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Failure of fracture fixation in osteoporotic bone

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ABSTRACT

This manuscript will provide an overview of how the age and osteoporosis related changes in mechanical properties of bone affect the stability of osteosynthesis constructs, both from a mechanical as well as from a clinical perspective. The manuscript will also address some of the principles of fracture fixation for osteoporotic fractures and discuss applications of osteoporotic fracture fixation at sites typically affected by fragility fractures, namely the distal radius, the proximal humerus, the femur and the spine. The primary aim of operative treatment in elderly individuals is the avoidance of immobilization of the patient. In selected cases conservative treatment might be required. Generally, choice of treatment should be individualized and based on the evaluation of patient-specific, fracture-specific and surgeon-specific aspects. The orthopaedic surgeon plays an essential role in enabling functional recovery by providing good surgery but a multidisciplinary approach is essential in order to support the patient to regain his/her quality of life after fragility fracture. Overall, the therapy of fractures in osteoporotic bone in the elderly requires a multidisciplinary therapeutic acute care concept including treatment of co-morbidities and correct choice of timing, and technique of the operative intervention.

Introduction

In an aging population the number of fractures seen in orthopedic institutions steadily increases. The treatment and care of these elderly patients constitutes a challenge for the individual orthopedic surgeon, the hospital staff and the health care systems worldwide. Many of these challenges are related to the age of the patient and the frequency of comorbidities. Therefore, the successful treatment of the fracture with fast recovery of the mobility is essential for the patient's survival and wellbeing. A reasonable return to function and a successful healing in the elderly requires a mechanical stable internal fixation and rapid rehabilitation. Elderly individuals will not be able to adhere to partial weight-bearing protocols and thus require osteosynthesis which tolerates full weight-bearing. Thus the need for stable internal fixation in osteoporotic bone is paramount. The hardware for fracture fixation is typically designed to maintain its stability during full weight bearing. However, the bone in elderly individuals often lacks mechanical strength for stable anchorage of plates, screws or nails. Age related degradation of bone and the additional bone weakening through age related diseases such as osteoporosis reduce the ability of bone to withstand increased loading. Often the bone around screws and nails fails prematurely and leads to subsidence, cut through or cut out of metal hardware and ultimately to failure of fracture fixation [1]. This manuscript will provide an overview of how the age and osteoporosis related changes in mechanical properties of bone affect the stability of osteosynthesis constructs, both from a mechanical as well as from a clinical perspective. Principles of fracture fixation for osteoporotic fractures will also be discussed. However, it should be recognized that fragility fractures require a multidisciplinary management of the acute fracture episode and ongoing activities to prevent secondary fractures [2]. The orthopaedic surgeon plays an essential role in enabling functional recovery by providing good surgery but a multidisciplinary approach is essential for the fracture patient to regain his quality of life.

Mechanical properties of bone in osteoporosis

The ability of bone to resist fracture and withstand loads depends on the amount of bone (bone mass), its distribution in space and the intrinsic material properties of the bone tissue [3]. Using engineering principles these factors can be used to predict failure load of a given bone with fairly high accuracy [4,5]. However, the failure load for a bone with certain strength will strongly depend on the loading mode. A proximal femur will fracture at considerably lower loads if the loading mode is a sideways fall on the greater trochanter as compared to loading applied to the femoral head in a stance configuration [5].

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In order to determine the risk of a fracture to occur the concept of factor of risk was introduced. The factor of risk can be computed as the ratio of applied load and load at which the bone structure would fail [6].

In osteoporosis bone mass is reduced and the microarchitecture of bone is deteriorated leading to enhanced bone fragility and increased fracture risk [7]. The reduction in bone mass mainly results from increased bone resorption and inadequate bone formation leading to a negative remodeling balance [8]. Although less well understood, also the intrinsic material properties of bone tissue are affected by aging and osteoporosis [9]. Intrinsic changes that have been previously described include compositional factors such as mineralization distribution, content of collagen and cross linking profiles of inter- and intrafibrillar collagen connections [10].

Aging and osteoporosis affect elastic properties as well as strength properties of bone. Elastic properties describe the deformation which occurs under loading (stiffness) before failure, while strength describes the stress (force per unit area) at which failure occurs. For cortical bone, stiffness decreases by 1–2% per decade and strength decreases by 2–5% per decade [11]. Most importantly the energy required to fracture a bone may decrease by up to 10% per decade beyond the age of 35 years [6,12]. For trabecular bone the mechanical competence is mainly determined by the apparent density and the orientation of the trabecular network, explaining up to 90% of its variance [13,14]. As the relationship of density with mechanical properties is non-linear, the decreasing apparent density of trabecular bone with aging is associated with accentuated deterioration of the mechanical properties. At age of 80 years the strength of the bone from the proximal femur is reduced by more than 50% from its strength at young age [15]. Even more pronounced is the loss of mechanical strength at the spine were the strength reduction during lifetime has been reported to amount to up to 70% [16]. As the load to fracture for a whole bone depends on both cortical and trabecular bone material properties the overall strength of bone is dramatically reduced with aging. The proximal femur loses about 50% of its strength and 70% of its energy to failure between the age of 35 years and 75 years [17]. Even more dramatic is the loss of strength at the spine where a loss of 80% of compressive strength have been reported in men and women [18]. These dramatic age related changes in the material properties indicate that the factor of risk for fracture is increased and traumatic events which are benign at young age will become enormously hazardous in the elderly.

Considering the concept of factor of risk for a fracture not only the strength of the bone but also the applied load has to be taken into account. With aging muscle performance and coordination deteriorate and lead to an increased risk of falling and also to a decreased ability to support falls. The potential energy which is generated during a fall from standing height largely exceeds the energy required to fracture the proximal femur. Thus without any energy absorption by soft tissue dampening, muscle contraction or compensatory movement, the load acting on the proximal femur during falling would inevitably lead to hip fracture [19].

Failure of fracture fixation

Failure of internal fixation in osteoporotic bone typically results from bone failure rather than implant breakage [20]. The deterioration of cortical and trabecular bone with aging and osteoporosis goes along with a considerable reduction of fixation strength of osteosynthesis materials [21]. This reduction in fixation strength has been demonstrated for most types of osteosynthesis materials including screws, plates, nails and fixators (Table 1). It appears that at locations which are prone to osteoporotic fractures also the effect of bone density on fixation stability is most pronounced. In cortical bone; in which the extent of deterioration of bone mechanical properties with age is less pronounced, the thickness of the cortical bone has shown to have a dramatic effect on the fixation stability of osteosynthesis implants [22,23]. Compared to thick cortices the holding force decreases by 1000 N (or 50%) per 1 mm loss of cortical thickness. This might generate differences in holding power of bone screws of up to 2000 N within an individual bone and highlights the importance of placing bone screws in the bone with thick cortices wherever possible.

The role of locked plating

It is generally assumed that locking plate constructs have mechanical advantages compared to conventional plate constructs and that these advantages are of particular benefit in osteoporotic bone [20,34]. Biomechanical studies so far have demonstrated that in osteoporotic bone locking plates create increased fatigue strength and increased ultimate failure loads compared to conventional plates [35,36]. Furthermore; it appears that the fixation stability of locked plates is less susceptible to reduction in bone mineral density compared to conventional plating constructs (Table 1). The major reason for failure in conventional plating of osteoporotic bone is break out of the screws and/or fracture of the bone through one of the screw holes. Thus the stress within the bone at the site of the screws appears

Table 1.
Loss of mechanical properties for osteosynthesis constructs related to age and osteoporosis

Type of implant	Location	Loading mode	Mechanical property	Loss in mechanical property (%)*	References
Pedicel screw	Vertebrae cervical	Axial screw pull out	Failure force	37	[24]
		Screw tightening	Failure torque	35	
Vertebral body replacement	Vertebrae lumbar	Axial compression	Force	55–75	[25]
Cage & Fixator	Vertebrae lumbar	Flexion/Extension	Stiffness (1/ROM**)	60–80	[26]
Pedicle Screw	Sacrum (S1)	Cantilever bending	Failure force	64	[27]
Conventional plate	Tibia proximal	Tibial plateau compression	Failure force	40	[28]
Conventional plate	Tibia distal	External rotation	Failure torque	70	[29]
Locking plate				14	
Locking screws	Tibia shaft	Axial pull out	Failure force	15	[22]
		Cantilever bending	Failure force	18	
Cancellous screws	Humerus head	Axial pull out	Failure force	18	[30]
Conventional plate	Humerus proximal	Cyclic fatigue	Cycles to failure	70	[31]
Locking plate				59	
Hip screw	Femural head	Cyclic fatigue	Stiffness (1/subsidence)	55	[32]
Proximal femoral nail	Femur proximal	Cyclic fatigue	Cycles to failure	48	[33]

*Loss in mechanical property was calculated as percentage reduction observed for the low density (osteoporosis) group or population with respect to the high density (normal bone) group or population.
**ROM: Range of motion.