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Articular impaction injuries in the lower limb

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- The effective management of articular impacted fractures requires the successful elevation of the osteochondral fragment to eliminate joint incongruency and the stable fixation of the fragments providing structural support to the articular surface.
- The anatomical restoration of the joint can be performed either with elevation through a cortical window, through balloon-guided osteoplasty or direct visualisation of the articular surface.
- Structural support of the void created in the subchondral area can be achieved through the use of bone graft materials (autologous tricortical bone), or synthetic bone graft substitutes.
- In the present study, we describe the available techniques and materials that can be used in treating impacted osteochondral fragments with special consideration of their epidemiology and treatment options.

Keywords: articular impaction; cartilage damage; void; bone grafts; bone graft substitutes

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Introduction

Treatment of impacted fractures of the lower limb is technically demanding and requires extensive experience of multiple forms of fixation and bone grafting. One of the primary challenges is the need for rigid fixation, which will allow the patient to weight-bear early, thus facilitating early post-operative rehabilitation and prevention of stiffness. When the joint surface is involved, anatomical restoration of the surface is of paramount importance to eliminate the risk of a residual step-off and inadequate joint congruency, which frequently leads to the development of post-traumatic arthritis. A 2-mm articular step or depression is considered the maximal limit of 'permitted' incongruency that can be managed by non-operative means.[1] The effective filling of the subchondral bone voids following successful elevation of osteochondral fragments remains an essential part of treatment as it provides structural support, eliminating the risk of secondary collapse and subsequent failure.

The aim of this manuscript is twofold: first, to describe the current techniques in reducing impacted osteochondral defects and the available bone filling materials; and second, to present our current understanding of impacted or depressed fractures of the lower limb, with special consideration of their epidemiology and the treatment options.

General principles and techniques of anatomical restoration of the depressed joint surface

The anatomical restoration of the joint surface in intra-articular impacted fractures can be achieved mainly by two popularised methods: a) a bone punch using a cortical window that allows access to the depressed fragment or b) the balloon inflation osteoplasty.[2-4] The first method involves the creation of a cortical window of 10 × 20 mm below the impacted osteochondral fragment. This allows a hollow trephine cutter of 10 mm to be introduced under fluoroscopic control 2 cm below the osteochondral defect. A bone punch of 9 mm is then introduced through the cutter and with a hammer, the osteochondral fragment is elevated.[5,6] The bone block inside the cutter is then impacted under the fragment providing the graft material that will support and fill the defect. In cases where larger voids are created, alternative bone graft material can be used to provide structural support to the osteochondral fragments. Alternative instrumentation to the hollow trephine cutter includes the use of bone punches, probes or a triple reamer from the sliding hip screw set.[3,4] The reduction of the articular surface congruency can be assessed either indirectly (arthroscopically or under fluoroscopy) or directly by an arthrotomy of the joint and direct visualisation of the affected area. Fixation of the fracture is then initiated depending on the fracture configuration.

A less invasive technique, previously developed for the management of osteoporotic vertebral compression fractures, utilises indirect fracture reduction by a balloon.

Guided inflation represents the second method.[2] This approach has gained great popularity recently and has been successfully applied in various anatomical sites including the distal radius, calcaneus, tibial pilon and the tibial plateau. In general terms, balloon inflation osteoplasty involves the introduction of an inflatable bone tamp under fluoroscopic guidance through the contralateral side of the fractured bone.[7] A pointed reduction clamp can be applied percutaneously to avoid displacement of bone fragments in the transverse plane. Buttress plating or prior fixation of large fragments can be used according to the indications and pre-operative planning. Inflation of the balloon is achieved by the use of an inflation syringe filled with radiopaque dye attached proximally to a luer-lock connection. It is imperative not to overcorrect the fragments and a progressive inflation technique with images taken every 0.5 to 1.0 cc (or 30 to 50 psi) should be followed. After ensuring anatomical reduction, K-wires can be used to safeguard the articular reduction and the void is filled with synthetic bone graft material. The final fixation by percutaneous or open means can be commenced following the filling of the bone void. This technique has several advantages including application on a minimally invasive basis, minimal soft tissue damage, improved accuracy of articular reduction, a lower risk of joint penetration and improved graft distribution.[8] The use of an inflatable bone tamp in association with calcium phosphate bone-void filler to reduce and maintain reduction of an articular fracture was found to achieve a more anatomical reduction with better resistance to subsidence than conventional tamps.[9] Pitfalls include the early identification of a ‘trap door’ phenomenon (the balloon does not inflate evenly and the articular fracture does not elevate) and bursting of the balloon with escape of radio-opaque dye within the local environment.[2,8,9] In the latter scenario, irrigation of the bone void using normal saline and re-insertion of the balloon should be performed.

While direct visualisation for confirming the anatomical reduction of the depressed fragment is advocated by many surgeons, others have utilised arthroscopy as a tool of the evaluation of fracture reduction. Advocates of this approach argue that there is an opportunity at the same time to deal with concomitant injuries of the affected extremity (particularly the knee) where feasible.[5] However, this might be impractical for the vast majority of intra-articular impacted fractures with the nature of peri-articular soft tissues often sustained. In the knee joint, common injuries include meniscal lesions in tibial plateau fractures which have been reported to occur in 47% of the cases.[10] Repair of such injuries can be performed at the same time with fixation and there is good evidence to support the view that it improves the long-term outcome.[11] Osteochondral fragments that are too small for fixation as well as bone debris can be removed. A theoretical risk of compartment syndrome exists but it is rare and only presented in case reports.[12] If an irrigation pump is used, a low pressure setting should be used ($>$ 50 mmHg) and the compartments should be monitored throughout the procedure and post-operatively.

Bone void-filling materials

Our armamentarium of bone void fillers has expanded in recent years. One option to consider is the autologous tri-cortical bone graft harvested from the iliac crest.[12] It possesses structural strength, and all the desirable properties of a graft material being osteo-conductive, osteo-inductive and osteogenic.[13,14] However, for its harvesting, it requires an extra procedure which adds to the operating time. In addition, its use can be limited by its limited size availability and the development of both minor and major complications associated with the surgical procedure.[14,15] On this basis, the use of bone graft substitutes has been popularised.

Synthetic materials commonly used to fill bone voids include ceramics, PMMA (polymethylmethacrylate bone cement), bio-active glasses, porous metals, corals and synthetic polymers.[15] They can be absorbable or permanent implants and can have a variable degree of stability following implantation. These materials can be combined with recombinant growth factors or cells of osteogenic lineages to attempt to improve their biological properties.[16] From the limited number of available studies that compare autologous bone grafting and bone substitute materials, it appears that both are equally effective. Some authors even claim that more favourable results can be attained from synthetic bone substitutes with no difference in the infection rate or transmissible diseases.[13,15,16] These studies showed that bone substitutes produced improved stability, facilitated early mobilisation, improved functional outcomes and reduced the operative time. A recent review on the use of bone graft substitutes for the prevention of secondary articular collapse of tibial plateau fractures indicated that synthetic substitutes outperformed the biologic autograft materials.[15] With regard to the decision-making process to define the ideal graft material, the literature provides limited evidence. Prior planning defining the targets to be achieved intra-operatively, the surgical approach, the biocompatibility and the characteristics of the implant should guide the selection process.

One category of bone substitutes that has gained increased acceptance recently is the injectable materials. Several authors highlighted that the use of injectable phosphate cement can accomplish a uniform filling of the void and reduce the risk of secondary collapse.[17,18] Phosphate bone cement was found to be statistically significantly stiffer that autologous bone and to have higher compressive strength.[16,17] Simpson and Keating compared the use of autograft and a calcium phosphate-based bone substitute for the treatment of proximal tibial fractures.[17] The authors presented an average residual plateau depression of 4 mm for the autograft group and 0.7 mm in the calcium phosphate based group at one-year follow-up.[17] Arguably, a reduction of post-operative immobilisation can be achieved. One of the drawbacks of injectable materials is the potential inadvertent escape of the graft into the joint space. The limited current evidence failed to highlight any adverse effects in cases where the injectable graft material escaped intra-articularly.[7,15] However, the surgical team should decide and adjust the treatment appropriately, especially if large volumes are leaked into the joint space. In such cases, irrigation and aspiration of the joint fluid remains the mainstay of treatment.

Biochemical changes in the overlying cartilage

The qualitative changes of the cartilage tissue that can occur following depressed intra-articular fractures should not be underestimated. Intra-articular fractures represent a unique type of injury necessitating anatomical reduction of the cartilage tissue with stable fixation. Such an approach allows early movement of the affected joint facilitating nourishment of the hyaline cartilage, which is essential for its viability.[19] A number of studies have demonstrated that abnormal impact loading increases the risk of progressive joint wear and tear leading to post-traumatic osteoarthritis (PA).[20-22] Qualitative changes in the cartilage can also occur in relation to the void graft material used. It has been previously postulated that increased subchondral bone mass and stiffness can cause increased cartilage loading, fibrillation and even destruction under physiological loading.[23] This theory is based on the fact that bone plays a protective shock-absorbing role on the overlying cartilage by deformation and the formation of microfractures. This theory is yet to be confirmed; however, several experimental studies using impacted autograft or other void-fillers failed to reveal any histological changes.[24,25] The use of PMMA as a void-filler has been reported by Weilin and Jinzhong to cause articular degeneration, possibly not due to the resulted subchondral stiffness but more likely due to the exothermic reaction and expansion of the cement.[26]

Articular impacted fractures of lower limb

Impacted fractures of the acetabulum

The terms impacted or depressed acetabular fractures were introduced by Letournel and Judet to describe a rotated impacted single or multi-fragment fracture of the acetabulum with depression of the osteochondral fragments into the underlying cancellous bone (denoted as qualifier $\gamma 2$ on the comprehensive classification).[27] These injuries are the result of high-energy trauma with the femoral head acting as a hammer, shattering the acetabulum. Low energy fractures are only seen in patients with osteopenia. As a result of significant forces transmitted, an impacted fracture pattern usually occurs in conjunction with a pure posterior fracture-dislocation of the hip or with a complex acetabular fracture. These fractures lack soft-tissue attachment and create severe articular incongruity. Impacted fracture patterns can occur in any part of the acetabulum according to the mode of injury. However, most co-exist with posterior wall, both column and posterior-wall with posterior-column acetabular fractures. Plain radiographs, including the iliac and obturator oblique views, are the primary diagnostic tools. CT scanning has an essential role in the diagnosis and pre-operative planning of these injuries as it provides additional details on the fracture configuration and the exact area of impaction.[28]

The treatment options for the impacted acetabular fractures are determined by the fracture configuration and location within the acetabulum as well as the patient's overall medical status and co-morbidities.[29-31] Age alone is not a contra-indication to operative management as the outcome of total hip arthroplasty (THA) in patients with unreduced acetabular fractures is worse than those who had open reduction and internal fixation (ORIF) prior to THA.[32]

The principles of management include the disimpaction of the osteochondral fragment with or without bone grafting of the subchondral area, anatomical reduction, stable fixation and early mobilisation. The disimpaction of the articular fragment can be performed through the pre-existing fracture (Fig. 1). Not infrequently, however, a columnar fracture is incomplete or does not provide an opportunity for direct visualisation of the displaced osteo-articular fracture. In such cases, cortical windows can facilitate the reduction, usually with the use of a bone punch or similar instrumentation. Bone graft material is then used to replace the osseous void left by the disimpacted articular fragment and supplemental screws may be used to support the reduction. In cases with complex circumscribed impaction of the articular surface, elevation of the fragments and moulding of the area against the femoral head can be performed. The final outcome is closely correlated with the accuracy of the underlying reduction achieved (Table 1).[18,33-43]

Impacted femoral head fractures

Osteochondral impaction fractures of the femoral head are the result of compression along the axis of the femur

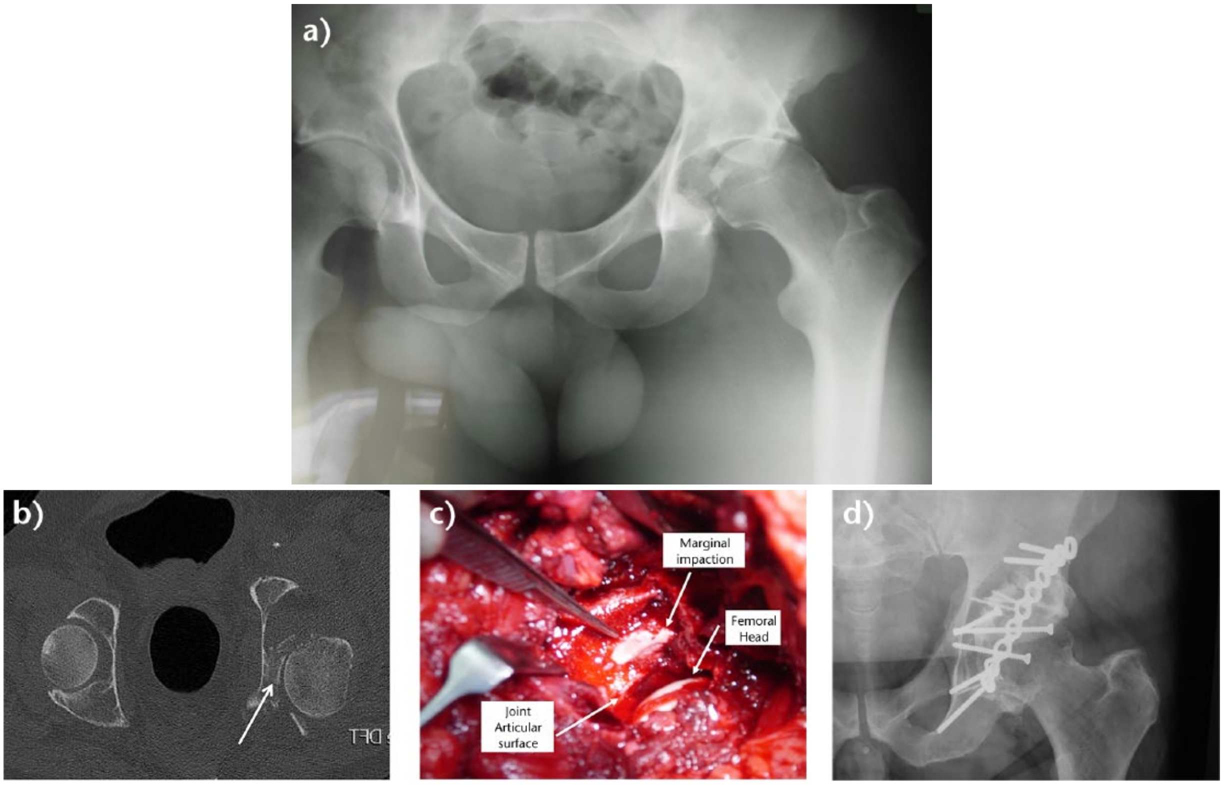

Fig. 1 a) Anteroposterior (AP) pelvis of a 44-year-old male who sustained a fracture dislocation of left acetabulum. b) CT axial cut demonstrating the area of marginal impaction (arrow); c) Intra-operative picture illustrating the impacted articular area, the acetabulum socket and femoral head; d) AP pelvic radiograph at two years follow-up demonstrating a congruent hip joint (impacted area was supported with a bone graft substitute (cement)).

following high-energy trauma. They are rare and are associated with acetabular fractures and/or hip dislocation.[44] These fractures require accurate alignment by surgical means as they are characterised by a fracture line that extends cephalad to the fovea into the weight-bearing surface of the femoral head. A CT scan should be obtained in order to identify the fracture and determine its morphology. An MRI may add additional information but occasionally its sensitivity to diagnose articular cartilage lesions is questionable. The incidence of impacted osteochondral fracture of the femoral head in patients sustaining a posterior hip dislocation is approximately 63% while their frequency in cases of anterior hip dislocation is significantly higher; 100% according to one study.[45] In patients with posterior dislocation, the impaction occurs anteriorly in most cases between the 11 o’clock and 1 o’clock positions.[45]

Several factors can guide the choice of the treatment modality to be used. The surgeon’s experience in addition to the amount of depression and the size of the fractured fragment are factors to be considered. Anatomical reduction of this rare injury with the restoration of injured cartilage generally yields good long-term results. Direct disimpaction of the depressed fragment followed by fixation with screws can be used.[46,47] Bone graft material to support the lifted osteochondral fragment can be used to avoid secondary collapse. In many cases where this approach is not feasible, arthroscopic lavage and debridement of the femoral head fragments with osteochondral allograft, autograft and autogenous chondrocyte implantation have been proposed for the restoration of damaged cartilage and chondral defects.[48,49]

Distal femoral fractures

Unicondylar or bicondylar impacted distal femoral fracture are rare and only reported as single case reports.[50,51] The lateral condyle is most commonly involved. These unusual injuries can result from axial compression or by an abrupt angular strain on the knee joint. Plain radiographs can be misleading and CT is recommended. Elevation of the fragment with fixation is recommended in young non-osteoporotic patients. Total knee arthroplasty could be considered in older individuals who already demonstrate arthritic changes within the knee joint.

Tibial plateau fractures

Tibial plateau fractures account for approximately 1% of all fractures in adults and 5% to 8% of the fractures of the

Table 1. Selective studies presenting the outcome of impacted osteochondral fractures of the lower extremity

Author, Year	Anatomical location	Implant(s) used	Outcome
Scollaro and Routt, 2013[33]	Acetabular fractures	Autogenous cancellous bone graft (2 patients)	• Satisfactory outcome in both patients
Zhuang et al, 2015[34]	Acetabular fractures	Autogenous cancellous bone graft (14 patients)	• All fractures healed • 78.5% of the patients had excellent and good results • The Matta acetabular fracture scores were 10-18 scores (mean, 16.4); the excellent and good rate being 71.4% (10/14) • Traumatic arthritis occurred in three patients and two patients received THR • One patient developed asymptomatic heterotopic ossification post-operatively
Laflamme et al, 2014[35]	Acetabular fractures	Calcium phosphate cement (9 patients)	• The quality of reduction was within 3 mm in 7 patients (78%) • The overall conversion rate to total hip arthroplasty was 33% • There were no infections • The average Harris Hip Score was 81
Giannoudis et al, 2013[36]	Acetabular fractures	Autologous corticocancellous graft (12 patients), hydroxyapatite granules or calcium phosphate cement (34 patients)	• The quality of the reduction was 'anatomical' in 44 hips (73.3%) and 'imperfect' in 16 (26.7%) • The originally achieved anatomical reduction was lost in 12 patients (25.8%) • Radiologically, 33 hips (55%) were graded as 'excellent', 11 (18.3%) as 'good', 1 (1.7%) as 'fair' and 15 (25%) as 'poor' • 11 further operations were reported • 6 patients underwent THR
Ozturkmen et al, 2010[37]	Tibial plateau	Calcium phosphate cement (28 patients)	• Resorption of the graft was observed in 25 knees (89%) • Rasmussen's radiologic score was excellent in 17 patients (61%), good in 9 patients (32%) • Rasmussen's clinical score was excellent in 9 patients (32%), good in 18 patients (64%) • According to the Lysholm knee score, functional results were excellent in 16 patients (57%), good in 8 patients (29%) • 22 patients (78%) achieved the pre-operative activity level after surgery
Veitch et al, 2010[38]	Tibial plateau	Fresh frozen femoral head (6 patients)	• 1 patient developed knee stiffness and 1 patient developed a painless valgus deformity and underwent a corrective osteotomy at 15 months • The height of the tibial plateau on radiographs has been maintained to less than 2 mm depression in all but 1 patient
Heikkila et al, 2011[39]	Tibial plateau	Bioactive glass granules (14 patients) *vs* autologous bone graft (11 patients)	• Subsidence of 1 mm for both groups at 12 months • No differences were identified in the subjective evaluation, functional tests and clinical examination between the two groups during 1-year follow-up
Ong et al, 2012[40]	Tibial plateau	Autograft/Allografts (10 patients) *vs* hydroxyapatite calcium carbonate (14 patients)	• Subsidence of 1.79 mm in hydroxyapatite group *vs* 1.49 mm in the autograft group (not significant) • Overall, no significant statistical difference between the groups for post-operative articular reduction, long-term subsidence and WOMAC scores
Yin et al, 2012[41]	Tibial plateau	β-tricalcium phosphate (42 patients) *vs* no graft (34 patients)	• The mean hospital for special surgery knee score was rated 'good' for both groups (the calcium phosphate cement group (82.3) and control group (79.4) at 12 months) • Comparable histological, radiological and functional findings in both groups
Berkes et al, 2014[42]	Tibial plateau	Structural bone graft using either Plexur P (29 patients) or fibular allograft (48 patients)	• No patients experienced subsidence > 2 mm • The rate of fracture malreduction was 11.7% • There was no difference in the outcomes between patients treated with Plexur P or fibula
Jonsson and Mjoberg, 2015[43]	Tibial plateau	Autograft *vs* porous titanium granules (10 patients in each group)	• Recurrent depression of an average 0.5 mm in the porous titanium group and 2.1 mm in the autograft group at 12 months • No difference in knee pain or function outcome at 12 months • Overall, the risk of recurrent depression of the joint surface was lower and the operating time less when titanium granules were used
Iundusi et al, 2015[18]	Tibial plateau	Injectable ceramic biphasic bone substitute CERAMENT	• Average subsidence of 1.18 mm • Excellent results in 14 patients and good in the remaining 10 patients

lower leg.[52,53] According to the Schatzker classification, the main impacted types are the Schatzker type II (AO/OTA type 41.B3) characterised by a lateral split plus depression and the Schatzker type III (AO/OTA type 41.B2) which involves an isolated depression configuration.[52-54] Their exact epidemiology is difficult to define as it varies in relation to the study population and geography. However, they are usually the results of road traffic accidents or falls and predominately affect males aged 20 to 50 years.[52,55,56] In addition, the active lifestyle of our aging population in conjunction with the associated age-related bone thinning predispose to a higher incidence of these fractures in this age group. CT scanning is ideal for assessing the extent of bony involvement and evaluating the degree of depression of the articular surface, which is important in determining management options. MRI is extremely useful in the detection of occult fractures and in the demonstration of associated internal derangement.

Schatzker type II and III fractures cannot be reduced by ligamentotaxis alone but require elevation through the techniques described above. The Schatzker type III fractures require restoration of the articular congruence and fixation with two subchondral cancellous bone screws. In patients with osteoporosis a third screw with a washer in an antiglide position can be used, while in cases of

Fig. 2 a) Anteroposterior radiograph of the right knee in a 58-year-old female patient demonstrating fracture of the lateral plateau with osteochondral area of impaction (arrow); b) Lateral radiograph of the right knee demonstrating fracture of the lateral plateau with the osteochondral area of impaction (area); c) Coronal CT scan slice revealing the area of joint impaction (arrow). d) Axial CT scan slice showing the area of articular impaction (arrow).

comminution a lateral buttress plate can be used. In Schatzker type II fractures, the depression is elevated and the fracture fixed with a buttress plate and positional screws to support the disimpacted fragment and restore the lateral wall. In cases of significant bone loss (residual void left following articular segment elevation), bone grafting to fill the void and support the osteochondral fragment should be considered (Figs 2 and 3).

Pilon fractures

Pilon fractures are the result of high-energy trauma and occur when the dense talus is axially compressed over the articular surface of the distal tibia. They represent 1% of all lower limb fractures and 5% to 10% of all tibial fractures.[57] The severity of this injury is substantial, reflecting the fact that approximately 20% to 30% of these fractures are open.[58] Impacted osteochondral fragments can exist in different subgroups of pilon fractures and they are not captured as a separate entity by the available classifications. Such osteochondral fragments can exist in the split depressed fractures (AO 43-B2), the multi-fragmentary depressed group (AO 43-B3) and the articular multi-fragmented fractures (43-C3). CT scanning is the imaging modality of choice and can greatly enhance our understanding of the injury and facilitate pre-operative planning. In multi-fragmented pilon fractures, it is preferable to perform a CT scan after the application of an external fixator as the restoration of the leg length will reduce the small fragments and make the anatomy more comprehensive. Another important aspect of the management of these fractures includes a thorough evaluation of the soft-tissue status. These fracture are associated with a high risk of wound complications with a historical incidence of approximately 50%; the appropriate management of the soft tissues cannot be overemphasised.[59]

Pilon fractures generally require surgery, with conservative management to be reserved possibly for un-displaced or poor candidates for surgical management. In complex pilon fractures, meticulous re-alignment of the joint surface is required to reduce the risk of post-traumatic arthritis. In

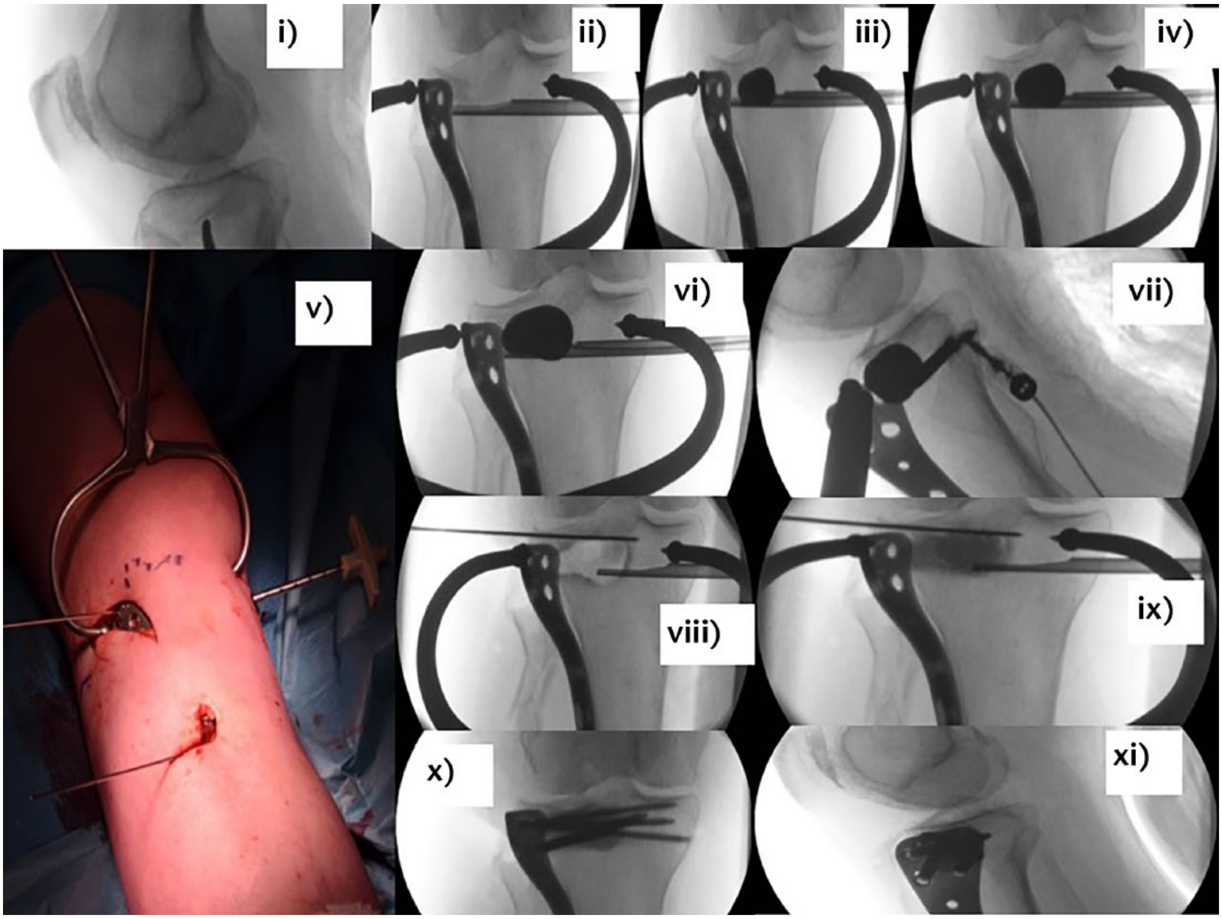

Fig. 3 i) Intra-operative lateral fluoroscopic image of the right knee facilitating identification and marking of the level of articular depression for the subsequent insertion of trocar and cannula for and balloon inflation; ii) Anteroposterior (AP) fluoroscopic image of the right knee showing support of the lateral wall of the tibial plateau with a locking plate and a reduction forceps as well as the trocar/cannula insertion from medial to lateral plateau side (underneath the lateral depressed area); iii) and iv) AP fluoroscopic images of the right knee demonstrating balloon inflation underneath the area of depression for indirect reduction; v) Intra-operative picture illustrating in real time the positioning of the reduction forceps and the cannula. vi) AP fluoroscopic image of the right knee; vii) Lateral fluoroscopic image of the right knee demonstrating steady elevation of the depressed articular segment as the balloon is gradually inflated. viii) AP fluoroscopic image of the right knee showing the bone void created after the balloon deflation; the elevated articular segment is supported with a laterally inserted K-wire for maintenance of reduction. ix) Delivery of bone substitute (cement) in the bone void area for structural support. x and xi) AP/Lateral fluoroscopic views after stabilisation of the lateral tibial plateau fracture with a locking plate; bone cement *in situ* is noted filling the void previously created; the previous depressed articular segment is now reduced.

many cases, one articular fragment is re-attached to another until the articular reconstruction is achieved. Loose non-reconstructible fragments are usually debrided. Then provisional stabilisation with Kirschner wires can be performed, which at a later stage can serve as guidewires for cannulated screws. Once the articular surface is restored followed disimpaction of the osteochondral fragments, the metaphyseal area should be analysed for the need of bone grafting. Autografts or bone graft substitutes are used to fill the resulted voids and support the reconstructed tibial plafond. Usually this is performed under direct vision as fragmentation provides windows allowing direct vision and cortical windows are rarely required. Balloon-guided inflation osteoplasty can be used and combined with a minimally invasive approach. Appropriate fracture configuration with a distinct depressed fragment centrally is required and careful preoperative planning is essential.[60] Arthroscopy has been previously used in the management of these fractures and, although technically challenging, it can be a valuable tool for the removal of loose chondral fragments, providing excellent visualisation of the articular surface, minimising soft tissue stripping and even accounting for a reduced risk of post-traumatic arthritis.[61]

Clinical outcomes

As far as the clinical outcomes are concerned, the presence of osteochondral impaction in acetabular fractures represents a poor prognostic factor and adversely effects the outcome of the operative management.[62,63] The long-term results following these injuries are positively associated with the level of the underlying reduction achieved.[64,65] Residual symptomatology of moderate intensity is found in 40% of these patients, while 20% will report severe complaints.[40] Several studies have shown that even if accurate reduction is achieved, 30% of the patients will develop post-traumatic arthritis.[64,65] Even if 'anatomical' reduction is achieved, the incidence of reduction loss is significant and occurs in approximately 25% of the cases.[36] Zhuang et al reported the results of 14 cases of impacted acetabular fractures treated with the use of autologous cancellous bone grafting.[34] They found that all fractures healed, with 78.5% of the patients reporting an excellent or good result. In a similar study including nine patients treated with the use of calcium phosphate cement, the authors reported that three patients (33%) required a later THR.[35]

In tibial plateau fractures a satisfactory fixation without secondary collapse of the fragments is associated with good to excellent results in over 90% of the patients (Table 1).[55] Tibial plateau fractures AO type 41-B2 and 41-B3 treated with minimally invasive bone tamp reduction, allograft and percutaneous screw fixation showed a high rate of anatomical reduction (82%), a low rate of complications (3.5%) and a high level of patient satisfaction.[56] Several studies have shown no significant difference in the clinical outcomes between cases treated with autografts or allografts and bone graft substitutes.[39,40,42,43] It should be mentioned that any concomitant injuries, such as meniscal tears or ligament ruptures, should be addressed simultaneously as they can negatively compromise the final outcome. Satisfactory results do not always correlate with the radiological appearance, possibly due to the function of the menisci that can bear weight and relieve pressure over the lateral compartment

The overall outcome of tibial plafond fractures is associated with the status of the overlying soft tissues. Wyrsch et al showed a 25% deep infection rate in closed pilon fractures and a 100% overall complication rate when they were treated with primary ORIF.[66] Tibial plafond fractures have an intermediate-term negative effect on ankle function and on general health.[67] Few patients require secondary reconstructive procedures and symptoms tend to decrease for a long time after healing. Minimally invasive surgery has reduced significantly the rate of complications.[67] Despite the latter, subsequent arthrodesis may be needed in up to 10% of cases with a significant number of patients complaining of pain even after two years post injury. The use of an Ilizarov frame with or without limited internal fixation is an alternative option in cases of complex or open fractures of the tibial pilon or cases with a questionable soft-tissue integrity.[6] In such cases, arthrodiastasis and percutaneous reduction of major fracture fragments can be achieved with the usage of percutaneous small diameter olive wires and the ring fixator.

Discussion

Intra-articular impacted fractures represent a unique subcategory of fractures. Their treatment involves the successful restoration of the articular surface. A 2-mm articular depression is considered safe to treat non-operatively, while any greater steps should be elevated to reduce the risk of post-traumatic arthritis.[1] It has been suggested that structural support of the subchondral void should be performed in cases where the original depression is greater than 6 mm or in older individuals or those with osteoporosis.[5]

There are two main approaches to elevating the depressed osteochondral fragment: direct elevation through a cortical window and balloon inflation osteoplasty. The surgical technique is dictated by the fracture pattern, the fixation method and surgical approach to be used, and the surgeon's prior familiarity with these techniques. Careful pre-operative planning with sound interpretation of the 'cortical envelope' and fracture configuration are essential elements. Balloon inflation osteoplasty causes minimal damage to the underlying soft tissues and can be an excellent adjunct to minimally invasive percutaneous approaches. Limitations of this technique are seen in more complicated fracture patterns, when the cortical envelope is disrupted. In such cases, a direct approach with the use of a cortical window can be more advantageous. Arthroscopy can be used to assess articular congruency but also it can be used to assist and guide the optimal elevation of the impacted osteochondral fragments.

In terms of the available void fillers, historically autologous cancellous bone has been the most used graft material. However, its mechanical strength is minimal and can result in a failure of treatment and painful disability to the patient. In contrast, autologous cortico-cancellous or tricortical pelvic bone grafts are capable of addressing the structural disadvantages of autologous cancellous bone but the donor site morbidity is not to be underestimated. Alternative materials, including allogeneic bone grafts and xenografts, which, although they have been previously used, can pose a risk of immune reaction and disease transmission. Bone cement (PMMA) can provide immediate mechanical strength, but it is a permanent implant which should be considered only for selective cases in the elderly. Lately, the use of bone graft substitutes has expanded due to their ease of use and the fact that they can be a valuable adjunct in minimally invasive approaches. To this end, a number of studies have shown no difference to the clinical outcome when compared with autologous bone grafting, a finding that has promoted their usage significantly (Table 1), even after two years post injury.[68,69]

The currently available literature on the treatment of impacted articular injuries has several limitations. The lack of randomised control trials looking into the different treatment options is apparent with the decision-making process mainly based on local policies, experience and training of the surgeon. The efficacy, safety and cost-effectiveness of each graft material and surgical technique is yet to be determined. The usage of any graft material should be performed with prior knowledge of the properties of each different product. With respect to health economics, for instance, the use of bone substitutes can significantly limit the operative time and can reduce the overall cost. Leug et al highlighted that each gram of transplantable allogenic bone graft costs $86, compared with $9 to $26 per gram for commercially available bone substitutes.[70] Although such differences can exist, the overall costs can vary significantly between different health systems and treatment pathways, so further studies are needed to elucidate their cost-effectiveness. The future will bring, without doubt, a material with the appropriate properties and significant mechanical integrity to eliminate the risk of secondary collapse. Well-structured studies independent from the influences of commercial factors are needed to define the best practice and the ideal graft material.

The successful treatment of intra-articular impacted fractures of the lower limb should include the restoration of the articular surface, the structural support of the raised osteochondral fragment and the fixation of the underlying fracture. While autologous cortico-cancellous bone is the ideal graft material, there is also positive evidence to support the use of bone graft substitutes as void fillers in this clinical setting. Further well-conducted studies are required to allow clinicians to identify the ideal material and approach in the treatment of these injuries.

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REFERENCES

1. **Giannoudis PV, Tzioupis C, Papathanassopoulos A, Obakponovwe O, Roberts C.** Articular step-off and risk of post-traumatic osteoarthritis. Evidence today. *Injury* 2010;41:986-995.

2. **Mauffrey C, Fader R, Hammerberg EM, Hak DJ, Stahel PF.** Incidence and pattern of technical complications in balloon-guided osteoplasty for depressed tibial plateau fractures: a pilot study in 20 consecutive patients. *Patient Saf Surg* 2013;7:8.

3. **Hake ME, Goulet JA.** Open Reduction and internal fixation of the tibial plateau through the anterolateral approach. *J Orthop Trauma* 2016;30:S28-S29.

4. **Duwelius PJ, Rangitsch MR, Colville MR, Woll TS.** Treatment of tibial plateau fractures by limited internal fixation. *Clin Orthop Relat Res* 1997;339:47-57.

5. **Burdin G.** Arthroscopic management of tibial plateau fractures: surgical technique. *Orthop Traumatol Surg Res* 2013;99:S208-S218.

6. **Rossi R, Bonasia DE, Blonna D, Assom M, Castoldi F.** Prospective follow-up of a simple arthroscopic-assisted technique for lateral tibial plateau fractures: results at 5 years. *Knee* 2008;15:378-383.

7. **Ollivier M, Turati M, Munier M, et al.** Balloon tibioplasty for reduction of depressed tibial plateau fractures: preliminary radiographic and clinical results. *Int Orthop* 2016;40:1961-1966.

8. **Pizanis A, Garcia P, Pohlemann T, Burkhardt M.** Balloon tibioplasty: a useful tool for reduction of tibial plateau depression fractures. *J Orthop Trauma* 2012;26:e88-e93.

9. **Heiney JP, Kursa K, Schmidt AH, Stannard JP.** Reduction and stabilization of depressed articular tibial plateau fractures: comparison of inflatable and conventional bone tamps: study of a cadaver model. *J Bone Joint Surg [Am]* 2014;96:1273-1279.

10. **Vangsness CT Jr, Ghaderi B, Hohl M, Moore TM.** Arthroscopy of meniscal injuries with tibial plateau fractures. *J Bone Joint Surg [Br]* 1994;76-B:488-490.

11. **Scheerlinck T, Ng CS, Handelberg F, Casteleyn PP.** Medium-term results of percutaneous, arthroscopically-assisted osteosynthesis of fractures of the tibial plateau. *J Bone Joint Surg [Br]* 1998;80-B:959-964.

12. **Belanger M, Fadale P.** Compartment syndrome of the leg after arthroscopic examination of a tibial plateau fracture. Case report and review of the literature. *Arthroscopy* 1997;13:646-651.

13. **Moroni A, Larsson S, Hoang Kim A, Gelsomini L, Giannoudis PV.** Can we improve fixation and outcomes? Use of bone substitutes. *J Orthop Trauma* 2009;23:422-425.

14. **Pountos I, Corscadden D, Emery P, Giannoudis PV.** Mesenchymal stem cell tissue engineering: techniques for isolation, expansion and application. *Injury* 2007;38:S23-S33.

15. Goff T, Kanakaris NK, Giannoudis PV. Use of bone graft substitutes in the management of tibial plateau fractures. *Injury* 2013;44:S86-S94.

16. Nauth A, Lane J, Watson JT, Giannoudis P. Bone graft substitution and augmentation. *J Orthop Trauma* 2015;29:S34-S38.

17. Simpson D, Keating JF. Outcome of tibial plateau fractures managed with calcium phosphate cement. *Injury* 2004;35:913-918.

18. Iundusi R, Gasbarra E, D'Arienzo M, Piccioli A, Tarantino U. Augmentation of tibial plateau fractures with an injectable bone substitute: CERAMENT™. Three year follow-up from a prospective study. *BMC Musculoskelet Disord* 2015;16:115.

19. Marsh JL, Buckwalter J, Gelberman R, et al. Articular fractures: does an anatomic reduction really change the result? *J Bone Joint Surg [Am]* 2002;84-A:1259-1271.

20. Buckwalter JA. Osteoarthritis and articular cartilage use, disuse, and abuse: experimental studies. *J Rheumatol Suppl* 1995;43:13-15.

21. Gelber AC, Hochberg MC, Mead LA, et al. Joint injury in young adults and risk for subsequent knee and hip osteoarthritis. *Ann Intern Med* 2000;133:321-328.

22. Lovász G, Park SH, Ebramzadeh E, et al. Characteristics of degeneration in an unstable knee with a coronal surface step-off. *J Bone Joint Surg [Br]* 2001;83-B:428-436.

23. Radin EL, Paul IL, Tolkoff MJ. Subchondral bone changes in patients with early degenerative joint disease. *Arthritis Rheum* 1970;13:400-405.

24. Frassica FJ, Gorski JP, Pritchard DJ, Sim FH, Chao EY. A comparative analysis of subchondral replacement with polymethylmethacrylate or autogenous bone grafts in dogs. *Clin Orthop Relat Res* 1993;293:378-390.

25. Welch RD, Berry BH, Crawford K, et al. Subchondral defects in caprine femora augmented with in situ setting hydroxyapatite cement, polymethylmethacrylate, or autogenous bone graft: biomechanical and histomorphological analysis after two-years. *J Orthop Res* 2002;20:464-472.

26. Weilin S, Jinzhong M. Articular cartilage changes. *Orthopedics* 2008;31:994

27. Judet R, Judet J, Letournel E. Fractures of the acetabulum: Classification and surgical approaches for open reduction. Preliminary Report. *J Bone Joint Surg [Am]* 1964;46-A:1615-46.

28. Rehman H, Clement RG, Perks F, White TO. Imaging of occult hip fractures: CT or MRI? *Injury* 2016;47:1297-1301.

29. Gusic N, Sabalic S, Pavic A, et al. Rationale for more consistent choice of surgical approaches for acetabular fractures. *Injury* 2015;46:S78-S86.

30. Hernefalk B, Eriksson N, Borg T, Larsson S. Estimating pre-traumatic quality of life in patients with surgically treated acetabular fractures and pelvic ring injuries: does timing matter? *Injury* 2016;47:389-394.

31. Hammad AS, El-Khadrawe TA. Accuracy of reduction and early clinical outcome in acetabular fractures treated by the standard ilio-inguinal versus the Stoppa/iliac approaches. *Injury* 2015;46:320-326.

32. Bastian JD, Savic M, Cullmann JL, et al. Surgical exposures and options for instrumentation in acetabular fracture fixation: pararectus approach versus the modified Stoppa. *Injury* 2016;47:695-701.

33. Scolaro JA, Routt ML Jr. Reduction of osteoarticular acetabular dome impaction through an independent iliac cortical window. *Injury* 2013;44:1959-1964.

34. Zhuang Y, Lei JL, Wei X, Lu DG, Zhang K. Surgical treatment of acetabulum top compression fracture with sea gull sign. *Orthop Surg* 2015;7:146-154.

35. Laflamme GY, Hebert-Davies J. Direct reduction technique for superomedial dome impaction in geriatric acetabular fractures. *J Orthop Trauma* 2014;28:e39-e43.

36. Giannoudis PV, Kanakaris NK, Delli Sante E, et al. Acetabular fractures with marginal impaction: mid-term results. *Bone Joint J* 2013;95-B:230-238.

37. Oztürkmen Y, Caniklioğlu M, Karamehmetoğlu M, Sükür E. Calcium phosphate cement augmentation in the treatment of depressed tibial plateau fractures with open reduction and internal fixation. *Acta Orthop Traumatol Turc* 2010;44:262-269.

38. Veitch SW, Stroud RM, Toms AD. Compaction bone grafting in tibial plateau fracture fixation. *J Trauma* 2010;68:980-983.

39. Heikkilä JT, Kukkonen J, Aho AJ, et al. Bioactive glass granules: a suitable bone substitute material in the operative treatment of depressed lateral tibial plateau fractures: a prospective, randomized 1 year follow-up study. *J Mater Sci Mater Med* 2011;22:1073-1080.

40. Ong JC, Kennedy MT, Mitra A, Harty JA. Fixation of tibial plateau fractures with synthetic bone graft versus natural bone graft: a comparison study. *Ir J Med Sci* 2012;181:247-252.

41. Yin X, Li J, Xu J, et al. Clinical assessment of calcium phosphate cement to treat tibial plateau fractures. *J Biomater Appl* 2013;28:199-206.

42. Berkes MB, Little MT, Schottel PC, et al. Outcomes of Schatzker II tibial plateau fracture open reduction internal fixation using structural bone allograft. *J Orthop Trauma* 2014;28:97-102.

43. Jónsson BY, Mjöberg B. Porous titanium granules are better than autograft bone as a bone void filler in lateral tibial plateau fractures: A randomised trial. *Bone Joint J* 2015;97-B:836-841.

44. Butler JE. Pipkin Type-II fractures of the femoral head. *J Bone Joint Surg [Am]* 1981;63-A:1292-1296.

45. Tehranzadeh J, Vanarthos W, Pais MJ. Osteochondral impaction of the femoral head associated with hip dislocation: CT study in 35 patients. *AJR Am J Roentgenol* 1990;155:1049-1052.

46. Henle P, Kloen P, Siebenrock KA. Femoral head injuries: which treatment strategy can be recommended? *Injury* 2007;38:478-488.

47. Mowery C, Gershuni DH. Fracture dislocation of the femoral head treated by open reduction and internal fixation. *J Trauma* 1986;26:1041-1044.

48. Kish G, Módis L, Hangody L. Osteochondral mosaicplasty for the treatment of focal chondral and osteochondral lesions of the knee and talus in the athlete. Rationale, indications, techniques, and results. *Clin Sports Med* 1999;18:45-66, vi.

49. Won Y, Lee GS, Kim SB, Kim SJ, Yang KH. Osteochondral autograft from the ipsilateral femoral head by surgical dislocation for treatment of femoral head fracture dislocation: a case report. *Yonsei Med J* 2016;57:1527-1530.

50. Mabry LM, Ross MD, Abbott JL. Impaction fracture of the medial femoral condyle. *J Orthop Sports Phys Ther* 2013;43:512.

51. Mahadevan D, Challand C, Keenan J. Depressed femoral condyle fracture. *Injury* 2008;39:30-33.

52. Albuquerque RP, Hara R, Prado J, et al. Epidemiological study on tibial plateau fractures at a level I trauma center. *Acta Ortop Bras* 2013;21:109-115.

53. Kim CW, Lee CR, An KC, et al. Predictors of reduction loss in tibial plateau fracture surgery: focusing on posterior coronal fractures. *Injury* 2016;47:1483-1487.

54. Schatzker J, McBroom R, Bruce D. The tibial plateau fracture. The Toronto experience 1968–1975. *Clin Orthop Relat Res* 1979;138:94-104.

55. Lobenhoffer P, Schulze M, Gerich T, Lattermann C, Tscherne H. Closed reduction/percutaneous fixation of tibial plateau fractures: arthroscopic versus fluoroscopic control of reduction. *J Orthop Trauma* 1999;13:426-431.

56. Elsøe R, Larsen P, Rasmussen S, Hansen HA, Eriksen CB. High degree of patient satisfaction after percutaneous treatment of lateral tibia plateau fractures. *Dan Med J* 2016;63:A5174.

57. Bourne RB. Pylon fractures of the distal tibia. *Clin Orthop Relat Res* 1989;240:42-46.

58. Matthews SJ. Fractures of the tibial pilon. *Orthop Trauma* 2012;26:171-175.

59. Teeny SM, Wiss DA. Open reduction and internal fixation of tibial plafond fractures. Variables contributing to poor results and complications. *Clin Orthop Relat Res* 1993;292:108-117.

60. Heiney JP, Redfern RE, Wanjiku S. Subjective and novel objective radiographic evaluation of inflatable bone tamp treatment of articular calcaneus, tibial plateau, tibial pilon and distal radius fractures. *Injury* 2013;44:1127-1134.

61. Bonasia DE, Rossi R, Saltzman CL, Amendola A. The role of arthroscopy in the management of fractures about the ankle. *J Am Acad Orthop Surg* 2011;19:226-235.

62. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. *J Bone Joint Surg [Am]* 2012;94-A:1559-1567.

63. Bhandari M, Matta J, Ferguson T, Matthys G. Predictors of clinical and radiological outcome in patients with fractures of the acetabulum and concomitant posterior dislocation of the hip. *J Bone Joint Surg [Br]* 2006;88-B:1618-1624.

64. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. *J Bone Joint Surg [Am]* 1996;78-A:1632-1645.

65. Wright R, Barrett K, Christie MJ, Johnson KD. Acetabular fractures: long-term follow-up of open reduction and internal fixation. *J Orthop Trauma* 1994;8:397-403.

66. Wyrsch B, McFerran MA, McAndrew M, et al. Operative treatment of fractures of the tibial plafond. A randomized, prospective study. *J Bone Joint Surg [Am]* 1996;78-A:1646-1657.

67. Paluvadi SV, Lal H, Mittal D, Vidyarthi K. Management of fractures of the distal third tibia by minimally invasive plate osteosynthesis - A prospective series of 50 patients. *J Clin Orthop Trauma* 2014;5:129-136.

68. Pollak AN, McCarthy ML, Bess RS, Agel J, Swiontkowski MF. Outcomes after treatment of high-energy tibial plafond fractures. *J Bone Joint Surg [Am]* 2003;85-A:1893-1900.

69. Sands A, Grujic L, Byck DC, et al. Clinical and functional outcomes of internal fixation of displaced pilon fractures. *Clin Orthop Relat Res* 1998;347:131-137.

70. Leung HB, Fok MW, Chow LC, Yen CH. Cost comparison of femoral head banking versus bone substitutes. *J Orthop Surg (Hong Kong)* 2010;18:50-54.