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Principles and current concepts in the surgical treatment of fragility fractures in the elderly

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A B S T R A C T

The constant rise in fragility fractures is proportional to the constant rise in life expectancy. Treatment of fragility fractures can be challenging because of severe fractures, poor bone quality, significant co-morbidities, and reduced mobility. However, new surgical techniques and implants have been developed that address these challenges and show improvement in overall patient outcomes. This review addresses general considerations including nonsurgical and surgical treatments of fractures as well as treatment of specific fragility fractures of the extremities. Based on these findings, this chapter gives treatment recommendations for a selection of common geriatric fractures. The aim of treating fragility fractures is on the early mobilization to prevent complications such as pneumonia. However, the patient's general situation should be taken into consideration while recommending appropriate treatment strategies.

Introduction

Fractures in the elderly are a constantly rising challenge in orthopedic surgery. The incidence and prevalence of fractures in the elderly is rising proportionately with the constant increase in life expectancy [1,2]. With increasing age, the risk of osteoporosis or osteopenia [3] rises, even though this

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risk is mitigated by the concomitant rise of body mass index in the geriatric population [4]. Obesity is associated with its own set of complications that may differ from those in osteoporosis [5]. Osteoporosis is a systemic disease that leads to loss of bone mineral content that weakens the bone, particularly in cancellous bone where the bone cannot compensate with an increase in cortical thickness as in diaphyseal bone [6,7]. The decreased bone quality is believed to be the result of an imbalance in osteoblast and osteoclast functions [8]. There are multiple pharmacologic options available to support osteogenesis or inhibit osteoclast function [9–11], but these have, to date, shown only limited success in the treatment of osteoporosis [12]. Consequently, fragility fractures are globally still rising with a rise in the incidence of hip fractures of 22% expected in Europe and the United States by 2040 [13].

From an orthopedic perspective, the challenges in treating osteoporotic fractures center around the stability of fracture fixation and prevention of secondary loss of fixation because of decreased bone mass [14,15]. Another important issue is the possibility of impaired fracture healing [16]. Age, possible impaired healing capacity, and decreased fracture fixation stability due to reduced bone mass challenge orthopedic surgeons to find a balance between minimally invasive and restrictive surgery versus high stability and early functional mobility.

This review focuses on recent developments in the geriatric treatment of ankle fractures as well as fractures around the elbow and knee, as the other commonly fractured periarticular regions have recently been reviewed [17]. In addition, we review the current state of augmentation techniques in fracture fixation.

General principles in fracture care of the elderly

Nonoperative treatment: casts and braces

Depending on soft tissue status, concomitant injuries, and comorbidities, nonoperative treatment is an option in various fractures. There are no absolute indications, and choosing conservative treatment should be made on an individual basis. Generally, the decision for nonoperative treatment is based on the stability of the fracture and is independent of bone quality [18]. Guidelines for initiating nonoperative treatment include stable fractures, unstable fractures after satisfactory reduction, or an initial attempt in borderline cases [18]. We recommend regular clinical and radiological follow up with x-rays after one and six weeks, as well as after three months. Conservative treatment usually involves immobilizing or sufficiently stabilizing the involved joint for 6-weeks [19]. An ever-increasing array of casting options and commercially braces is available. Modern casting techniques and improved bracing allow for lightweight-bearing, stable, and removable immobilization devices (e.g., VACOped) that improve mobility and reduce complications, such as pressure sores [20]. Further, modern braces with mobile joints that allow for early functional treatment are gaining traction and play an especially valuable role in the geriatric population where lengthened immobilization leads to poor outcomes [21]. This is especially true for the elbow, where every effort should be made to begin early functional motion.

Nonoperative treatment in the geriatric population provides many advantages, especially when the risks of surgery are high or the activity and mobility of the patient are very low. Limitations of nonoperative treatment include insufficient stability resulting in secondary displacement of the fracture. Another potential disadvantage revolves around patient compliance. The patient should have adequate mental and physical health for weight-bearing and mobilization as directed, while completing activities of daily living (with access to adequate domestic support) despite the handicap produced by the cast or brace. Finally, nonoperative treatment in the elderly is associated with decreased mobility with higher risk of associated morbidities as a result [22]. Table 1 summarizes our recommendations for cast immobilization in the elderly.

Locked plating in the elderly

Modern locked plates have been studied since the 1990s. They were introduced as a possible fixation technique for weakened cancellous bone and since then have been proven to be an invaluable treatment option for osteoporotic fractures, with several advantageous properties relative to

Table 1
Recommendations for nonsurgical treatment of fractures in the elderly.

Patient specific	Examples
Patient refuses surgery	informed consent denied
Informed consent not obtainable	delirium, dementia
Patient medically unfit for surgery	cardiopulmonary co-morbidities, poor soft tissues, poor peripheral vascular status, pre-existing immobility

conventional plating techniques [23]. The variable angles of metaphyseal screws that lock to the plate fixate bone regardless of its quality. Further, risk of plate and screws loosening is lower than in conventional plating, especially in osteoporotic bone [24,25]. Additionally, locking plates, as opposed to conventional plates, offer the advantage of stabilizing fractures without the need to compress the bone to the plate. This allows for improved vascularization and perfusion, and therefore, healing of the underlying bone. For the locking plate to achieve maximal fracture stability, a certain degree of stability in the bone should be guaranteed. Because the bone-implant interface is significantly diminished in osteoporotic bone, the potential for insufficient fixation is quite high. However, augmentation techniques can be utilized to strengthen the bone-implant interface, thereby increasing stability and screw-fixation in osteoporotic bone [26,27]. Disadvantages to locked plating are primarily attributable to the high rigidity of the construct. The mismatch between the highly rigid construct of the plate and screws and the low rigidity of osteoporotic bone produces a stress-riser that can lead to peri-implant fractures in up to 2.6% of cases [17]. Further, high stiffness minimizes micromotion at the level of the fracture, thereby inhibiting secondary fracture healing that can lead to high levels of nonunion. Modified locking plate constructs, such as far cortical locking plates, have been developed to reduce stiffness while maintaining the advantages of locked plating [28].

Intramedullary nails

Intramedullary nailing also has several advantages. They provide a less invasive operative technique with a resulting decrease in soft tissue damage. Nailing provides good stability even in cases of comminuted fractures and severe osteoporosis while maintaining fracture elasticity. Finally, nailing is associated with reduced operating time [29].

The minimally invasive nature of nailing preserves blood supply, fracture hematoma, and surrounding soft tissues of fractured bone that may improve fracture healing [30,31].

Prior to nailing, a decision of whether to ream or not to ream must be made. Reamed nailing allows for larger diameter nails and may therefore provide greater stability at the price of higher fat embolization rates [32,33]. The embolic effects of reaming have been studied in a sheep model. This effect could be minimized using an RIA-System (reamer, irrigator, and aspirator), a reamer that simultaneously irrigates and removes intramedullary debris as it reams [34].

Like locked plating, intramedullary nails show limited fixation strength in metaphyseal osteoporotic fractures. Insufficient nail interlocking in low bone density is associated with insufficient fracture fixation [35]. Attempts to improve fixation stability with augmentation, with the use of interlocking blades instead of screws, or with the use of angle stable locking screws have shown improved stability [36–38].

Bone augmentation techniques

Augmentation serves to increase the stability of bone structure to fixate the fracture and reduce pain or to provide a more stable anchor to enhance screw and plate fixation. Over three decades ago, bone augmentation was first described when polymethyl methacrylate (PMMA) cement was injected into vertebral bodies to treat vertebral hemangiomas [39]. This was the precursor to vertebroplasty for the treatment of osteoporotic vertebral compression fractures. Since then, augmentation techniques have been evaluated in numerous orthopedic subspecialties, including recent use in symptomatic nonunions of the calcaneus [26,40–42].

Pechon et al. investigated in a cadaveric model whether pullout strength of stripped screws in osteoporotic bone could be increased. They showed significantly higher pullout strength after augmenting the bone with stainless steel wire [43]. This has also been shown in screw augmentation with cement [26,27,40,44,45]. Today, PMMA screw augmentation is commonly used in spine surgery as well as in fractures of metaphyseal bone [26,40–42]. However, more research is needed to fully evaluate the role of bone augmentation. For example, the effect of augmentation on fracture healing is unknown, and there have been no studies investigating the effect of cement augmentation in ankle surgery.

PMMA

PMMA is a polymerized methyl ester of methacrylic acid. It has been successfully implemented in the treatment of various osteoporotic fractures, and is the standard of care in the surgical treatment of osteoporotic vertebral compression fractures [46,47]. PMMA is also used in the treatment of long-bone defects as described by Masquelet [48].

However, controversy over its use remains because of possible complications [49] including, but not limited to, thermal damage from the exothermic reaction, inability to remodel, inhibition of fracture healing, and difficulties in subsequent removal [41].

Hydroxyapatite

The mineral component of bone and teeth has been used as a prosthetic aid and in the prevention and treatment of osteoporosis {National Center for Biotechnology Information. https://pubchem.ncbi.nlm.nih.gov/compound/14781 (accessed Nov. 20, 2017)}. It was described as an excellent osteoconductive scaffold for bone ingrowth by Bucholz et al., in 1989 [50]. In more recent studies, hydroxyapatite is being evaluated as a regulator for calcium homeostasis and inducer of bone formation [40,44,45].

Specific fracture care in the elderly

Ankle fractures

The rate of ankle fractures in the geriatric population is increasing and is associated with poor outcomes [51]. They are the third most common fracture in the elderly population, accounting for approximately 10% of all fractures in this population [52]. These fractures provide a unique challenge in fracture care because of significant morbidity associated with surgery in this patient population.

Casting

Surgical complications are primarily due to poor fracture fixation of osteoporotic bone and significant risks of poor wound healing or infection due to poor soft tissue or vascular status. For this reason, nonoperative treatment is often considered even in unstable fracture patterns. This includes immobilization with a cast or ankle-foot orthosis, usually for no more than 6 weeks [19]. However, casting in unstable fractures is associated with nonunion, secondary loss of reduction, malunion, pressure sores, and pain [53]. A Cochrane Review from 2012 based on 292 patients across 3 clinical trials assessing conservative vs. surgical treatment in adults could not make a recommendation because of insufficient clinical data [54]. However, at 7-year follow-up, there was no difference in the rate of ankle arthritis. Adequate thromboembolic prophylaxis is recommended during partial weight-bearing [55]. Should surgical treatment be necessary, several newer fracture fixation options are available that address poor bone and soft tissue quality (see Table 2 and 3).

One third tubular plate

This is the most commonly used option in the surgical treatment of lateral malleolus fractures. The plate serves as the standard in most studies examining fractures of the lateral malleolus [56–59]. It can function as an antiglide plate when placed posterolaterally to prevent posterior and proximal

Table 2
Contraindications for nonoperative treatment of fractures in the elderly.

Contraindications for Nonoperative Treatment
Open fractures
Neurovascular damage
Severe pain

Table 3
Summary of our recommendations in periarticular fracture treatment of the elderly.

Scenario	Recommendation
Ankle fractures	
Minimal displacement, maintained joint congruency, stable fracture, vascular disease, other co-morbidities that contraindicate surgery	Casting
Low demand patients with domestic support	Casting
Severe soft tissue swelling	Casting or external fixation followed by ORIF or CRIF with plate or nail depending on soft tissue status
Poor soft tissues	Casting or CRIF with nail
Fracture with acute neurovascular compromise	ORIF
Open injury, severe pain, unstable fracture, intraarticular displacement, secondary dislocation	ORIF or CRIF with nail
Elbow fractures	
Olecranon fractures	Tension band wiring Locked plating in severely comminuted fractures
Distal humerus fractures	ORIF
highly complex distal humerus fractures in older, low demanding patients	Consider total elbow arthroplasty
Knee fractures	
Medically unfit for surgery, Denied informed consent for surgical treatment	Nonoperative treatment
Primary surgical treatment	ORIF
Pre-existing osteoarthritis	TKR
Isolated intraarticular distal femur fractures with destruction of the joint Frail patient unable to partial weight-bearing High risk of post-traumatic arthritis	

displacement of the distal fragment. Additionally, the plate can function as a neutralization plate when combined with a lag screw, which may be inserted through the plate [18,19]. It remains the preferred treatment option in fracture fixation of the elderly if the fracture is not majorly comminuted and bone quality is sufficient.

Locked plating of the fibula

In osteoporotic bone, or in comminuted fractures of the fibula as in pronation-abduction injuries common in the elderly [59], locked bridge plating provides an alternative to conventional plating of the fibula. They can provide superior fracture fixation and stability over conventional AO plating techniques, especially when bone quality is poor [60,61]. It should therefore be considered in osteoporotic fragility fractures, especially in comminuted fractures.

Current evidence for management of geriatric ankle fractures

In a recent large randomized clinical trial, Willett et al. investigated 6-month outcomes after close contact casting versus ppen reduction internal fixation (ORIF) for initial treatment of unstable ankle fractures in the elderly [62]. Patients without serious concomitant disease or vascular disease of the limb were randomly assigned either to close contact casting ($n = 311$) or ORIF ($n = 309$) group. In the casting group, treatment was based on nonweight-bearing or toe touch weight-bearing for 4 weeks with transition to full weight-bearing after 6–8 weeks and close radiographic follow-up to assess for

loss of reduction. Due to secondary loss of reduction, 19% of patients in the casting group switched to surgery. After 6 months, the Olerud–Molander ankle score was determined, along with quality of life, pain, range of motion, and complications. The study showed no significant difference in functional outcome or secondary outcome measures. Infections were more common in the surgery group (10% vs. 1%), while malunion (15% vs. 3%) was higher in the casting group. The authors conclude that close contact casting may be an adequate treatment modality even in unstable ankle fractures usually reserved for surgical treatment.

Intramedullary nailing has been investigated for use in fractures of the ankle in the elderly. In a prospective randomized controlled trial, White et al. investigated the one-year outcome of a fibular nailing versus standard plating in fibular fractures with or without syndesmotic lesions [63]. Fifty patients each were randomly assigned to the fibular nail group or the ORIF group. The latter group was treated according to AO/OTA guidelines with a one-third tubular neutralization plate with or without a lag screw. Both groups were treated postoperatively with full weight-bearing as tolerated in a synthetic cast postoperatively. At one-year follow-up, they showed similar functional outcomes with no significant difference in the Olerud– Molander ankle score [64] and the numeric analogue scale [1–10]. The group treated with the fibular nail suffered with significantly fewer wound infections. The authors conclude similar functional outcomes with less wound complications in the nail group. The surgical treatment of ankle fractures has not fundamentally changed since the 1960s; the advent of nailing provides an exciting alternative in the geriatric population with marginal soft tissues.

Special indication in the frail, multimorbid geriatric patient: the calcaneotalotibial nail

An additional option in unstable ankle fractures of the frail elderly patient is closed reduction and internal fixation by ankle arthrodesis with a calcaneotalotibial nail. A major advantage is immediate full weight-bearing postoperatively. Al Namari et al. investigated 48 frail, elderly patients with a displaced ankle fracture [65]. The patient group had a mean age of 82 years, was 85% female, and had mean ASA score of 3 or 4. All patients had multiple comorbidities and were only minimally mobile, with all patients requiring walking aids. Surgery was performed using a retrograde T2 Femoral Nailing System from Stryker; there was no intention to remove the nail unless necessary. Complications include infection (superficial 2%, deep 4%), distal screw loosening (6% of cases), valgus malunion (4%), and 1 below knee amputation in a case of severe peripheral vascular disease. There were no cases of nonunion, hardware failure, or peri-prosthetic fracture.

Another option in the frail patient is the short-retrograde calcaneotalotibial nail. It was investigated by Jonas et al. [58] in 31 consecutively treated patients. There were no cases of nonunion or infection, but 10% of patients suffered peri-prosthetic fractures and two nails failed within 2 years postoperatively. All patients returned to a similar level of mobility postoperatively. Peri-prosthetic fracture rates may be reduced by using a longer nail. The low rate of infection, high rate of union, and immediate full weight-bearing postoperatively suggest that closed reduction and calcaneotalotibial arthrodesis are viable options in the low-demand elderly patient.

Practice points

- The aim of treating ankle fractures should be early mobilization
- When plating, take poor bone quality into consideration and use locking-compression plates
- Take calcaneotalotibial nail into consideration in frail, multimorbid geriatric patients

Elbow fractures

Fractures in the elderly occur most often after a low-energy fall from standing height. Determining the incidence of falls is very difficult and potentially underestimated [66]. After fractures of the hip, the

most commonly fractured region in the elderly is the upper extremity. Palvanen et al. studied the injury mechanisms of osteoporotic upper extremity fractures in older adults and compared these mechanisms with control fallers. Their aim was to obtain insight into the etiology and pathogenesis of upper extremity fractures [67]. They studied 112 patients with fresh fractures of the proximal humerus, 65 patients with an elbow fracture, 110 patients with a wrist fracture, and 108 controls (no fracture or nonupper extremity fracture). The patients were older than 50 years at the time of accident, and the injury occurred due to low-energy trauma. Most patients who suffered an elbow fracture reported an oblique forward fall (38%) or a fall to the side (26%). Most of the fractures occurred outdoors (57%), and the main activity was walking straight ahead. The best possible functional outcome should be aimed for especially when treating fractures of the elbow [68]. Coupled to that are much lower incidences of postoperative complications due to generally superior soft tissue and vascular status when for example compared to geriatric fractures of the ankles. This is offset slightly by the increased risk of iatrogenic neurovascular damage.

Casting

Nonoperative treatment often results in loss of motion due to prolonged immobilization [69,70]. We generally do not recommend immobilizing the elbow for greater than 14 days and therefore focus on treatment that allows early functional aftercare.

We generally recommend surgical treatment of the distal humerus and olecranon fractures as they are often displaced, intraarticular, and/or comminuted with casting associated with poor functional outcomes [69]. This is especially true in olecranon fractures where even in nondisplaced fractures the pull of the triceps tendon often secondarily displaces the fracture [71]. Conservative treatment should be reserved for nondisplaced fractures in patients unfit for surgery. Immobilization should be minimized and a switch to a hinged brace should be considered as early as possible.

Tension band wiring of the olecranon

Olecranon fractures account for approximately 10% of all upper extremity fractures [68]. Primary treatment goals are anatomical reconstruction of the joint and early functional aftercare. Weber and Vasey first described tension band wiring in 1963 [72]. In the simple fractures without comminution of the osteochondral bone, it remains the standard of care and should be the treatment of choice regardless of the level of osteoporosis [68,73,74].

Plating of the olecranon

In comminuted fractures of the olecranon, bridge plating becomes the treatment modality of choice. Many studies have evaluated various bridge plate designs, either locking or nonlocking. No major differences in fixation strength in comminuted fractures between locking and nonlocking plates have been observed, even in osteoporotic bone [75]. Recent trends have shown a general shift of olecranon fracture fixation toward plating even in simple fractures. Recent biomechanical studies have shown increased fracture compression with compression plating techniques over tension band wiring as tension bands show, contrary to common belief, only minimal dynamic compression of the subchondral cortex [76].

Plating of distal humerus fractures

Fractures of the distal humerus account for 30% of elbow fractures. Although they are relatively rare, an increased incidence of these fractures has been noted in the geriatric population. Due to their complex articular anatomy, fractures of the distal humerus can be challenging to treat. Plating fractures of the distal humerus remains the standard surgical treatment [77,78]. The most important goal in surgical treatment is the stabile anatomic reconstruction of the articular surface as well as sufficient stability to allow early functional motion [18,19]. Thinner, well-contoured double locking plates that bridge or buttress distal humeral fractures have become the standard of care because they show

significant biomechanical advantages [79]. The question of plating location has been further evaluated in recent years. The AO recommends a medial and lateral plate separated by 180°. The Mayo Clinic recommends orthogonal plating with one plate placed dorsally and another medially or laterally. The Korosec group developed a less invasive approach that applies both plates dorsally to minimize surgical exposure. Few clinical studies exist to compare the options. A prospective randomized trial by Lee et al. compared orthogonal and parallel plating methods to treat distal humerus fractures [80]. At short- and long-term follow-up, no significant differences in radiologic or clinical outcomes including complication rates were shown. Several biomechanical studies have been done with differing results. A recent study by Bogataj et al. showed that in fractures with persisting diastasis between main fracture fragments, i.e., in significantly comminuted fractures, the parallel plate configuration showed the highest overall stability, followed by the perpendicular and dorsal Korosec configurations. If no diastasis is present, no significant differences in fixation stability between plate configurations were found [81]. Another retrospective clinical study by Korner et al. investigated the clinical outcome after ORIF in patients with a mean age of 73 years [82]. The results were good to excellent. Immobilization of no more than 14 days was recommended. Screw loosening and implant failure were the most common complications. Biz et al. investigated the radiologic and functional outcome of 51 elderly patients who underwent ORIF with dual pre-contoured locking plates in a retrospective study [83]. They showed satisfactory clinical and functional outcomes even in octogenarian patients (>85 years) with complex fractures. However, in maximally comminuted fractures (AO Type 13-C3), an average extension deficit of 24° and flexion deficit of 26° was shown. Such a significant loss of range of motion suggests the need for further investigation in Type C3 fractures.

Pre-contoured double locked plating remains the standard in distal humerus fractures. No significant difference in fracture fixation seems to exist between differing options for plate positioning. We recommend basing the choice of plate positioning on fracture pattern and surgeon preference.

Total elbow arthroplasty (TEA)

On a case-by-case basis, TEA serves as an alternative treatment option for severe fractures of the distal humerus. Evidence with respect to proper patient selection, complication rates, and functional outcomes varies in the literature [84–89]. Most significantly, long-term outcomes of TEA are unknown. In a landmark trial from Barco et al., the first long-term 10-year study results for TEA were published this year. They showed an overall revision rate of 18%. However, revision in patients without rheumatoid arthritis was only 8% at 10-year follow-up [90]. These results may suggest a promising future for TEA in the treatment of severe fractures of the elbow. Overall, however, many studies with differing outcomes and treatment recommendations have been conducted. Definitive guidelines on which to recommend TEA therefore remain elusive and show the necessity for further investigation.

ORIF versus TEA

Biz et al. and others have shown that functional outcomes in maximally comminuted and possibly nonreconstructable elbow fractures are poor. TEA may ultimately prove to be a viable and even preferred option in the frail, geriatric patient. In a retrospective review, Frankle et al. summarized and compared the Mayo Elbow Performance score of 24 patients with severe distal humerus fractures (AO Type 13-C2 or 3) [84]. Half of the patients were assigned to ORIF and half of them to total elbow arthroplasty. After a mean follow up of 45 months (TEA) and 57 months (ORIF), the mean Mayo Elbow Performance score was 95 in the TEA group and 81 in the ORIF group, with a lower complication rate in the TEA group. These findings are supported by the results of McKee et al. [89].

In a retrospective study, Medvedev et al. discuss predictive factors to identify risk factors associated with postoperative complications while comparing ORIF and TEA [91]. Clinical complications were generally low in both groups, with bleeding requiring transfusion being the most common complication. ASA class 3 or 4 was the most significant predictive factor for the risk of postoperative complications. At 30-day follow up, significant differences in morbidity, mortality as well as complication rates between ORIF and TEA were not observed.

Due to significant risk of complication and still largely unknown long-term outcomes, the use of TEA should only be considered on a case by case basis in severe fractures of frail, older patients with low functional demands [90,92]. However, there is promising and ever-increasing evidence to suggest that

TEA offers a viable treatment option in severe fractures of the distal humerus. If the fractured elbow consists of acceptable bone quality, is not severely comminuted, and the patient is physiologically younger, then ORIF is recommended.

Practice points

- Aim for minimal immobilization time of the upper extremity
- The patient's usual activities of daily living define the degree of movement needed

Treating elbow fractures in the elderly patient presents multiple challenges due to complex anatomy and risks of poor functional outcomes primarily due to loss in range of motion.

Knee fractures

Fractures of the knee include the distal femur, proximal tibia/tibia plateau, proximal fibula, and patella. In an epidemiologic review of adult fractures, Court-Brown and Caesar showed a total fracture rate of 1.2% for the proximal tibia, 1% for the patella, and 0.4% for the distal femur [1]. However, fracture rates around the knee rise sharply in the elderly population, with 86% of distal femur fractures occurring in patients more than 70 years of age. They therefore comprise an important aspect of fragility fracture care.

Conservative treatment

Nonsurgical treatment should only be considered in nondisplaced fractures of patients that can ambulate, and where early functional treatment of the knee can be performed. This is due to poor functional outcomes associated with long periods of knee immobilization [93,94].

Plating

Locked bridge plating techniques are the standard of care for osteoporotic fractures of both the distal femur and proximal tibia. Several newer techniques have been developed to reduce post-operative complications.

While technically demanding, minimally invasive percutaneous plate osteosynthesis is a valid option to reduce postoperative morbidity associated with standard surgical exposure in the geriatric population [95]. In some cases of proximal tibial fractures, hybrid locked plating can grant additional stability by using conventional screws to add a buttress fixation component, while minimizing screw pullout through use of locking screws in the rest of the plate. This hybrid technique was described by Gardner et al. using a large fragment locking compression plate [96]. The regions of highest cancellous bone density in the proximal tibia are found posterolaterally and posteromedially [97]. This should be taken into consideration when planning screw fixation. In tibial plateau fractures, it is essential to stabilize each column [98] to prevent secondary loss of reduction. If further fixation stability is necessary, augmentation with PMMA has been shown to decrease cut-out in biomechanical models of both distal femoral and proximal tibial fractures [99,100].

ORIF vs. immediate total knee replacement (TKR) in periarticular fractures of the knee

In 2012, Bohm et al. reviewed whether osteoporotic fractures about the knee should be treated by ORIF or immediate TKR [101]. Since TKR after unsuccessful ORIF is challenging, the choice of operative treatment can be difficult. ORIF is still the preferred operative treatment of choice in most fractures of the distal femur and proximal tibia. When choosing ORIF, every attempt to maintain the joint surface should be made to prevent symptomatic posttraumatic arthritis that may necessitate future TKR [102].

Challenges of ORIF in osteoporotic bone include secondary loss of fixation, post-traumatic arthritis, malunion/nonunion, as well as medical morbidity associated with postoperative immobilization [103–105]. In severe osteoporotic fractures about the knee, especially with pre-existing osteoarthritis and destruction of the joint surface, the threshold for treatment with primary TKR is lowered when considering the postoperative complications of ORIF, especially if postoperative partial weight-bearing is not possible [104–106]. Immediate TKR usually allows immediate postoperative weight-bearing as tolerated and negates the risk of an additional surgery in the form of TKR to treat posttraumatic arthritis. However, correlation between failed ORIF and clinical outcomes seems to be poor, and the potential for symptomatic posttraumatic arthritis may not justify prophylactic TKR [107,108].

Practice points

- If surgical fixation is needed, ORIF through locked compression plating as standard treatment is conducted
- Aim for early mobilization and early weight-bearing
- Primary TKR may be indicated in some periarticular fractures of the knee

Research agenda

This review highlights different treatment strategies of fragility fractures in the elderly. However, as this patient group represents a relatively new cohort, there is a high demand of well-conducted clinical trials to define the optimal treatment for fractures in the elderly. Currently, there is a lack of evidence in the indication for surgical treatment of fragility fractures, especially with focus on functional outcome in general:

- Are there different indications for surgical treatment of fractures in the elderly compared to standard recommendations?
- What characteristics determine the functional outcome and the subjective satisfaction of the patient when treating a fracture nonsurgically versus surgically?
- Is there a correlation of cost-effectiveness functional outcome with the quality of life of the patient after surgical treatment?

Next to the need of high-quality research assessing these general points, there still is need for identification of the best treatment recommendation on specific fractures:

- Is the outcome after treatment of fractures around the elbow superior after total elbow arthroplasty or after plate osteosynthesis
- Which patient specific factors influence the outcome comparing treatment of fractures around the shoulder with shoulder prosthesis to osteosynthesis?
- Is the quality of life of elderly higher after surgical treatment of fragility fractures than after nonsurgical treatment?

The main focus of future research should lie in the evaluation of the currently well-established indications for surgical treatment of specific fractures in each anatomic location: Do these indications differ in the geriatric trauma patient?

Summary

The aim in treating fragility fractures in the elderly is early mobilization. With early mobilization, the risk of complications such as pneumonia or thrombosis decreases. Further patients' needs and expectations should be taken into consideration when treating fractures. The comorbidities of the elderly as well as the soft tissue status may present as limiting factors when it comes to surgical treatment of the fracture. Next to these factors, the quality of the bone presents a limiting factor of surgical treatment. These limitations can be overcome by using LCP, cement augmented techniques, or intramedullary nailing as appropriate.

While the aim of treating fractures of the lower extremities aims for appropriate and early weight-bearing to mobilize the patient as soon as possible, treatment of fractures of the upper extremity should include as little immobilization of the extremity as possible.

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None of the authors have any conflict of interests.

References

[1] Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury 2006;37(8):691–7.
[2] Johnell O, Kanis J. Epidemiology of osteoporotic fractures. Osteoporos Int 2005;16(2):S3–7.
[3] Riggs BL. Age-related osteoporosis. Nutr Aging 2012:207.
[4] Johansson H, Kanis JA, Odén A, et al. A meta-analysis of the association of fracture risk and body mass index in women. J Bone Miner Res 2014;29(1):223–33.
[5] Sturm R. Increases in morbid obesity in the USA: 2000–2005. Publ Health 2007;121(7):492–6.
[6] Lerner U. Bone remodeling in post-menopausal osteoporosis. J Dent Res 2016;85(7):584–95. https://doi.org/10.1177/154405910608500703.
[7] Court-Brown CM, Clement ND, Duckworth AD, et al. The changing epidemiology of fall-related fractures in adults. Injury 2017 Apr;48(4):819–24. PubMed PMID: 28283181. Epub 2017/03/12.
[8] Rachner TD, Khosla S, Hofbauer LC. Osteoporosis: now and the future. Lancet 2011;377(9773):1276–87.
[9] Antebi B, Pelled G, Gazit D. Stem cell therapy for osteoporosis. Curr Osteoporos Rep 2014;12(1):41–7.
[10] Eriksen EF, Díez-Pérez A, Boonen S. Update on long-term treatment with bisphosphonates for postmenopausal osteoporosis: a systematic review. Bone 2014;58:126–35.
[11] Weaver C, Alexander D, Boushey C, et al. Calcium plus vitamin D supplementation and risk of fractures: an updated meta-analysis from the National Osteoporosis Foundation. Osteoporos Int 2016;27(1):367–76.
[12] Kanis JA, Svedbom A, Harvey N, McCloskey EV. The osteoporosis treatment gap. J Bone Miner Res 2014;29(9):1926–8.
[13] Omsland T, Magnus J. Forecasting the burden of future postmenopausal hip fractures. Osteoporos Int 2014;25(10):2493–6.
[14] Chao EY, Inoue N, Koo TK, Kim Y. Biomechanical considerations of fracture treatment and bone quality maintenance in elderly patients and patients with osteoporosis. Clin Orthop Relat Res 2004;425:12–25.
[15] Strømsøe K. Fracture fixation problems in osteoporosis. Injury 2004;35(2):107–13.
[16] Giannoudis P, Tzioupis C, Almalki T, Buckley R. Fracture healing in osteoporotic fractures: is it really different?: a basic science perspective. Injury 2007;38(1):S90–9.
[17] Kammerlander C, Erhart S, Doshi H, et al. Principles of osteoporotic fracture treatment. Best Pract Res Clin Rheumatol 2013;27(6):757–69.
[18] Rüedi TP, Murphy WM. AO principles of fracture management. Davos: AO Publishing & Stuttgart New York: Georg Thieme Verlag; 2000.
[19] Colton C, Krikler S, Schatzker J, Trafton P. AO surgery reference. AO Foundation; 2011.
[20] Stockle U, Konig B, Tempka A, Sudkamp N. Cast immobilisation or vacuum stabilizing system? Unfallchirurg 2000;103(3):215–9.
[21] Stuby FM, Döbele S, Schäffer S-D, et al. Early functional postoperative therapy of distal radius fracture with a dynamic orthosis: results of a prospective randomized cross-over comparative study. PLoS One 2015;10(3):e0117720.
[22] Epidemiology and risk factors for venous thrombosis. In: Cushman M, editor. Seminars in hematology. Elsevier; 2007.
[23] Miclau T, Remiger A, Tepic S, et al. A mechanical comparison of the dynamic compression plate, limited contact-dynamic compression plate, and point contact fixator. J Orthop Trauma 1995;9(1):17–22.
[24] Fulkerson E, Koval K, Preston CF, et al. Fixation of periprosthetic femoral shaft fractures associated with cemented femoral stems: a biomechanical comparison of locked plating and conventional cable plates. J Orthop Trauma 2006;20(2):89–93.

[25] Strauss EJ, Schwarzkopf R, Kummer F, Egol KA. The current status of locked plating: the good, the bad, and the ugly. J Orthop Trauma 2008;22(7):479–86.
[26] Osterhoff G, Dodd AE, Unno F, et al. Cement augmentation in sacroiliac screw fixation offers modest biomechanical advantages in a cadaver model. Clin Orthop Relat Res® 2016;474(11):2522–30.
[27] Grechenig S, Gänsslen A, Gueorguiev B, et al. PMMA-augmented SI screw: a biomechanical analysis of stiffness and pull-out force in a matched paired human cadaveric model. Injury 2015;46:S125–8.
[28] Bottlang M, Lesser M, Koerber J, et al. Far cortical locking can improve healing of fractures stabilized with locking plates. J Bone Joint Surg Am Vol 2010;92(7):1652.
[29] Boileau P, d'Ollonne T, Clavert P, Hatzidakis AM. Intramedullary nail for proximal humerus fractures: an old concept revisited. Simple and complex fractures of the humerus. Springer; 2015. p. 91–112.
[30] Sanders R, Haidukewych GJ, Milne T, et al. Minimal versus maximal plate fixation techniques of the ulna: the biomechanical effect of number of screws and plate length. J Orthop Trauma 2002;16(3):166–71.
[31] Bogunovic L, Cherney SM, Rothermich MA, Gardner MJ. Biomechanical considerations for surgical stabilization of osteoporotic fractures. Orthopedic Clin 2013;44(2):183–200.
[32] Blachut P, O'brien P, Meek RN, Broekhuyse H. Interlocking intramedullary nailing with and without reaming for the treatment of closed fractures of the tibial shaft. A prospective, randomized study. Orthop Trauma Dir 2005;3(05):25–9.
[33] Pape H-C, Dwenger A, Regel Q, et al. Pulmonary damage after intramedullary femoral nailing in traumatized sheep-is there an effect from different nailing methods? J Trauma Acute Care Surg 1992;33(4):574–81.
[34] Pape H-C, Zelle BA, Hildebrand F, et al. Reamed femoral nailing in sheep: does irrigation and aspiration of intramedullary contents alter the systemic response? JBJS 2005;87(11):2515–22.
[35] Wähnert D, Hoffmeier KL, von Oldenburg G, et al. Internal fixation of type-C distal femoral fractures in osteoporotic bone. JBJS 2010;92(6):1442–52.
[36] Ito K, Hungerbühler R, Wahl D, Grass R. Improved intramedullary nail interlocking in osteoporotic bone. J Orthop Trauma 2001;15(3):192–6.
[37] Wähnert D, Stolarczyk Y, Hoffmeier KL, et al. Long-term stability of angle-stable versus conventional locked intramedullary nails in distal tibia fractures. BMC Muscoskelet Disord 2013;14(1):66.
[38] Wähnert D, Stolarczyk Y, Hoffmeier KL, et al. The primary stability of angle-stable versus conventional locked intramedullary nails. Int Orthop 2012;36(5):1059–64.
[39] Galibert P, Deramond H, Rosat P, Le Gars D. Preliminary note on the treatment of vertebral angioma by percutaneous acrylic vertebroplasty. Neurochirurgie 1987;33(2):166–8.
[40] Jang SH, Lee JH, CHo JY, et al. The efficacy of hydroxyapatite for screw augmentation in osteoporotic patients. Neurol Med -Chir 2013;53(12):875–81.
[41] Kammerlander C, Neuerburg C, Verlaan J-J, et al. The use of augmentation techniques in osteoporotic fracture fixation. Injury 2016;47:S36–43.
[42] Zaryanov AV, Park DK, Khalil JG, et al. Cement augmentation in vertebral burst fractures. Neurosurg Focus 2014;37(1):E5.
[43] Pechon PH, Mears SC, Langdale ER, Belkoff SM. Salvaging the pullout strength of stripped screws in osteoporotic bone. Geriatr Orthop Surg Rehabil 2013;4(2):50–2.
[44] Zhao R, Xie P, Zhang K, et al. Selective effect of hydroxyapatite nanoparticles on osteoporotic and healthy bone formation correlates with intracellular calcium homeostasis regulation. Acta Biomater 2017;59:338–50.
[45] Yi S, Rim D-C, Park SW, et al. Biomechanical comparisons of pull out strengths after pedicle screw augmentation with hydroxyapatite, calcium phosphate, or polymethylmethacrylate in the cadaveric spine. World Neurosurg 2015;83(6):976–81.
[46] Deramond H, Depriester C, Galibert P, Le Gars D. Percutaneous vertebroplasty with polymethylmethacrylate: technique, indications, and results. Radiol Clin 1998;36(3):533–46.
[47] Anagnostakos K, Fürst O, Kelm J. Antibiotic-impregnated PMMA hip spacers: current status. Acta Orthop 2006;77(4):628–37.
[48] Masquelet AC, Begue T. The concept of induced membrane for reconstruction of long bone defects. Orthop Clin N Am 2010;41(1):27–37.
[49] Salles AG, Lotierzo PH, Gemperli R, et al. Complications after polymethylmethacrylate injections: report of 32 cases. Plast Reconstr Surg 2008;121(5):1811–20.
[50] Bucholz RW, Carlton A, Holmes R. Interporous hydroxyapatite as a bone graft substitute in tibial plateau fractures. Clin Orthop Relat Res 1989;240:53–62.
[51] Davidovitch RI, Walsh M, Spitzer A, Egol KA. Functional outcome after operatively treated ankle fractures in the elderly. Foot Ankle Int 2009;30(8):728–33.
[52] Sporer SM, Weinstein JN, Koval KJ. The geographic incidence and treatment variation of common fractures of elderly patients. J Am Acad Orthop Surg 2006;14(4):246–55.
[53] Lehtonen H, Järvinen TL, Honkonen S, et al. Use of a cast compared with a functional ankle brace after operative treatment of an ankle fracture: a prospective, randomized study. JBJS 2003;85(2):205–11.
[54] Donken C, Al-Khateeb H, Verhofstad M, van Laarhoven C. Surgical versus conservative interventions for treating ankle fractures in adults. Cochrane Database Syst Rev 2012;(8):CD008470. https://doi.org/10.1002/14651858.CD008470.pub2.
[55] Bruntink MM, Groutars YM, Schipper IB, et al. Nadroparin or fondaparinux versus no thromboprophylaxis in patients immobilised in a below-knee plaster cast (PROTECT): a randomised controlled trial. Injury 2017 Apr;48(4):936–40. PubMed PMID: 28279428. Epub 2017/03/11.
[56] Asloum Y, Bedin B, Roger T, et al. Internal fixation of the fibula in ankle fractures. A prospective, randomized and comparative study: plating versus nailing. Orthop Traumatol: Surg Res 2014;100(4):S255–9.
[57] Hoogervorst P, Van Bergen C, Van den Bekerom M. Management of osteoporotic and neuropathic ankle fractures in the elderly. Curr Geriatr Rep 2017;6(1):9–14.
[58] Jonas SC, Young AF, Curwen CH, McCann PA. Functional outcome following tibio-talar-calcaneal nailing for unstable osteoporotic ankle fractures. Injury 2013 Jul;44(7):994–7. PubMed PMID: 23237604. Epub 2012/12/15.
[59] Rammelt S. Management of ankle fractures in the elderly. EFORT Open Rev 2016;1(5):239–46.

[60] Dingemans SA, Lodeizen OA, Goslings JC, Schepers T. Reinforced fixation of distal fibula fractures in elderly patients; A meta-analysis of biomechanical studies. Clin Biomech 2016;36:14–20.
[61] Switaj PJ, Wetzel RJ, Jain NP, et al. Comparison of modern locked plating and antiglide plating for fixation of osteoporotic distal fibular fractures. Foot Ankle Surg 2016;22(3):158–63.
[62] Willett K, Keene DJ, Mistry D, et al. Close contact casting vs surgery for initial treatment of unstable ankle fractures in older adults: a randomized clinical trial. JAMA 2016;316(14):1455–63.
[63] White TO, Bugler K, Appleton P, et al. A prospective randomised controlled trial of the fibular nail versus standard open reduction and internal fixation for fixation of ankle fractures in elderly patients. Bone Joint J 2016;98(9):1248–52.
[64] Olerud C, Molander H. A scoring scale for symptom evaluation after ankle fracture. Arch Orthop Trauma Surg 1984; 103(3):190–4.
[65] Al-Nammari S, Dawson-Bowling S, Amin A, Nielsen D. Fragility fractures of the ankle in the frail elderly patient. Bone Joint J 2014;96(6):817–22.
[66] Pape H-C, Schemmann U, Foerster J, Knobe M. The 'Aachen Falls Prevention Scale'-development of a tool for self-assessment of elderly patients at risk for ground level falls. Patient Saf Surg 2015;9(1):7.
[67] Palvanen M, Kannus P, Parkkari J, et al. The injury mechanisms of osteoporotic upper extremity fractures among older adults: a controlled study of 287 consecutive patients and their 108 controls. Osteoporos Int 2000;11(10):822–31.
[68] Rommens P, Küchle R, Schneider R, Reuter M. Olecranon fractures in adults: factors influencing outcome. Injury 2004; 35(11):1149–57.
[69] John H, Rosso R, Neff U, et al. Operative treatment of distal humeral fractures in the elderly. Bone Joint J 1994; 76(5):793–6.
[70] Zagorski JB, Jennings JJ, Burkhalter WE, Uribe JW. Comminuted intraarticular fractures of the distal humeral condyles: surgical vs. Nonsurgical treatment. Clin Orthop Relat Res 1986;202:197–204.
[71] Brolin TJ, Throckmorton T. Olecranon fractures. Hand Clin 2015;31(4):581–90.
[72] Weber BG, Vasey H. Osteosynthesis in olecranon fractures. Z Unfallmed Berufskr 1963;56:90–6. PubMed PMID: 14049893. Epub 1963/01/01. Osteosynthese bei olekranonfraktur.
[73] Claessen FM, van den Bekerom MP, van Dijk CN, et al. Tension band wiring for simple olecranon fractures: evaluation of surgical technique. J Orthop Traumatol 2017;18(3):275–81.
[74] Wiegand L, Bernstein J, Ahn J. Fractures in brief: olecranon fractures. Springer; 2012.
[75] Edwards SG, Martin BD, Fu RH, et al. Comparison of olecranon plate fixation in osteoporotic bone: do current technologies and designs make a difference? J Orthop Trauma 2011;25(5):306–11.
[76] Wilson J, Bajwa A, Kamath V, Rangan A. Biomechanical comparison of interfragmentary compression in transverse fractures of the olecranon. Bone Joint J 2011;93(2):245–50.
[77] Pajarinen J, Björkenheim J-M. Operative treatment of type C intercondylar fractures of the distal humerus: results after a mean follow-up of 2 years in a series of 18 patients. J Shoulder Elb Surg 2002;11(1):48–52.
[78] Pape H-C, Hildebrand F, Kart I. Basis OPs-top 20 in der Unfallchirurgie. Elsevier Health Sciences; 2014.
[79] Jacobson S, Glisson R, Urbaniak J. Comparison of distal humerus fracture fixation: a biomechanical study. J South Orthop Assoc 1997;6(4):241–9.
[80] Lee SK, Kim KJ, Park KH, Choy WS. A comparison between orthogonal and parallel plating methods for distal humerus fractures: a prospective randomized trial. Eur J Orthop Surg Traumatol 2014;24(7):1123–31.
[81] Bogataj M, Kosel F, Norris R, et al. Biomechanical study of different plate configurations for distal humerus osteosynthesis. Med Biol Eng Comput 2015;53(5):381–92.
[82] Korner J, Lill H, Müller LP, et al. Distal humerus fractures in elderly patients: results after open reduction and internal fixation. Osteoporos Int 2005;16(2):S73–9.
[83] Biz C, Sperotto SP, Maschio N, et al. The challenging surgical treatment of closed distal humerus fractures in elderly and octogenarian patients: radiographic and functional outcomes with a minimum follow-up of 24 months. Arch Orthop Trauma Surg 2017;137(10):1371–83.
[84] Frankle MA, Herscovici D, DiPasquale TG, et al. A comparison of open reduction and internal fixation and primary total elbow arthroplasty in the treatment of intraarticular distal humerus fractures in women older than age 65. J Orthop Trauma 2003;17(7):473–80.
[85] Ali A, Shahane S, Stanley D. Total elbow arthroplasty for distal humeral fractures: indications, surgical approach, technical tips, and outcome. J Shoulder Elb Surg 2010;19(2):53–8.
[86] Chalidis B, Dimitriou C, Papadopoulos P, et al. Total elbow arthroplasty for the treatment of insufficient distal humeral fractures. A retrospective clinical study and review of the literature. Injury 2009;40(6):582–90.
[87] Cobb TK, Morrey BF. Total elbow arthroplasty as primary treatment for distal humeral fractures in elderly patients. JBJS 1997;79(6):826–32.
[88] Garcia J, Mykula R, Stanley D. Complex fractures of the distal humerus in the elderly. Bone Joint J 2002;84(6):812–6.
[89] McKee MD, Veillette CJ, Hall JA, et al. A multicenter, prospective, randomized, controlled trial of open reduction—internal fixation versus total elbow arthroplasty for displaced intra-articular distal humeral fractures in elderly patients. J Shoulder Elb Surg 2009;18(1):3–12.
[90] Barco R, Streubel PN, Morrey BF, Sanchez-Sotelo J. Total elbow arthroplasty for distal humeral fractures: a ten-year-minimum follow-up study. JBJS 2017;99(18):1524–31.
[91] Medvedev G, Wang C, Amdur R, et al. Operative distal humerus fractures in older patients: predictors for early complications based on a national database. HSS J® 2017:1–5.
[92] Schoch BS, Werthel J-D, Sánchez-Sotelo J, et al. Total elbow arthroplasty for primary osteoarthritis. J Shoulder Elb Surg 2017;26(8):1355–9.
[93] Butt M, Krikler S, Ali M. Displaced fractures of the distal femur in elderly patients. J Bone Joint Surg Br 1996;78(1):110–4.
[94] Moore TM, Patzakis MJ, Harvey JP. Tibial plateau fractures: definition, demographics, treatment rationale, and long-term results of closed traction management or operative reduction. J Orthop Trauma 1987;1(2):97–119.
[95] Krettek C, Schandelmaier P, Nliclau T, Tscherne H. Minimally invasive percutaneous plate osteosynthesis (MIPPO) using the DCS in proximal and distal femoral fractures. Injury 1997;28:A20–30.

[96] Gardner MJ, Griffith MH, Demetrakopoulos D, et al. Hybrid locked plating of osteoporotic fractures of the humerus. JBJS 2006;88(9):1962–7.
[97] Khodadadyan-Klostermann C, von Seebach M, Taylor WR, et al. Distribution of bone mineral density with age and gender in the proximal tibia. Clin Biomech 2004;19(4):370–6.
[98] Luo C-F, Sun H, Zhang B, Zeng B-F. Three-column fixation for complex tibial plateau fractures. J Orthop Trauma 2010; 24(11):683–92.
[99] Kawagoe K, Saito M, Shibuya T, et al. Augmentation of cancellous screw fixation with hydroxyapatite composite resin (CAP) in vivo. J Biomed Mater Res A 2000;53(6):678–84.
[100] Wähnert D, Lange J, Schulze M, et al. The potential of implant augmentation in the treatment of osteoporotic distal femur fractures: a biomechanical study. Injury 2013;44(6):808–12.
[101] Bohm E, Tufescu T, Marsh J. The operative management of osteoporotic fractures of the knee. J Bone Joint Surg Br 2012; 94(9):1160–9.
[102] Giannoudis P, Tzioupis C, Papathanassopoulos A, et al. Articular step-off and risk of post-traumatic osteoarthritis. Evidence Today. Injury 2010;41(10):986–95.
[103] Civinini R, Carulli C, Matassi F, et al. Total knee arthroplasty after complex tibial plateau fractures. Musculoskelet Surg 2009;93(3):143–7.
[104] Rosen AL, Strauss E. Primary total knee arthroplasty for complex distal femur fractures in elderly patients. Clin Orthop Relat Res 2004;425:101–5.
[105] Vermeire J, Scheerlinck T. Early primary total knee replacement for complex proximal tibia fractures in elderly and osteoarthritic patients. Acta Orthop Belg 2010;76(6):785.
[106] Weber O, Goost H, Mueller M, et al. Mid-term results after post-traumatic knee joint replacement in elderly patients. Zeitschrift fur Orthopadie und Unfallchirurgie 2011;149(2):166–72.
[107] Frattini M, Vaienti E, Soncini G, Pogliacomi F. Tibial plateau fractures in elderly patients. Musculoskelet Surg 2009; 93(3):109–14.
[108] Roerdink WH, Oskam J, Vierhout PA. Arthroscopically assisted osteosynthesis of tibial plateau fractures in patients older than 55 years. Arthroscopy: J Arthrosc Relat Surg 2001;17(8):826–31.