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Research Article

DEPRESSED TIBIAL PLATEAU FRACTURES TREATED WITH A MINI-INVASIVE TECHNIQUE: BALLOON-ASSISTED REDUCTION AND CALCIUM PHOSPHATE AUGMENTATION

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ABSTRACT

Introduction: Restoring the articular congruency in depressed tibial plateau fractures can be demining with traditional techniques. Alternate methods have therefore been suggested. In the current study we present our experience with the balloon-assisted reduction and tricalcium phosphate augmentation technique in the treatment of tibial depressed plateau fractures.

Materials and Methods: Nine consecutive patients with Schatzker type II (n.5) and type III (n.4) fractures were treated with the balloon-assisted reduction and tricalcium phosphate augmentation technique. All patients were available for clinical and radiographic follow-up at an average of 14 months Pre and post-operatively, conventional radiographs, computerized tomography scans, and complications were evaluated. Functional evaluation was performed using the method of Rasmussen. The Rasmussen's anatomical grading system was used for the radiological evaluation of the knee.

Results: Fractures healed uneventfully in all patients; no cases of nonunion, malunion or deep infection were detected. No cases of calcium phosphate migration were found. At the last follow up the mean Rasmussen's functional score was 26.1 (good). No differences in terms of Rasmussen's functional score and Rasmussen's anatomical grading were detected between patients with Schatzker type II and Schatzker type III fractures during the follow-up.

Conclusions: Balloon-assisted reduction and calcium phosphate augmentation represents an effective mini-invasive technique in the treatment of depressed tibial plateau fractures, allowing early weight bearing with good functional results.

INTRODUCTION

Tibial plateau fractures are one of the most challenging problems in orthopedic surgery, occurring due to a combination of axial loading and varus/valgus applied forces. Even if lateral depression and split with lateral depression fractures (type II and III according to Schatzker classification) are not the prevalent patterns, their treatment can be demanding even for highly trained surgeons (Hsu CJ *et al.*, 2001).

With conventional techniques the reduction of depressed fragments is hard to achieve and subchondral bone defects may remain. This results in subsidence of the articular surface when the patient becomes mobile again, with consequent valgus malalignment of the limb (Russell TA, 2008) (Mayr R *et al.*, 2015). Alternate methods of treatment such as the cement augmentation have therefore been suggested (Russell TA, 2008) (Mayr R *et al.*, 2015) (Larsson S *et al.*, 2002).

The main purpose of the cement is to fill voids in metaphyseal bone, improving the holding strength around metal devices in osteoporotic bone. Early clinical results have shown reduced time to full weight-bearing when cement has been used for augmentation of tibial plateau and calcaneal fractures (Larsson S *et al.*, 2002). However when the cement augmentation is combined with open reduction and internal fixation conventional bone tamps are used and bone windows are created. This may lead to further complications (Pizanis A *et al.*, 2012).

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On the basis of our promising results obtained with the use of the calcaneoplasty we adopted the balloon-assisted reduction and calcium phosphate augmentation technique in the treatment of tibial depressed plateau fractures. The technique is already in use apart from calcaneal and vertebral surgery, in acetabular, cuboid and distal radius fractures with variable results (König B *et al*., 2007) (Heim KA *et al*., 2008) (Iida K *et al*., 2010). In the current study we present our experience with the mini-invasive tibioplasty technique in 9 patients.

MATERIALS AND METHODS

Between November 2012 and May 2014, 9 consecutive patients underwent balloon-assisted reduction and calcium phosphate augmentation for tibial plateau fractures. All patients were treated by the same surgeon.

Our study sample consisted of 3 man and 6 women with an average age of 59,4 years (35 to 78). Patient injuries included 5 road traffic accidents, 3 accidental falls and 1 sport injury. All patients had antero-posterior and lateral knee view radiographs at our emergency department and a knee CT scan was always performed in order to evaluate the fracture pattern or amount of depression. Tibial condylar depression was measured from a reference line level with the uninjured plateau. In 4 cases the fracture involved the right knee and in 5 cases the left knee. According to the Schatzker classification there were 5 Schatzker type II (split-depression) and 4 Schatzker type III (central-lateral depression). In all cases no displacement of posterior wall was detected (Table 1)

Table 1 Demographic data

Case n.	Sex	Age	Side	Accident	Schatzker type
1	F	58	R	road traffic	II
2	F	67	L	accidental fall	II
3	M	61	L	road traffic	III
4	F	61	L	road traffic	II
5	M	49	R	road traffic	III
6	M	35	R	sport injury	II
7	F	78	L	accidental fall	III
8	F	72	L	road traffic	III
9	F	54	R	accidental fall	II

The mean time between day of admission and surgery was 4 days (range 2–7 days) and the timing of surgery was influenced by the patient's general and the soft-tissue envelope conditions, in particular edema and skin blisters.

Surgical technique

Procedures were performed under spinal anesthesia, with prophylactic antibiotic coverage administered. All patients underwent surgery in the supine position, with a double image intensifier control in the lateral and AP. In all cases the Medtronic - InflateFX® Gen II was used.

Patients with a split-depression fracture underwent an initial stabilization of the split fragment. A 3.5-mm plate or 2 percutaneous screws were used depending on the size of the fragment. In the 3 cases with a larger fragment the plate was preferred (Fig.1). An incision of 2 to 3 cm over the proximal aspect of the lateral tibia was performed. A submuscular plane was created and a stainless steel 3.5-mm plate was slid in the anterior submuscular plane and attached with bicortical screws inserted into the distal holes of the plate. The plate was used as protection of the lateral split prior to inflating the IBT. In the 2 patients with a smaller split fragment 2 parallel percutaneous 4 mm screws were placed to stabilize the split fragment. The screws were useful to direct the resultant reduction force of the expanding balloon acting as a palisade placed just below the trocar. In Schatzker type III fractures only temporary k wires were placed under the depressed fragment.

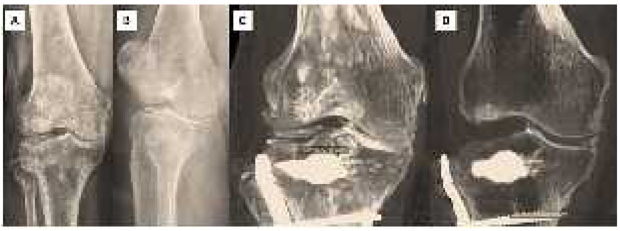

Figure 1 67-years-old female sustained a Schatzker type II fracture treated with cement augmentation and a 3.5mm plate; pre-operative radiographs (A-B); 1 month follow-up CT scan (C-D) showing the cement placed at 7.9 mm from the articular surface.

To determine the correct trajectory for trocar placement, CT, plain film and fluoroscopic images were used. As reported on manufacturer's instruction the trocar should point at 2 – 10 mm distal to the lowest point of the depression on the AP and LL views. The trocar was introduced in the lateral tibial plateau through a medial stub incision and advanced below the depressed fragment under fluoroscopic control. We started slowly inflating the balloon with contrast solution to an initial pressure of 50 psi, without any radiographic evidence of balloon asymmetry, indicative of malpositioning. We then fully inflated the balloon to approximately 250psi, effectively raising the depressed tibial plateau.

When adequate reduction was achieved, the balloon was then deflated. The volume of contrast solution needed determined the minimum quantity of cement injected. Bone cement (Kyphon® Injectable Bone Void Filler) was prepared immediately prior to its injection into the defect and the balloon was removed. Under accurate fluoroscopic control, we injected calcium phosphate cement through the trocar, filling the balloon-created cavity of the lateral tibial plateau and augmenting the fracture (Fig.2).

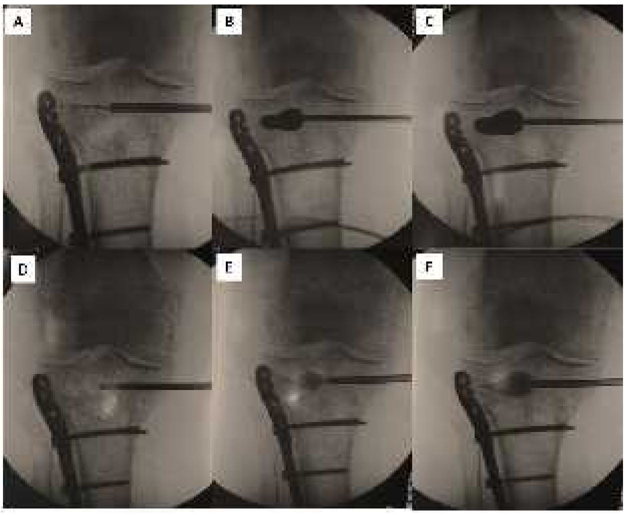

Figure 2 Intraoperative fluoroscopic monitoring of the reduction process by balloon and progressive cement injection

The mean volume of calcium phosphate used was 4–6 mL. The final reduction and osteosynthesis were radiologically verified. Then K-wires were removed and the stub incisions were closed.

Post-operative management

In the immediate post-operative the knee was placed in a CPM machine set to move from 0–90 degrees of knee flexion. Passive knee flexion was performed 2 times a day throughout the first 3 weeks after surgery. Isometric quadriceps exercise and hip raising exercises were started from postoperative day 1. At the same time a knee brace blocked in extension preventing varus and valgus stress was used. The brace was unlocked only to allow passive knee mobilisation. Patients were instructed not to bear weight on the operated limb for the first 3 post-operative weeks. After that partial weight bearing was allowed using 2 crutches and a knee brace. Full weight bearing deferred until 5 weeks.

Patients were discharged from the hospital at average 4 postoperative day, depending on their general condition. After discharge, all patients were followed regularly in our trauma clinic. Patients were followed closely with clinical examinations and follow-up x-rays obtained at 1 month, 3 months, 6 months, 12 months; than every 6 months. During follow-up visits the functional assessment was made using the Rasmussen scoring system. Excellent is indicated by a score of 28– 30, good by a score of 24–27, fair by a score of 20–23, and poor by a score. The Rasmussen's radiological score system was used for the radiological evaluation of the knee (0 - 18, based on depression, condylar widening, and angulation) (Rasmussen PS *et al.*, 1973).

Statistical Analysis

We used the t-test, with 5% confidence level, to check the difference in continues variables.

RESULTS

All 9 patients were available for clinical and radiographic follow-up at an average of 14 months (range 12 to 18 months). Fractures healed uneventfully in all patients; no cases of nonunion, malunion or deep infection were detected. No cases of calcium phosphate migration were found.

No differences in terms of Rasmussen's functional score were detected between patients with Schatzker type II and Schatzker type III fractures during the follow up as shown in Table 2. At the last follow up the mean Rasmussen's functional score was 26.1 (good) (23.2 – 26.7) (Fig.3)

Table 2 Rasmussen's functional score

Follow-up	Schatzker type II	Schatzker type III	P value
3 months	24 ± 0.63	24 ± 1.41	0.35
6 months	25.4 ± 1.01	25.2 ± 1.65	0.28
12 months	27.4 ± 1.49	27 ± 2.2	0.42

A comparison between Schatzker type II and Schatzker type III fractures in terms of Rasmussen's radiological score showed no difference on postoperative radiographs, taken at months zero, one, three, six, and 12. At the last follow-up the mean Rasmussen's radiological score was 16,6 with 5 patients having excellent results and 4 patients with good results (Table 3). Only 1 case of articular subsidence of 4 mm was found in a patient with a Schatzker type III fracture at 12 months follow-up. However this radiographic result did not affect the functional outcome (25 – good). At the last follow-up only partial signs of calcium phosphate reabsorption were evident in our sample.

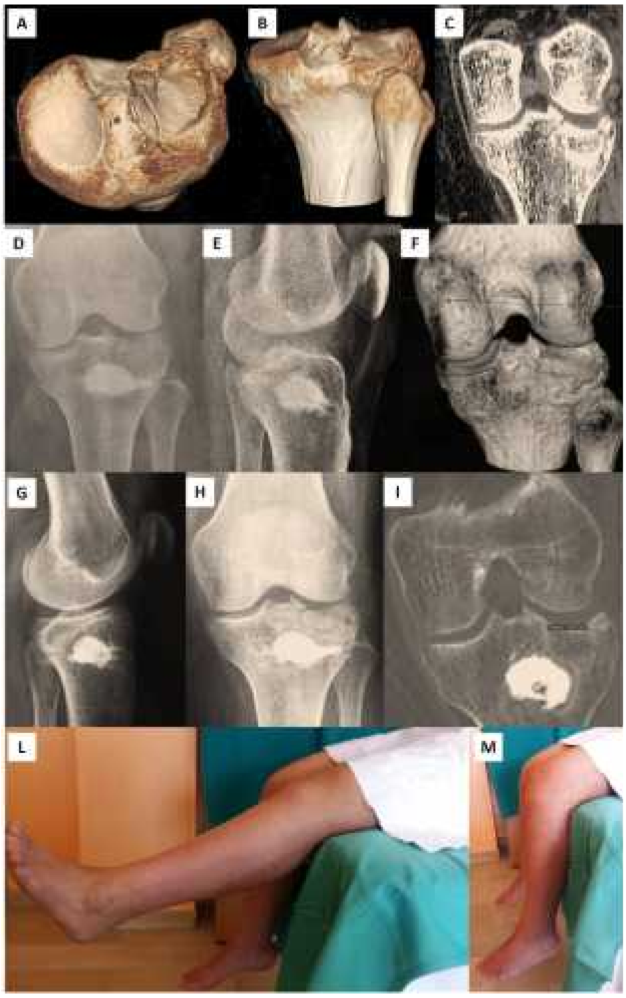

Figure 3 54-years-old female sustained a Schatzker type III; pre-operative CT scan (A-B-C); post-operative radiographs and CT scan (D-E-F) ; 3 months follow-up radiographs (G-H); 6 months follow-up CT scan (I); 12 months follow-up clinical evaluation (L-M).

Table 3 Rasmussen's Radiological Score at the last follow-up

Rasmussen radiological score	Patients (n.9)
Excellent	5 (55%)
Good	4 (45%)
Fair	0
Poor	0

DISCUSSION

Tibial plateau fractures occur in an important load-bearing joint. A correct anatomical reconstruction of the fracture site is necessary especially in more complex patterns. However significant bone defects can remain after reduction of the articular surface. Fracture depression and displacement are the most important factors affecting surgical management. If left untreated, depression results in joint incongruity, valgus deformity, and a sense of instability (Markhardt BK *et al.*, 2009). Functional outcome studies of greater than 20-year follow-up have shown an inconsistent relationship between residual osseous depression of the joint surface and the development of osteoarthritis (Lansinger O *et al.*, 1986) (Timmers TK *et al.*, 2014). However joint deformity or depression associated with knee instability, increase the likelihood of a poor outcome (Lansinger O *et al.*, 1986) (Timmers TK *et al.*, 2014) (Honkonen SE *et al.*, 1994).

In the light of our results obtained with the balloon-assisted reduction in calcaneal fractures (Vittore D *et al.*, 2014), we adapted the inflatable instruments and used the balloon technique to reduce depressed fragments of the tibial plateau.

This is a relative new technique with only few papers published (Pizanis A *et al.*, 2012) (Yu B *et al.*, 2009) (Mauffrey C *et al.*, 2014) (Ahrens P *et al.*, 2012) (Broome B *et al.*, 2012) (Hahnhaussen J *et al.*, 2012). One of these is a biomechanical study conducted on six intra-articular depression-type fractures created in paired cadaveric specimens. The inflatable bone tamp was compered to a conventional metal tamp used on the contralateral side of the balloon. This tool was equivalent to conventional methods in large, minimally displaced fracture fragments and proved superior when comminution was present at the articular surface. No instances of over-reduction or penetration into the joint were encountered with the balloon, whereas this was a common occurrence with conventional metal tamps. The Authors concluded that the inflatable device is safe and effective in reducing depressed articular fractures around the tibial plateau and offers the advantage of being minimally invasive and creating a symmetric, contained defect to hold bone filler for subchondral support (Broome B *et al.*, 2012). Similar results were reported by Ahrens *et al*. (2018) in the treatment tibial plateu depression fractures.

In one of the first series published, Yu *et al*. (2009) demonstrated the efficacy of the balloon-technique with high strength injectable calcium sulphate in a sample of 31 patients, including more complex fracture patterns (Schatzker type IV-V-VI). At one year follow-up the Authors reported good clinical and radiographical results for all groups with no major complications and no relevant articular subsidence occurring. According to the Authors the adequate immediate stability and high compressive strength provided by calcium sulphate helped to prevent subsidence of the articular surface. Moreover in comparison with others bone fillers, calcium sulphate has a fairly rapid resorption rate. This means that is not necessary to remove the escaped calcium from the joint space or soft tissues because the graft materials will be absorbed in 15 days according to Watson's research (Watson JT *et al.*, 2004). However no cases of intra-articular leakage of graft material were reported.

In our case series, only tricalcium phospate was used. The efficacy of this bone filler in the treatment of tibial plateau fractures has been demonstrated in various studies (Russell TA *et al.*, 2008) (Welch RD *et al.*, 2003) (McDonald E *et al.*, 2011) (Simpson D *et al.*, 2004) (Yetkinler DN *et al.*, 2001).

McDonald *et al*. (2011) compared the biomechanical fatigue strength of calcium phosphate augmented repairs versus autogenous bone graft (ABG) repairs in lateral tibia plateau fractures. Their results showed that calcium phosphate repairs have significantly higher fatigue strength and ultimate load than ABG repairs and may increase the immediate weight-bearing capabilities of the repaired knee. Similar results were reported by Welch *et al*. (2003). In their model, the Authors found that cancellous autograft did not maintain an anatomical reduction of the tibial plateau fractures. In contrast, augmentation with calcium phosphate cement prevented subsidence of the fracture fragment and maintained articular congruency as the fracture healed. The improved articular congruency reduced the prevalence and severity of degenerative changes in the joint.

As confirmed in different papers, most of the calcium phosphate-based bone substitute remain several years after injection (Larsson S *et al.*, 2002) (Frankenburg EP *et al.*, 1998). In our patients the calcium phosphate was still evident on the x-ray obtained at 12 months post-operative and was only partially reabsorbed. Concerns about calcium phosphate remain due to its slow resorption rate that may lead to complications in case of intra-articular migration or soft tissue extrusion. Although no cases of cement migration were observed in the current study, our experience with this filler in the treatment of calcaneal fractures teach us that no additional stiffness or pain occur in these cases (Vittore D *et al.*, 2014). Similarly Cassidy *et al*.(2003) reported no adverse sequelae even in the presence of intra-articular extrusion into wrist joint.

Only split-depression (Schatzker type II) and pure depression (Schatzker type III) fractures were included in our study. In all cases the pre-operative x-rays and CT demonstrated no displacement of the posterior wall. A posterior wall breach represents a contraindication to the use of the balloon inflation technique; it makes fracture reduction difficult and increases the risk of further displacement. In these fracture patterns standard reduction techniques with conventional bone tamps should be used (Mauffrey C *et al.*, 2013) (Stahel PF *et al.*, 2008).

The position of the cement in the proximal tibia is highly debated in literature. Some Authors support the need for placing the cement more distal to the subchondral plate reducing the risk of balloon penetration and cement leakage into the joint, that may result in cartilage damages (Mayr R *et al.*, 2015) (Mauffrey C *et al.*, 2013). On contrary Goetzen *et al*. (2015) have recently investigated whether subchondral PMMA injection compromises the homeostasis of the subchondral bone and/or the joint cartilage on a animal model. The authors concluded that cement augmentation in the metaphyseal region appears to be a safe procedure without harming the subchondral plate and the adjacent cartilage. In our study the cement was placed approximately 10 mm under the subchondral plate. No cases of balloon penetration and cement leakage into the joint were observed.

Unlike other studies, we decided not to use any additional fixation in cases of pure depression fractures (Schatzker type III). Only 2/3 temporary k-wires were used. In split-depression patterns (Schatzker type II) a 3.5 mm plate or 2 percutaneous screws were implanted. In both cases no screws were placed under the subchondral plate or trough the calcium phospate. In our opinion plates and percutaneous screws act only as stabilizers of the lateral split prior to inflating the IBT and help to guide the correct expansion of the balloon. For this reason we believe that no additional screws are needed once the cement is in place. These intuitions were confirmed by our results that are broadly in line with the literature (Pizanis A *et al*., 2012) (Yu B *et al*., 2009) (Ahrens P *et al*., 2012). No differences in terms of Rasmussen's functional score were detected between patients with Schatzker type II and Schatzker type III fractures during the follow up with a good overall score at the last follow-up. At the same time the mean Rasmussen's radiological score was 16,6 with 5 patients having excellent results and 4 patients with good results. No differences were detected between the two groups of fracture during the follow-up. Only one case of articular subsidence of 4 mm was found in a patient with a Schatzker type III fracture but it did not affect the clinical outcome at the final follow-up. Is important to remember that there is no consensus about the amount of articular depression and displacement that can be accepted. Studies evaluating the long-term development of secondary OA showed no statistical difference between less than 2 mm of depression and less than 4 mm (Rademakers MV *et al*., 2007). Moreover animal models have demonstrated development of OA when the step-off from the articular surface exceeds the thickness of the articular cartilage (Llinas A *et al*., 1993).

The main advantage of the balloon tibioplasty is the minimally invasive percutaneous approach which preserve the soft tissue envelope and allow earlier weight bearing, especially when compared to traditional techniques (Ebraheim NA *et al*., 2004) (Young MJ *et al*., 1994) (Manidakis N *et al*., 2010). In our series partial weight bearing was allowed after 3 weeks post-operative; full weight bearing deferred until 5 weeks. Fractures healed uneventfully in all patients; no cases of nonunion, malunion or deep infection were detected.

CONCLUSIONS

Based on our findings, balloon-assisted reduction and calcium phosphate augmentation represents an effective mini-invasive technique in the treatment of depressed tibial plateau fractures. The balloon-assisted reduction is useful in restoring the congruency of the articular surface while the calcium phosphate provides adequate mechanical stability preventing secondary collapse without the necessity of additional fixation. Early knee mobilization and early weight bearing are therefore permitted.

In our group' s experience, a posterior wall breach represents a contraindication to the use of the balloon technique. For this reason traditional techniques such as the ORIF or the External Fixation should be used in more complex fracture patterns.

The retrospective nature of the study and the size of the sample represent a limit of this paper. Moreover our promising results should be confirmed in future studies with a longer follow-up in order to draw correct conclusions about the development of late complications, particularly of post-traumatic osteoarthritis.

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