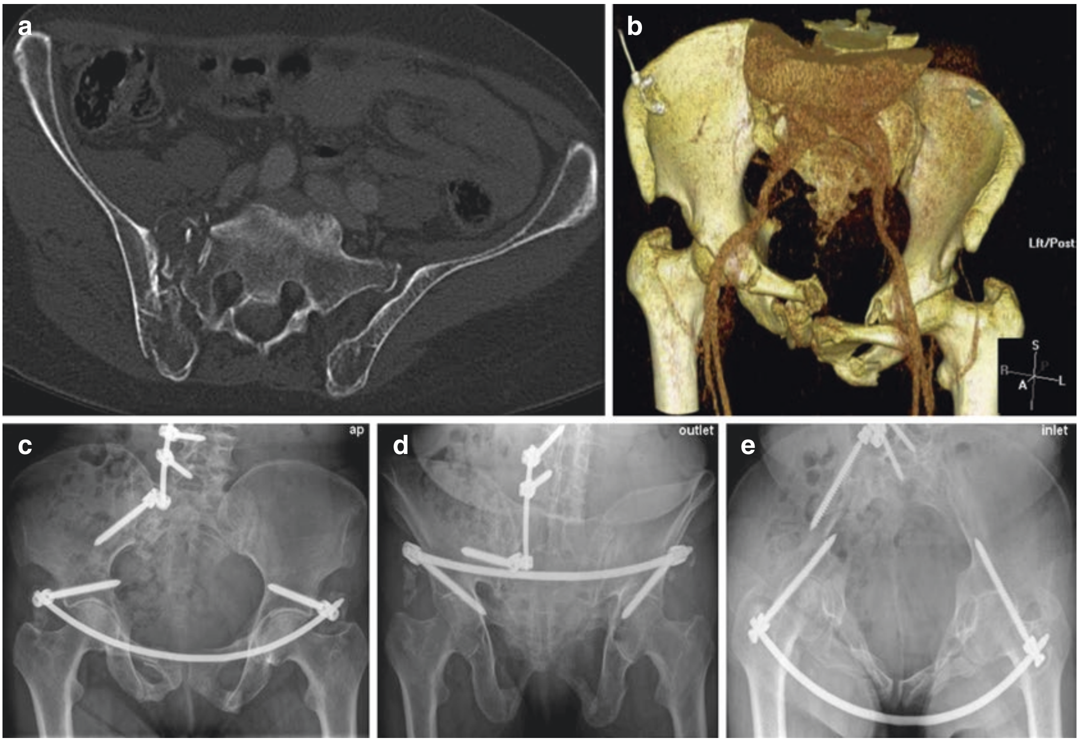

Fig. 20.9 A 65-year-old male was hit by a car while crossing the street. (**a**) Among other lesions, he suffered a fracture-dislocation of the right sacroiliac joint. Transverse CT-cut through the posterior pelvic ring shows the internal rotation of the broken right hemipelvis. (**b**) 3D–reconstruction of the pelvic ring shows bilateral fractures of the superior and inferior pubic rami. (**c**) Postoperative a.p. pelvic view. A right unilateral lumbopelvic fixation has been performed. For stabilization of the fractures of the anterior pelvic ring, an INFIX was inserted. (**d**) Pelvic inlet view. (**e**) Pelvic outlet view. (From Scheyerer et al. [41])

provide some indirect compression along the sacroiliac joints, which can be beneficial if internal fixation of the posterior pelvic ring is contraindicated [38].

20.3.2.2 Results

Several retrospective case series that have been published to date represent short and mid-term results after application of the anterior subcutaneous crossover pelvic fixator, in patients who sustained combined anterior and posterior high-energy osseoligamentous injuries of the pelvic ring (Fig. 20.9). No similar data for the treatment with INFIX on fragility fractures of the pelvic ring has been identified; therefore, all results should be extrapolated with caution with regard to application in the elderly.

Early data is favorable, demonstrating adequate healing at the average 3 months after the surgery without loss of fixation. The majority of patients remained reasonably comfortable after the surgery and quickly reached rehabilitation milestones—they were able to sit, stand and lay on the side or prone before discharge with minimal discomfort and achieved more than 90° of hip flexion even with the construct in place. A subcutaneously located internal fixator did not obstruct surgical treatment for spinal fractures in the prone position in the way that an external frame does. Nursing care was also noted to be easier, compared to that of the external fixator, especially in ICU settings. The implants were routinely removed in 4–6 months after the index operation; however, those patients who retained the fixator did not exhibit any apparent discomfort.

Despite favorable initial clinical results, several complications have been particularly associated with INFIX. Benign, Grade 1 heterotopic

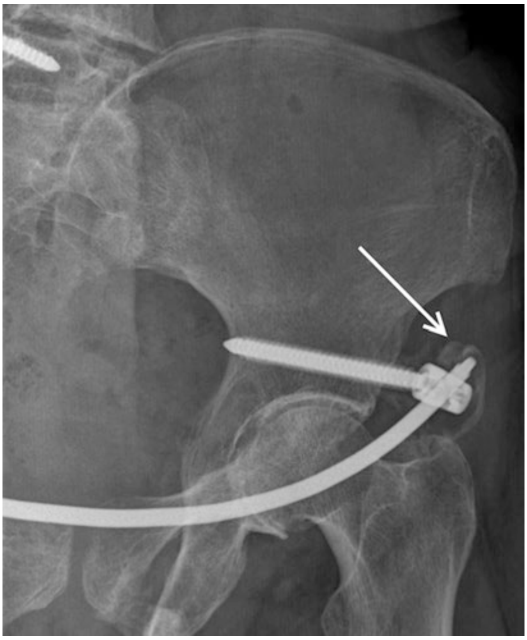

Fig. 20.10 Heterotopic ossification around the left screw head of INFIX 2 months after its insertion. Ala view of the left innominate bone. (From Scheyerer et al. [41])

ossification around the screw heads was noted in 25–30% of the patients (Fig. 20.10); however, the most notorious complication, noted in 32% of the patients, was lateral femoral cutaneous neuropraxia. Most were temporary [39–42, 45]. Branches of the lateral femoral cutaneous nerve (LFCN) are located 1–3 cm lateral to the AIIS; therefore the complication may be attributed to direct damage during surgical dissection or compression injury by a deeply recessed head of the pedicle screw [46]. Other complications included deep surgical site infection, aseptic loosening with loss of reduction due to technical errors when placing the fixator, and entrapment of the anterior abdominal wall leading to deepening of the infraabdominal crease and significant discomfort. All cases required revision surgeries with either debridement or repositioning of the instrumentation to salvage the fixator.

Even though a majority of the surgical adverse effects were classified as minor and were able to be resolved with revision surgery, some complications could be potentially devastating and irreversible. In a recent case series of six patients, who were treated for their unstable pelvic injuries by the INFIX instrumentation in tertiary referral trauma centers, the authors encountered eight acute and delayed femoral nerve palsies (two patients had bilateral lesions), a femoral artery occlusion and one intraabdominal placement of the implant. In all cases, the instrumentation was removed; however, only one nerve demonstrated full recovery, the rest were left with permanent motor and sensory deficit. The complication was attributed to excessively deep placement of the screw in four cases; etiology of other nerve palsies was explained to possible femoral nerve compression due to iliopsoas compartment syndrome [36].

20.3.3 Anterior Pelvic Bridge

The anterior pelvic bridge represents a subcutaneously placed internal fixator to interconnect an ipsilateral iliac crest to a contralateral pubic tubercle and, by virtue of that, spans a fracture of the anterior pelvic ring. Cole et al. described the technique in 2012 [27, 47].

Surgical indications include high and low energy injuries of the pelvic ring when additional stability of the anterior segment is desired. Stability of the posterior pelvic ring and adequate bony alignment must be achieved prior to the contemplating anterior pelvic surgery. The pelvic bridge also proved to be a useful treatment adjunct in case of an osteoporotic insufficiency fracture of the anterior pelvis in elderly patients. It provides quick pain relief and the opportunity of rapid postoperative mobilization along with minimal surgical insult. Bone cement was successfully used to improve screw purchase in osteoporotic bone in that situation [23, 26].

Contraindications of the procedure include pure ligamentous dislocations of the pubic symphysis, severe soft tissue injuries and active infectious processes in the hypogastric abdominal region, pregnancy and pelvic ring disruption in the emergent setting, when rapid pelvic stabilization is indicated for lifesaving reasons [27].

Advantages of the pelvic bridge include low perioperative morbidity of the procedure, ability to apply the fixator either in unilateral or bilateral mode and provide selective fixation of injured

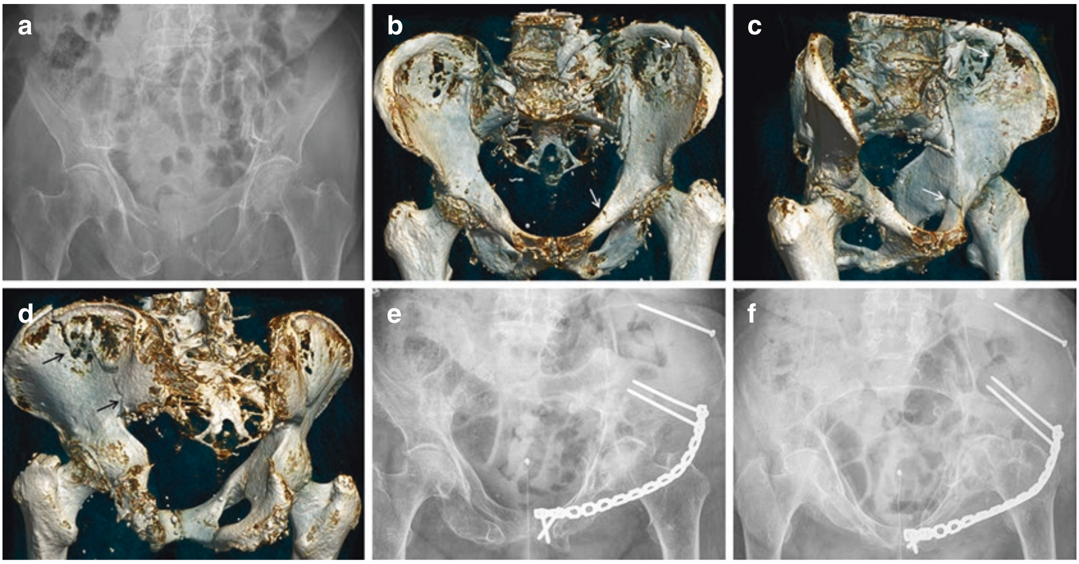

Fig. 20.11 A.p. pelvic overview (**a**) and 3D–CT-reconstructions (**b**–**d**) showing an FFP Type IIIa lesion in a female 80-year-old patient. The fracture in the posterior pelvic ring runs through the left ilium, there also is a left-sided pubic ramus fracture (*arrows*). The reconstructions also show an extreme reduction of bone mineral density in the sacrum. (**e** and **f**) Postoperative a.p. and inlet pelvic overviews. The fracture of the iliac crest has been stabilized with a lag screw. A pelvic bridge spans the superior pubic ramus fracture (courtesy of Gerich T, Luxembourg)

osseous structures. There is less risk to compress intraabdominal content, since the construct takes the "upper route" along the abdominal wall, compared to INFIX, which takes the "lower route".

Disadvantages of the pelvic bridge include the need for precise contouring of the implant and fluoroscopic verification during the procedure, which in turn renders the surgery time consuming and inapplicable for emergent situations except in very facile hands. Like INFIX, the authors have recommended removal of the fixator and hardware.

20.3.3.1 Surgical Technique

Both a precontoured low profile locking reconstruction plate or a rod-plate construct, originally designed for occipito-spinal fusion, can be utilized as a "pelvic bridge" construct. The fixator is applied in the operating room under general anesthesia through small incisions along the anterior aspect of the iliac crest and suprapubic area. The precontoured implant is passed subcutaneously above the external oblique fascia of the abdomen along the course of the inguinal ligament and anchored to the ipsilateral anterior portion of the iliac crest and the medial part of the contralateral superior pubic ramus. In case of bilateral anterior pelvic injuries, two fixators are separately attached to both iliac crests and overlap over the pubic symphysis.

The patients are allowed to mobilize as tolerated with protected weight bearing on the injured side; full weight bearing is advanced according to osseous healing [23, 27, 47, 48].

20.3.3.2 Results

No results of formal biomechanical testing of the technique have been reported up to date. Gerich et al. published results of treatment of fragility pelvic fractures in nine elderly patients with a device, similar to pelvic bridge (see Figs. 20.11 and 20.12). They used a precontoured pelvic reconstruction non-locking plate, placed epifascially in the anterior abdominal wall. The plate was anchored to the ipsilateral antero-superior iliac spine and the pubic body with two crossing cortical screws on each side of the plate. Fixation to pubic bone frequently required cement augmentation. The procedure was quick (30–40 min) and associated with minimal perioperative morbidity and blood loss, provided immediate pain relief and allowed aggressive postoperative physical therapy. Authors observed no complications after surgery; however, two patients died of unrelated causes. Even though neither detailed description of the fractures nor follow up beyond discharge were provided, this series remains the only published evidence to date, reflecting on application of the pelvic bridge type fixation in elderly population with FFP [26].

Clinical results of 48 patients from a comparative cohort study of high-energy pelvic fractures showed that the pelvic bridge was well tolerated by the patients and minimally interfered with activities of daily living. Patients reported significantly lower surgical site pain and discomfort persistent throughout all clinical follow up, lower incidence of morbidity events and wound complications, when compared with external fixation. When given a choice, patients preferred pelvic bridge instrumentation to anterior external frame. No implant failure and loss of pelvic reduction were documented throughout the observation period. The fixator was routinely removed in 16 weeks at the average after the implantation [26, 27, 44]. In contrast to INFIX, the pelvic bridge allowed selective percutaneous stabilization of only a compromised hemipelvis, without involving the uninjured counterpart in the construct [28].

Complications related to the pelvic bridge occurred in 4% of the cases and included superficial wound infection, pubic fracture, asymptomatic nonunion and temporary lateral femoral cutaneous neuropraxia. All complications had a benign course and resolved with local wound care, oral antibiotics and simple observation.

Relationships of both the pelvic bridge and INFIX to the important anatomical structures of the anterior abdominal wall were investigated in several anatomic studies [46, 48, 49]. The area, where the fixators are being placed, belongs to the hypogastric region of the abdominal wall and is being referred as “a bikini area” [46]. The pubic symphysis along with lower abdominal and bilateral inguinal creases border the area that is better defined in obese individuals. Both implants were found to be located in close proximity to lateral femoral cutaneous nerve (LFCN): 1–3 cm for the INFIX and 0.6–4 cm for the pelvic bridge. The distance to the femoral neurovascular bundle was 1–4 cm for the INFIX and 0.8–3.7 cm for the pelvic bridge. Male reproductive structures were located within 2 cm relative to the pelvic bridge and 3–6 cm below the spanning bar of the INFIX. Aside from absolute numbers, it is important to notice that the pelvic bridge stays completely epifascial above the inguinal ligament, external oblique fascia and rectus sheath, thus being safely walled off the important intrapelvic organs and subinguinal vessels, whereas INFIX pedicle screw placement requires deep dissection in the interval between sartorius and tensor fasciae latae muscles where LFCN is extremely vulnerable. The latter fact may explain the high incidence of lateral thigh paresthesias after INFIX placement. With the 2.9–4% incidence of the unusual superolateral course, the nerve can also be endangered during dissection over the anterior aspect of the iliac wing when the attachment of the pelvic bridge construct is contemplated [27, 50–52]. To avoid potential impingement on LFCN and reproductive structures—spermatic cord in males and round ligament in females—medial and lateral fixation of the pelvic bridge should be performed under direct visualization and after careful dissection [45].

Even though both implants are located in subcutaneous tissues above the fascia, their anatomical course is very different. A spanning bar of the INFIX takes the “lower route” over a hypogastric area of the abdominal wall; therefore, it may serve as a rigid object against that abdominal content and a femoral neurovascular bundle may potentially abut. It is very important to retain the pedicle screw heads above the fascia, at least 1.5 cm above the AIIS, otherwise permanent compressive injuries to a femoral nerve, artery and bowel content may encounter [36]. Even though the pannus of an obese patient can easily accommodate the proud instrumentation, it can be tenuous in a thinner individual, when a prominent screw head may lead not only to subjective discomfort but to frank skin erosion and infection. On the contrary, the pelvic bridge implant takes an “upper route” just antero-superior to the inguinal ligament, does not cross over the inferior aspect of the abdominal wall and theoretically poses lesser risk of the iatrogenic compressive injury.

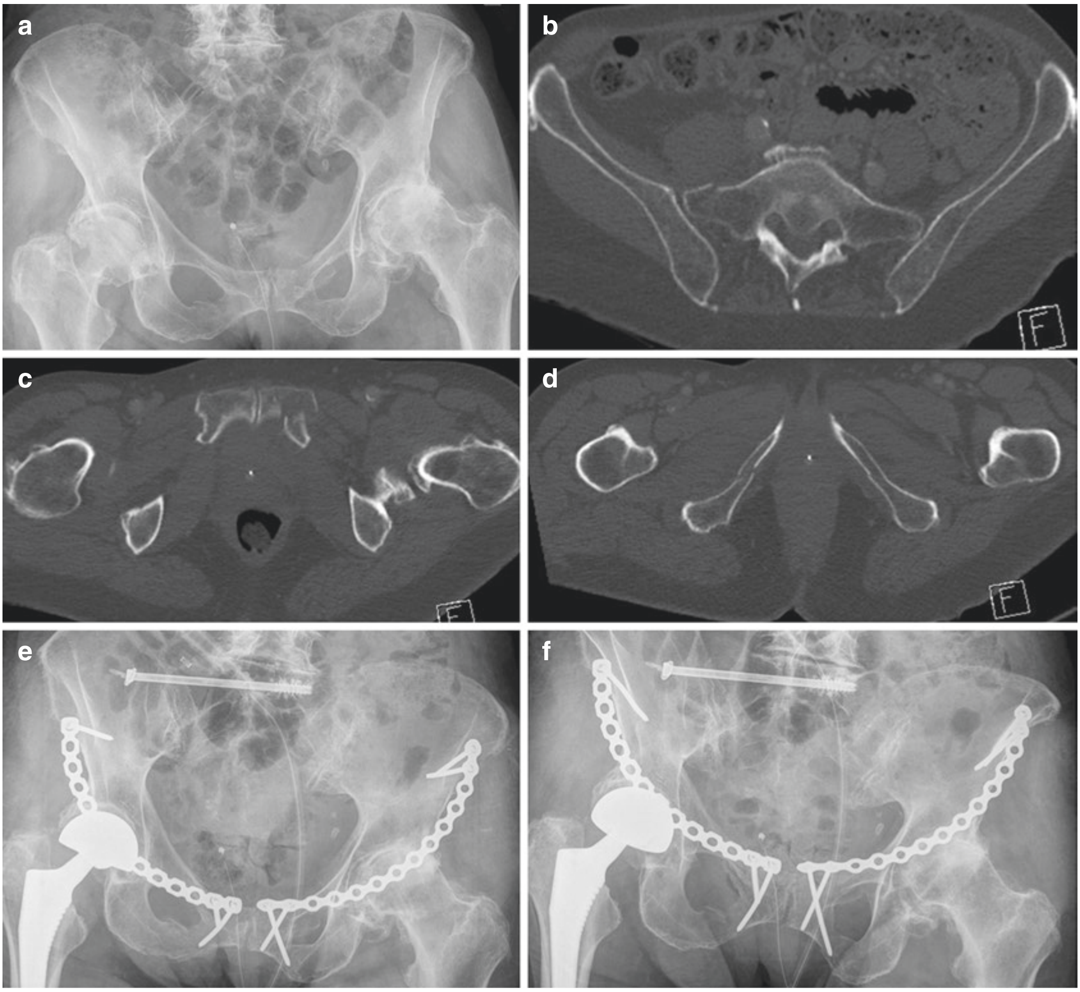

Fig. 20.12 A.p. pelvic overview (**a**) and CT-reconstructions (**b–d**) showing a right-sided femoral neck and sacral ala fracture as well as bilateral pubic ramus fractures in a 78-year-old female. (**e** and **f**) Postoperative a.p. and outlet pelvic overviews. The femoral neck fracture has been treated with a bipolar hip prosthesis, the sacral ala fracture with a cement-augmented iliosacral screw. The bilateral pubic rami fractures have been bridged with bilateral pelvic bridges

The common disadvantage of the INFIX and pelvic bridge compared to formal open reduction and plating is that both subcutaneous implants have to be removed once bone healing has been achieved, which corresponds to the time when the external fixator usually has to be removed as well (3–4 months after the surgery). When some patients may experience only slight discomfort with deep palpation, the removal procedure aims to eliminate any potential of compression even though it has not been shown with the pelvic bridge.

20.3.3.3 Own Results

Twenty-one patients older than 70 years (mean age 78.4 years, range 71–92 years) with FFP underwent surgical treatment of their bony injuries in our institution over the last decade. Only six of them sustained low energy injuries, such as fall from standing or spontaneous fracture while walking, 14 patients were injured in high energy collisions e.g. motor vehicle accident, pedestrian struck or fall from significant height. One patient presented with a symptomatic pelvic nonunion after low-energy fracture. Injuries in three patients were classified as FFP Type II according to the Rommens and Hofmann classification, in four patients as FFP Type III, the rest of the patients sustained FFP Type IV lesions [10]. In two patients, displaced femoral neck fractures were identified in addition to pelvic injuries.

Thirteen patients underwent posterior fixation by iliosacral screws, and five underwent open plating of iliac wing fractures. Nineteen patients underwent surgical fixation of anterior pelvic ring injuries. Among them, only one patient had an external fixator placed, in the rest of the cases (18 patients), internal fixation was chosen to control stability of the anterior hemipelvis. Open reduction and internal fixation with a plate was performed in four cases of ligamentous pubic symphysis dislocations. The pelvic bridge was applied unilaterally in nine cases and bilaterally in five cases to address the residual instability of the anterior pelvic ring.

The average follow up was 10 months after surgery (range 1.2–60 months). Three patients died during admission of the associated injuries. Complications were observed in four patients. One patient developed an infected deep pelvic hematoma that resolved after formal irrigation and debridement in combination with antibiotic therapy. Another patient developed lateral femoral cutaneous neuropathy on the site of insertion of the pelvic bridge construct. In two patients, loosening of the anterior pubic symphyseal screws were observed. It was attributed to an inherent mobility of the anterior pelvic subcutaneous fixation. Anterior pelvic instrumentation was electively removed in eight cases after an average of 6 months (range 1–11 months).

20.4 Anterior Subcutaneous Three-Point Pelvic Fixator

20.4.1 Introduction

Surgical therapy of instabilities of the anterior pelvic ring in osteoporotic bone is demanding. Even when minimal invasive stabilization of the pubic rami using intraosseous screws is successful and meanwhile well accepted, this procedure is not possible in some cases of fragility fractures of the pelvic ring (FFP). Often these fractures are located close to the symphysis, so that the short medial fragment does not offer good enough anchorage for such screws. In such situations a conventional plate osteosynthesis has to be performed. Inevitably, this surgical approach is relatively excessive. The fracture has to be bridged over a wide distance in order to achieve a high enough stability. In case of a bilateral fracture of the pubic rami, 12- to 14-whole plates may become necessary to reach at least with one screw the supraacetabular region on both sides. The worse the bone quality, the longer the plate has to be to guarantee adequate stability via a long lever arm of the fixating device.

It is not advisable that the screws are loaded by axial extraction forces only. Together with poor bone quality this strongly enhances the risk of secondary screw dislocations and failure of the osteosynthesis. An additional typical complication of plate osteosynthesis of the anterior pelvic ring is the breakage of the plates, which is favored by the use of relative weak reconstruction plates.

20.4.2 The Anterior Subcutaneous Three-Point Pelvic Fixator

As an alternative to the abovementioned methods of osteosynthesis (intraosseous screws, plate osteosynthesis), we developed a minimal invasive stabilization frame for the anterior pelvic ring using the internal fixator system of the implants for spinal fusion. The principle corresponds to a three point buttressing of the anterior pelvic ring. Thereby a pedicle screw is positioned into the iliac wing just below the anterior superior iliac spine on both sides. One or two additional screws are positioned into the pubic bone close to the symphysis. All pedicle screws run completely intra-osseous. The three to four screws are then connected by a 5.5 mm thick rod which is curved in a way that it runs parallel to the inguinal ligament on both sides (Fig. 20.13). This rod is positioned epifascial to prevent direct

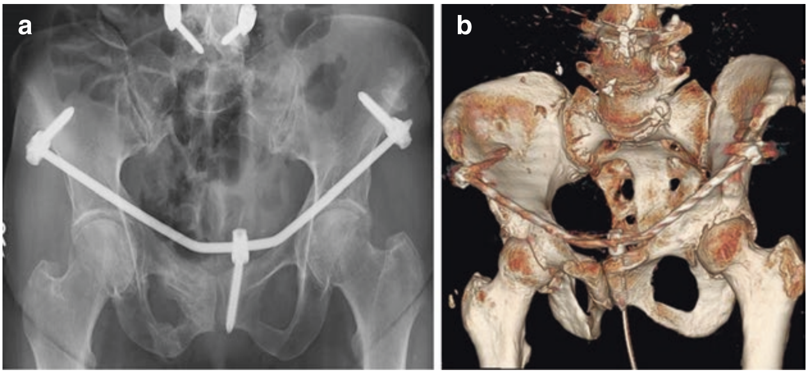

Fig. 20.13 (**a**) A.p. pelvic overview of FFP Type IIb, stabilized with the anterior internal fixator. The construct offers a three-point buttressing of the anterior pelvic ring. Overlapping of the rod over the pedicle screw head should not be more than 1 cm on both sides. (**b**) Right iliac oblique view of 3D–reconstruction of the pelvic ring shown in Fig. 20.13a. The three pedicle screws are completely located intra-osseous

pressure on neural or vascular structures of the inguinal region.

20.4.2.1 Operative Procedure

The patient is placed in supine position on a radiolucent carbon table to offer free intraoperative imaging in different views. Draping has to offer free access to the pubic symphysis as well as to the two anterior superior iliac spines.

On both sides, a vertical incision of 2 cm of length is performed below the lateral border of the anterior superior iliac spine. The bone directly below the spine is palpated bluntly with closed scissors. A Jamshidi-needle is positioned at this point onto the bone and the cortex is opened with it. Consecutively, the needle is pushed into the bone for 5–10 mm only. Thereby the needle is angulated 15° towards cranially in the sagittal plane. The angulation in the axial plane is orientated according to the anatomical situation like it is given in the axial planes of the CT-scan. As a rule the needle is angulated about 15° towards medially in women and about 15° towards laterally in men (Fig. 20.14). Passing through the needle, a guide wire is pushed into the cancellous bone of the iliac wing for 4–5 cm. Thereby it is important to feel the wire continuously bypassing the cancellous structures of the bone and not to penetrate through the cortex. In this way, a strict intraosseous position of the later screw is guaranteed. After thread cutting a 55–60 mm long pedicle screw of 6–7 mm thickness can be placed over the guiding wire into the iliac bone (Fig. 20.15) (see also Fig. 20.13b). The position of the guiding wire as well as of the screw itself can be controlled by fluoroscopy.

For positioning the screws into the pubic bone, a 4–5 cm transverse incision is performed just above the palpable pubic symphysis. After transsection of the cutaneous and subcutaneous layers, the anterior fascia of the rectus muscle is transsected nearby the pubic bone. If possible the posterior layer of the rectus fascia remains intact. The joint can be located with the help of a K-wire or using an image intensifier. About 8 mm lateral to the pubic symphysis, the cranial cortex of the pubic ramus is opened using a Jamshidi-needle. The needle thereby is positioned parallel to the symphysis and angulated 45° towards distally in the sagittal plane. Also here the needle is pushed into the bone for only 5–10 mm. After that the guiding wire of the internal fixator system is pushed into the cancellous bone parallel to the symphysis for 4–5 cm. Consecutively, the screw is positioned over the guiding wire. According to the fracture situation one screw is inserted on one or on both sides of the pubic symphysis. Regularly a pedicle screw of 45–55 mm of length and 5–6 mm of thickness from the internal fixator system is used.

Now the bending of the 5.5 mm thick rod of 30–32 cm of length follows. There is a short

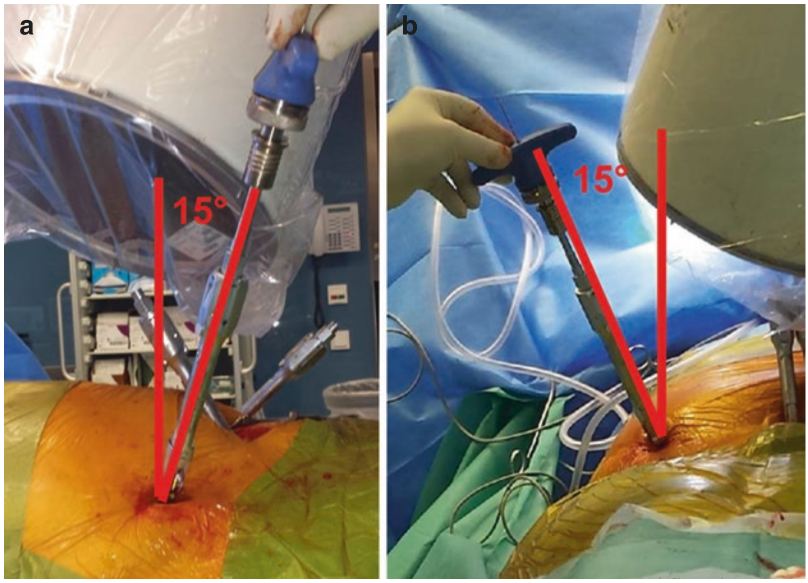

Fig. 20.14 Intra-operative views showing the lower abdomen and inguinal regions of a female patient in supine position. (**a**) View from right lateral. The angulation of the pedicle screw just below the anterior superior iliac spine is about 15° to cranial in the sagittal plane. (**b**) View on the right inguinal region and iliac wing from distally. The angulation of the pedicle screw in the axial plane depends on the anatomic situation and is about 15° towards medially in women

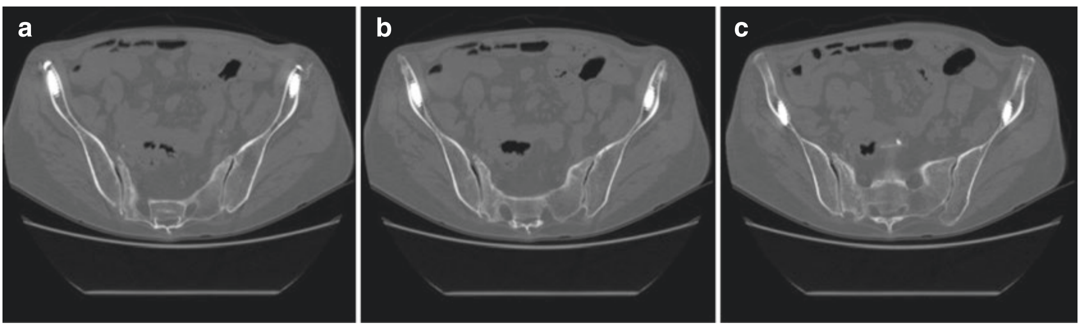

Fig. 20.15 Axial CT-cuts through the posterior pelvis and iliac wings. There is a 6–7 cm long cancellous corridor under the anterior superior iliac spine that can be instrumented with a 6–7 mm thick screw. (**a**) CT-cut at the level of the screw insertion, just below the anterior superior iliac spines. (**b**) CT-cut 1 cm more proximally than shown in Fig. 20.15a. (**c**) CT-cut 1 cm more proximally than shown in Fig. 20.15b

straight part of 5 cm length in the middle of the rod. At the ends of this central part, the rod is angulated symmetrically by 15–20° on both sides. This rod now is brought into the pedicle screws from lateral running strictly epifascial. It runs parallel to the inguinal ligament on both sides (Fig. 20.16). The rod is first provisionally fixed into the tulpes of the medial screws followed by the lateral screws. If the length of the rod is correct and overlaps the lateral screws laterally by only 5 mm, the whole system is fixed with the set screws. If appropriate, the pedicle screws can be augmented with bone cement before inserting the rod (Fig. 20.17). Penetration of the cortex by the pedicle screws is a contraindication of cement augmentation.

20.4.2.2 Advantages and Disadvantages of the Procedure

Main advantage is the minimal-invasive procedure. Anterior internal fixation is performed via very small incisions. An opening of the retroperitoneal space is not necessary. This is only the case if the posterior layer of the rectus abdominis muscle sheet is ruptured by the trauma. Another advantage is that the fracture hematoma is not touched. The described procedure can therefore

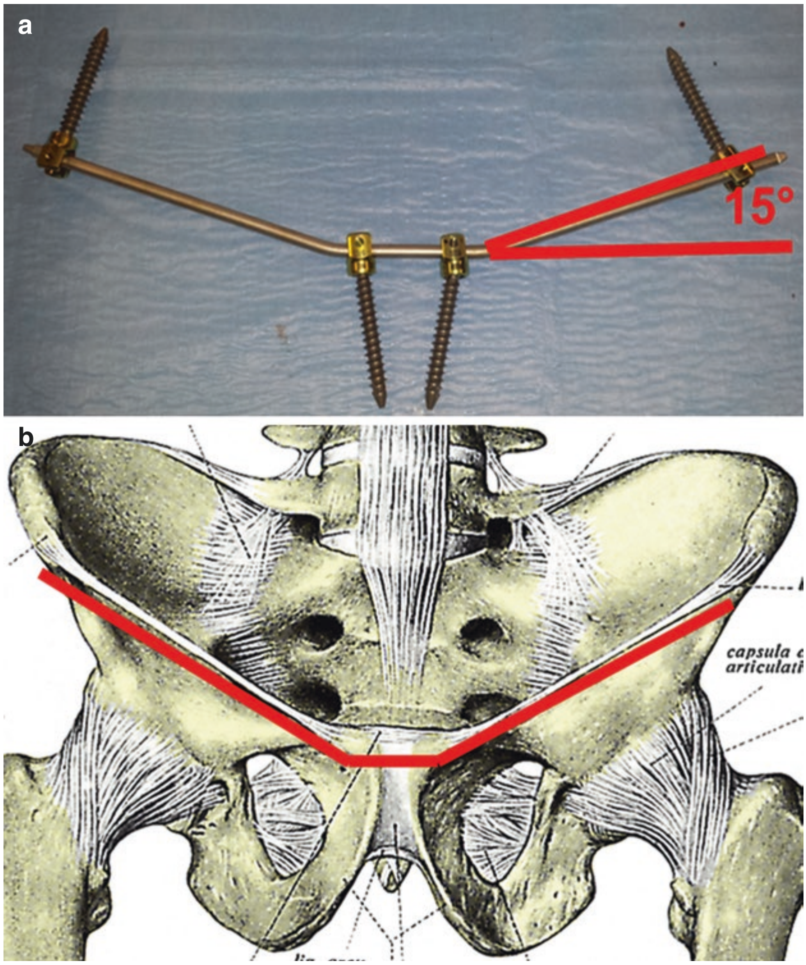

Fig. 20.16 (**a**) The anterior pelvic internal fixator assembled on the instruments' table of the scrub nurse. The rod is bended 15° on both sides of a 5 cm long middle part. (**b**) The middle part of the rod is situated above the pubic symphysis, the lateral parts of the rod run parallel to inguinal ligament on both sides (*red line*).

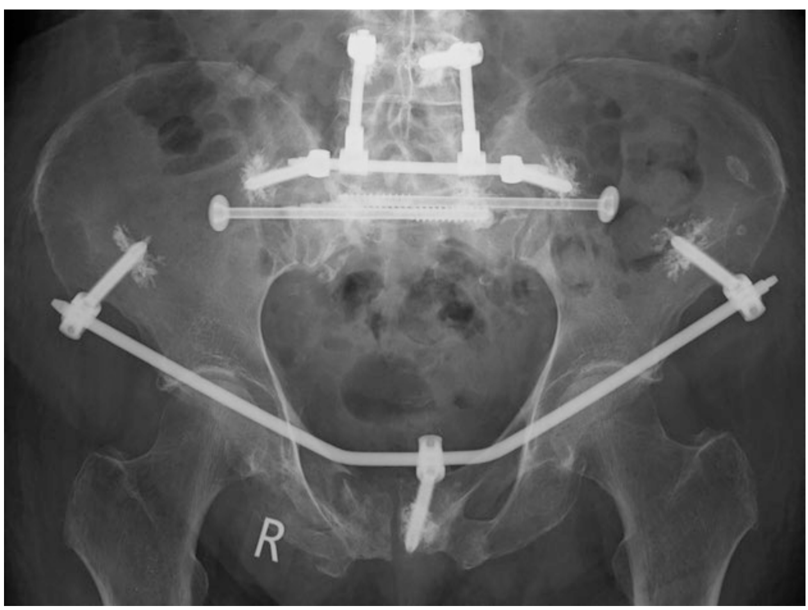

Fig. 20.17 A 96-year-old women with very poor bone quality suffered a FFP Type IVb instability. The pelvic ring was stabilized with a cement-augmented minimal invasive internal fixator anteriorly and a cement-augmented lumbopelvic fixation frame and iliosacral screws posteriorly

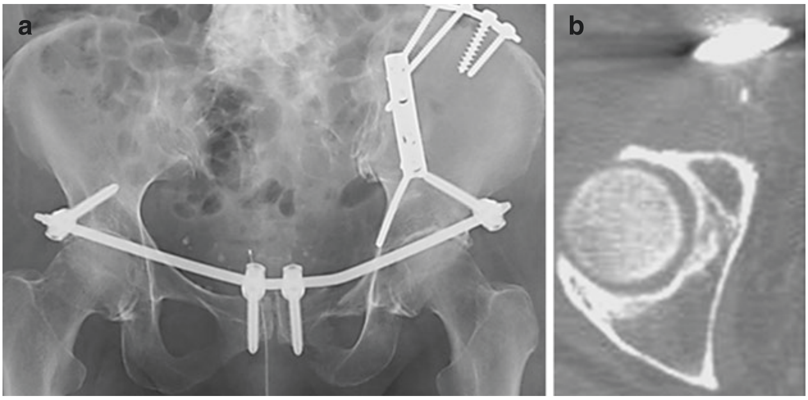

Fig. 20.18 (**a**) A.p. pelvic overview of a FFP Type IIIa. The pedicle screws have been inserted at the level of the anterior inferior iliac spines. (**b**) Axial CT-cut at the level of the right acetabulum of the same patient. If the rod is inserted too low, it can cause impingement of neural and vascular structures of the inguinal region

be regarded as a biological osteosynthesis. From the biomechanical standpoint, the construct is not absolutely rigid. It provides two very long lever arms and the elasticity of the rod offers some mobility in the fracture zone(s), which is a stimulus for healing. The construct is a bridging osteosynthesis.

The main disadvantage is the restricted comfort for the patient because the rod is palpable in the subcutaneous layer. In case of complaints related to the prominent hardware, we perform a removal of the implants once the fracture is healed. We see such healing after 3–4 months so that the time of discomfort seems to be acceptable.

20.4.2.3 Risks and Limitations

The skin incisions at the anterior superior iliac spine should be performed at the lateral edge of the palpable spine to minimize the risk of damage to the lateral femoral cutaneous nerve. The screws should be positioned directly under the anterior superior spine and not at the level of the anterior inferior spine.

During insertion of the rod, it is mandatory to strictly respect the epifascial layer to prevent any violation of subfascial structures such as vessels and nerves of the inguinal region. By the epifascial position of the rod, damage due to direct pressure on the spermatic bundle can also be prevented in men. The rod preliminary should be fixed to the pubic bone screw(s) first. If the rod is first fixed to the anterior superior iliac spine screws, the pubic bone screw(s) can be pulled out the bone due to axial traction while tightening the set screws.

If the screws are inserted too distally, impingement of the femoral nerve can be caused by direct pressure of the rod and this can lead to paralysis of the quadriceps muscle (Fig. 20.18). The pedicle screws should not penetrate cortical bone. Only in case if complete intraosseous position, cement augmentation is safe.

Closure of the soft tissues over the pubic bone pedicle screws does not create any problem. An adequate suture of the subcutaneous and cutaneous layer has to be performed over the anterior superior iliac spine screws. In most cases, the rod can be palpated in the subcutaneous region. But this does not seem a problem for most patients.

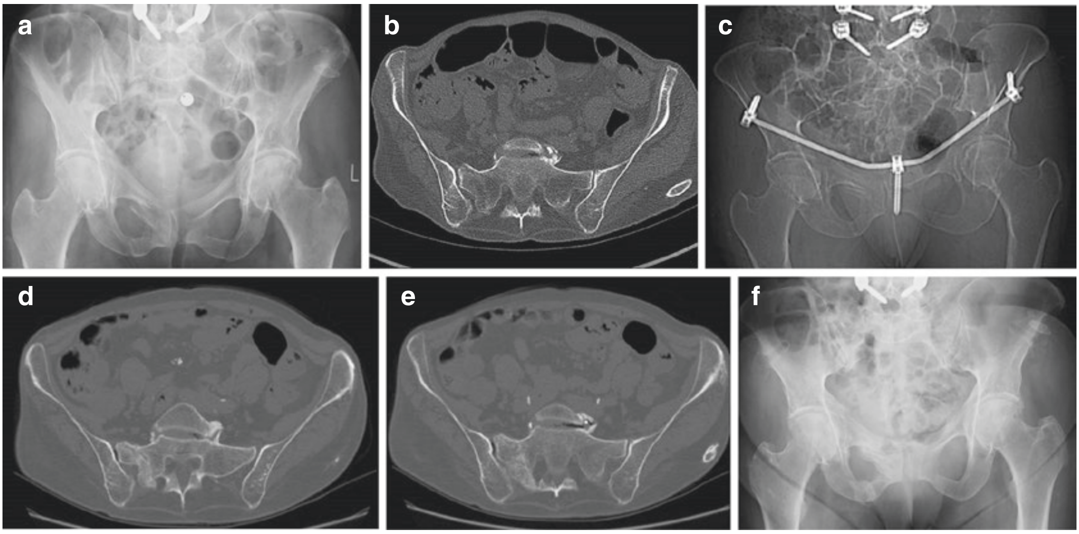

Fig. 20.19 A 76-year-old women with BMI of 18 suffered a FFP II C with immobilizing pain. (**a**) The a.p. pelvic overview reveals a right-sided superior and inferior pubic ramus fracture. The patient previously was treated for lumbar stenosis by a lumbar fusion between L4 and L5. (**b**) The transverse CT-cut through the posterior pelvic ring shows a non-displaced fracture of the right sacral ala. (**c**) Postoperative a.p. pelvic overview. The patient is treated with an anterior internal fixator with three pedicle screws. (**d**) Transverse CT-cut through the posterior pelvic ring after 3 months. (**e**) Transverse CT-cut through the posterior pelvic ring after 6 months before hard ware removal showing a complete healing of the sacral ala fracture. (**f**) A.p. pelvic overview after hard ware removal shows complete healing of the anterior pelvic ring

20.4.3 Indications

The minimal invasive internal fixator of the anterior pelvic ring is our standard procedure for unstable fragility fractures of the anterior pelvic ring. We perform it isolated in cases of FFP Type II C to prevent an increase of instability towards FFP Type III C (Fig. 20.19). Even in case of a FFP Type II B with immobilizing pain in the dorsal pelvic ring, we perform the minimal invasive internal fixator of the anterior pelvic ring in an isolated manner. In case of higher-grade instability, we perform a combination of the described internal fixator with an appropriate posterior stabilization procedure. In cases of FFP Type III C and FFP Type IV B fractures, we favor a minimal invasive lumbopelvic buttressing with an internal fixator, sometimes in combination with iliosacral screws (Fig. 20.20).

In complex fracture patterns of both pubic rami very near to the pubic symphysis, a sufficient support for the pubic bone screws cannot be achieved. In extreme cachexia, the implants may be very prominent. Nevertheless, we have treated a 76- year-old lady with BMI of 18 using the described minimal invasive anterior internal fixator (Figs. 20.20). In our experience, the minimal invasive internal fixator leads to secure healing of anterior and posterior instabilities.

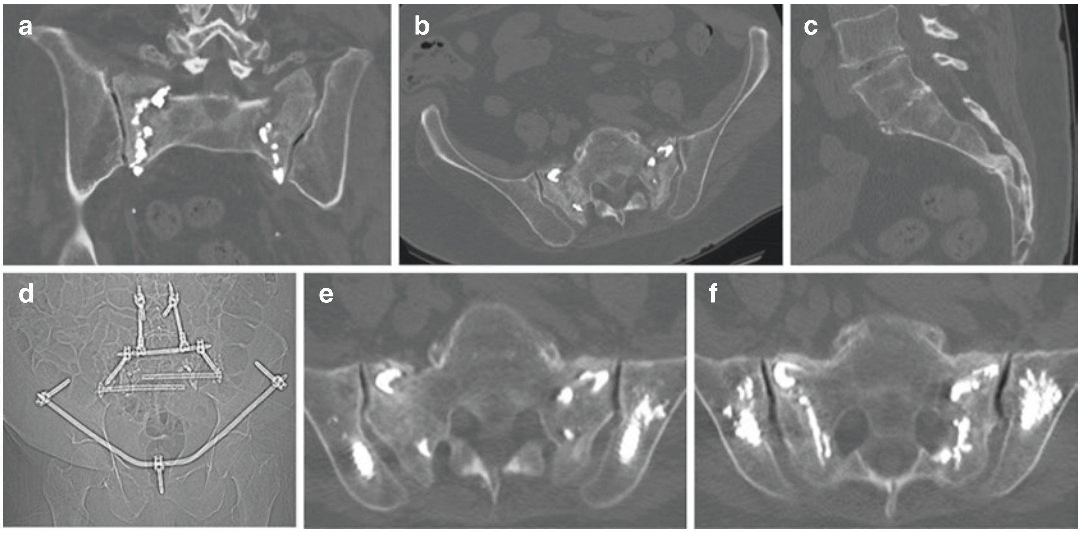

Fig. 20.20 FFP Type IVb instability in an 84-year-old woman treated with sacroplasty. She is unable to walk since 6 months. (**a**) Coronal CT-cut through the posterior pelvic ring showing bilateral cement application in the sacral ala with bilateral anterior cement extravasation, but without signs of bony healing. (**b**) Transverse CT-cut through the posterior pelvic ring. (**c**) Sagittal CT.-cut through the mid-sacrum showing a non-healed fracture between S2 and S3. (**d**) Postoperative CT-scout-view. The anterior and posterior pelvic ring were stabilized surgically. Anteriorly, a minimal invasive anterior internal fixator was inserted. Posteriorly, a cement-augmented lumbopelvic buttressing frame and bilateral iliosacral screw fixation were performed. (**e**) Transverse CT-cut through the sacrum 5 months postoperative showing signs of bony healing. (**f**) Transverse CT-scan of the sacrum after 10 months showing complete healing. At this time point, the ventral internal fixator was removed

Conclusion

Open reduction and internal fixation of anterior pelvic ring fragility fractures can be achieved by plating or modern spanning subcutaneous internal fixators. Each modality has distinct advantages and disadvantages. Plating remains a gold standard procedure for the treatment of pure ligamentous symphyseal injuries or parasymphyseal fractures of a pubic body. Long, anatomically precontoured, pelvic reconstruction plates with the longest possible screws should be preferred for fixation. Augmentation with bony cement can be used to increase strength of screw purchase. INFIX, pelvic bridge fixation and subcutaneous three-point pelvic fixation allow minimally invasive bridging of the anterior pelvic ring and are ideally situated for transforaminal or far lateral extraforaminal pubic rami fractures. Both plating and subcutaneous internal constructs provide appropriate stability of the anterior pelvic ring, with improved patient satisfaction, nursing care and diminished perioperative morbidity. The procedures remain technically demanding and require throughout understanding of the pelvic anatomy and principles of fracture fixation to avoid serious complications. Further laboratory and clinical testing is warranted to clarify the role of the minimally invasive fixators in treatment of fragility fractures of anterior pelvic ring.

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Part VII

Adjuvant Drug Therapy

21 Anti-Resorptive Therapy

Emily E. Carmody

21.1 Introduction

Over the past two decades, a variety of medications have been shown to be effective in the treatment of postmenopausal osteoporosis. The goal of medical management is to reduce fracture risk, preferably at all skeletal sites, including, but not limited to spine, hip, distal radius and proximal humerus. We have a variety of medications in our armamentarium including anti-resorptive agents, bone-forming agents, as well as strontium ranelate (not in the US), which has a dual mechanism of action. The two approaches to treatment of osteoporosis are decreasing bone resorption (anti-resorptive therapy) and increasing bone formation (anabolic therapy). Currently, most therapies are anti-resorptive.

Currently available anti-resorptive therapies include calcium plus vitamin D, selective estrogen receptor modulators (raloxifene), hormone replacement therapy, bisphosphonates (alendronate, risedronate and zolendronic acid), RANKL antagonist denosumab, and strontium ranelate. Guidelines on when to initiate anti-resorptive therapy state that therapy may be started in patients with a prior fragility fracture, or in patients with a T-score of less than −2.5. Some guidelines state that anti-resorptive therapy may be initiated in patients with a T-score in the osteopenic range from −1 to −2.5, (i.e. not frank osteoporosis) in the presence of other risk factors [1]. Although all of these medications have a reasonable risk/benefit profile, selection of a specific agent should be based on the individual patient, the severity of their osteoporosis, fracture history, as well as any specific contraindications or relative contraindications due to the patients' medical history.

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21.2 Calcium and Vitamin D

Maintaining an adequate calcium and vitamin D intake, whether through diet, supplementation, or both, is a standard part of the treatment of osteoporosis. Calcium and vitamin D play an important role in bone physiology, but the exact effect these two treatments have on bone mineral density (BMD) and fracture reduction risk, is not entirely clear. Calcium is required for the bone formation phase of bone remodeling, while vitamin D is necessary for calcium absorption from the intestine. With aging there is a decline in calcium absorption. This may be due to either a loss of vitamin D receptors, or a resistance of these receptors. Calcium and vitamin D have been promoted as an inexpensive treatment option to prevent bone loss and reduce fracture risk in patients with osteoporosis. Although early clinical trials

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_21

did show that calcium supplementation reduced fracture rates in postmenopausal women [2, 3], these results were not reproducible in larger multicenter trials [4–6]. Meta-analyses, however, show that calcium supplementation either alone, or in combination with vitamin D, has an effect on BMD loss and fracture risk reduction in postmenopausal women [7]. Treatment is similarly effective whether the patients take calcium or a combination of calcium and vitamin D. A meta-analysis of randomized controlled trials shows that vitamin D supplementation lowers the risk of hip fracture by 26% and any no vertebral fracture by 23% [8]. Treatment results are similar regardless of patient sex, fracture history, and types of fractures sustained. In patients taking calcium, 1200 mg daily is recommended as the minimum dose for optimal therapeutic effect. In patients taking calcium and vitamin D a minimum dose of 800 IU is recommended [7–10]. In addition, both young and older patients with higher serum vitamin D levels have been found to have higher BMD in the hip [11]. Treatment is less effective in patients who are poorly compliant, which historically tends to be a significant problem with this treatment regimen. When trials, in which patients have at least an 80% compliance rate with calcium supplementation, are examined separately, the risk reduction doubles [7]. Most evidence does support the use of calcium or calcium and vitamin D supplementation in the treatment of osteoporosis in patients 50 years or older. Adequate intake of calcium and vitamin D are an essential component to the treatment regimen of osteoporosis, and many patients will require supplementation to meet suggested daily intake requirements.

21.3 Hormone Replacement Therapy (HRT) and Selective Estrogen Receptor Modulators (SERMs)

Sex steroids play an important role in bone metabolism throughout life. Estrogen deficiency is the most recognized risk factor for the development of osteoporosis. Bone remodeling increases during menopause, with more active bone resorption than bone formation. There is increased osteoclast recruitment, activity, and survival, resulting in increased bone resorption [12]. This negative balance leads to disruption of the cancellous bony architecture, and loss in BMD can be seen as early as 1 year after menopause. Bone loss in the setting of estrogen deficiency is mediated through pro-inflammatory cytokines such as interleukin-1 (IL-1), interleukin-6 (IL-6), and Tumor Necrosis Factor- α (TNF-α), thereby activating the receptor activator of nuclear factor Kappa B ligand (RANK/RANKL), which leads to bone resorption by osteoclasts. Estrogen also inhibits bone resorption and stimulates bone formation through activation of the TGF-β pathway [13, 14]. Although studies in the 1990s illustrated that bone loss and vertebral fracture risk can both be reduced with relatively small doses of HRT [15, 16], since the Women Health Initiative (WHI) studies, HRT is no longer recommended as a first line therapy for the treatment or prevention of osteoporosis [17]. This study was halted before the intended observation period, because the Data Safety Monitoring Board observed excess harm in the HRT group. The WHI studies demonstrated that prolonged use of HRT, especially in elderly women, increased the risk of breast cancer, thromboembolic disease, and cerebrovascular accidents. A patient history of one of these conditions would be an absolute contraindication to HRT therapy. In patients who have risk factors for one of these conditions, HRT should be used very cautiously. Although prolonged use of HRT may reduce bone loss and fracture risk in postmenopausal women, the benefits need to be weighed against the potential side effects of HRT.

SERMs (raloxifene) are non-hormonal medications that act as estrogen receptor agonist/antagonists depending on the tissue type. In bone, when estrogen deficiency has caused an imbalance in bone turnover, SERMs bind to estrogen receptors and act as agonists to decrease bone resorption and normalize bone turnover, resulting in preservation of BMD [18]. The effects of SERMs on bone turnover and BMD are less effective than those seen with full doses of estrogen as well as bisphosphonate therapy. Raloxifene has been shown to increase BMD, improve bone strength and reduce the risk of vertebral fractures, but has not been shown to be effective in the prevention of non-vertebral fractures [19–21]. Meta-analysis has shown that raloxifene can reduce vertebral fracture risk by up to 40% [22]. In addition to its protective effects on the skeleton, treatment with raloxifene reduces the risk of invasive breast cancer, especially estrogen-receptor-positive breast cancers [23]. However, its use is associated with an increased risk of fatal stroke and venous thromboembolism. Because of their isolated fracture reduction risk on the vertebrae, SERMs are predominantly prescribed to women with trabecular osteoporosis and low risk for hip fracture. Raloxifene has not been shown to be beneficial in premenopausal women.

21.4 Bisphosphonates

Bisphosphonates are the most extensively used and widely studied drug class for the treatment of osteoporosis. Because of their efficacy, ease of administration, and relatively low side effect profile, they are generally considered first line agents in the treatment of osteoporosis. Bisphosphonates are anti-resorptive agents which act via the inhibition of osteoclasts, leading to reduced bone turnover, increased bone mass, and improved mineralization [24, 25]. There are two classes of bisphosphonate medications: nitrogen containing and non-nitrogen containing. Non-nitrogen containing bisphosphonates incorporate into ATP and produce metabolites that cause osteoclast apoptosis. Nitrogen containing bisphosphonates inhibit bone resorption by binding and blocking the enzyme farnesyl diphosphate synthase (FPPS) in the HMG-CoA reductase pathway (also known as the mevalonate pathway). Disruption of this pathway induces changes in the cytoskeleton of the osteoclast. The osteoclast cytoskeleton is vital for maintaining the ruffled border that is required for contact between a resorbing osteoclast and the bone surface [26]. The fracture risk reduction in postmenopausal women treated with bisphosphonates has been well documented [27–29]. The evidence base for bisphosphonates in the prevention of fracture in postmenopausal women is well established. Several studies have shown that use of bisphosphonates decreased vertebral fracture risk by approximately 50% as well as non-vertebral fracture risk by up to 50% as well [28, 30].

In order to reach high levels of efficacy and lower incidences of side effects, medication compliance is very important. However, in clinical practice medication compliance, especially with oral bisphosphonates, is relatively poor. It has been estimated that 75% of women, who start medical treatment of osteoporosis are non-compliant with their medications in the first year of initiating treatment and will discontinue therapy on their own within this time [31].

Oral bisphosphonates are generally well-tolerated. The most frequent complications seen are GI disturbances. Osteonecrosis of the jaw is often presented as a significant complication of bisphosphonate treatment. According to the literature, however, osteonecrosis of the jaw is actually a rare complication with an estimated incidence of less than 1 case per 100,000 person years of exposure [32]. Atypical subtrochanteric proximal femur fractures have also been reported in some patients receiving bisphosphonates, predominantly in patients who have received prolonged alendronate treatment for osteoporosis [33–35, 73]. This is likely due to prolonged suppression of normal bone turnover, leading to damage and disruption of bone architecture. There is an acute phase reaction that is common with the administration of both oral and intravenous nitrogen-containing bisphosphonates, which can result in flu-like symptoms: fever, chills, arthralgias, and fatigue. These are more common with intravenous forms of bisphosphonate treatment and symptoms tend to be self-limiting [36, 37].

21.5 Denosumab

Denosumab is also an anti-resorptive drug but its mechanism of action differs from bisphosphonates. It is the first biologic agent for the treatment of osteoporosis. Receptor activator for nuclear factor Kappa B ligand (RANKL), a member of the Tumor Necrosis Factor (TNF) family and their immature precursors, is expressed by osteoblasts, and is an important mediator of osteoclastogenesis. RANKL activates its receptor, RANK, which is expressed on both osteoclasts and their precursors, thus promoting osteoclasts formation and activation. In addition, RANKL prolongs osteoclast survival by suppressing apoptosis. The effects of RANKL are counteracted by its decoy receptor osteoprotegerin (OPG). Elderly women with hip fractures exhibit an increased RANKL/OPG mRNA content of iliac bone [38]. Denosumab is a monoclonal antibody that binds to and neutralizes the activity of RANKL, thereby inhibiting osteoclastogenesis [39]. In phase 3 clinical studies, denosumab was shown to significantly reduce vertebral, non-vertebral and hip fractures compared with placebo and increase BMD compared with alendronate. The anti-resorptive effect of a 60 mg subcutaneous injection of denosumab is significantly greater than that seen with oral alendronate [39]. A large placebo-controlled trial (the FREEDOM trial) illustrated the anti-fracture efficacy of denosumab. In the FREEDOM trial, 3 years' treatment with denosumab (60 mg as a subcutaneous injection every 6 months) resulted in reductions in vertebral fractures, hip fractures, and non-vertebral fractures in postmenopausal women with osteoporosis [40]. In the FREEDOM study, the risks of vertebral and non-vertebral fracture were significantly reduced in the denosumab group. Risk reductions at 12, 24 and 36 months were 61%, 71% and 68% for vertebral fractures and 16%, 21% and 20% for non-vertebral fractures, respectively. At 3 years, the reduction in the risk of hip fracture was 40% [40, 41]. Wrist fracture risk decreased with the severity of osteoporosis [42]. This trend continued when the FREEDOM trial was extended to 5 years [43] and 6 years [44], with reductions of 37% and 45% in vertebral fractures and 58% and 50% in non-vertebral fractures, respectively. In a Japanese study, denosumab fracture intervention randomized placebo controlled trial (DIRECT) involving men and women with osteoporosis, compared with placebo, denosumab reduced the risk of new vertebral fractures by 74% after 2 years of follow-up. Compared to alendronate, this additional reduction was statistically significant at 59% [45]. The effectiveness of denosumab and its biannual administration make it a promising anti-resorptive agent. In addition, unlike bisphosphonates, it can be administered to patients with moderate or severe renal impairment, for whom there was previously no reasonable therapeutic option [46]. Denosumab is generally well tolerated. The largest reported side effects are skin site reactions at the injection site and infections including urinary tract infection, sinusitis, pharyngitis, bronchitis, and cellulitis.

21.6 Strontium Ranelate

Strontium ranelate is a newer treatment for postmenopausal osteoporosis (not approved in the US), which reduces both the risk of vertebral as well as non-vertebral fractures. It is the first medication that appears to simultaneously increase bone formation as well as decrease bone resorption. This is due to its dual effects on both osteoclasts as well as osteoblasts [47]. The exact mechanism of action of strontium ranelate is uncertain, although a dual mode of action has been suggested [48]. It is thought that strontium ranelate increases preosteoblast replication, osteoblast differentiation, collagen type I synthesis, and bone matrix mineralization, probably through a calcium-sensing receptor (CaR)-dependent mechanism. In addition to this potentially anabolic effect, it is thought that there is inhibition of osteoclast differentiation and activity mediated by an increase in OPG and a decrease in RANKL [49]. Bone-biopsy specimens from postmenopausal women with osteoporosis treated with strontium ranelate show a reduction in bone resorption but no evidence of increased bone formation [50]. *In vivo* studies performed in rodent models such as immobilization-induced osteopenia and ovariectomy-induced osteoporosis indicate that strontium causes increased bone formation [51, 52]. There is evidence to support the use of strontium ranelate for the reduction of fracture risk in postmenopausal women with osteoporosis. A meta-analysis of four trials of strontium ranelate revealed a 37% reduction in vertebral fractures and a 14% reduction in non-vertebral fractures in postmenopausal women with osteoporosis receiving strontium ranelate 2 g/day for 3 years [53]. A significant reduction in hip fractures has been demonstrated in patients at high risk of hip fracture (women aged 74 or over, femoral neck BMD ≤ -3) [54]. In addition, a double-blind, randomized, placebo controlled trial examined the effect of strontium ranelate in men with primary osteoporosis [50]. After 2 years of treatment they observed an approximately 10% increase in BMD in the spine, and a significant increase in femoral neck BMD when compared to the placebo group. Strontium ranelate is relatively well tolerated. Side effects include nausea, diarrhea, and headache, which usually resolve over time. There is a risk of skin hypersensitivity reactions as well as an increased risk of thromboembolic events with strontium ranelate use, and it should not be used in patients with a history of venous thromboembolisms or in patients at high risk for the development of clots.

21.7 New Therapeutic Targets for Osteoporosis

There is a great interest and clinical need for developing new therapeutic targets for the treatment of osteoporosis, given that the current medications used have variable potencies and side effect profiles.

21.7.1 Cathepsin K Inhibitors

Cathepsin K (CatK) is a member of the papain family of cysteine proteases. It is a digestive enzyme that breaks down type I collagen in osteoclast resorption pits, thereby assisting in bone resorption [55]. Activation of the bone resorption requires tight adhesion of osteoclasts to bone surfaces to seal off the resorption pit. Osteoclasts secrete protons into the resorption pit to create an acidic environment to aid in the degradation of the bone mineral, followed by release of proteases capable of digesting collagen and non-collagenous bone matrix proteins [56].

Cathepsin K is the most abundant cysteine protease expressed in osteoclasts and plays a pivotal role in bone resorption [57]. Genetic and pharmacological evidence supports a central role of CatK in mediating bone resorption [58]. In preclinical studies, CatK inhibitors reduce levels of biochemical markers of bone resorption and increase bone mineral density in a dose-dependent manner [59]. These findings have supported CatK as a target for novel molecules to treat osteoporosis. Odanacatib (ODN) is a cathepsin K inhibitor which has completed phase I and phase II clinical trials [60–62]. ODN has been shown in earlier clinical trials to reduce bone resorption while preserving bone formation in postmenopausal women. In animal studies, ODN reduced trabecular and intracortical bone formation at the femoral neck and proximal femur, but preserved endocortical bone formation and stimulated periosteal bone formation [63]. Unlike bisphosphonates, ODN inhibits osteoclast digestion of type I collagen, but does not reduce osteoclast number. Preservation of osteoclast signaling pathways may account for the finding that bone formation is less affected by treatment with ODN than by treatment with conventional anti-resorptive therapy.

In animal models, treatment with ODN increased vertebral and femoral bone mass, and exhibited reduction of the bone resorption biomarker urinary helical peptide of collagen type I [64]. Upon discontinuation of ODN, the treatment effects on bone mass, strength, and remodeling, as well as biomechanical properties of the spine and hip returned to baseline levels. In addition, bone resorption markers also returned to baseline. Treatment of rhesus monkeys with ODN prevents loss of BMD at the spine and hip, and decreased the bone resorption markers, serum C-telopeptide (CTX), and urinary N-telopeptide (NTX) [63, 65].

The most common side effects reported in study subjects who received ODN included headache, flu-like symptoms and sore throat. Side effects possibly drug related are headache, fatigue, nausea, decreased appetite, increased appetite, dry mouth and abdominal discomfort.

21.7.2 Anti-Sclerostin Therapy

With the discovery of the role of the Wnt/β-- catenin pathway in the maintenance of bone density and in the pathogenesis of both low and high bone mass, there has been an increased focus on determining how activation of this pathway might be manipulated to aid in the treatment of osteoporosis. Sclerostin, an endogenous inhibitor of Wnt signaling, is an important regulator of bone formation [66]. Sclerostin production results in decreased osteoblastic bone formation and increased osteoclastic bone resorption. Inhibition of sclerostin, which can be expected to increase osteoblastic bone formation, and decrease osteoclastic bone resorption, has emerged as a potential strategy in the management of osteoporosis. Understanding the expression and activity of sclerostin has led to the development of humanized monoclonal antibodies (MAb) against sclerostin, including romosozumab and blosozumab. Based on data in animal models, a sclerostin neutralizing MAb was developed by Amgen and has been investigated in Phase I and Phase II studies. Phase III studies are currently ongoing. Another neutralizing MAb, blosozumab, has been developed by Eli Lilly, and Phase I and II studies have been completed.

The first study with the humanized sclerostin MAb, romosozumab, illustrated there was a dose-dependent increase in bone formation markers including P1NP, bone-specific alkaline phosphatase (BSAP), and osteocalcin, as well as a dose-dependent decrease in the bone resorption marker serum C-telopeptide (sCTX) [67]. In addition, dose-dependent increases in BMD were noted both in the lumbar spine and in the hip. A Phase II, multicenter, international, randomized, placebo-controlled study was conducted [68]. All of the groups treated with romosozumab had significant increases in BMD at the lumbar spine, hip and femoral neck at 12 months. Increases in bone formation markers (P1NP, osteocalcin, and BSAP) were also observed, and in all of the romosozumab groups, the bone resorption marker, sCTX, decreased from baseline measurements. Based on the promising results seen in initial studies, there are several additional Phase I and II studies that have been completed or are in progress [69]. Other humanized MAbs against sclerostin are also being developed. Blosozumab has been investigated in Phase I and Phase II studies [70]. They have shown that like romosozumab, there was a dose-dependent increase in bone formation markers including P1NP, bone-specific alkaline phosphatase (BSAP), and osteocalcin, as well as a dose-dependent decrease in the bone resorption marker serum C-telopeptide (sCTX) [71, 72]. In addition, dose-dependent increases in BMD were noted in both the lumbar spine and in the hip. In Phase I and Phase II trials, romosozumab has been generally well tolerated with common side effects including injection site reactions and decreases in serum calcium levels.

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Parathyroid Hormone

22

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22.1 Introduction

Parathyroid hormone (PTH) secreted by the parathyroid glands plays various important roles in calcium homeostasis and in bone remodeling. The secretion of PTH is regulated by extracellular calcium levels and other humoral factors including vitamin D.

PTH induces its biological effects by regulation of gene expression. The human gene encoding for PTH is located on chromosome 11 [1]. Several genetic factors have been identified that are associated with osteoporosis by influencing bone mineral density (BMD), bone turnover, calcium homeostasis, and susceptibility to osteoporotic fractures [2]. Some PTH polymorphisms have been identified showing an association with osteoporosis, fracture risk and fracture healing [3]. Polymorphisms in genes encoding for PTH may contribute to genetic regulation of BMD and thus the susceptibility to fracture risk [3].

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PTH stimulates the proliferation of osteoprogenitor cells, synthesis of alkaline phosphatase, and bone matrix proteins that contribute to hard callus formation and increases strength at the site of fractured bone. During remodeling, PTH promotes osteoclastogenesis restoring the original shape, structure, and mechanical strength of the bone.

22.2 Parathyroid Hormone Physiology

PTH consists of 84 amino acids, whereas the PTH-related peptide (PTHrP) consists of 141 amino acids. Eight of the first 13 amino acids of the PTHrP are identical to those in PTH; others have a large degree of structural homology [1]. Hypercalcemia associated with malignancy has been attributed to a pathological secretion of PTHrP [2, 3].

PTH maintains the physiological extracellular calcium levels utilizing three different mechanisms: regulation of the gastrointestinal calcium absorption, regulation of the renal reabsorption of calcium and phosphate, and regulation of the osteoclastic bone resorption. These activities of PTH reside within the 1–34 N-terminal fragment [2].

A chronic hyperparathyroidism produces hypercalcemia with subsequent osteoporosis and kidney stones and can be primary or secondary to vitamin D deficiency. Hypoparathyroidism is rare and leads to abnormally low blood levels of ionized calcium and elevated levels of phosphorus.

P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_22

A paradox effect of PTH, which is in contrast to the known effects of hyperparathyroidism has been described. Osteoanabolic effects have been shown with low-dose intermittent administration of PTH or its fragments. In animal models of post-ovariectomy osteopenia, intermittent PTH therapy increases trabecular osteoblastic activity and increases BMD [2]. Also in humans, the intermittent administration of recombinant human PTH has been shown to stimulate bone formation to a higher extent than bone resorption. This effect is now used in the management of osteoporosis [4].

Secretion of PTH is regulated by extracellular calcium levels and other humoral factors including vitamin D [5]. PTH regulates gene expression and induces biological effects both directly and indirectly. PTH stimulates proliferation and differentiation of osteoblasts and osteoclasts and promotes the synthesis of osteocalcin, fibronectin, and α-1 collagen. PTH also increases trabecular bone mass and skeletal responses to weight bearing and to treatment with estrogen, calcitonin, and vitamin D. As some of these factors may change with age, a modulation of bone metabolism by altered PTH secretion may occur [5]. Furthermore, serum levels of PTH increase with age and are thought to participate in involutional osteoporosis. The age-associated rise in serum PTH is likely related to vitamin D deficiency [6].

The PTHrP is another protein in the PTH pathway, which plays an important role in the skeletal development during the early bone growth through the regulation of chondrocyte proliferation and differentiation [7].

The human gene encoding for PTH is located on chromosome 11. The parathyroid hormone-like hormone gene (PTHLH) encoding for PTHrP is located on chromosome 12, whereas the genes encoding for the PTH-receptor 1 (PTHR1) and PTHR2 are located on chromosomes 3 and 2, respectively [1].

22.3 Genetic Variations of PTH with Bone Mineral Density and Fracture Risk

Decreased BMD is an index of osteopenia, osteoporosis, reduced bone strength, and increased risk of fracture. Association analyses of polymorphisms of candidate genes can suggest markers for genetic risk of osteoporosis. There is a number of papers dealing with PTH gene polymorphism and BMD [1, 5, 8, 9]. Also twin and family studies show that genetic factors influence BMD and hence the risk for osteoporosis [10–14]. Thus, genetic factors are associated with osteoporosis by influencing BMD, bone turnover, calcium homeostasis, and susceptibility to osteoporotic fractures. Polymorphisms in genes encoding PTH may contribute to genetic regulation of BMD and thus susceptibility to fracture risk [15]. Alterations in the PTH gene have associations with fracture risk. Tenne et al. showed that variations in the PTH gene contributed to fracture risk in elderly women [1].

22.4 PTH—The Paradox Effect

In the 1980s and 1990s, studies demonstrated that intermittent treatment with PTH increases osteoblast number and bone formation in growing and adult rats and also increases trabecular bone [4, 16]. The cellular mechanism for this increase in osteoblast number was investigated in 16-month-old female rats. PTH treatment resulted in dramatic increases of osteoblast numbers (626%), and steady state mRNA levels of osteocalcin (946%) and type 1 collagen (>1000%). Similar changes were observed in PTH-treated ovariectomized rats. As the PTH-induced increases of osteoblast numbers did not require proliferation of progenitor cells, we carried out an additional experiment in adult ovariectomized rats to determine the onset of PTH action. Incorporation of [3H]proline in the distal femoral epiphysis of PTH-treated adult ovariectomized rats was increased within 24 h. The authors concluded that the rapid PTH-induced rise in bone formation did not require cell proliferation and was most likely due to activation of preexisting bone lining cells to osteoblasts [17].

In a clinical pivotal trial, the effects of once-daily injections of PTH 1–34 on fractures were tested. 1637 postmenopausal women with prior vertebral fractures were randomly assigned to receive whether 20 or 40 μg of PTH 1–34 or placebo, administered subcutaneously daily. Vertebral radiographs were obtained at base line and at the end of the study (median duration of observation: 21 months) and serial measurements of bone mass by dual-energy X-ray absorptiometry (DXA) were performed. The results showed that new vertebral fractures occurred in 14% of the women in the placebo group and in 5 and 4%, respectively, of the women in the 20 and 40 μg PTH groups; the respective relative risks of fracture in the 20 and 40 μg groups, as compared with the placebo group, were 0.35 and 0.31 (with a 95% confidence intervals, 0.22–0.55 and 0.19–0.50). New nonvertebral fragility fractures occurred in 6% of the women in the placebo group and in 3% of those in each parathyroid hormone group (relative risk, 0.47 and 0.46, respectively, 95% confidence intervals, 0.25 to 0.88 and 0.25–0.861). As compared with placebo, the 20 and 40 μg doses of PTH increased BMD by 9 and 13% in the lumbar spine and by 3 and 6% more in the femoral neck; the 40 μg dose increased BMD in the shaft of the radius by 2%. Both doses increased total-body bone mineral by 2 to 4% over the placebo group. It was concluded that PTH 1–34 decreases the risk of vertebral and nonvertebral fractures; increases vertebral, femoral, and total-body BMD. The 40-μg dose increased BMD more than the 20 μg dose but had similar effects on the risk of fracture and was more likely to have side effects [18].

22.5 Fracture Healing

The role of PTH treatment in fracture healing is currently an intensive area of research. Studies showed that PTH promotes hard callus formation and increases bone osteoporosis at the site of the fracture [18, 19]. PTH influences fracture healing at various levels. These include increased expression of chondrogenic transcription factors resulting in increased chondrocyte differentiation, proliferation, and cartilage formation in the callus [20]. PTH also stimulates the proliferation of osteoprogenitor cells and production of alkaline phosphatase and bone matrix proteins that contribute to hard callus formation. During the remodeling process, PTH promotes osteoclastogenesis by restoring the original shape, structure, and mechanical strength of the bone [2].

22.6 Experimental Studies

The effect of the intermittent application of PTH 1–34 on fracture healing was initially studied in experimental settings in rats by two groups. Andreassen et al. studied the effect of 60 μg/kg and 200 μg/kg PTH 1–34 on callus formation and mechanical strength in a rat tibia shaft fracture model at 20 and 40 days of healing. Control animals with fractures were given vehicle. The 200 μg/kg dose of PTH 1–34 increased the ultimate load by 175% and the external callus volume by 72% after 40 days of healing time. The 60 μg/kg dose of PTH 1–34 increased the ultimate load by 132% and the external callus volume of fractures by 42% after 40 days of healing time. The callus bone mineral content (BMC) increased in all groups. After 40 days, callus BMC in the 200 μg/kg PTH 1–34 group was 108% and callus BMC in the 60 μg/kg PTH 1–34 group was 76% of the control group [21]. Holzer et al. studied the effects of PTH 1–34 in 20 3-month-old male rats that had closed mid-diaphyseal femur fractures and stabilization with retrograde intra-medullary pin. Ten rats received placebo in form of daily subcutaneous injection of 0.9% saline, whereas the other ten rats got a daily subcutaneous injection of 80 μg/kg PTH 1–34. Twenty-one days after fracture, the rats were euthanized, the femurs were removed and subjected to biomechanical testing, bone densitometry (DXA, peripheral quantitative computed tomography (pQCT)), and histologic examination. The treatment group showed significant increases in callus area and mechanical strength. Results of DXA and pQCT indicated an increase in density, although these BMD changes did not achieve statistical significance. Histological examination of the calluses showed an increase in the amount of new bone formed. No differences were observed in the weights of the animals or the sizes of the bones [22]. Both groups concluded that the use of PTH would potentially stimulate fracture healing and should be further tested clinically.

The effect of RS-66271, a PTHrP analogue, on fracture healing has also been studied in rabbits receiving corticosteroids [23]. In rabbit ulnae, a 1-mm defect was created surgically and healing of fractures was delayed by daily injections of prednisone 2 months before surgery and continued throughout the healing process. Daily injection of RS-66271, starting 1 day after surgery, resulted in union of 9 of 10 ulnae after 6 weeks. In the control group (saline), two bones healed at the same time point. Ulnae of the treatment group showed increased callus size, radiodensity and stiffness compared to controls.

Various experimental studies tried to identify the potential mechanism of PTH on the healing of fractures. Nakajima et al. confirmed the beneficial effect of 10 μ/kg PTH 1–34 in fracture healing in a rat femoral shaft fracture model. Furthermore, they found an increased number of proliferating osteoprogenitor cells at the second day after fracture. mRNA analysis showed increased expression of type I collagen, alkaline phosphatase, osteocalcin and osteonectin suggesting that PTH 1–34 stimulates the proliferation of mesenchymal stem cells and their differentiation into matrix-producing osteoblasts [24].

Alkhiary et al. produced fractures of the femoral diaphysis in 270 rats. Subsequently, the rats were treated with either 5 or 30 μg/kg of PTH 1–34 or vehicle. After 3 weeks, femoral fractures in the group with 30 μg/kg PTH 1–34 showed increased callus formation compared to controls in plain X-rays. Cartilage volume, torsional strength, stiffness, BMC and BMD were maintained at 3 months after fracture [20].

Similar results were seen in the same fracture model by Nakazawa et al. At week two after fracture, there was an increased callus formation in the treatment group (daily subcutaneous injections of PTH 1–34) compared to controls. However, this difference was not seen at week 3 and 4. Furthermore, the cartilage transcription factor sox-9 was up-regulated in the treatment group suggesting a role of PTH 1–34 in the early chondrogenesis and an acceleration of endochondral bone formation [25].

Komatsubara et al. identified an accelerated bone remodeling from woven to lamellar bone due to PTH 1–34 use in the rat femur fracture model compared to controls. Furthermore, increased percentage of cortical bone formation and ultimate load to failure was noticed in the 30 μg/kg PTH 1–34 treated rats compared to controls after 3 months [26].

22.7 Clinical Studies

Data obtained from animal studies cannot predict results in humans, but based on the preclinical findings of accelerated fracture healing in almost all studies, the expectations that PTH may also stimulate bone healing in humans are very high. Up to date, there are only few published reports studying the effects of PTH on healing of fractures in humans. It is already known that PTH accelerates the natural fracture healing process and provides a faster remodeling as it was described through a more rapid shrinkage of the callus and a simultaneous increase of the degree of mineralization of the fracture callus. However, in this study, the observed effects did not result in any significant improvement in mechanical strength at 26 weeks [27].

22.8 Delayed-Unions and Non-Unions

There are some case reports published that support a beneficial role of PTH use on the delayed-unions or non-unions after fractures. A report by Oteo-Alvaro et al. showed healing of a non-union of a traumatic right diaphyseal humerus fracture that underwent intramedullary osteosynthesis. At 6 months postoperative, no radiological signs of healing were seen. Subsequently, daily injections of PTH 1–34 were initiated. At 3 months, bone bridging and after 5 months of PTH 1–34 therapy, healing was seen [28].

Furthermore, Lee et al. showed a potential effect of PTH 1–34 in a series of three cases with non-unions after osteosynthesis in femoral fractures. Daily injections of 20 μg PTH 1–34 were administered for a 3–9-month period resulting in healing without any further need of surgery [29].

22.9 Fracture Healing in Osteoporotic Fractures

The first prospective clinical study of PTH 1–34 was performed in 102 postmenopausal women who had sustained a dorsally angulated distal radial fracture (Colles' fracture), which needed a closed reduction, but not surgery [30]. The study was a multi-center, randomized, prospective, double-blinded, placebo-controlled clinical trial. The patients received either daily injections with 20 or 40 µg of PTH 1–34 or placebo within 1 week from the day of fracture and continued for 8 weeks in addition to 1000 mg elemental calcium and 800 IU Vitamin D per day. Healing was assessed by both X-rays and CT imaging and defined as healing of 3 of 4 cortices in X-rays. Radiographs and CT scans were assessed by a central quality assurance and reading service. Functional assessments included the self-administered Patient-Rated Wrist Evaluation (PRWE) questionnaire and assessment of grip strength via a Jamar dynamometer. The time to healing was significantly accelerated in the PTH 1–34 20 µg group compared to placebo (7.4 vs. 9.1 weeks). Pain and grip strength were not significantly different. In a subgroup analysis of 27 women from one of this study centers, a dose-dependent improvement in the quality of early callus formation in X-rays at 5 weeks was found [31].

Peichl et al. studied the effect PTH 1–84 on the healing course of osteoporotic pubic fractures. Included patients ($n = 65$) were above the age of 70 years, had osteoporosis and a stable unilateral pubic fracture with no need of surgery. Every third patient received a daily subcutaneous injection of PTH 1–84, which is roughly equivalent to 40 µg of PTH 1–34. However, due to differences in pharmacokinetics and actions between the forms of PTH, the anabolic effect of 100 µg of PTH 1–84 is more comparable to 20 µg of PTH 1–34. Fracture healing was assessed by CT and analysed blinded to treatment allocation. The primary endpoint was percentage of fracture healing at 8 weeks. Furthermore, patients had functional assessment at 8 weeks after fracture by the use of the timed "up and go" test and pain assessment using the visual analogue scale (VAS) every fourth week. Median time to cortical bridging was 7.8 weeks in the PTH group compared to 12.6 weeks in the control group. Healing at 8 weeks follow-up was 100% in the PTH group compared to 9.1% in the controls. Furthermore, patients in the intervention group had significant improvement in functional outcome (pain and mobility) compared to control [19].

Furthermore, the effect of PTH 1–34 on fracture healing of proximal humerus fractures was studied. The main inclusion criterion was a fracture suitable for non-surgical treatment or fixation with osteosutures. Fourty post-menopausal women with a proximal humerus fracture that were suitable for non-operative treatment or fixation with osteosutures were included in this single-center study. Patients were randomized to receive either daily injections with 20 µg PTH 1–34 for 4 weeks or no injection in the control treatment. Initially, pain at rest and during activity was assessed by VAS and prefracture function by using the DASH score. It was repeated at 7 weeks and again at 3 months postfracture. Fracture healing was evaluated by two radiologists by blind qualitative scoring of the callus at 7 weeks. Callus formation was classified as "normal" or "better". Thirty-nine patients completed the follow-up. Radiographically, a correlation of "better" in the PTH 1–34 group and "normal" in the control group was seen. However, there were no statistically significant differences in pain, in use of strong analgesics, or in function between the groups at the follow-up examinations [32].

Another single-center prospective randomized comparative pilot study has been initiated to study the effect of a 6-week course of 20 µg daily subcutaneous injections of PTH 1–34 on the functional recovery after trochanteric hip fractures in elderly patients [33]. Functional outcome will be assessed at 6 and 12 weeks using the Short Physical Performance Battery. The trial is finished by now and results are to be expected soon.

22.10 Stress Fractures

The acceleration of fracture healing by PTH 1–34 has also been described in two cases of metatarsal stress fractures in a 35-year-old patient and a 40-year-old patient. After 4 weeks of daily subcutaneous injections of PTH 1–34, callus formation was observed in X-rays. Furthermore, patients were free of pain [34].

22.11 Atypical Fractures Associated with Bisphosphonate Therapy

Chiang et al. conducted a small prospective study in 14 patients that were long-term bisphosphonate users (4–10 years) and experienced an atypical femoral fracture. Twenty micrograms of PTH 1–34 was administered daily subcutaneously in 5 of these patients for 6 months, whereas the other had no treatment with PTH 1–34. In the PTH 1–34 group, fracture union was seen in two and two further patients were free of pain. All of the treated patients showed increased bone remodelling markers. In the group that did not receive any PTH 1–34 treatment ($n = 9$), six patients had non-union and persisting pain and one had pain and poor signs of healing [35].

Conclusions

The relationship between PTH and bone was acknowledged almost 100 years ago. Up to the 1980s and 1990s, it was thought that PTH has primarily a negative effect on bone as seen in diseases like chronic hyperparathyroidism. Later on, the so-called "paradox" effect of PTH was described and could be proven both experimentally and clinically. So, for more than 12 years, PTH is well established as an anabolic treatment in osteoporosis to reduce the future fracture risk in patients at high risk and with severe osteoporosis. Its main indication can be seen in the secondary prevention of fractures.

Although widely appreciated among orthopedic surgeons, who use PTH in patients with osteoporosis, the use of PTH 1–34 or PTH 1–84 to accelerate fracture healing is off-label. Several attempts to show a stimulating effect of PTH on fracture healing in clinical trials failed due to various methodological problems. Up to now, reports on PTH effects on fracture healing are limited to case reports, small case series and few prospective studies. Additional results from well-designed and executed clinical studies are needed to clarify the potential effect of PTH on fracture healing in humans.

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Part VIII

Aftertreatment

23 Aftercare

Stephen L. Kates and Gillian Soles

23.1 Non-operative Treatment

23.1.1 Introduction

Fragility fractures of the pelvis (FFP) are increasingly common occurrence and associated with advancing age, osteoporosis, and a longer life expectancy of populations around the world [1]. These are most commonly the result of a ground-level fall and the patients may experience a variety of fracture patterns [1]. In contrast to younger patients, the fracture pattern seems to be less likely to influence the outcome than the patient's comorbid conditions and preinjury functional status. Many FFP never come to the attention of the orthopedic trauma surgeon. Such cases are frequently cared for by medical physicians or geriatricians on the medical wards. This chapter will describe the numerous considerations required for care following both operative and non-operative treatment of FFP.

23.1.2 Setting of Care

The majority of patients with FFP are admitted to an acute care hospital. Often times, if the injury does not appear particularly significant on the plain radiographs, patients are admitted to the medical service or geriatric service for care and rehabilitation placement. Hospital lengths of stay are variable depending upon the healthcare system being considered. Many healthcare systems have a shortage of acute or subacute rehabilitation beds and therefore patients with FFP often have a significant length of hospital stay. If acute or subacute rehabilitation is available, once the pelvic fracture patient is medically stabilized, they are frequently discharged for rehabilitation. Similar aftercare will occur in both settings. The care will be described in the sections that follow.

23.1.3 The Fracture Pattern, Presence of a Sacral Fracture

Distinct fragility fracture patterns of the pelvis are observed. These commonly include pubic rami fractures, acetabular involvement, particularly with the superior pubic ramus fracture, lateral compression type patterns resulting from a fall on the side. In many cases, a sacral fracture is also present [1, 2]. The sacral fracture has an adverse event on pain and length of stay, and has been associated with more difficult recovery and longer lasting pain. Sacral fracture should be considered if the patient reports acute lower back pain or pain in the posterior pelvic region [1, 2]. Work-up for the sacral fracture can be performed

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_23

in the acute care setting or through the rehabilitation setting with CT scan, MRI scan or less commonly bone scintigraphy [1–3]. The sacral fracture is frequently quite painful and the pain is slow to resolve [2]. Stable fracture patterns are frequently treated with non-operative care [1]. The pelvic fracture pattern seems to have limited impact on the patient's ultimate recovery in this subset of patients.

23.1.4 Comorbidities and Their Management

Patients sustaining a FFP frequently have numerous comorbidities similar to patients with hip fracture. These comorbidities have a significant effect on clinical outcomes and should be carefully managed to keep them in a state of equilibrium. Common comorbidities include cognitive dysfunction, dementia, cardiovascular disease, diabetes, COPD, significant osteoporosis, and other comorbidities associated with the aging population. One particular problem that should be identified is the syndrome known as *geriatric frailty*. This condition is characterized by weakness, weight loss, diminished physical function and a variety of other reductions in function. Patients with geriatric frailty are more likely to experience short-term complications after hip fracture and this seems to have a significant effect, regardless of the reason for hospitalization. Assistance with management of these comorbidities should be sought upon admission. Typically, a geriatrician or hospitalist familiar with care of frail older adults will be very helpful in the management of these patients, should they be admitted to the orthopedic surgery service. Many centers have by design chosen to admit their fragility pelvic fracture patients to the medical service.

Medical co-management has been shown to be extremely beneficial with hip fracture patients, who have similar comorbidities and outcomes as the pelvic fragility fracture patient group. Particular attention should be paid to and avoiding development of new problems, such as pressure sores, aspiration pneumonia and delirium.

23.1.5 Acute Medical Conditions

Several acute medical conditions may develop in the early aftercare treatment for pelvic fracture patients. Problems include bleeding from the fracture site, which result in acute anemia, immobility, resulting in pressure sores, hypoxia, venous thromboembolic events, and aspiration pneumonia. A systematic approach to the patient should include monitoring of red cell mass, frequent checks of oximetry, frequent repositioning, including early mobilization to a chair, and elevation of the head of bed greater than 30° at all times. Particular attention should be paid to patients admitted on anticoagulation therapy. This group of patients may experience significant bleeding within 24 h of admission [1, 4]. Bleeding seems to be more common in elderly patients than younger fragility fracture patients. Progressive deterioration in clinical situation and decrease of hemoglobin should prompt concern for bleeding from the pelvic fracture. CT scan may be useful to demonstrate this (Fig. 23.1). Correction of coagulopathy and possible arterial embolization with the help of an interventional radiologist may be required in extreme cases [1, 5].

In patients highly likely to develop aspiration pneumonia, an early swallowing evaluation by a speech therapist may be useful. Delirium is common and frequently develops acutely in the hospital, but can be avoided in many cases. It is a particularly insidious problem as it results in the inability to cooperate with rehabilitation, in the development of pressure sores, repeated falls, aspiration pneumonia, and many other adverse events. Much has been written about delirium [6, 7]. Family involvement, retention of the patient's glasses and hearing aids, avoidance of harmful medicines, avoidance of tethers such as urinary catheters, oxygen lines, compression boots, and any form of restraint, and careful management of the other medical conditions help to prevent or milder delirium [8]. Such management has been instilled into care providers on geriatric units and careful attention to avoidance of delirium will likely improve patient outcomes. Additionally, many acute medical conditions can be lessened or

Fig. 23.1 An 83-year-old male patient was admitted due to severe pain in the groin after a domestic fall. (**a**) A pelvic a.p. overview shows a fracture of the right superior pubic ramus. (**b** and **c**) Coronal reconstructions of the CT-scan did not show any fracture in the posterior part of the pelvic ring, but only a horizontal fracture line of the superior pubic ramus on the right (*white arrow*). The patient was taking an oral factor Xa-inhibitor due to atrial fibrillation. Soft-tissue windows of the transverse (**d**) and sagittal (**e**) CT-cuts demonstrate a big suprasymphyseal, extraperitoneal hematoma (*white arrow*). (**f**) Hemodynamic monitoring, several ultrasonographic follow-ups and a CT follow-up performed after 6 h did not show any progress of the bleeding (*white arrow*). The patient was further treated non-operatively. (Courtesy of P.M. Rommens et al.)

avoided by a careful assessment of the patient's medication list upon admission by the medical physician. Polypharmacy is very common in this subset of patients. Many of the admission medicines can likely be discontinued, as they are unnecessary or may even be harmful to the patient's well-being [8]. This form of medication reconciliation should be carried through to discharge, so that improvements to the patient's medication regimen are continued upon discharge.

23.1.6 Chronic Medical Conditions

Although pelvic fragility fracture patients commonly have many chronic medical conditions, there are several conditions that are more challenging than others. Of course, this must be assessed on a case-by-case basis. Chronic cardiac disease is common in this group of patients. This may involve coronary artery disease, congestive heart failure, arrhythmia or significant valvular heart disease. The blood loss associated with pelvic fracture may be significant and may result in exacerbation of the patient's coronary artery disease causing chest pain or a demand mediated myocardial infarction. Additionally, the patient with severe valvular heart disease may be intolerant of loss of volume. This can be corrected with transfusion and fluid management. The pain associated with pelvic fracture can be quite significant and may exacerbate an underlying arrhythmia, such as atrial fibrillation. In such cases, a rapid response of heart rate may result, requiring assistance from the medical physicians and possibly from a cardiologist. Although congestive heart failure is rarely present upon admission, it may become an issue with fluid resuscitation necessary to manage the acute blood loss anemia from the pelvic fracture. In such cases, it becomes essential to manage the condition with the assistance of the medical physician or cardiologist.

Chronic obstructive pulmonary disease is another problem that is common in the group of patients with a FFP. The main goal in such cases is to keep the patient in equilibrium with use of their standard inhalers and bronchodilators. Such patients seem to be at higher risk for development of pneumonia and this should be carefully watched for. Another condition that should be carefully managed is chronic constipation. With the use of opioid pain medicines, constipation is common and may get worse then becoming a critical problem. Proactive management with stool softeners and laxatives is recommended.

23.1.7 Osteoporosis Work-Up and Management

The presence of a fragility fracture signifies the presence of osteoporosis [9]. Many authors have noted that patients with FFP have a history of prior fragility fractures [2]. Depending on the setting, the patient may or may not have been previously treated for osteoporosis or have received a work-up for osteoporosis. In the rehabilitation phase, it is important to perform a baseline assessment with a mini metabolic bone workup including 25-OH vitamin D level, calcium level, and if indicated a parathyroid hormone (PTH) level [9, 10]. Additional work-up may consist of a thyroid stimulating hormone level assessment. If the patient has a reasonable life expectancy, obtaining a DXA scan is helpful for monitoring ongoing treatment in the event that one has not been recently performed. After work-up, if the vitamin D level is found to be insufficient or deficient, vitamin D repletion should be carried out with vitamin D2 or vitamin D3 on a daily basis [9]. The specific dosing should be adjusted based on the 25-OH vitamin D level result [9].

Other secondary causes of osteoporosis may be identified and should be treated [11]. If it is determined that the osteoporosis is primary, it is safe to initiate therapy with a bisphosphonate agent. Assuming that the patient has not already been taking one, bisphosphonate agents given orally will not interfere with fracture healing and have been shown conclusively to prevent refractures. If the patient has been previously treated with long-term bisphosphonate therapy, additional options should be discussed with an endocrinologist or metabolic bone specialist. Additional work-up for such patients is likely needed. The patient should also be informed by the physician of their diagnosis of osteoporosis and the need for treatment. This helps to place the patient on the correct pathway for long-term treatment.

An additional part of secondary fracture management is a falls assessment. This has a fairly prescribed methodology and should include analysis of gait, assessment of eyesight, balance, and consideration of cognitive dysfunction and its contribution to falling [12]. Many causes of falls can be avoided such as replacement of a patient's glasses, having a cataract removed, use of an appropriate assistive device, lower extremity strengthening, and optimization of a patient's medication regimen [12]. The medication regimen, in particular, is a readily fixable problem. Many medications (benzodiazepines, psychotropic drugs, diphenhydramine and other centrally acting antihistamines, cimetidine, and meperidine) are associated with an increased likelihood of falls in older adults. In this case, the assistance of the medical physician is vital and can help to avoid future mishaps.

23.1.8 Pain Management

Pain following FFP can be significant. Management of pain should be multimodal and may include acetaminophen, oral anti-inflammatory agents, opioid therapy, regional nerve blockade, or supplemental medications such as gabapentin. Specific choice of medications, dosing and monitoring of efficacy can be effectively carried out with the medical physician and if needed, a pain treatment specialist. Significant effort should be put into pain relief, which can help prevent delirium and can reduce the likelihood of the patient having other adverse events during their aftercare. Particularly for frail patients, it is helpful to have assistance from a specialist in managing pain. Pain may persist for a considerable period of time following the pelvic fracture and medication may need to be adjusted during the course of aftercare.

23.1.9 Supportive Care

23.1.9.1 Rehabilitation

Rehabilitation following a FFP consists of gentle mobilization using a walker frame, gentle range of motion of the lower extremities and early weight-bearing for patients with stable fractures [1]. Most patients in the fragility fracture group are not able to protect weight-bearing during recovery. Therefore, "weight-bearing as tolerated" is usually appropriate for this subset of patients [1]. Patient should not be left in bed for a prolonged time or in a chair for a prolonged time as pressure ulceration may occur [11].

23.1.9.2 Discharge Destination

In most series reported in the literature, the majority of patients with a FFP come from a home setting. However, the majority of patients with a FFP are unable to return to their pre-injury living situation after hospital discharge [1, 2, 11]. The majority of these patients will be managed in an acute or subacute rehabilitation setting. FFP is associated with a high likelihood of need for use of a walker, cane or other assistive device [11]. Most patients do not regain their pre-injury function. When choosing a discharge destination, the goal should be to restore the patient to their pre-injury functional status and pre-injury living status, if at all possible.

23.1.9.3 System of Care and Its Importance

The system of care used for care of fragility fracture patients makes a difference. Most of the literature published in this regard comes from hip fracture patients. In that situation, it has been conclusively shown that systematized care with standard order sets, medical co-management, and an organized care pathway seems to improve outcome. Many hospitals are beginning to adopt an organized approach to their fragility fracture patients. In some cases, this only extends to hip fracture patients while in others it extends to every fragility fracture patient admitted to the hospital. Because the subset of patients is increasing in prevalence, it is important to establish an organized approach to their care.

Specific aspects of an organized system to consider are trained nurses, specially trained physical therapists, medical physicians/geriatricians who are focused on care of older adults with many comorbidities, orthopedic surgeons interested in the care of older adults and a geriatric social worker. Once discharged from acute care setting, it is also important to have a systematic approach to this subset of patients at subacute and acute rehabilitation facilities. This represents a significant challenge to healthcare systems to develop the post-acute aspect of care. It requires excellent communication, sharing of health information, alignment of care incentives and goals, and sharing of a standard set of goals for the patient's recovery. Few places have developed such systems. When such a system is implemented, improved results can be expected.

23.1.10 Outcomes

Outcomes of patients with FFP have been likened by several authors to those of hip fracture patients.

There is a high short- term and 1 year mortality rate associated with pelvic fracture. Mortality rates at 1 year in the range of 16–30% are frequently reported [1, 11, 13, 14]. Comorbid conditions, venous thromboembolic events, aspiration pneumonia and other medical problems are frequent causes for poor outcome. Pressure sores and urinary tract infections are additional common adverse events [11]. Additionally, many older adults with a pelvic fracture failed to regain their pre-injury functional status, resulting in a more dependent living situation [2]. This loss of independence carries with it high personal and socioeconomic costs [2].

Most but not all of the pelvic fractures go on to fracture union without further intervention. However, a subset of these patients develops painful non-unions and may require surgical intervention to relieve pain and improve function (Fig. 23.2). Additionally, it is well known that repeated falls may occur in the healing phase, resulting in additional injury or fracture.

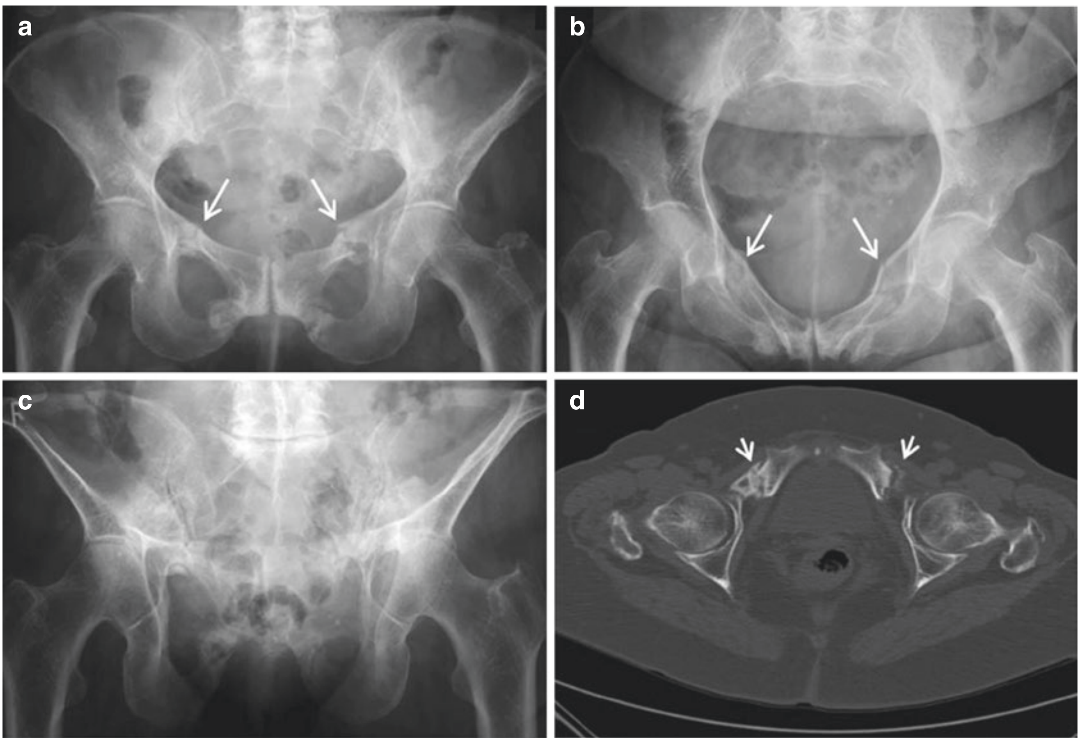

Fig. 23.2 Seventy-nine-year-old female with non-displaced fracture of the right posterior ilium and bilaterally displaced fractures of the pubic rami. The fragility fracture of the pelvis was treated conservatively. One year after trauma, the patient complains of persistent and disabling pain in the left and right groin. (**a**) The a.p. pelvic overview shows bilateral non-healed pubic rami fractures (*white arrows*) and a glimpse of the healed right posterior ilium fracture. (**b**) Pelvic inlet view showing the pubic rami fractures (*white arrows*). (**c**) Pelvic outlet view. There is a healed posterior ilium fracture on the right. (**d**) Transverse CT-cut through the anterior pelvic ring showing non-healed pubic rami fractures (*white arrows*). (**e**) Coronal CT-cut through the anterior pelvic ring with the abovementioned pubic rami fractures (*white arrows*). (**f**) Postoperative a.p. pelvic overview. The old fractures have been debrided and fixed with long curved reconstruction plates. Bilaterally, a modified Stoppa approach was used. One screw uses the infra-acetabular corridor; two screws are inserted above the acetabulum. The screws, which take the infra-acetabular corridor, are curved around the medial wall of the acetabulum. (**g**) Pelvic inlet view. (**h**) Pelvic outlet view nicely show the length of the screws, which are inserted into the pubic bones and medial-inferior to the acetabulum. Also the screws above the acetabulum have the largest possible trajectory in the ilium body. (Courtesy of P.M. Rommens et al.)

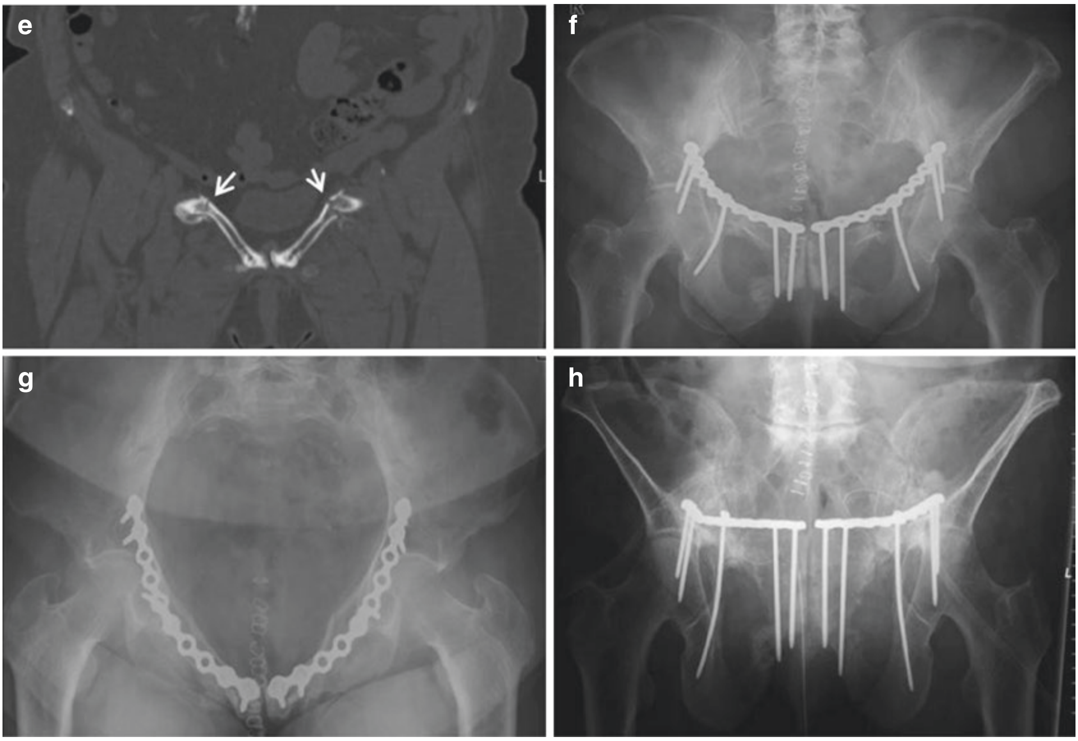

Fig. 23.2 (continued)

23.2 Operative Treatment

23.2.1 Indications and Techniques of Operative Treatment

Management goals of FFP include pain control, early mobilization, and initiation of osteoporosis treatment, fracture union and personal independence. These goals should be implemented with both non-operative and operatively treated patients. A separate classification has been developed, taking into consideration fracture morphology as well as stability in order to guide treatment [15].

Type I injuries include anterior pelvic ring fractures only. The majority of these fractures can be treated non-operatively. Type II injuries are non-displaced posterior ring injuries. Type II injuries include isolated posterior ring injuries, posterior crush injury combined with anterior pelvic ring disruption, and complete posterior ring fracture with anterior pelvic ring disruption. Non-operative treatment is the preferred management for FFP Type I and Type II, which are frequently the result of a fall from standing height or while walking or transferring [16]. The fracture patterns, typically observed, are stable disruptions of the pelvic ring. Physical and psychologic dysfunction can occur with immobility; therefore early mobilization is the cornerstone of non-operative treatment. A brief period of rest, analgesia, and physical and occupational therapy are employed. Weight bearing is permitted to the degree of pain tolerance and follow-up radiographs are performed at routine intervals (2 weeks, 6 weeks, 3 months, 6 months, and 1 year) to evaluate for displacement and fracture healing.

Type III injuries represent unilateral displaced posterior ring injuries with an associated anterior ring injury. Type IV injuries are bilateral displaced posterior ring injuries, among them displaced “H” or “U” type sacral fractures. Both type III and IV injuries are managed operatively. However, there is a lack of good evidence to guide the type of surgical treatment. Sacroplasty or closed versus open reduction techniques can be carried out. Sacroplasty with the use of polymethylmethacrylate (PMMA) has been described in several series with small cohorts and limited follow-up [17–19]. While the thought is that PMMA may provide pain relief from mechanical stabilization, this has not yet been proven. In addition, extravasation into the pre-sacral space, spinal canal, sacral foramen, or SI joints can result in nerve root compression or SI joint dysfunction. Closed versus open reduction with screw fixation or tension band plating can be undertaken to stabilize the posterior pelvic ring. Sacroiliac screw fixation can be performed with the patient in either the supine or prone position. Large fragment (7.3 or 8.0 mm) screws are inserted percutaneously into the body of S1 and S2, or can be inserted transsacrally, across the S1 and/or S2 body and anchoring into the contralateral outer ilium (Fig. 23.3). Tension band plating requires a limited open approach overlying each posterior sacroiliac joint to anchor the fixation. In the elderly patient population, an “alar void” indicative of osteoporosis is often noted and may result in a higher risk of screw loosening or failure due to lower pullout strength [15]. Fixation can be augmented with metallic washers, bone washers fashioned from femoral strut graft, or cement. Limited experience and evidence exists with these techniques. A transsacral bar can also be used through the body of S1 or S2 secured with washers and nuts on each side of the ilium. This provides the advantage of percutaneous insertion, compression perpendicular to the plane of the sacral fracture, and the support of the dorsal ilium as opposed to the vacuous sacrum to anchor fixation. Mehling et al. published a small series utilizing this technique and no loosening or pullout was noted [20]. The anterior pelvic ring can be treated without additional fixation, or with percutaneous or open reduction techniques. External fixation should be avoided in the elderly population. External fixation carries the risk of loosening, pin tract infection, and patient discomfort or intolerance. In patients with gross instability, spinal-pelvic dissociation, or lack of safe transsacral corridor, iliolumbar fixation should be considered. This involves pedicle screw placement into L4 and L5 and screw fixation into the ilium. Indication for surgical treatment using these techniques is based on evaluation of the fracture pattern using radiographs and CT, and implementation requires careful preoperative planning.

23.2.2 Soft Tissue Management

Prevention of infection and wound complications is paramount. All patients should receive a first generation cephalosporin or vancomycin if allergic to penicillin or known to be colonized with Methicillin Resistant Staphylococcus aureus (MRSA) within 1 h before the surgical incision. Prophylactic antibiotics should be discontinued 24 h following the surgical procedure. Careful adherence to sterile technique and soft tissue handling are also important to minimize complications. Posterior pelvic

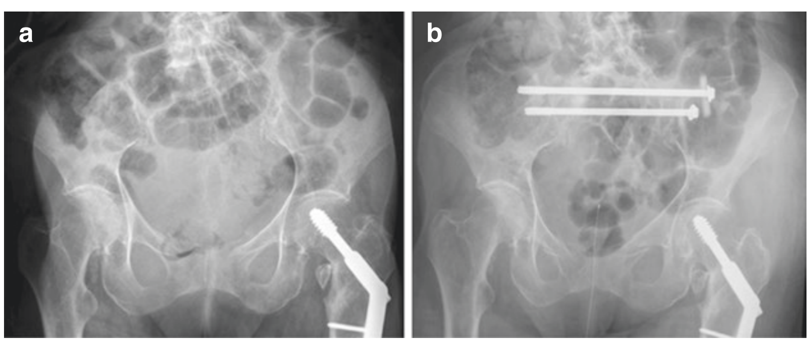

Fig. 23.3 (**a**) A.p. pelvic overview taken from a patient with bilateral superior pubic rami fractures and a fracture of the sacrum. (**b**) The fracture of the sacrum was fixed with two long iliosacral screws inserted through S1 and S2

ring fixation can often be performed using percutaneous techniques; therefore wound management is of less concern. If open approaches are undertaken posteriorly over the spine or sacroiliac joints, then frequent turning and change of position should be performed postoperatively to alleviate pressure on the surgical wounds and prevent breakdown and decubitus ulcers. Postoperative infections should be recognized early and treated appropriately with antibiotics and irrigation and debridement, if indicated.

23.2.3 Rehabilitation After Surgery

Physical and occupational therapy are important parts of the aftercare of FFP. Mobilization is adapted to the pre-injury functional status of the patient. Especially in osteoporotic fractures, a too aggressive aftercare may lead to implant loosening, delayed union, and non-union. Typically, patients are permitted short transfers, sitting in a chair or wheelchair, and limited weight bearing until signs of healing are noted on follow-up radiographs. After 6 weeks' time, fracture callus is recognized at the anterior pelvic ring fractures and weight bearing is progressed to patient's pain tolerance. Involvement of both physical and occupational therapy for non-operative or operatively treated fractures is important to support patients in regaining mobility, ability to perform activities of daily living, and return to some level of independence.

23.2.4 Anticoagulation

Patients with fractures of the hip and pelvis are at high risk of having peri-operative thromboembolic events. As a result, it is standard practice to provide prophylaxis. Currently, there is not a universal standard and the debate is ongoing as to the best method of prophylaxis. Typically, mechanical and pharmacologic agents are combined. The use of compression stocking, sequential compression devices, and early mobilization make up the mechanical limb of prophylaxis. Multiple pharmacologic agents can be used including unfractionated heparin, low molecular weight heparin, warfarin, and factor Xa inhibitors. In selecting an agent, consideration should be given to risk of ongoing bleeding, the need to rapidly reverse the effects of the agent, and the risk of fall and further injury. While a consensus has not been reached as to a preferred agent, the duration of treatment is accepted at 28–35 days post injury. All patients should receive prophylaxis unless a strong contraindication exists.

23.2.5 Healing Time and Outcome

Fracture healing and recovery range from 6 to 15 months across multiple reports. Early healing with callus is typically noted at 6 weeks post-injury. Healing is determined both by evidence of fracture callus on radiographs as well as by patient's mobilization with full weight bearing with no or minimal pain. Consolidation and complete healing usually occurs by 3–4 months. While we are unable to fast forward time, recent evidence suggests the use of bisphosphonates and recombinant PTH can increase bone mineral density, reduce fracture risk and accelerate fracture healing. A randomized controlled trial by Peichl et al. compared PTH 1–84 with placebo in a cohort of patients with FFP and found a statistically significant improvement in the time to fracture healing (7.8 vs. 12.6 weeks) [21]. Non-union of pelvic insufficiency fractures is rare with most fractures uniting after a few months of non-operative treatment. However, a small number may be slow or fail to unite and result in pain and/or instability. Mears et al. treated pelvic non-unions due to insufficiency fracture or pathologic fracture with in situ fixation and found within 6 months of surgery healing in 82% of patients [22]. In addition, a decrease in pain and instability and improved walking ability was noted. Despite high union rates with or without surgical intervention, patients with fragility fractures of the pelvis may experience persistent pain and disability.

FFP carry high morbidity and mortality rates, similar to those of hip fracture patients. In a series reported by Hill et al. of 286 patients with pubic rami fractures, nearly half of the patients (48.9%) were either using walking aids or were wheelchair bound or non-ambulatory at final follow up [23]. A separate series of patients over age 65, published by Morris et al. found that, at the time of hospital discharge, all patients required walking aids and more than half required physical assistance [16]. Decline in functional status and autonomy is commonly noted following FFP. Limited data exists on surgically treated patients and outcomes do not seem to differ from those of non-surgically treated patients. Further research should focus on non-operative versus operative management and methods to improve outcomes of these injuries.

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Part IX

Outcome

24 Outcome

Georg Osterhoff and Kelly A. Lefaivre

24.1 Outcome Measurement

The goals of medical care can be summarized as simply to increase health and well-being and to prevent death or disability [1]. When measuring outcome, we need to look for tools that allow for assessment of these goals. For pelvic fractures, there are no widely accepted, well tested outcome measures and different clinical and radiographic outcomes are used by different individual centers and groups [2]. Studies on the outcomes of pelvic fractures have often focused on radiographic measurements or simplified estimates of function [3], with other commonly chosen clinical outcomes being mortality, morbidity and pain [1].

The reporting of radiographic outcomes in these injuries has been done using largely unstandardized and universally untested measurement techniques. In a recent systematic review, only three of 31 articles reporting radiographic outcome after pelvic fractures described the way they had measured displacement in a standardized and reproducible manner [4]. The two grading systems that are most commonly used to interpret the extent of displacement after pelvic ring fixation, the systems established by Matta/Tornetta [5] and by Majeed [6], do both not delineate a reproducible method of how to take measurements from the pelvic radiograph. The interobserver reliability on common methods, including the grading system described by Matta and Tornetta [5], has shown to be poor [7]. Nonetheless, the authors of the articles included in the systematic review by Lefaivre et al. [4] reported good or excellent radiographic outcomes in 88.4% of their patients after internal fixation.

The modern standard for outcome measurement in medical research is the use of functional and patient-reported health outcome measures. Studies on pelvic fractures have either tried to adapt hip scores, such as the Harris Hip Score [8], or to establish pelvic specific scores, such as the Majeed Pelvic Score [9], the Orlando Pelvic Score [10], or the Iowa Pelvic Score [11]. These outcome instruments achieve a high degree of construct validity based on their correlation with previously established scoring systems that measure general physical health (i.e. physical component of the Short Form-36 [12], the Short Musculoskeletal Functional Assessment [13]). However, their validity (extent to which an instrument measures what it is supposed to measure), reliability (ability of an instrument to measure the same thing twice) and responsiveness (ability of the instrument to change as the status of the patient changes) have not been clearly demonstrated [14].

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_24

Most individuals who have sustained a pelvic injury weight mental and emotional aspects of their health at least as important as their pure bodily function [15]. None of the common pelvic outcome questionnaires are able to depict these characteristics sufficiently. In addition, all mentioned pelvic specific scores show relevant ceiling effects [15], which calls into question their responsiveness and were mainly designed for the evaluation of patients with unstable high-energy pelvic injuries. Thus, even the pelvic specific scoring systems so far only have descriptive value, their ability to compare the efficacy of different treatments of pelvic fractures still has to be proven.

As has been discussed extensively in the previous chapters, fragility fractures of the pelvis are a unique entity. The mechanism of trauma, the clinical picture and the goals of treatment in patients with fragility fractures of the pelvis are very different from those observed in young individuals with a higher level of activity, stronger bone and less comorbidities [16, 17]. Fragility fractures of the pelvis are usually isolated injuries as a result of a minor trauma [18], while prognosis and outcome in younger patients with pelvic fractures—usually after a high-energy trauma—are mainly determined by the frequently present concomitant injuries [16, 18, 19]. More than 80% of the patients with fragility fractures of the pelvis have at least two systemic diseases in their past medical history [18]. Pre-existing disability, gait abnormalities and impaired bone quality are common in this population and can be risk factors for future fractures and thus influence the outcome [20–22]. In contrast to younger patients, patients with fragility fractures of the pelvis need to be mobilized as early as possible to avoid the characteristic complications of the immobilized elderly. Due to the impaired ability of this population to comply with weight bearing recommendations [23], any treatment has to aim for immediate full-weight bearing. As mentioned in previous chapters, the standard systems for classification (Tile, OTA/AO, Young & Burgess, Denis) that have been used in most of the outcome studies on pelvic fractures were mainly customized for high energy osteo-ligamenteous injuries of the pelvic ring [24–26]. Their purpose is to predict instability, need for transfusion and the presence of concomitant injuries. This does not resemble the injury pattern found in pelvic fragility fractures after a low-energy trauma, where instability has to be defined differently [27, 28]. Hence, the current literature on outcome after pelvic injuries, especially after surgical treatment, not only has significant limitations, but is difficult to apply to fragility fractures of the pelvis.

Some studies on elderly patients with pelvis or hip fractures have tried to focus on mortality as a very basic outcome [29–31]. However, in view of the demographic changes in developed countries during the last decades with increasing life expectancies, a good functional outcome and quality of life has become a legitimate demand in elderly individuals who survive a pelvic fracture and its sequelae. Similar to the evolution of treatment assessment and expectation after hip fracture, mortality can no longer be regarded as an isolated measure when testing the efficacy of a treatment.

When reviewing the outcome after pelvic fragility fractures we have to realize that our knowledge on functional and general health outcome in these patients is strongly limited by the absence of instruments that allow for a comprehensive assessment of the relevant factors.

24.2 Outcome

24.2.1 Mortality

Low-energy fractures of the pelvis, especially in the elderly, are rarely associated with a relevant or life-threatening loss of blood [19, 32]. It is the combination of pain, immobilization and its sequelae and a loss of independency associated with pelvic ring fractures in the elderly that has led to increased mortality rates in these patients. When compared to other individuals of same age and gender without a fracture, most deaths occur within the first 3 months [29, 33]. Rapp et al. [33] conducted a retrospective cohort study where they compared 1154 individuals with fragility fractures of the pelvis to a matched non-fracture cohort of 5770. For those with a fracture, the hazard risk ratio for death was 1.83 in females and 2.95 in males for the first month and 1.52 in females and 2.22 in males for the second months. In-patient mortality rates reported for non-operative treatment range from 7.0 to 10.4% [34, 35]. Marrinan et al. found a 3-month mortality rate of 13% [36].

One-year mortality rates in the same patients range from 13.3 to 27% [29–31, 34, 36–39]. In their population of patients with pelvic fragility fractures, Mears and Berry found mortality rates of 7% at 30 days, 23% at 1 year and 47% at 2 years [37]. In a very similar cohort, Hill et al. observed a mortality of 13.3% at 1 year and of 45.6% at 5 years [29]. They also showed that a history of dementia increased the mortality rate.

In their retrospective matched case-control study overlooking a follow-up of 10 years with 99 patients that were treated non-operatively for an "isolated single fracture of the pubic ramus", van Dijk et al. found mortality rates of 24.7%, 64.4%, and 93.8 at 1, 5 and 10 years [30]. One-third of the mortality in this study was due to cardiovascular events [30].

There are only two retrospective cohort studies that give information on mortality rates after operative and non-operative treatment in elderly patients with fractures of the pelvis. Lau et al. [40] included 37 patients with fragility fractures of the pelvis and reported a 1-year mortality of 14% (1/7 patients) for operative and 26.7% (8/30) for non-operative management; however, their sample sizes were too small to be significant. Dechert et al. [41] reviewed 157 pelvic fractures after blunt trauma in patients 65 years or older, 137 of them being treated non-operatively. They reported in-patient mortality rates of 22.3% (31/139) and 5.5% (1/18) in the non-operative versus operative group. However, the investigated cohort was identified from a database of trauma team activations with a motor vehicle accident being the mechanism of trauma in 71% and a mean Injury Severity Score (ISS) of 21 [41]. Thus, this study population might not represent the typical patient with a pelvic fragility fracture. Further, there is likely a significant selection bias towards more robust patients being selected for surgical treatment.

All other case series on operative treatment of fragility fractures of the pelvis known to the authors do not report mortalities rates as an outcome [42–48].

24.2.2 Length of Hospital Stay

With non-operative treatment of pelvic fragility fractures, mean hospitalization durations between 21 and 60 days have been reported [30, 31, 34–36, 38, 39, 49, 50]. Prolonged length of hospital stay is associated with age and acute medical problems on admission [36]. The few studies on operative treatment reporting this outcome show a tendency towards shorter hospital stays from 5 to 24 days [44, 46].

Comparison of operative versus non-operative management remains difficult, though. Often, operative treatment is being used in patients that do not respond well to a certain period of non-operative treatment [43, 45, 46, 48]. Hopf et al. [46], for example, report a mean hospital stay of 24 days but had only operated on them after 9 days of conservative treatment. In addition, most patients in these studies are transferred to nursing homes or other sites of institutional long-term care. The duration of the acute care hospitalization could, therefore, have been influenced by regional differences in long-term care placement. This might add to the fact that the length of stay is longer for patients with limited independency prior to the hospitalization [31].

24.2.3 Medical Complications

In contrast to younger patients and as mentioned before, mortality in patients with fragility fractures of the pelvis is driven by the consequences of long-lasting immobilization. Thus, a large part of deaths occurs during hospitalization and within the first 3 months [29, 33]. Even with non-operative treatment, in-hospital complication rates between 20 and 40% can be expected [30, 31, 34, 36, 38, 39]. This includes urinary tract infections, pneumonia, thrombo-embolic and cardiovascular events, pressure ulcers, and side effects of the analgesic medication.

The only study on operative treatment of pelvic fragility fractures reporting non-surgery related complications observed medical complications in 13.3% (4/30) of their cohort—with an incidence of pneumonia and urinary tract infections of 6.7% (2/30) each [46].

Again, the availability of rehabilitation units and regional differences in long-term care placement might have affected the duration of stay and, thus, in-patient complication rates in the different studies.

24.2.4 Surgical Complications

While, based on the current literature, it remains unclear whether surgical treatment of pelvic fragility fractures can help to avoid medical complications that result from pain and immobilization, surgery clearly adds its perioperative risks.

Intraoperative bleeding or a postoperative gluteal hematoma, most likely from branches of the superior gluteal artery, was seen in 0 to 10% after posterior screw fixation [43, 46, 47] and in 10.5% after transsacral bar fixation [44]. No such bleeding was reported with sacroplasty [42].

Implant malposition requiring revision surgery was documented in 1/30 (3.3%) [46] of the cases with posterior fixation. In patients who underwent sacroplasty alone, cement leakage requiring reoperation for S1 radicular pain was seen in 1/52 (2.0%) [48] and 1/204 (0.5%) [42]. No symptomatic cement leakage was observed when posterior screw fixation was combined with cement augmentation in a small case series of 12 patients [43]. Mehling et al. described one intraoperative superficial lesion of the urinary bladder with anterior plating in their series of 11 patients [45].

Screw loosening was reported by Reuther et al. in 12/85 (14.1%) screws, requiring revision surgery in 8/69 (11.6%) patients [47]. Kortman et al. describe a case (1/204, 0.5%) of early fracture dislocation through the sacroplasty site [42]. Late contralateral fractures of the sacrum were seen in 1.5–8.3% [42, 47].

Therefore, perioperative complication rates reported by studies on fragility fractures do not differ substantially from complication rates known for minimal-invasive fixation procedures for the stabilization of pelvic injuries in younger patients [51–53]. In line with this, increased age was not found to be a risk factor for more perioperative complications with sacroiliac screw fixation [54]. However, loss of reduction in a series of percutaneously stabilized pubic ramus fractures was more common in the elderly and female patients, most likely linked to osteoporotic bone [55].

24.2.5 Pain

Most of the studies that investigate non-operatively managed cohorts focus on mortality, morbidity and complications [29–31, 33, 36, 39]. Pain is usually only depicted indirectly as a cause for immobilization and independency. There is one randomized controlled trial that observed a significant improvement of pain with the administration of parathyroid hormone 1–84 in patients treated non-operatively [56].

A systematic review on the treatment of unstable pelvic ring fractures in patients of all age groups could show that the capacity of walking was significantly better in patients treated operatively compared to the non-operative group, and that surgical treatment improves pain better than non-operative treatment [57]. However, controlled studies on pain reduction in fragility fractures of the pelvis are missing.

There are only three small retrospective studies reporting pain reduction after minimal-invasive internal fixation of fragility fractures [43, 44, 46]. In a series of 12 patients treated with sacroiliac screw fixation, Wähnert et al. [43] found a pain reduction from preoperatively 8.2 to postoperatively 2.6 on the Visual Analogue Scale (VAS [58]). Hopf et al. (n = 30) report a decrease of pain from a preoperative score of 6.0 on a numeric rating scale (NRS) to 1.8 at the time of discharge [46]. They were able to include 22/30 patients into a telephone follow-up (mean 31 months), where 16/22 (73%) patients stated to have “no relevant back pain”. Vanderschot et al. [44] observed pain improvement from VAS 6.8 before transsacral bar fixation to 2.3 at a mean follow up of 9 months.

Similar short-term pain improvement from VAS 8–9 to VAS 2–3 was seen in two large multicenter cohort studies including patients with pelvic fragility fractures that were treated with sacroplasty [42, 48]. Long-term results were presented only by Frey et al. [48] with a mean VAS of 0.8 at 1 year from 8.2 before the intervention.

Again, in most of the studies, the decision for surgery was made after conservative treatment failed or did not result in noticeable pain reduction after some days or weeks. Even though none of the studies included a non-operative control group, this might suggest that operative treatment can achieve better immediate improvement of pain.

24.2.6 Mobility and Independence

If we postulate that mortality and morbidity in patients with fragility fractures of the pelvis both are driven by the lack of mobility and independence, it becomes clear that one of the major goals in their treatment is to restore self-sufficiency and the ability to walk.

At the time they sustained their pelvic fragility fracture, about 90% of the patients had been living at home [35, 36]. With non-operative treatment, this figure drops to a range of 46–64% with about 25–33% being institutionalized at the time of discharge [30, 31, 36]. About 80% of those that are able to return to their previous living situation require support of social services [34]. Excluding those already living in a nursing home, Morris et al. [34] reported a drop in the level of independency in 80% of the patients at a follow up of 52 months (>4 years), resulting in 42% of them requiring residential or nursing home care and 29% being institutionalized. Only about 10% of the patients who have sustained a pelvic fragility fracture are fully independent when they leave the hospital [35]. The odds of changing from independent to institutionalized accommodation are associated with age and length of hospital stay [36].

When managed non-operatively, patients usually are not able to walk independently at the time of discharge and about half of them require the use of an aid, the other half physical assistance [34]. At 5 years after the fracture only half of the patients are independently mobile, while about 40% are using walking aids and about 10% depend on a wheelchair or are bed ridden [29].

Hopf et al. report that 22/30 (73%) patients treated with sacroiliac screw fixation were fully mobile at the time of discharge, the rest was mobile on crutches or a walker [46]. At follow up (mean 31 months), 16/22 (73%) patients stated to have “no or minor restrictions of their usual mobility”. In the series published by Wähnert et al., all patients could be mobilized “to their preoperative status without pain at the fracture site” during hospitalization [43]. Vanderschot et al. found 9/19 (47%) patients to depend on a crutch or walker and 2/19 (11%) patients were only mobile with assistance of a caregiver [44].

There is no data available with regard to the long-term effect of sacroplasty on mobility and independency [42, 48].

Directly comparing non-operative versus operative management, Lau et al. [40] observed a fracture-related deterioration of the walking ability in 80% of the whole cohort. In the non-operative group, the walking status changed from 16/30 (53%) on crutches or a walker, 3/30 (10%) in a wheelchair, and 11/30 (37%) unaided to 16/21 (76%) crutches/walker, 5/21 (24%) wheelchair, and 1/21 (5%) unaided (8 died). In the surgical group, it changed from 4/7 (57%) on crutches/walker and 3/7 (43%) unaided to 6/6 on crutches or a walker (one died). Again, the small sample size did not allow for the detection of statistically significant differences.

24.2.7 Functional Outcome

The only two studies on the treatment of pelvic fragility fractures that used a standardized instrument for functional outcome were those by Peichl et al. [59] and Mehling et al. [45]. Peichl et al. could show that the “Timed Up and Go” test [56] improved in elderly osteoporotic women who had sustained a pubic ramus fracture after regular administration of PTH 1–84 [59].

Mehling et al. observed an excellent outcome in 2/11 (18%) cases, good outcome in 5/11 (45%) cases and fair outcome in 4/11 (36%) cases after

Table 24.1 Assessment of bony union

Study	Treatment	N	N at F/U	F/U [months]	Union rate (%)	Definition union	Radiograph/CT
Peichl [59]	Non-operative	65	65	3.5	100/ 68	"Cortical bridging"	CT
Vanderschot [44]	Transsacral bar	19	7	3	100	?	CT
Mehling [45]	Transsacral bar	11	11	14	100	?	CT
Reuther [47]	Sacroiliac screws	135	135	? (3–38)	81	?	Radiograph 99 CT 46

F/U follow up, *CT* computer tomography

transsacral bar fixation of these injuries [45] according to the pelvic outcome score of the German Multicentre Pelvis Study Group [60].

24.2.8 Bony Union

The only radiographic outcome assessed in some of the studies on fragility fractures of the pelvis is bony union. A recently published randomized controlled trial observed a significant acceleration of bone healing by almost 5 weeks after administration of PTH 1–84 [59]. Fracture healing was "defined as cortical bridging" and assessed by two of the authors on sequential CT scans. The union rates at 12 weeks follow up were 100% for the PTH 1–84 group and 68% for the control group.

Union rates for operative fixation of pelvic fragility fractures by sacroiliac screws or a transsacral bar were stated to range from 81 to 100% [44, 45, 47]. However, the follow up intervals were up to several years in some of these studies, the definition and assessment of "union" was in some cases difficult to reproduce, and sample sizes were either small or drop-out rates high. Some studies used CT, some plain radiographs and some both for the radiographic follow up, and the definition of 'union' has varied widely (Table 24.1).

24.3 Recommendations and Level of Evidence

Modern medical decision-making is driven by evidence based medicine, and an ever improving quality of research [61]. As is the case in many areas of orthopaedic research, the level of evidence in the area of pelvic fracture management in general has been low [4, 7, 15]. Using the standard assessment of research quality, the body of literature in this area is dominated by case series and poor quality case controlled studies, or level 4 studies. As such, any recommendation based on these studies would be considered a Grade C recommendation (Table 24.2). Thus, although there have been reports of benefit to surgical management with regards to pain, mobility and length of hospital stay, strong treatment recommendations cannot be made based on the current body of literature.

Table 24.2 Recommendations and level of evidence

Level of evidence	Grading criteria	Grade of recommendation
Ia	Systematic review of RCTs including meta-analysis	A
Ib	Individual RCT with narrow confidence interval	A
Ic	All and none studies	B
IIa	Systematic review of cohort studies	B
IIb	Individual cohort study and low quality RCT	B
IIc	Outcome research study	C
IIIa	Systematic review of case-control studies	C
IIIb	Individual case-control study	C
IV	Case series and poor quality cohort and case-control studies	C
V	Expert opinion	D

Based on the method described by Guyatt et al. [61]. *RCT* randomized controlled trials

Conclusion

Our knowledge on functional and general health outcome in patients with fragility fractures of the pelvis is limited by the absence of instruments that allow for a reliable and comprehensive assessment of all relevant factors. The injury itself and the goals of treatment in patients with fragility fractures of the pelvis differ distinctively from the pelvic injuries that have commonly been described and investigated and, thus, comparison of results of new treatments and their outcome with the current literature has to be done very carefully.

Historically, surgery has been advocated in unstable pelvic ring injuries throughout all age groups. However, stability and pain are inherently linked and early mortality seems to occur during the initial period of painful immobilization. As far as conclusions can be drawn on basis of the small case series with surgically treated pelvic fragility fractures, in the short term, patients who fail conservative treatment appear to benefit from minimal-invasive operative stabilization with regard to pain, mobility, and the length of hospital stay. Fracture related morbidity and mortality in the elderly is multifactorial, though, and surgery is just one aspect of a comprehensive patient care.

Randomized controlled trials with standardized, validated and reliable instruments to assess outcomes that count are necessary in order to develop evidence-based protocols for the treatment of fragility fractures of the pelvis.

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Part X

Case Presentations

25 Case Presentations

Pol Maria Rommens and Alexander Hofmann

25.1 Introduction

The last chapter of this book presents 20 cases of patients with fragility fractures of the pelvis, which have been treated operatively. The pictures and legends are assembled to depict the chronology of the case starting with preoperative conventional pelvic views, CT-cuts through the anterior and posterior pelvic ring and 3D–reconstructions. With these pictures, the reader can follow the diagnostic work-up of the presenters. The significance of correct classification for a realistic estimation of the degree of instability and for decision making is underlined. Radiological diagnosis, patient's history and clinical picture lead to a treatment recommendation. Postoperative and follow-up figures show the treatment concept, which has been chosen for these patients. As the reader certainly will have realized, many alternatives for treatment are available. Clinical evidence today is not strong enough to recommend each of these treatment methods being the optimal solution for the specific pathology shown. The case presentations, therefore, are rather meant as an incentive for critical assessment and interaction with the chapter authors, the editors or within your own team. How would I classify this lesion? Would I also operate on this patient? Would I choose the same operative procedure? How do I estimate the advantages and limits of the chosen procedure, when I use it in my setting? What could be valid alternatives and why?

The spectrum of pathologies presented in this series impressively shows the importance of the subject "fragility fractures of the pelvis" as well as the multitude of clinical, biomechanical and surgical questions, which remain after reading the large experience of the chapter authors and editors. Case presentations with discussion are always well accepted in courses and conferences. We hope that the presented case series will booster a critical interaction with FFP patients in your practice and create the opportunity for the start of in-depth clinical research, together with further development of optimally adapted instruments, implants and surgical techniques for the surgical treatment of this specific and increasingly frequent pathology.

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6_25

Case 1 (Fig. 25.1)

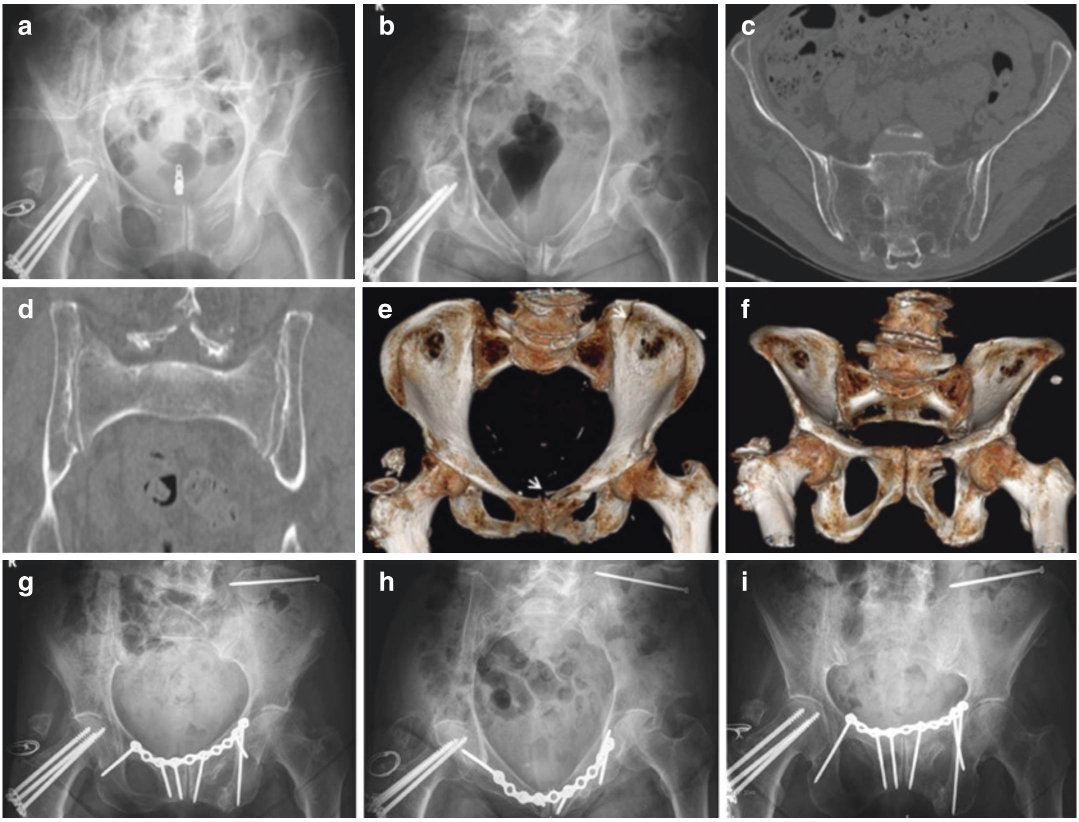

Fig. 25.1 An 89-year-old female fell from a small step and suffered a left-sided pubic ramus fracture. She was treated operatively for a femoral neck fracture and avulsion of the greater trochanter many years earlier. (**a**) The a.p. pelvic overview reveals a left-sided pubic rami fracture. (**b**) Pelvic inlet view. A fracture or displacement in the posterior pelvic ring cannot be detected in these pelvic overviews. (**c**, **d**) Transverse (**c**) and coronal (**d**) CT-cuts through the posterior pelvic ring do not show any fracture. (**e**, **f**) 3D–reconstructions of the pelvic ring. An incomplete fracture of the left posterior ilium and the left-sided pubic rami fractures (*white arrows* in figure **e**) are detected. It concerns a FFP Type Ia lesion. (**g**) The patient was treated conservatively for 2 weeks. Mobilization out of bed was not possible due to intense pain at the pubic symphysis. The decision for operative treatment was taken. The incomplete posterior ilium fracture was stabilized with a lag screw, placed parallel to the iliac crest and between the inner and outer cortex. The anterior pelvic ring fracture was stabilized with a bridging reconstruction plate. The infra-acetabular corridor was used for one screw on the right and for two screws on the left side. Also at the pubic symphysis, the screw length was as long as possible. A.p. pelvic overview one and a half year after surgery shows complete healing of the fractures. The patient was walking independently. (**h**) pelvic inlet view. (**i**) pelvic outlet view

Case 2 (Fig. 25.2)

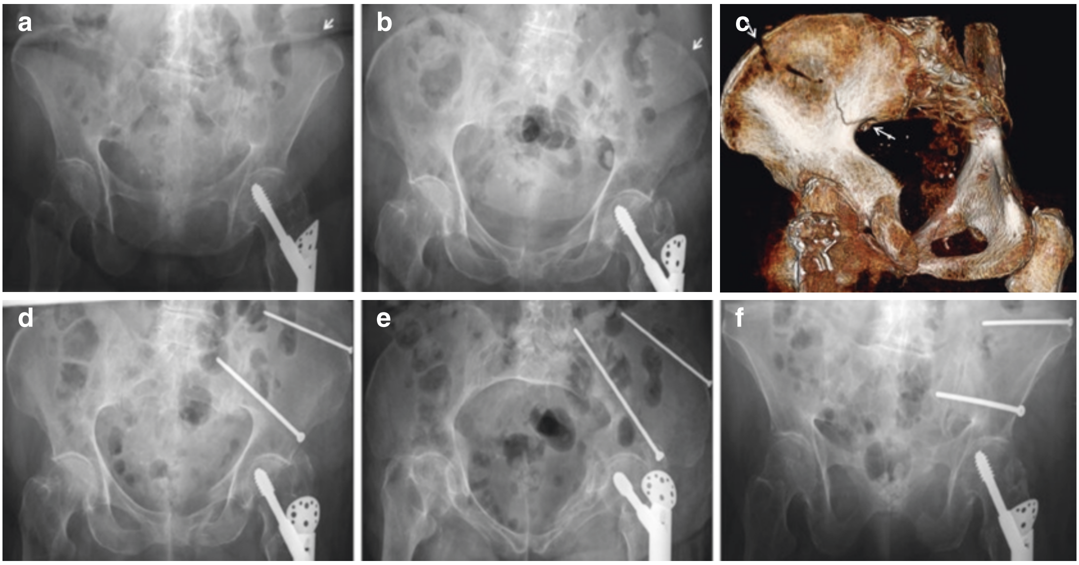

Fig. 25.2 An 88-year-old female was admitted after a fall in her nursing home. She already had been treated for a pertrochanteric fracture on the left with a dynamic hip screw and trochanteric buttress plate. (**a**) The a.p. pelvic overview reveals a left-sided pubic rami fracture. A small gap and fracture line are also visible at the left iliac crest and ilium (*white arrow*). (**b**) Pelvic inlet view. The left pubic rami fractures and the fracture of the ilium (*white arrow*) are visible. It is not clear if the ilium fracture is complete or incomplete. (**c**) 3D–reconstruction of the pelvic ring. View on the left posterior and lateral side. A complete ilium fracture, starting at the inner curvature and running to the iliac crest is now visible (*white arrows*). It concerns a FFP Type IIc lesion. (**d**) A minimal-invasive surgical procedure was chosen. The ilium fracture was reduced by closed manner and fixed with two long lag screws. The upper screw is a small fragment screw running parallel to the iliac crest and between the inner and outer cortex of the ilium. The lower screw is a large fragment screw running from the anterior inferior to the posterior inferior iliac spine. Due to compromised soft tissue conditions at the anterior pelvic ring (fungus infection), the surgeon refrained from surgical fixation of the pubic rami fractures. Patient mobilization was restricted for 6 weeks. (**e**) Pelvic inlet view. (**f**) Pelvic outlet view after 6 weeks

Case 3 (Fig. 25.3)

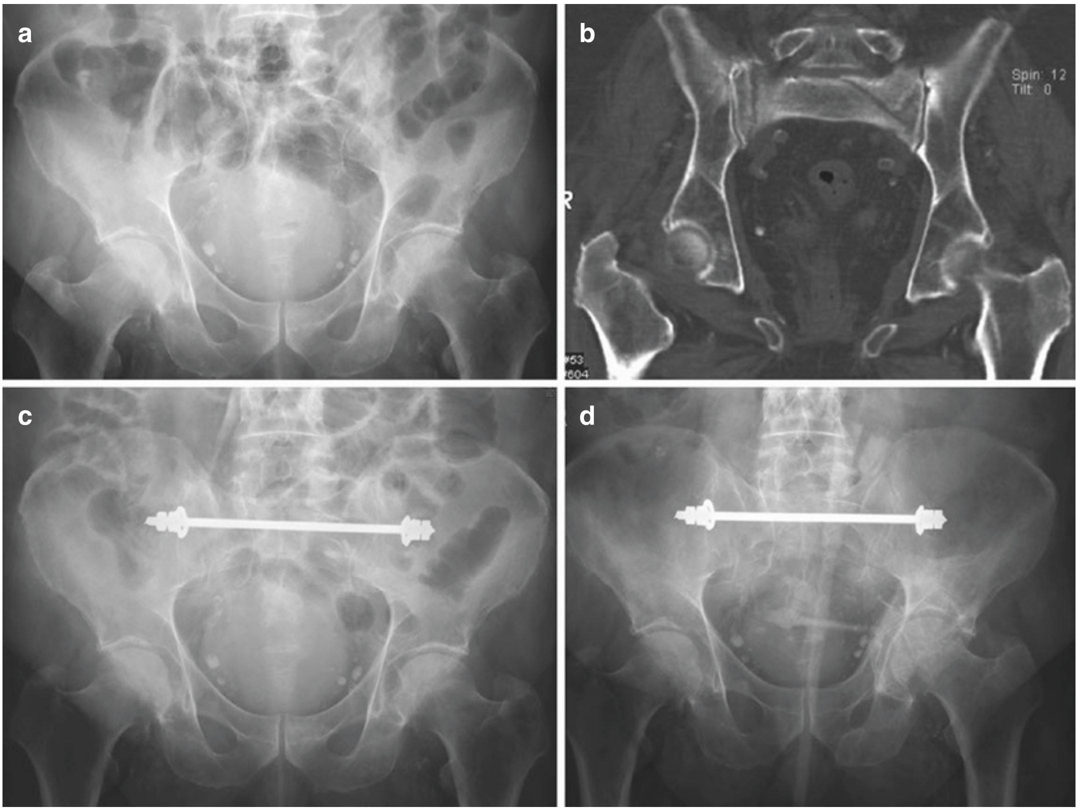

Fig. 25.3 An 86-year-old male with Alzheimer's disease suffered recurrent falls at home. No radiographs were taken until the patient was nearly completely immobilized due to lower back pain. (**a**) The a.p. pelvic overview does not reveal any fracture of the anterior pelvic ring. Due to bowel gases, the posterior pelvic ring cannot be assessed. (**b**) A coronal CT-cut through the posterior pelvic ring reveals a bilateral sacral fracture: a vertical sacral ala fracture near to the IS joint on the right and a more oblique fracture running from the sacral ala to the sacral body on the left. It concerns a FFP Type IIa lesion. (**c**) Postoperative a.p. pelvic overview. The sacral fractures were stabilized with a transsacral bar, going through S1. (**d**) A.p. pelvic overview 3 years later, when the patient was admitted with an acetabulum fracture on the left. The sacral fractures healed and the patient regained pain-free limited mobility

Case 4 (Fig. 25.4)

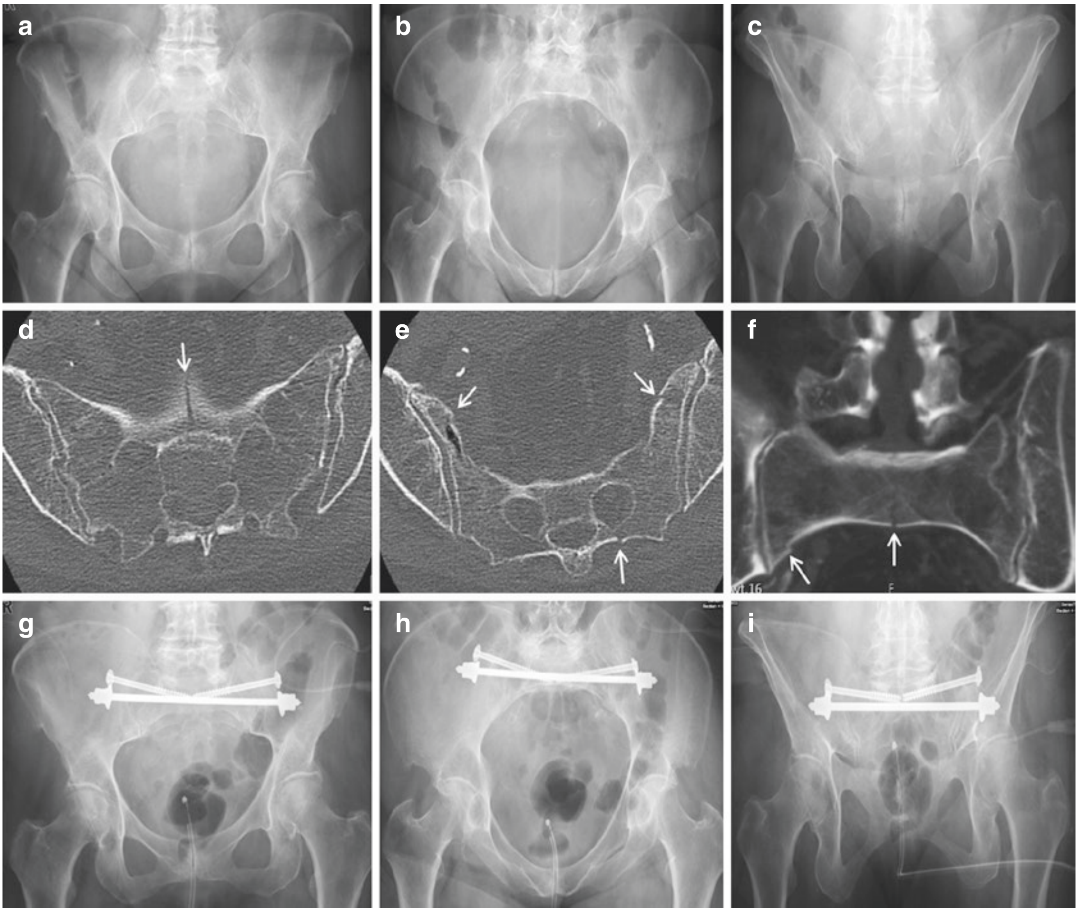

Fig. 25.4 Eighty-year-old female with history of severe lower back pain and decreasing mobility. (**a**) A.p. Pelvic overview (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. A fracture or dislocation in the anterior and posterior pelvic ring cannot be detected. (**d**, **e**, **f**) Transverse (**d** and **e**) and coronal CT-reconstructions through the posterior pelvic ring. There are several complete but non-displaced fractures going through the sacral body and through both sacral ala (*white arrows*). It concerns a FFP Type IIa lesion. (**g**) Postoperative a.p. pelvic overview. The sacral fractures were stabilized with a transsacral bar through S1. One IS screw was placed additionally in S1 on each side, with the goal of enhancing rotational stability. (**h**) Postoperative pelvic inlet view. (**i**) postoperative pelvic outlet view. Pain disappeared and patient regained mobility soon

Case 5 (Fig. 25.5)

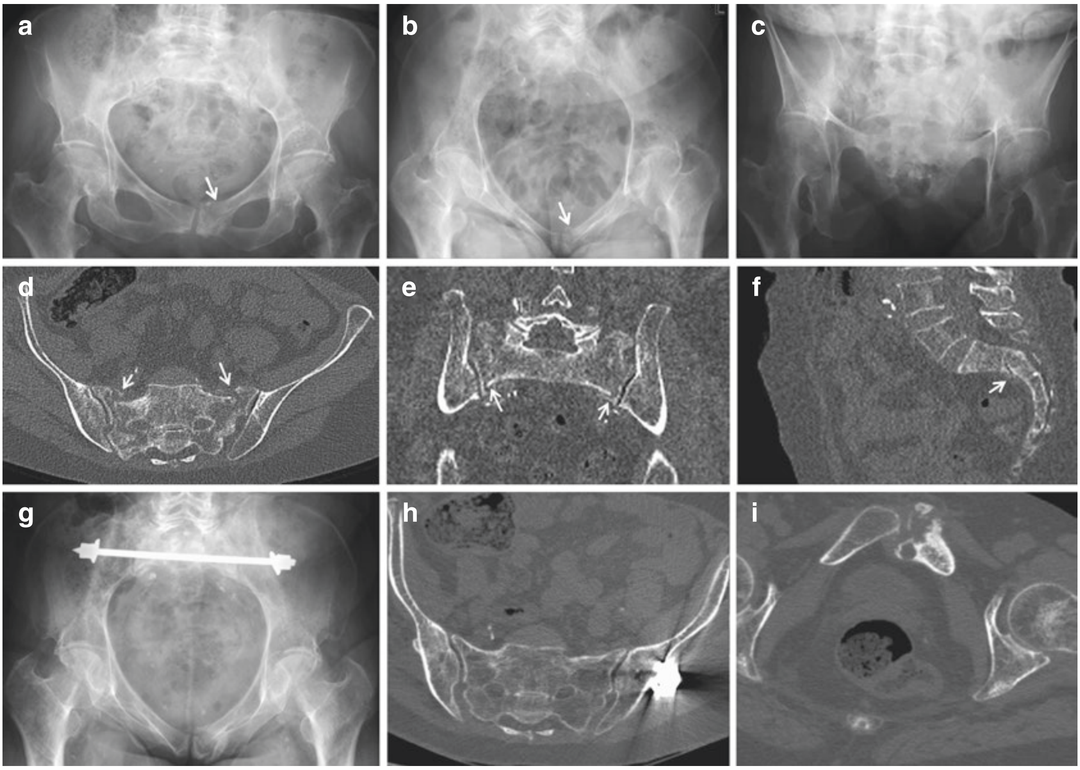

Fig. 25.5 Seventy-eight-year-old female suffers intense pain at the anterior and posterior pelvic ring after a fall and turned immobile. (**a**) The a.p. pelvic overview only reveals a non-displaced left pubic ramus fracture (*white arrow*). (**b**) The pelvic inlet view confirms the left pubic ramus fracture. (**c**) Pelvic outlet view. No fractures of the posterior pelvic ring can be detected. (**d**, **e**, **f**) Transverse (**d**), coronal (**e**) and sagittal (**f**) reconstructions reveal bilateral displaced sacral ala fractures and a horizontal fracture component between S1 and S2. It concerns a FFP Type IVb lesion. (**g**) Pelvic inlet view 1 year after surgery. The fractures of the posterior pelvic ring were stabilized with a transsacral bar through S1. In this view, the tight connection between the washers and nuts and the lateral cortex of the posterior ilium clearly can be seen. (**h**, **i**) Transverse CT cuts through the posterior (**h**) and anterior (**i**) pelvic ring. The sacral fractures healed completely, the anterior pubic fracture did not heal. Hypertrophic callus and a large non-united fracture gap are visible. The patient regained mobility, but still complains of pain at the pubic region

Case 6 (Fig. 25.6)

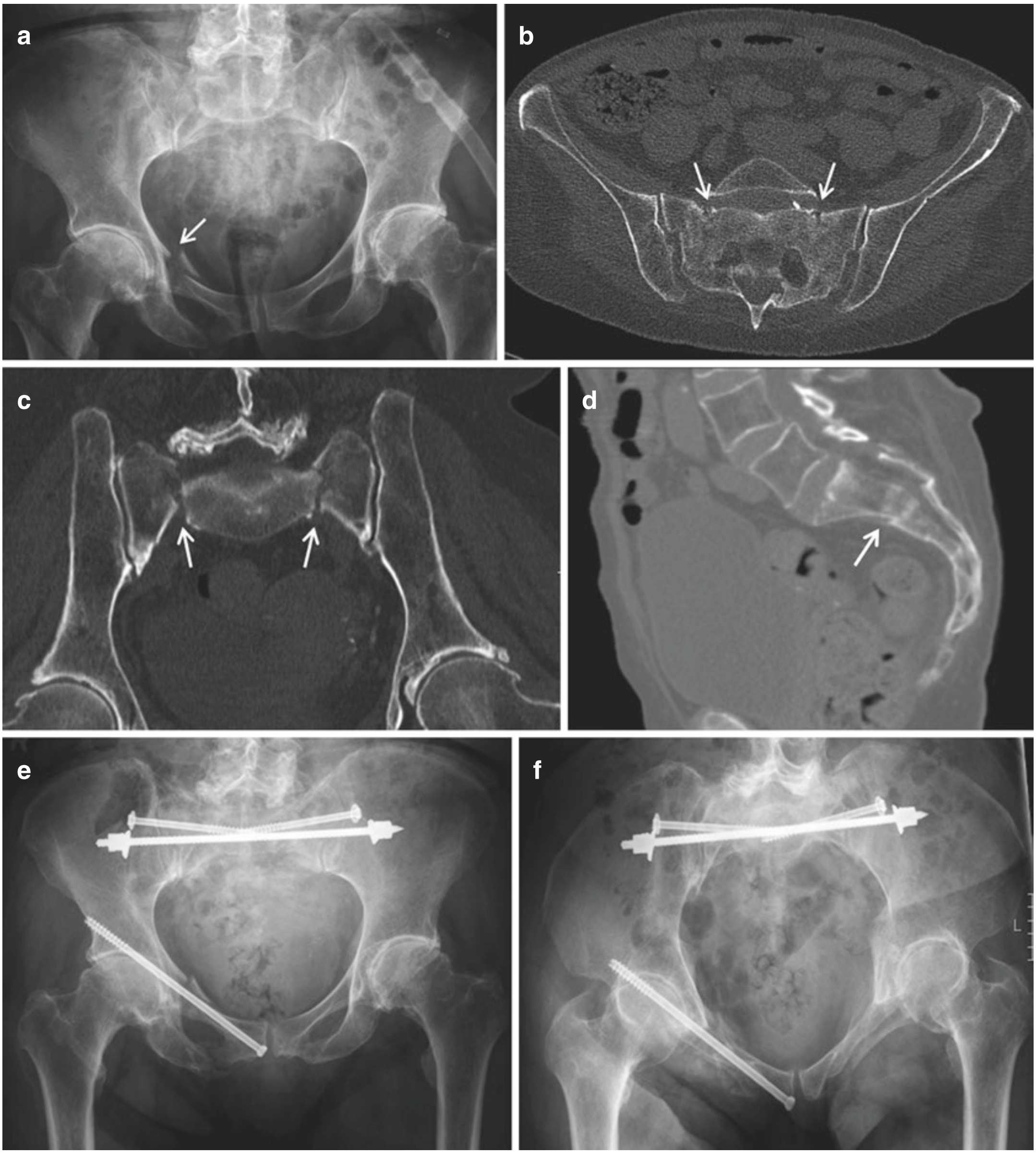

Fig. 25.6 A 75-year-old patient suffered from severe pelvic pain after a fall on the street. (**a**) The a.p. pelvic overview shows a right-sided superior pubic ramus fracture with a displaced wedge fragment (*white arrow*). (**b**, **c**, **d**) Transverse (**b**), coronal (**c**) and sagittal CT-cuts through the posterior pelvis. There are bilateral displaced sacral ala fractures and a horizontal fracture component between S1 and S2 (*white arrows*). It concerns a FFP Type IVb lesion. (**e**) Postoperative a.p. pelvic overview. The instabilities of the posterior pelvic ring were stabilized with a transsacral bar through S1. One IS screw was inserted on both sides additionally. The pubic ramus fracture was stabilized with a retrograde transpubic screw. (**f**) Pelvic inlet view 1 month after surgery. Bridging callus is visible at the right pubic ramus fracture. The patient is painlessly and partially regained mobility

Case 7 (Fig. 25.7)

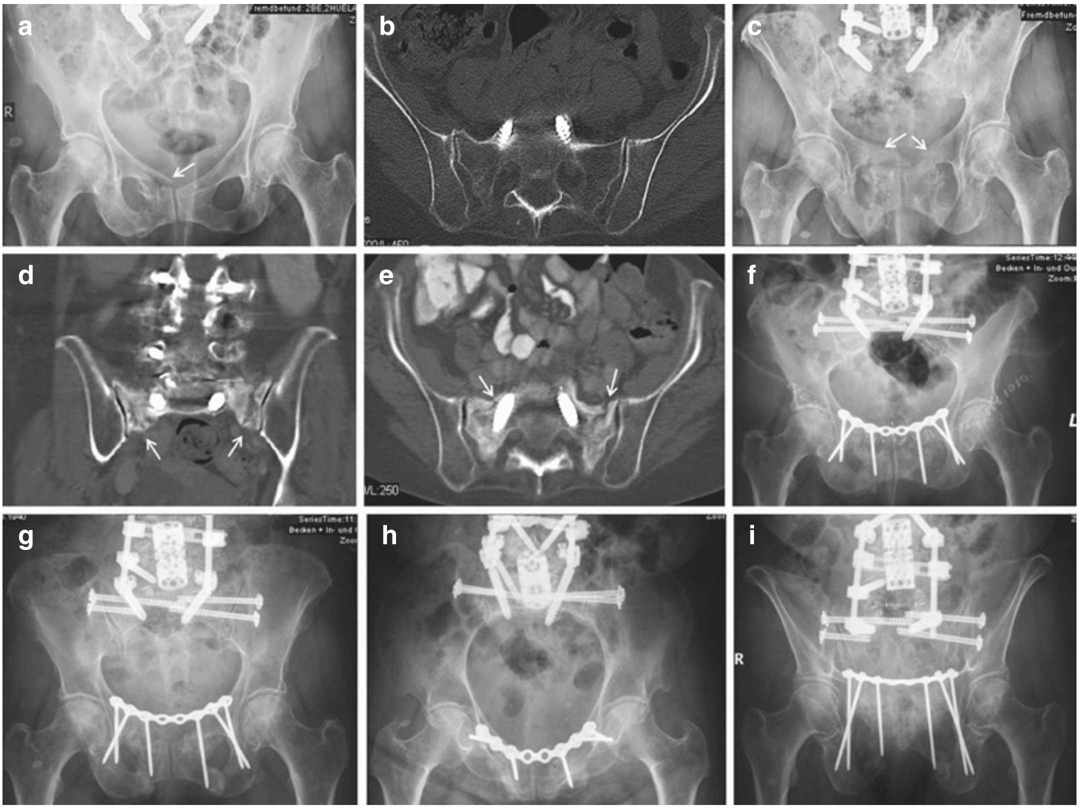

Fig. 25.7 A 72-year-old female was operated on the lumbar spine for immobilizing low back pain. She received a spinal fusion between L4 and S1 with vertebral body replacement of L5. During rehabilitation, she suffered a sideward fall. (**a**) A.p. pelvic overview revealed right-sided displaced pubic rami fractures (*white arrow*). (**b**) On the transverse CT-cut through the posterior pelvic ring, no sacral fracture was detected. Treatment was conservative. (**c**) The patient returned 6 weeks later with increasing and immobilizing pain in the whole pelvic ring. The a.p. pelvic overview shows bilateral displaced pubic rami fractures (*white arrows*). (**d**, **e**) Coronal (**d**) and transverse (**e**) CT-cuts through the sacrum show a bilateral sacral ala fracture (*white arrows*). (**f**) A.p. pelvic overview after operative stabilization. The sacral ala fractures were stabilized with two IS screws from each side in the S1 sacral body. The bilateral pubic rami fractures were stabilized with a bridging reconstruction plate and three long screws on each side. Two screws on each side use the infra-acetabular corridor; the third screw is inserted in the pubic bone. (**g**) A.p. pelvic overview 3 months after operative stabilization. (**h**) Pelvic inlet view showing the complete healing of the pubic rami fractures. (**i**) Pelvic outlet view

Case 8 (Fig. 25.8)

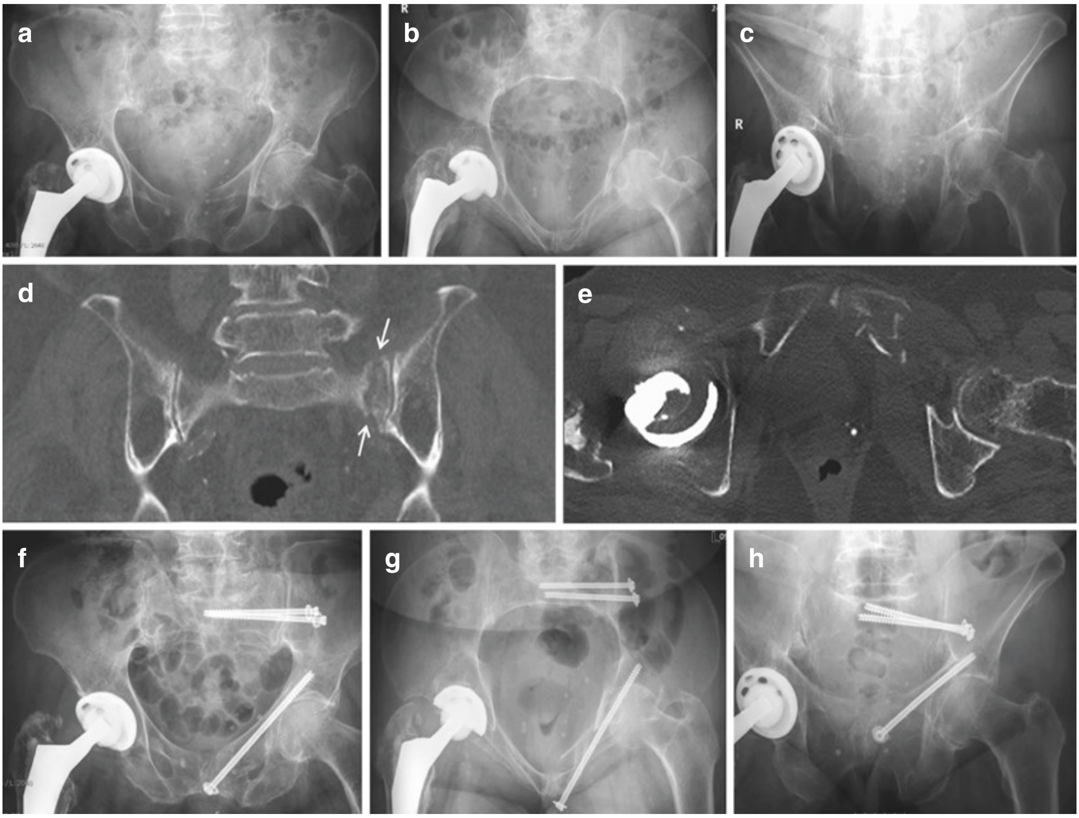

Fig. 25.8 Eighty-five-year old female with immobilizing pain after a fall at home. (**a**) A.p. pelvic overview showing a left-sided displaced pubis ramus fracture. (**b**) Pelvic inlet view. (**c**) Pelvic outlet view. (**d**) Coronal CT-cut through the sacrum shows a complete fracture of the left sacral ala. (**e**) Transverse CT-cut through the anterior pelvic ring shows the left-sided pubic fracture. It concerns a FFP IIc lesion. A conservative treatment was initiated, but due to intense pain, mobilization was not possible. (**f**) After 3 weeks, surgical fixation was performed. The sacral ala fracture was fixed with two iliosacral screws, the pubic ramus fracture with a retrograde transpubic screw. A.p. view of the pelvic ring after 2 years shows complete healing of the anterior and posterior pelvic ring. There is a slight loosening of all implants. (**g**) Pelvic inlet view. (**h**) Pelvic outlet view

Case 9 (Fig. 25.9)

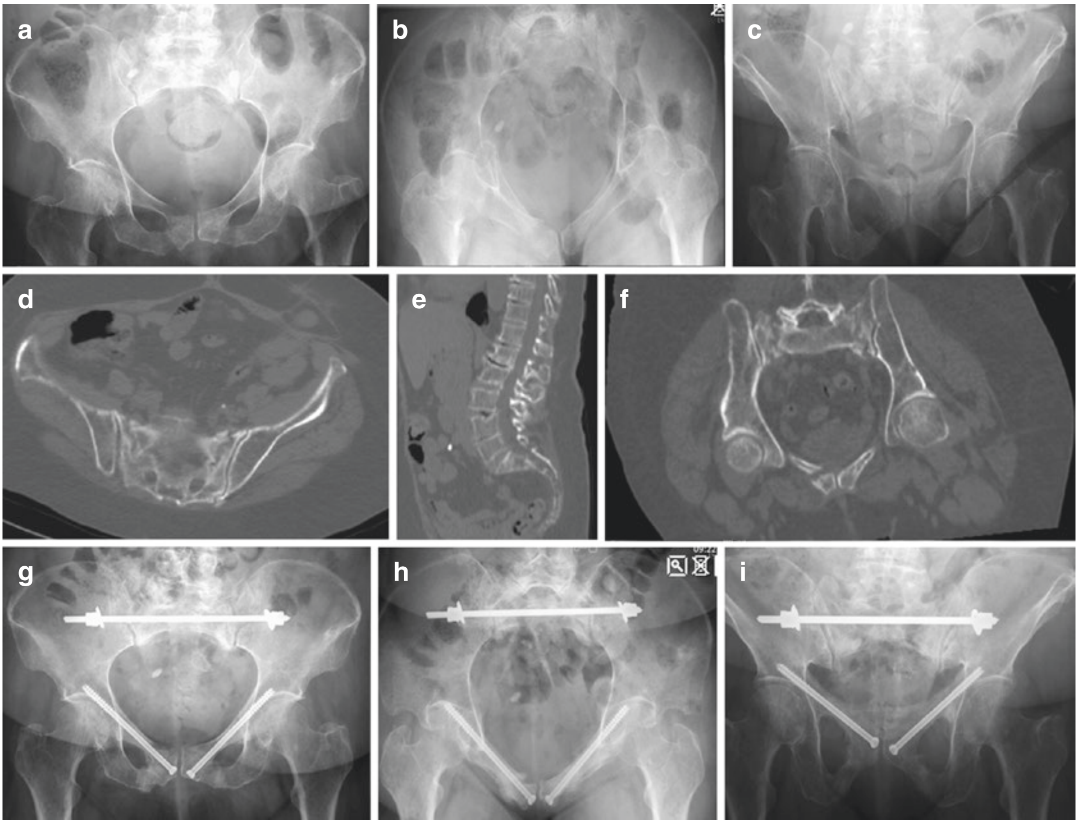

Fig. 25.9 Seventy-four-year-old female with persisting pain 3 months after a fall. (**a**) A.p. pelvic overview shows a right pubic ramus fracture. A fracture or dislocation in the posterior pelvic ring is not clearly visible. (**b**) The pelvic inlet view confirms the pubic ramus fracture. (**c**) Pelvic outlet view. (**d**, **e**, **f**) Transverse (**d**), sagittal (**e**) and oblique CT-reconstruction in the pelvic inlet plane (**f**) reveal a bilateral vertical sacral ala fracture and a horizontal fracture component between S1 and S2 with slight flexion of the S1 fracture fragment. On the left side, a non-displaced pubic ramus fracture was discovered. It concerns a FFP IVb lesion. (**g**) The posterior pelvic ring was stabilized with a transsacral implant in S1, the bilateral pubic rami fractures were splinted with retrograde transpubic screws. The a.p. pelvic overview taken 6 months after surgery shows a complete healing of the pubic rami fractures. (**h**) Pelvic inlet view. (**i**) Pelvic outlet view. The patient is pain-free and regained previous mobility

Case 10 (Fig. 25.10)

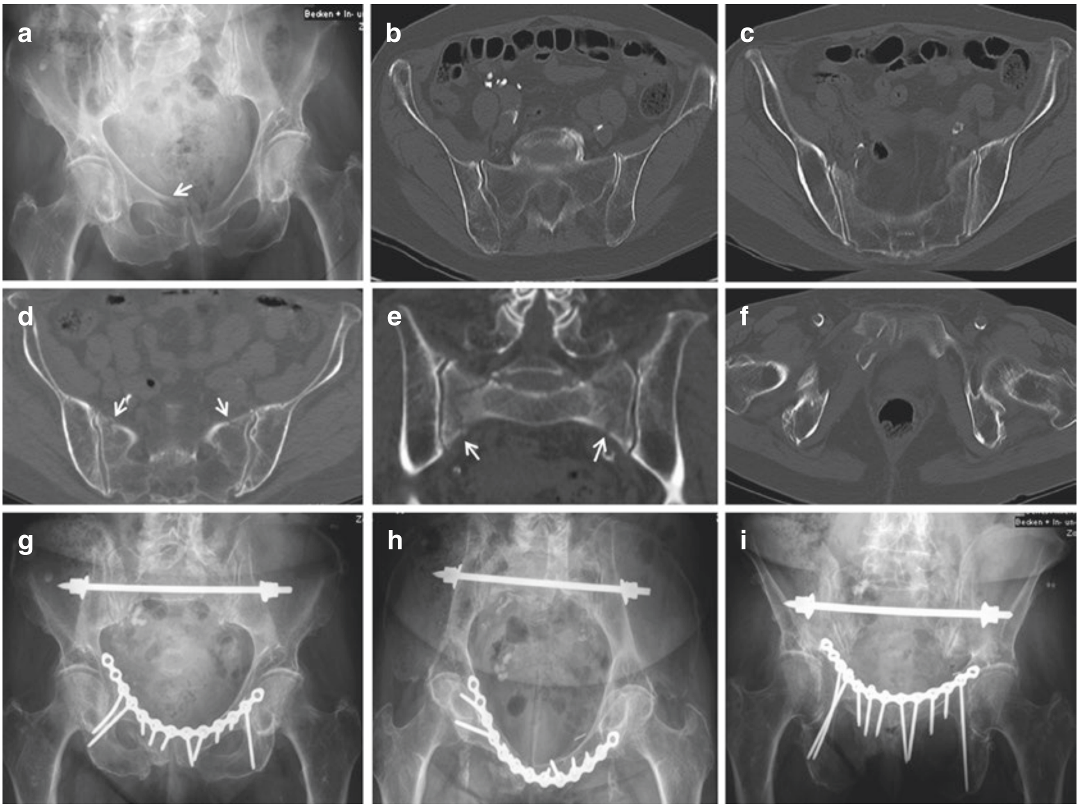

Fig. 25.10 Eighty-three-year-old female with sideward fall while walking. (**a**) The a.p. pelvic overview shows a right displaced superior pubic ramus fracture (*white arrow*). (**b**, **c**) Two transverse CT-cuts through the posterior pelvic ring do not show a fracture of the sacrum or posterior ilium. A conservative treatment was initiated. The patient presented 1 month later with increasing pain in the lower back. (**d**, **e**) Transverse (**d**) and coronal (**e**) CT-cuts through the posterior pelvic ring show bilateral non-displaced sacral ala fractures (*white arrows*). (**f**) Transverse CT-cut through the anterior pelvic ring shows the displaced right pubic ramus fracture. It concerns a FFP Type IIc lesion. (**g**) A.p. pelvic overview taken 6 months after surgical treatment. The posterior pelvic ring is stabilized with a transsacral bar through S1. The anterior instability is stabilized with a long reconstruction plate. Two long screws use the right infra-acetabular corridor; one long screw the left infra-acetabular corridor. (**h**) Pelvic inlet view. The tight connection between the washers and nuts and the lateral cortex of the posterior ilium is clearly seen on both sides. (**i**) Pelvic outlet view. Patient regained mobility and independence of activities of daily life

Case 11 (Fig. 25.11)

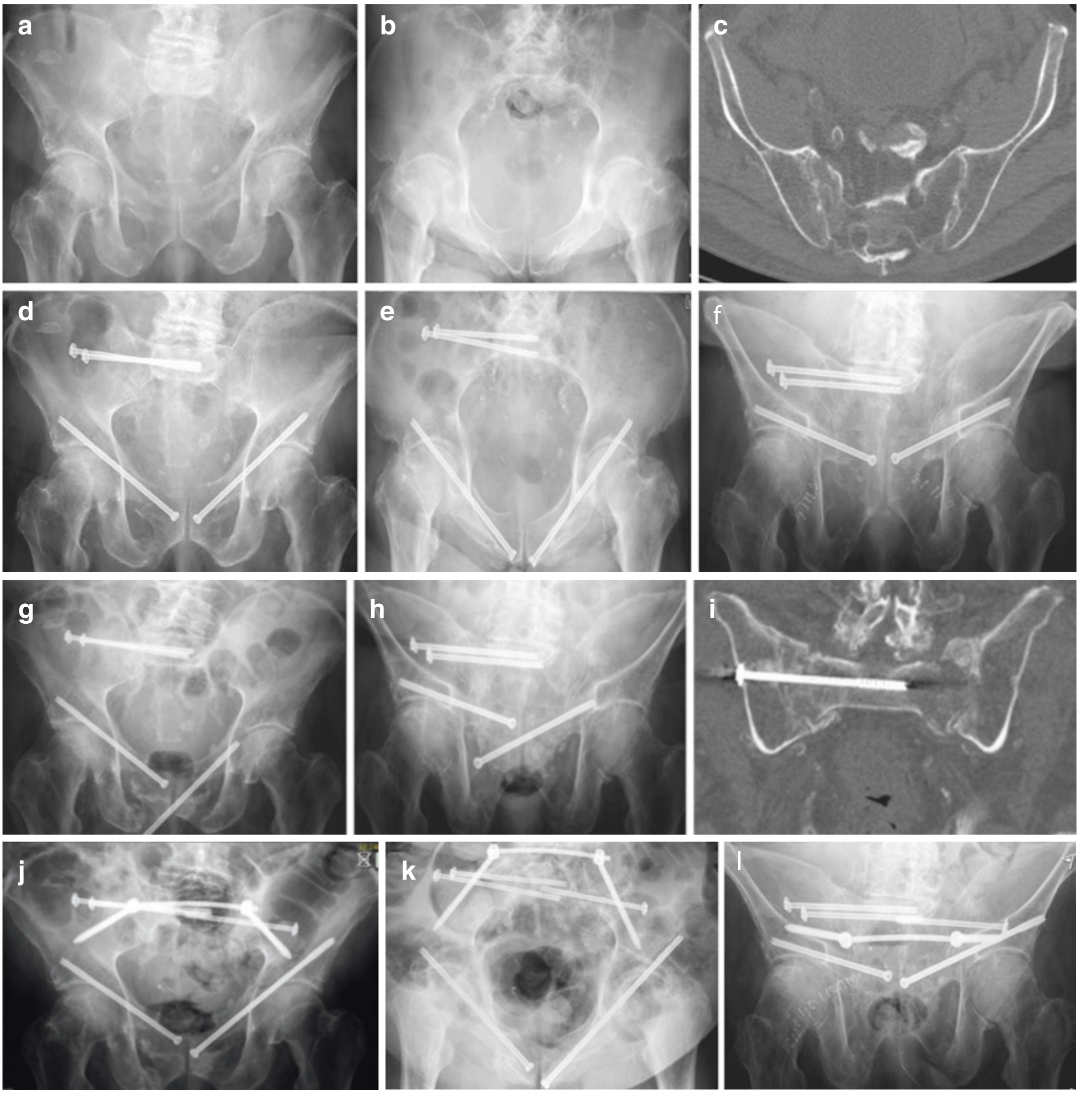

Fig. 25.11 A 66-year old male with history of alcohol abuse and chronic liver insufficiency suffered a fall at home. (**a**) The a.p. pelvic overview reveals superior and inferior pubic ramus fractures on the right and left side (*white arrows*). (**b**) The pelvic inlet view confirms the anterior pelvic ring fractures. A fracture or dislocation in the posterior pelvic ring is not visible. (**c**) Transverse CT-cut through the posterior pelvic ring showing a sacral ala fracture on the right. It concerns a FFP Type IIc lesion. (**d**) Postoperative a.p. pelvic overview. The patient was treated operatively. A double IS screw osteosynthesis was performed on the right side. Both superior pubic rami fractures were splinted with retrograde transpubic screws. (**e**) postoperative pelvic inlet view. (**f**) Postoperative pelvic outlet view. (**g**) Three months later, the patient suffered another fall and was admitted with intense pain on the left posterior pelvic ring. The a.p. pelvic overview shows a dislocation of the left retrograde transpubic screw. (**h**) Pelvic outlet view. (**i**) Transverse CT-cut through the sacrum showed a new, left-sided sacral ala fracture. The right sacral ala fracture showed signs of bony healing with callus formation. There was no dislocation of the right IS screws. (**j**) Postoperative a.p. pelvic overview. The new fracture was treated operatively as well. One IS screw was placed in the S1 sacral body from the left side. A transiliac internal fixator was placed to enhance posterior stability. The dislocated retrograde transpubic screw was replaced with a longer one, which perforates the lateral cortex of the ilium above the acetabulum. (**k**) Postoperative pelvic inlet view. (**l**) Postoperative pelvic outlet view. There was an uneventful postoperative follow-up

Case 12 (Fig. 25.12)

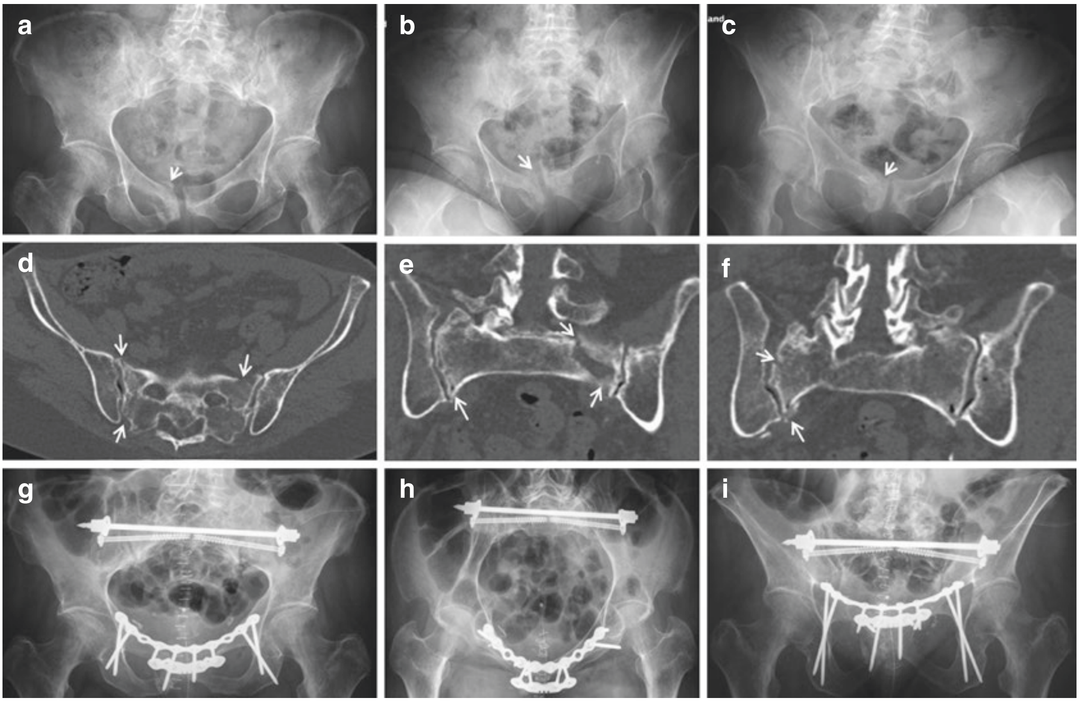

Fig. 25.12 A 74-year-old female suffered a domestic fall 9 months ago. As no fractures of the pelvic ring were detected on a conventional a.p. pelvic radiograph (not visible), treatment was conservative. The patient had continuous and increasing pain during the following months with limited mobility. (**a**) The a.p. pelvic overview taken after 9 months showed a slight widening and instability of the pubic symphysis (*white arrow*). (**b**, **c**) Pelvic overviews with one-leg-stance on the right (**b**) and left (**c**) leg showed a major instability of the pubic symphysis (*white arrows*). (**d**, **e**, **f**) Transverse (**d**) and coronal (**e** and **f**) CT-cuts through the posterior pelvic ring show bilateral displaced sacral ala fractures (*white arrows*). It concerns a FFP Type IVb lesion. (**g**) The patient was treated surgically. The posterior pelvic ring was stabilized with a transsacral implant and two IS screws in S1. The pubic symphysis instability is stabilized with a double plate osteosynthesis. The longest plate is a bridging reconstruction plate. Two long screws were inserted through the infra-acetabular corridor on each side. The shorter plate is an anterior angular-stable symphysis plate. (**h**) Postoperative pelvic inlet view. (**i**) Postoperative pelvic outlet view. There is an excellent recovery, which enables pain-free activities of daily life

Case 13 (Fig. 25.13)

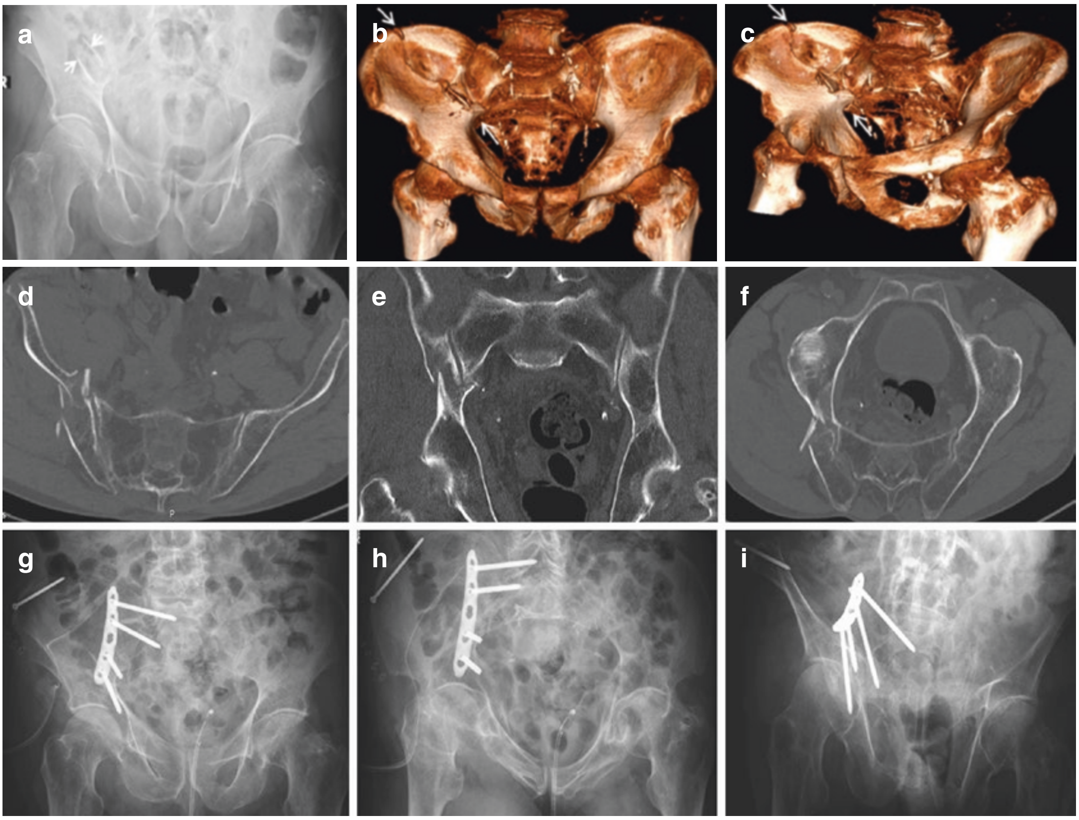

Fig. 25.13 A 78-year-old male suffered a fall while shopping. One week later, he presented because of continuing pain. (**a**) On the a.p. pelvic overview, a fracture of the right iliac wing, visible from two cortical densities (*white arrows*) is suspected. (**b**, **c**) 3D–reconstructions from the pelvic CT-scan confirm a complete fracture of the right ilium, running from the inner curve to the iliac crest. View from anterior (**b**) and iliac oblique view (**c**). (**d**, **e**, **f**) transverse (**d**), coronal (**e**) and reconstruction in the pelvic inlet plane show a displaced ilium fracture starting near to the IS joint. There was no fracture in the anterior pelvic ring. It concerns a FFP Type IIIa lesion. (**g**) Postoperative a.p. pelvic overview. The ilium fracture was stabilized with an angular stable large fragment plate, which is inserted along the pelvic brim. A lag screw is inserted parallel to the iliac crest and between the inner and outer cortex. (**h**) Pelvic inlet view. (**i**) Pelvic outlet view showing long screws running parallel to the IS joint and in the ilium body above the acetabulum

Case 14 (Fig. 25.14)

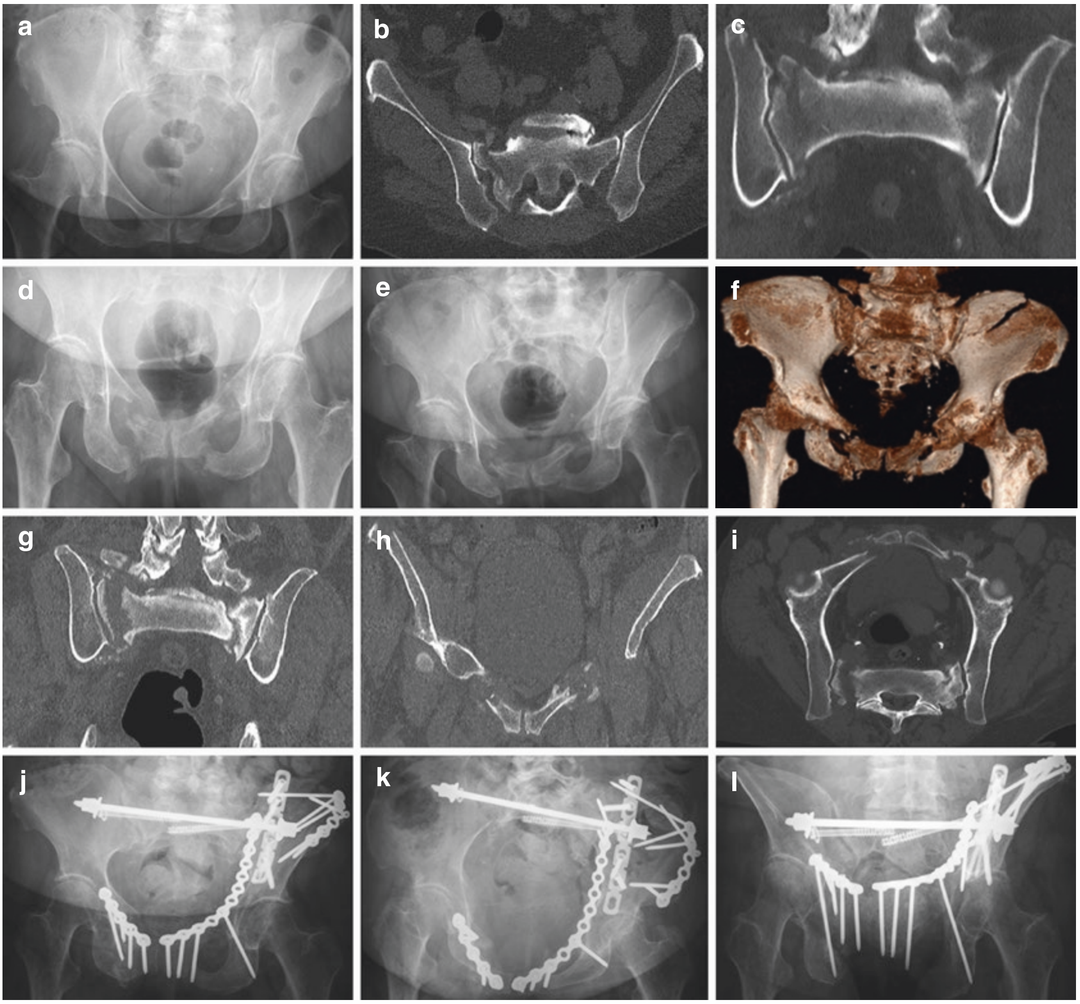

Fig. 25.14 A 67-year-old morbid obese female suffered a domestic fall. (**a**) The a.p. pelvic overview showed left-sided superior and inferior pubic rami fractures. A fracture or dislocation of the posterior pelvic ring was not visible. (**b**, **c**) Transverse (**b**) and coronal (**c**) CT-cuts through the posterior pelvic ring showed a right-sided sacral ala fracture. In the coronal CT-cut, a fissure in the left sacral ala was suspected. The patient was treated conservatively and mobilization was recommended. (**d**, **e**) Three months later, the patient was admitted because of increasing pain. The pain did never disappear after the fall and mobility steadily decreased. A low a.p. pelvic overview (**d**), taken to rule out a hip fracture showed bilateral displaced pubic rami fractures. A fracture of the posterior pelvic ring could not be discovered. On an a.p. pelvic overview, which showed the entire pelvic ring (**e**), a displaced fracture of the left ilium was visible. (**f**) 3D–reconstruction of the pelvic CT-scan showed a complete ilium fracture, which starts at the inner curve and runs towards the iliac crest. (**g**, **h**) Coronal CT-cut of the posterior (**g**) and anterior (**h**) pelvic ring showed bilateral complete and displaced fractures of the sacral ala and bilateral displaced fractures of the pubic rami. (**i**) The CT-cut in the pelvic inlet plane showed bilateral anterior and posterior pelvic ring fractures with the exception of the ilium fracture. It concerns a FFP Type IVc lesion. (**j**) A.p. pelvic overview 1 month after surgical treatment. All fractures have been addressed. The sacral ala fractures are treated with a transsacral bar and two IS screws in S1. The ilium fracture is stabilized with an angular stable large fragment plate placed along the pelvic brim and a reconstruction plate over the iliac crest. The pubic rami fractures are treated with bridging reconstruction plates through a bilateral modified Stoppa approach. (**k**) Pelvic inlet view. (**l**) pelvic outlet view

Case 15 (Fig. 25.15)

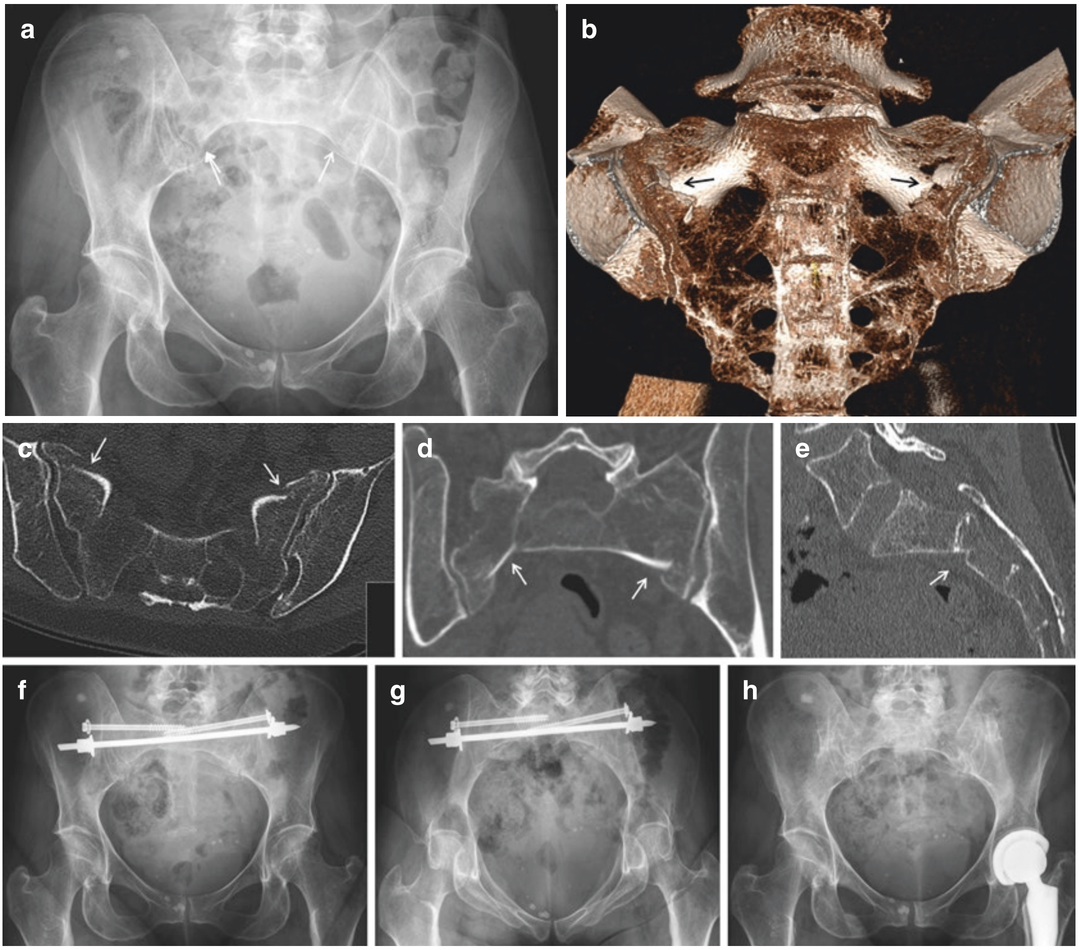

Fig. 25.15 A 65-year-old female with chronic alcohol abuse and repetitive falls was admitted with immobilizing and severe pain in the posterior pelvic ring. (**a**) the a.p. pelvic overview showed a cortical interruption at the anterior sacral cortex of both sacral ala (*white arrows*). There was no fracture of the anterior pelvic ring. (**b**) The 3D–reconstruction of the sacrum showed fractures of the anterior cortex at both sacral ala of S1 (*black arrows*). (**c**, **d**, **e**) transverse (**c**), coronal (**d**) and sagittal (**e**) CT-cuts through the sacrum showed bilateral sacral ala fractures and a horizontal fracture component between S1 and S2 (*white arrows*). (**f**) Postoperative a.p. pelvic overview. The patient was treated with a transsacral bar and two IS screws through S1. (**g**) Postoperative pelvic inlet view. (**h**) The implants were removed after 3 years. The patient suffered meanwhile a left femoral neck fracture, which was treated with a total hip prosthesis

Case 16 (Fig. 25.16)

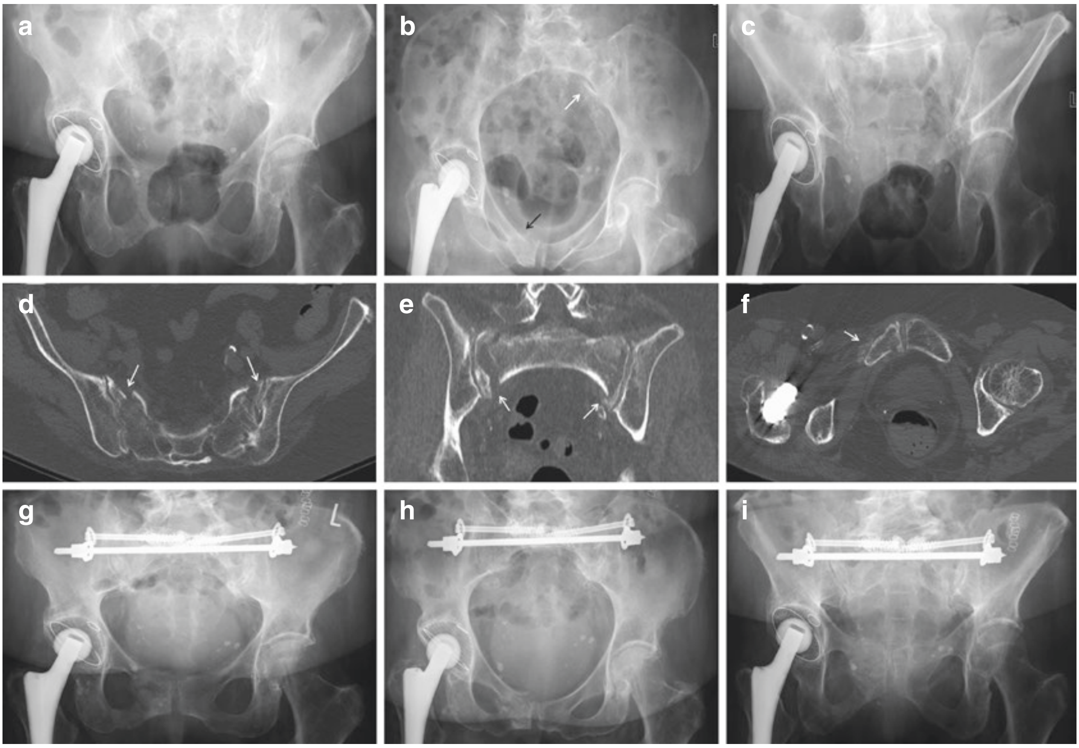

Fig. 25.16 A 70-year-old female suffered a domestic fall, which was primarily neglected. She presented after 3 months with increasing pain at the posterior pelvic ring with reduced mobility. (**a**) Due to bowel gas and content a thorough analysis of the anterior and posterior pelvic ring was not possible on the a.p. pelvic overview. (**b**) In the pelvic inlet view, there was a right-sided anterior pubic ramus fracture with surrounding callus (*black arrow*) and a cortical break at the anterior cortex of the left sacral ala (*white arrow*). (**c**) In the pelvic outlet view, a more precise analysis of the pelvic ring structures is not possible. (**d**, **e**) Transverse (**d**) and coronal (**e**) CT-cuts through the posterior pelvic ring showed bilateral displaced sacral ala fractures (*white arrows*). (**f**) The transverse CT-cut through the anterior pelvic ring revealed the right-sided pubic ramus fracture with surrounding callus (*white arrow*). (**g**) Postoperative a.p. pelvic overview. Only the posterior pelvic ring was stabilized. A transsacral implant was inserted in S1. Two IS screws with cement augmentation were additionally used. (**h**) Pelvic inlet view. (**i**) Pelvic outlet view. Full weight bearing was allowed immediately

Case 17 (Fig. 25.17)

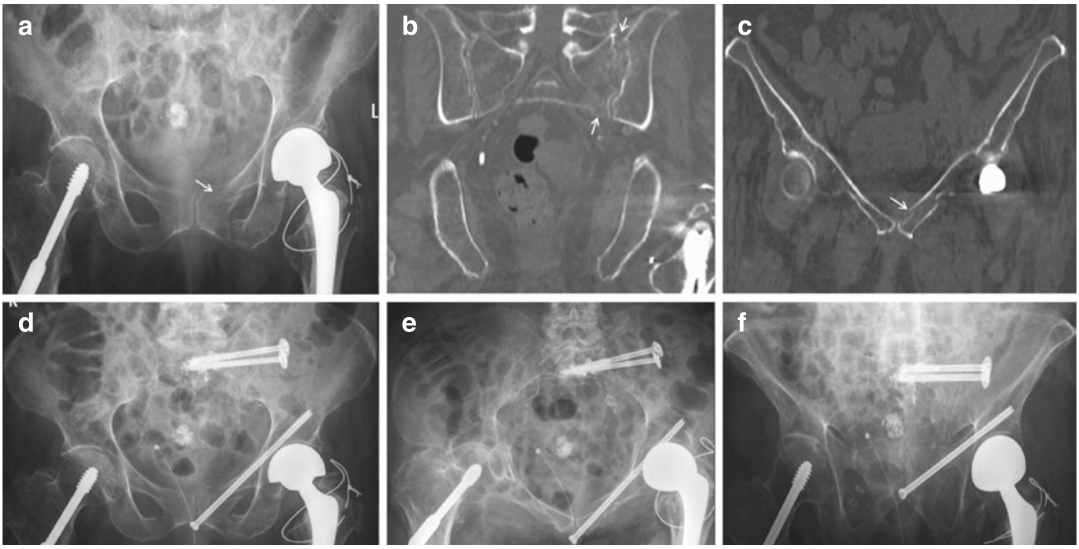

Fig. 25.17 An 86-year-old female suffers a fall in her nursing home. The patient already suffered a femoral neck fracture on the left and a trochanteric fracture on the right. She did not receive medication against osteoporosis. (**a**) A.p. pelvic overview showing a superior (*white arrow*) and inferior pubic ramus fracture on the left. The posterior pelvic ring cannot be analyzed due to osteoporosis and superimposed soft tissues and bowel content. (**b**, **c**) The coronal CT-reconstructions through the posterior (**b**) and anterior (**c**) pelvic ring show a complete left-sided sacral ala fracture and the left superior pubic ramus fracture (*white arrows*). It concerns a FFP Type IIc lesion. (**d**) Postoperative a.p. pelvic overview. The sacral ala fracture was stabilized with two cement-augmented IS screws in S1. The superior pubic ramus fracture was splinted with a retrograde transpubic screw. (**e**) Postoperative pelvic inlet view. (**f**) Postoperative pelvic outlet view

Case 18 (Fig. 25.18)

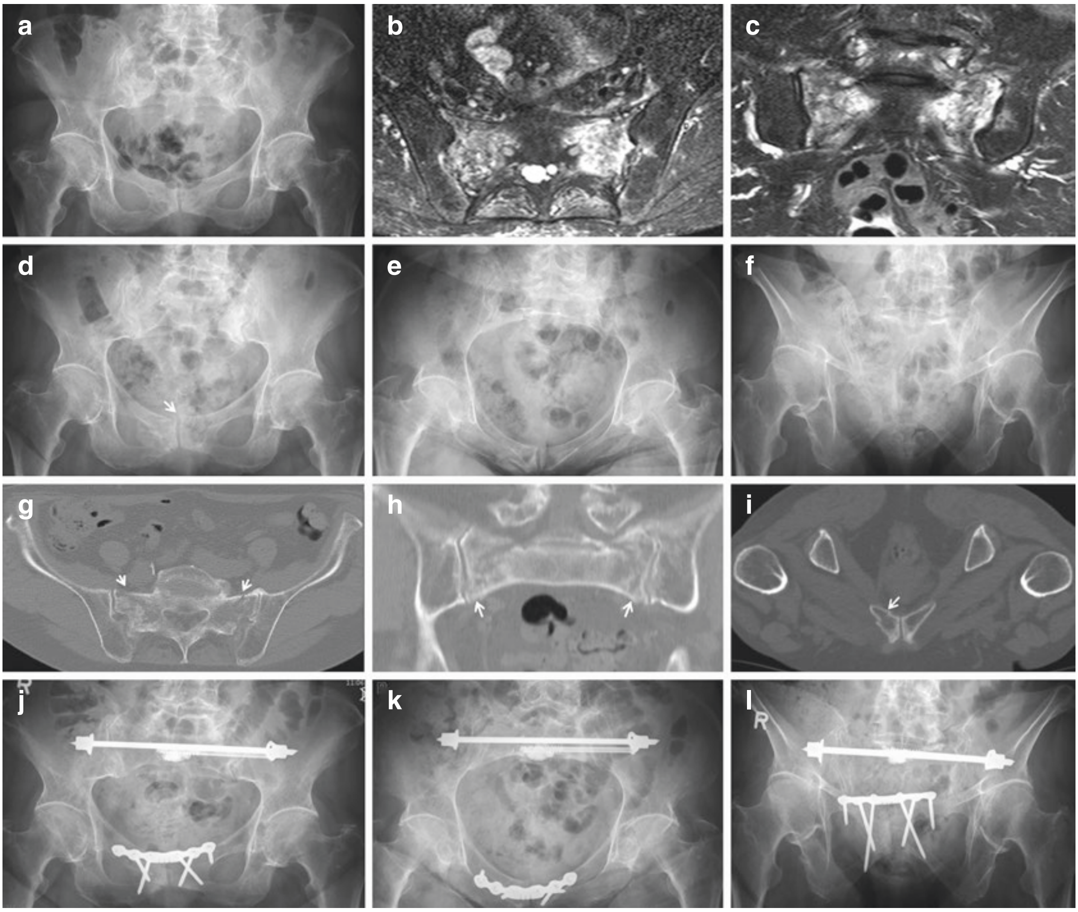

Fig. 25.18 A 77-year-old female complained intense pain in the posterior pelvic ring and at the pubic symphysis region. There was no history of a fall. (**a**) On the a.p. pelvic overview, a pelvic fracture could not be identified. (**b**, **c**) transverse (**b**) and coronal (**c**) MRI transections through the posterior pelvic ring shows "bone bruises" in both sacral alae, which is suggestive for fractures in the trabecular bone. The patient was treated with pain killers. One month later, the patient was admitted because of immobilizing pain in the anterior and posterior pelvic ring. Walking had become very difficult and only possible for very short distances. (**d**) The a.p. pelvic overview shows a slight vertical displacement in the pubic symphysis (*white arrow*) and callus formation at the right pubic bone and in the medial edge of the obturator foramen. This callus was not present on the a.p. pelvic overview taken 1 month earlier. A thorough analysis of the posterior pelvic ring was again not possible. (**e**) The pelvic inlet view confirms callus formation in front of the right pubic bone. (**f**) Pelvic outlet view. (**g**) The transverse CT-cut through the posterior pelvic ring shows complete bilateral sacral ala fractures (*white arrows*). (**h**) Coronal CT-cut through the posterior pelvic ring showing bilateral non-displaced sacral ala fractures with resorption of trabecular bone (*white arrows*). (**i**) The coronal CT-cut through the anterior pelvic ring shows a fracture of the right pubic bone (*white arrow*). It concerns an FFP Type IIc lesion. Because of its bilateral pathology, this FFP has a high risk of becoming displaced during continuing mobilization. If displacement occurs, the classification changes from FFP type IIc to FFP type IVb. (**j**) Pelvic a.p. overview taken 1 month after surgical treatment. The posterior pelvic ring was stabilized with a transsacral bar and an additional cement-augmented IS screw in S1 on the left. Anteriorly, there was a complete instability of the pubic symphysis in combination with a non-displaced right pubic bone fracture. The anterior pelvic ring was stabilized with a six-hole symphysis plate. (**k**) Pelvic inlet view. (**l**) Pelvic outlet view. On each side, two long screws could be inserted in the pubic bone, giving the plate construct a high stability. The pain level significantly decreased and the patient was again able to walk longer distances

Case 19 (Fig. 25.19)

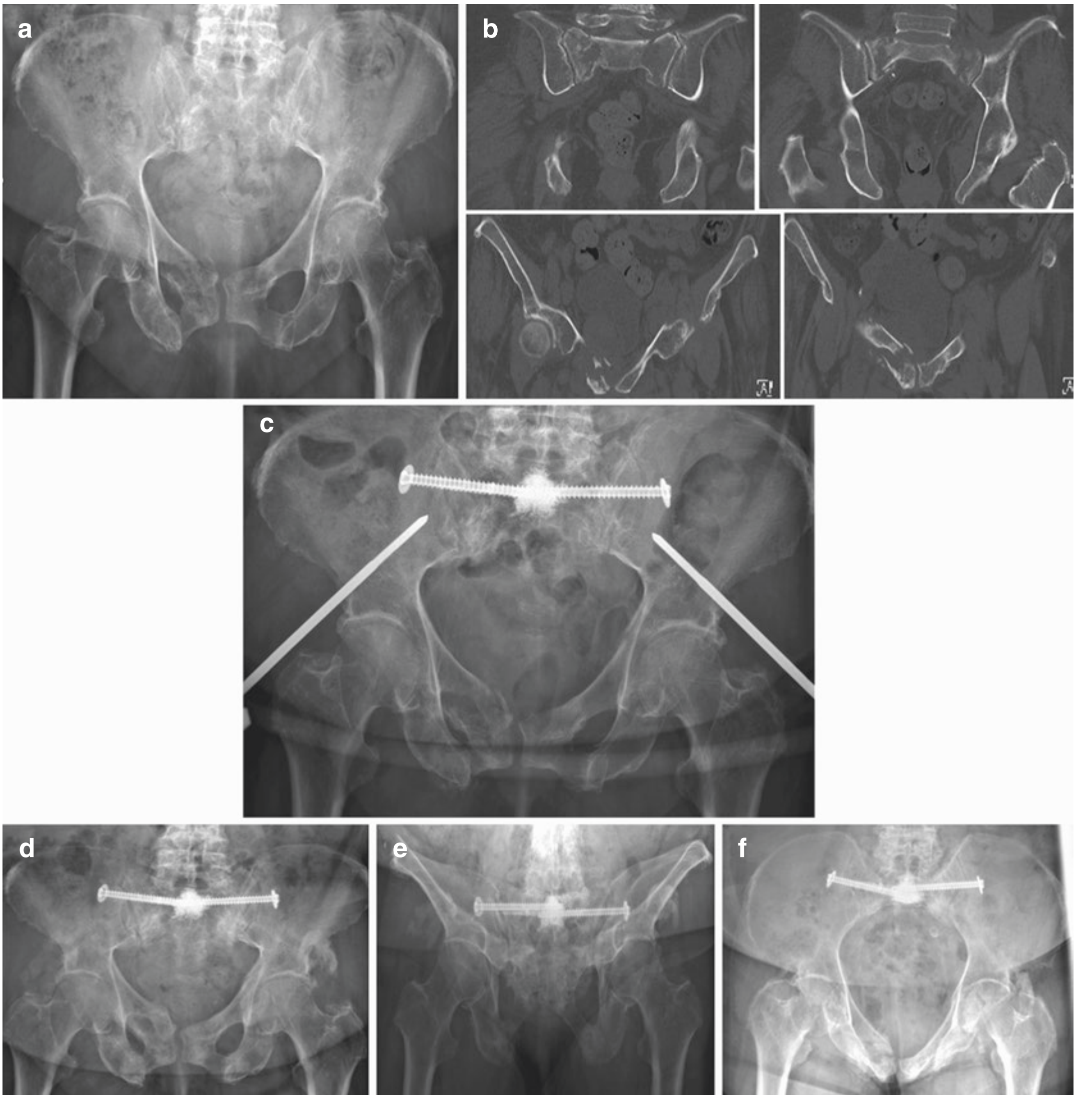

Fig. 25.19 A 76-year-old female suffered recurrent falls in the garden within 5 weeks. (**a**) An a.p. pelvic overview reveals a right-sided superior pubic ramus fracture. (**b**) Coronal CT-cuts through the anterior and posterior pelvic ring show bilateral sacral ala fractures and confirm the right-sided superior pubic ramus fracture. It concerns a FFP Type IVb. (**c**) Postoperative a.p. pelvic overview. The posterior pelvic ring was stabilized with two cement-augmented IS screws. The anterior pelvic ring was bridged with a supraacetabular external fixator with a curved carbon rod. (**d**, **e**, **f**) The external fixator was removed after 4 weeks. The a.p., inlet and outlet pelvic overviews were taken 6 months after surgery. Periarticular ossifications are visible at the previous pin tracks on both sides. The patient returned to her initial level of activity. (Courtesy of S. Herath, Homburg, Germany)

Case 20 (Fig. 25.20)

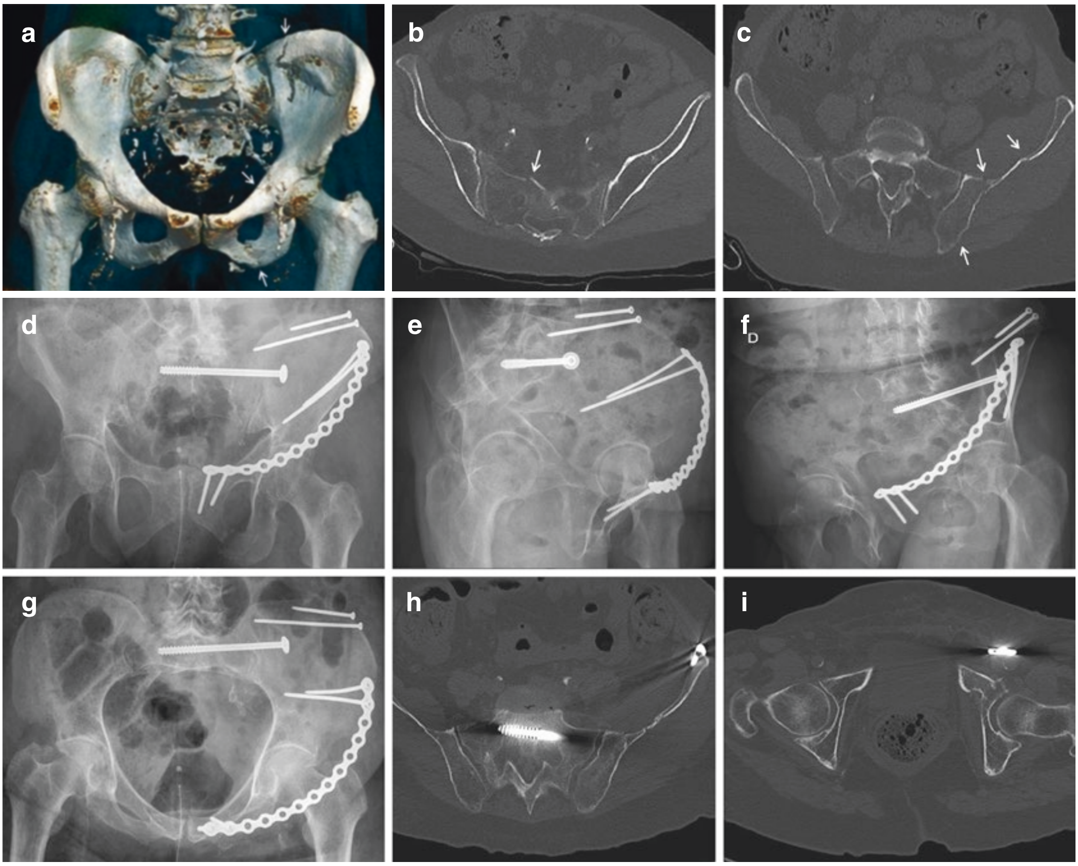

Fig. 25.20 An 83-year-old female suffered a domestic fall 3 weeks before admission. (**a**) 3D–reconstruction of the pelvic CT showed an incomplete left posterior ilium fracture and a left-sided superior and inferior pubic ramus fractures (*white arrows*). (**b**) Transverse CT-scan through the posterior pelvic ring showed an additional fracture of the sacral body (*white arrow*). (**c**) Transverse CT-scan at the level of the posterior superior iliac spines depicted the fracture of the left ilium located at the iliac wing and running parallel to the iliosacral joint (*white arrows*). It concerned a FFP Type IIc lesion. (**d**, **e**, **f**, **g**) Postoperative a.p. (**d**), ala oblique (**e**), obturator oblique (**f**) and inlet (**g**) pelvic views. The sacral fracture was stabilized with an IS screw and the left ilium fracture with two small fragment lag screws running parallel to the iliac crest. The anterior pelvic ring instability was bridged with an anterior internal fixator using a reconstruction plate and screws in the anterior iliac crest and the pubic bone. (**h**, **i**) Transverse CT-cuts through the posterior pelvic ring (**h**) and the anterior pelvic ring (**i**) showing the location of the iliosacral screw and the reconstruction plate on top of the iliac crest. The subcutaneous location of the reconstruction plate at the level of the hip joint is visible in (**i**). All implants were inserted minimally invasive with a total length of the skin incisions of not more than 10 cm. (Courtesy of T. Gerich, Luxembourg)

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P.M. Rommens, A. Hofmann (eds.), *Fragility Fractures of the Pelvis*,
DOI 10.1007/978-3-319-66572-6

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