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When is the stability of a fracture fixation limited by osteoporotic bone?

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Failure

ABSTRACT

This article is concerned with the search for threshold values for bone quality beyond which the risk of fixation failure increased. For trochanteric fractures we recognized a BMD lower than 250 mg/cm^3 as an additional risk for cut out. For medial femoral neck fractures since joint replacement surgery is available and produces excellent functional results, we see no indication for further differentiation or analysis of bone quality in relation to fracture fixation. In the area of osteoporotic vertebral body fractures, there are many experimental studies that try to identify BMD limits of screw fixation in the cancellous bone on the basis of QCT analysis. However, these values have not yet been introduced for application in clinical practice. In case of indication for surgical fixation, we favor minimally invasive, bisegmental, fourfold dorsal instrumentation with screw-augmentation for a T-value less than −2.0 SD (DXA analysis, total hip or total lumbar spine). For proximal humerus fractures, BMD value of 95 mg/cm^3 could be seen as a threshold value below which the risk of failure rises markedly. In relation to osteoporotic distal radius fractures, based on our clinical experience and scientific analyses there are virtually no restrictions as far as bone quality is concerned on the application of palmar locking implants in the surgical management of distal radius fractures. Optimization of preoperative diagnostics might help to revise the treatment algorithm to take bone density into account, thus reducing the risk of failure and, at the same time, acquiring additional data for future reference.

Introduction

Osteoporosis is a widespread disease process and is now not only prevalent in Europe and north America but has become a worldwide challenge [1] due to an increase in life expectancy. Orthopaedic traumatology is particularly impacted by this phenomenon for two reasons: firstly, fracture rates have increased markedly and, secondly, fracture treatment of osteoporotic bones differs in several ways from treatment of non-osteoporotic bones. Typical locations of osteoporotic fractures include the proximal femur, proximal humerus, distal radius and spine. Many fractures can be treated surgically or non-surgically so a choice has to be made between these options with their associated advantages and disadvantages. Ultimately, surgery may be unavoidable, especially for fractures of the lower extremities.

If the treatment of choice is surgical intervention, success depends on three important parameters: Selection of the ideal implant, best possible anatomical reduction, and correct positioning of the implant [2]. Slight deficits in any one of these three areas can generally be compensated for by non-osteoporotic bone during fracture healing. However, two main characteristics differentiate osteoporotic bone from the healthy skeleton: firstly, implant anchorage (generally in trabecular bone) tends to be insufficient [3], secondly, fracture healing takes longer due to a decelerated bone metabolism [4]. These factors combined repeatedly lead to fatigue failure that is manifest as screw migration through cancellous bone (cut out [3]) with resultant dislocation of the fracture and fixation failure, even when none of the three critical areas show any relevant deficits. This article is concerned with the search for threshold values for bone quality and/or bone density beyond which the stability of the osteosynthesis is limited and the risk of fixation failure increased. Identifying threshold values will make it possible to modify the treatment concept to accommodate individual bone quality and predict complication risk more accurately, e.g. in relation to non-surgical and surgical fracture treatment or joint replacement. The data are based on published literature and derived from the author's own experimental findings and clinical experience.

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Trochanteric femur fractures

Proximal femur fractures in the region of the trochanter are one of the most frequent and most serious osteoporotic fractures due to the lack of alternatives to surgical management. Surgical intervention is unavoidable in the majority of cases; joint replacement may be possible in principle, but will be a highly complex challenge; osteosynthesis often remains the best therapeutic option despite the presence of osteoporosis. Fixation failure often signals the end of patient mobility [5,6], whereby the appropriate fixation is physiologically destined to experience relatively high loads in the region of the hip [7]; in many cases it is not reasonable to expect partial loading given the reduced condition of general health typical of these patients. It is all the more important that proper consideration be given to the afore-mentioned key concerns in fracture management – reduction, appropriate choice of implant and correct implant placement. Fracture reduction and correct implant positioning are the responsibility of the surgeon for which he has some guiding criteria available [2]. With regard to the choice of implants, modern and clinically proven solutions are available from most manufacturers. In particular rotationally stable implants have clearly lowered complication rates in osteoporotic bone in recent years [8]. Nevertheless, failures that lead to cut out even where detailed analysis of the three key areas showed no relevant deficits can be clinically observed. In these cases, it can be assumed that bone quality had reached a critical threshold that limited the efficacy of fracture fixation.

Biomechanical experiments were employed to identify a possible threshold of bone mineral density for a reliable fixation of implants in the proximal femur [3]. First, we tested 30 proximal femurs from human body donors for bone mineral density (BMD) at the femoral head using quantitative computed tomography (QCT). We selected this region of interest because load transfer during weight bearing takes place at the interface between the cancellous bone of the femoral head and the femoral head screw. It is in this area that BMD is especially important for the stable anchorage of the load carrier. After determining BMD, osteotomy was performed to simulate an unstable trochanteric AO type 31 A2.3 fracture followed by intramedullary nailing with insertion of the most recent generation of nails (PFNA from Synthes, Trigen Intertan from Smith&Nephew and Targon PFT from Aesculap). After fracture fixation cyclic dynamic loading of the constructs was performed until failure. The primary endpoint of the study was calculation of the relative risk of cut out in relation to the BMD values (Figure 1). The incidence of cut-out for BMD less than 250 mg/cm^3 was 0.55 (5 of 9) and for BMD greater than 250 mg/cm^3 0.05 (1 of 21). Therefore, the risk of cut-out for BMD <250 mg/cm^3 was almost 11 times greater than for BMD >250 mg/cm^3. The conclusion can be summarized as follows. There is a very high risk of implant failure after surgical management of trochanteric fractures where BMD is below 250 mg/cm^3 in the region of the femoral head. A threshold value like this for bone density could be helpful, for example, when deciding for or against cement augmentation [9] at the bone-screw interface in the femoral head. Currently, there are no definitive decision-making criteria for implant augmentation [10] and widespread application of augmentation to all trochanteric fractures would not be advisable because of the associated complication risks as well as for socio-economic reasons. On the other hand, determining bone density in the region of the femoral head is not easy logistically. In principle, it is not very difficult to perform QCT, however, some institutions do not have the necessary infrastructure and the software of the CT manufacturers is often not sophisticated enough for this special application. Despite these constraints and based on our own experimental findings and data from the literature [11], a BMD threshold of 250 mg/cm^3 appears to be a clinically relevant values for the prediction of stability of intramedullary osteosynthesis of proximal femur fractures.

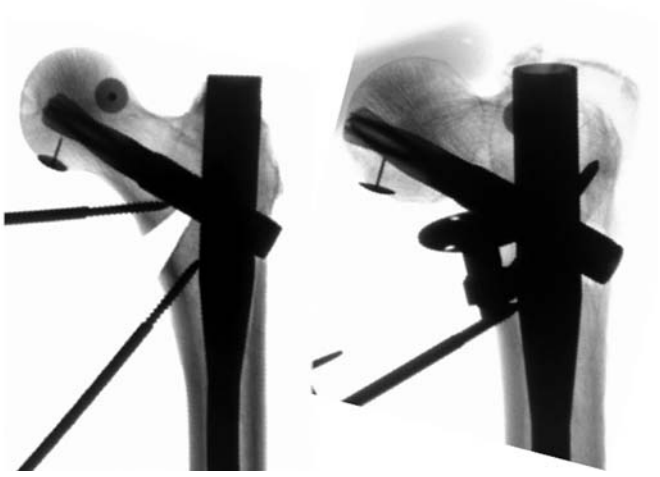

Fig. 1. Radiological images of a construct incorporating proximal femoral nail osteosynthesis (PFNA, DePuy-Synthes) before loading (left) and after 10,000 load cycles (right) at 2100N. It shows cut out typical of a clinical complication involving medialization of the PFNA blade, varus dislocation and collapse of the osteotomy gap, which corresponds to comminution in the clinical environment.

Medial femoral neck fractures

Medial femoral neck fractures occur at an incidence similar to that of trochanteric fractures and are likewise a typical osteoporotic fracture type. In practice, treatment depends on the classification of the fracture, whereby international and national directives for fracture management do not provide practical guidelines and leave the surgeon great freedom to make treatment decisions. Nevertheless, it can be broadly stated that stable femoral neck fractures should be treated by osteosynthesis [12] and unstable fractures by joint replacement [13]. Osteosynthesis of stable fractures is not susceptible to any relevant mechanical failures in the sense of cut-out or fracture dislocation [12], provided that the classification of the fracture as stable or unstable is correct. The risk of complications does however increase for unstable fractures, but since joint replacement surgery is available for unstable femoral neck fractures and produces excellent functional results [13], alloplastic treatment is a viable option for unstable fractures with osteoporosis. Given this situation, we see no indication for further differentiation or analysis of bone quality in relation to fracture fixation for medial femoral neck fractures.

Vertebral body fractures

Pathological vertebral body fractures without relevant trauma or after low energy trauma represent a major challenge in the context of osteoporosis. In many cases, non-surgical treatment is extremely promising and offers satisfactory functional outcomes [14]. However, in some cases surgery is indicated, either to alleviate pain or to reverse some marked deformity such as spinal canal stenosis, which is associated with pain and neurological deficits. This section is concerned with the challenges of screw fixation in osteoporotic vertebral bodies, but not with vertebroplasty or kyphoplasty, which represent more or less invasive approaches to pain therapy with low levels of evidence to date [15].

Typical failures of dorsal instrumentation are cut out and also pull-out of the pedicle screws [16]. In contrast to trochanteric fractures it is bone quality that is more frequently responsible for failure rather than reduction or precise screw placement, which is generally exactly transpedicular because of the anatomical features of the region. Various technical methods are available if the treatment of choice for osteoporotic vertebral fractures is dorsal instrumentation: Simple, bisegmental dorsal bridging of the fractured vertebra is the