MINIMALLY INVASIVE TREATMENT OF DISPLACED INTRA-ARTICULAR CALCANEAL FRACTURES USING THE BALLOON KYPHOPLASTY TECHNIQUE: PRELIMINARY STUDY

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KEYWORDS
Intra-articular joint depression fracture; Calcaneus; Balloon osteoplasty; Cement stabilisation

Summary
Background: The balloon kyphoplasty approach to the treatment of vertebral fractures can be adapted to achieve the reduction and cement stabilisation of intra-articular compression fractures at other sites, such as the calcaneus.

Patients and method: We studied six patients with a median follow-up of 12 months (range, 6–30 months). Fluoroscopy guidance was used to obtain optimal balloon positioning under the joint depression site. Reduction was achieved by expanding the balloon and stabilisation by injecting the cavity with resorbable tricalcium-phosphate cement in the younger patients and polymethyl-metacrylate cement in the two elderly patients with osteoporosis. No internal fixation was used.

Results: No intra-operative, postoperative, or delayed complications were recorded. Median hospital stay length was 4.5 days (range, 3–7 days). All the fractures healed within the usual timeframe, without loss of reduction. Median time to full weight-bearing ambulation was 52.5 days (range, 15–75 days). The functional outcomes correlated with the good anatomic results, with a median American Orthopaedic Foot and Ankle Society score of 87.0 (range, 86–97).

Discussion: This preliminary study shows that balloon reduction and cement fixation of intra-articular calcaneal fractures is easy to perform, reproducible, and devoid of specific complications. Good-quality reduction and stabilisation until fracture healing were achieved, and time to recovery of self-sufficiency was short, even in elderly patients with osteoporosis. These results support the use of this minimally invasive technique.

Level of evidence: Level IV, retrospective study.

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Introduction

Kyphoplasty is a surgical procedure developed in the past decade by applying the principles of balloon angioplasty to the vertebrae [1]. Kyphoplasty consists in reducing A1 compression fractures of osteoporotic vertebrae by gradually inflating two balloons introduced percutaneously through the pedicles. The cavity left after removal of the balloons is filled with polymethyl-metacrylate cement (PMMAc). A recent advance is the development of resorbable tricalcium-phosphate cement (Ca-Pc) that is well suited to the mechanical loads through the spine and can be combined with short-segment percutaneous internal fixation to treat more complex vertebral fractures in young patients.

Based on our experience and on reports of good outcomes after kyphoplasty [2], we decided to adapt this minimally invasive technique to the treatment of intra-articular calcaneal fractures.

We hypothesised that balloon reduction with cementoplasty is a simple and reproducible technique providing satisfactory anatomic reduction and stabilisation until fracture healing with functional outcomes similar to those obtained using other techniques.

Patients and methods

Patients

We retrospectively reviewed the medical charts of the six patients managed at our centre for displaced intra-articular fractures of the calcaneus between 2009 and 2011. There were five men and one woman with a median age of 46.5 years (range, 41–67 years) and a median follow-up of 12 months (range, 6–30 months). All six patients had closed fractures due to falls, of which two occurred at work. The two oldest patients had untreated osteoporosis (Table 1).

The radiographs and reconstructed computed tomography (CT) images showed a horizontal fracture in 1 patient and combined fractures in 5 patients, according to the Utheza classification [3]. In the Sanders classification [4], all six fractures were type II (2 IIA, 3 IIB, and 1 IIC) with one or two secondary fracture lines involving the plantar cortex. Median initial Böhler’s angle was $-1.5^\circ$ (range, $-14^\circ$ to $+14^\circ$). The CT reconstruction images were used to determine the optimal balloon position in each patient.

Surgical procedure and postoperative management

Set Up

All patients were positioned on an orthopaedic traction table with trans-calcaneal traction and no tourniquet. Fluoroscopic monitoring in the sagittal plane and the 30° Broden incidence was used [5]. The traction pin was placed in the poster-inferior part of the posterior calcaneal tuberosity to achieve immediate reduction of the hindfoot ascension and varus and to distract the subtalar joint. Two patients were in the supine position with the knee flexed on a popliteal support and the other four patients were in the prone Trendelenburg position ($10–20^\circ$) with the affected lower limb extended (Fig. 1).

The kyphoplasty kit (Kyphon, KPT 1502, Medtronic Inc., Minneapolis, MN, USA) included an inflatable bone tamp connected to an inflation syringe with manometric control, intra-osseous trocars, a guide-pin, and cannulae. The inflation syringe was filled with a radio-opaque solution to allow fluoroscopic visualisation of balloon inflation during the procedure.

Balloon introduction

A cannulated trocar was introduced percutaneously into the cancellous bone (Fig. 2). For the patients in the prone

<table>
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<th>Patients</th>
<th>1</th>
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<th>4</th>
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<td>IIB</td>
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<td>PMMAc</td>
<td>Posterior</td>
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<td>Ca-Pc</td>
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<td>$+4^\circ$</td>
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<td>$-6^\circ$</td>
<td>$-14^\circ$</td>
<td>$+4^\circ$</td>
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<tr>
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<td>$+12^\circ$</td>
<td>$+30^\circ$</td>
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<td>$+16^\circ$</td>
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<td>87</td>
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<td>97</td>
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PMMAc, polymethyl-metacrylate cement; Ca-Pc, tricalcium-phosphate cement; AOFAS, American Orthopaedic Foot and Ankle Society ankle-hindfoot score.
position, the trocar was inserted via a posterior approach through the postero-superior prominence of the heel, to the sub-talar joint, in the forward and lateral direction. For the patients in the supine position, trocar insertion was via the direct lateral approach. A guide wire was inserted through the trocar and advanced towards the fracture site 3 to 4 mm under the apex of the lesion. Then, the trocar was removed and replaced by a cannula, and the guide wire was removed. The deflated balloon with its two metallic markers was introduced through the cannula (Fig. 2b). Care was taken to ensure that the balloon could be advanced and removed without resistance to avoid tearing, rupture, or extraction difficulties. The kit contained a trephine for use in preparing the introduction canal if needed.

Reduction
Once the balloon was positioned at the site identified pre-operatively on CT scan images, it was expanded gradually. Ascension of the osteo-articular fragment(s) up to the joint space was monitored on the fluoroscopy screen. Balloon inflation resulted in compaction of the cancellous bone underlying the fracture and maintained adhesion between the fragments (Fig. 2c). A 15-mm/4 mL balloon with a maximum pressure of 300 PSI (20 bar; rupture threshold, 400 psi) was consistently sufficient to reduce the fracture and offered sufficient plasticity to allow a small degree of off-centring.

Stabilisation
The balloon was deflated and removed and the cavity was then filled with radio-opaque cement (Fig. 2d). In the two patients older than 65 years of age, we used high-viscosity PMMAc (Kyphon HV-R, Medtronic). The slow polymerisation rate of this cement translated into a working time of 8–10 min, and the resulting good user control and ease of handling allowed complete filling of the cavity, with no drawbacks. In the younger patients, we used Ca-Pc (Kyphos FS, Medtronic), which hardened quickly via an isothermic reaction and was both osteoconductive and resorbable [2]. As recommended, we followed the precautions required during the crystallisation phase of the Ca-Pc, with a 20-min wait period between the last injection and joint mobilisation, as well as a 24-h delay before achieving optimal resistance to compression.

When there was a risk of cement leakage into the joint or outside the bone, or when balloon removal was followed by loss of reduction, we used the "eggshell" procedure. After injection of 1 mL of cement, the balloon was re-introduced into the cavity and inflated to induce peripheral displacement of the cement around the balloon and against the cavity wall, while perfecting the reduction (Fig. 3a). Once the cement hardened, the balloon was removed (Fig. 3b). The shell stabilized and sealed the cavity, allowing filling with no risk of leakage (Fig. 3c).

When Broden’s view showed diastasis in the coronal plane between the thalamic fragments, compression of the
Figure 2  Technique: a1 and a2: sagittal and coronal computed tomography (CT) reconstructions of a Sanders type IIB fracture. Intra-operative sagittal fluoroscopic view: b: introduction of the balloon (patient in the prone position); c: fracture reduction by inflation of the balloon; d: cementoplasty (tricalcium-phosphate cement); e1 and e2: CT 1 year after surgery.
Minimally invasive treatment of displaced intra-articular calcaneal fractures

Postoperative assessment methods

The patients underwent clinical re-evaluation after 30, 60, and 90 days; 6 months; and more than 1 year. We recorded the complications, median hospital stay length, time to walking resumption, and time to work resumption. At the 6-month follow-up evaluation, the functional outcome was assessed by determining the American Orthopaedic Foot and Ankle Society (AOFAS) score [6].

The anatomical result was assessed based on the quality of reduction of the fractures and on the radiographs and CT scans obtained 45 days, 3 months, and 6 months after surgery; in some patients, imaging was also obtained after more than 1 year. The Böhler’s angle improvement and the criteria developed by Rammelt et al. [7] for evaluating joint surface step-offs were recorded. Given the limited follow-up in our patients, we did not evaluate a score for osteoarthritis.

Results

Functional outcomes

Median time from injury to surgery was 2 days (range, 1–5 days). There were no intra-operative, postoperative, or delayed complications, particularly involving the skin. Median hospital stay length was 4.5 days (range, 3–7 days).

Median time to full weight-bearing ambulation was 52.5 days (range, 15–75 days). The 2 older patients with osteoporosis spontaneously resumed full weight bearing after 2 and 3 weeks, respectively. Hindfoot motion range was normal or only slightly limited for inversion-eversion (75–100% of normal) and flexion-extension (30° or more), with a stable plantigrade foot. Functional outcomes were considered good with a median AOFAS score of 87 (range, 86–97). In the patients who were still employed, time to work resumption was 3 months.

Anatomic results

At last follow-up, all six patients had healed fractures with no loss of reduction. Median Böhler’s angle increased from −1.5° (range, −14° to +14°) preoperatively to +27.0° (range, +12° to +30°) postoperatively; the value on the unaffected side was +25.5° (range, 21° to 36°). None of the patients had more than 5° of residual varus or a joint surface step-off greater than 2 mm (0 in 4 patients and 1–2 mm in 2 patients). In patients with residual diastasis between the thalamic fragments, the joint remodelling induced by immediate mobilisation promoted compression of the separation during the first 2 months followed by secondary filling (Fig. 4b). Healing was achieved within the expected timeframe in all six patients. After 1 year, none of the patients exhibited complete Ca-Pc resorption or lysis at the cancellous bone cement interface.

Discussion

Surgery has superseded non-operative orthopaedic methods for intra-articular calcaneal fractures as it decreased...
the rates of osteoarthritis and secondary arthrodesis, produced better outcomes in several comparative studies, and increased the ease of arthrodesis if osteoarthritis develops [8—10]. However, even after perfect reduction and healing, no means are available for predicting the course of irreversible damage to the cartilage involved by the fracture [11].

Open surgery is associated with high rates of complications, most notably involving the skin, of nearly 25% in some case-series, with a 21% rate of iterative surgery [12]. Consequently, surgeons have developed minimally invasive techniques, which however produce poorer outcomes in terms of fracture reduction and joint stabilisation [7,13]. The use of arthroscopy improves overall short- and medium-term outcomes [7,14]. However, the use of a metal bone tamp carries a risk of trajectory error, joint cavity penetration, and dispersion of the fragments during elevation, particularly when the fracture is comminuted, which may require conversion to open surgery to achieve reduction [7]. Percutaneous screw-plate fixation is difficult to perform and the use of K-wires, Steinman pins, or external fixation is unreliable and increases the risk of infection [15]. Filling the underlying cavity to support the reduced fragments seems indispensible. Bone grafting in this situation was first described by Palmer [16]. Controversy ensued, with opponents arguing that well-performed fixation was sufficient [4]. Although minimally invasive methods are gaining in popularity, caution is required to ensure that they perform at least as well as open surgery. This is not the case at present, due to the use of technical means that are unreliable or even unusable in certain comminuted fractures.

Appropriate adaptations of the balloon reduction and cement stabilisation procedures used in vertebral balloon kyphoplasty may constitute a valid option for similar intra-articular compression fractures, most notably at the calcaneus. The single tiny stab incision avoids the occurrence of skin complications. Gradual balloon expansion reverses the effects of fracture impaction while maintaining fragment adhesion and eliminates the complications associated with the use of metal tamps. Fluoroscopy with the sagittal and Broden’s views provides sufficient intra-operative monitoring, as confirmed by the postoperative reconstructed CT images. We did not use arthroscopy, as this procedure increases the operating time, risk of iatrogenic complications, and treatment costs. However, arthroscopy

Figure 4 Course of the inter-fragment diastasis: a1: joint remodelling seen on the coronal computed tomography (CT) reconstruction on the 2nd postoperative day; a2: 2 months after surgery; b1: filling with restoration of subchondral bone continuity seen on the coronal CT reconstruction on the 2nd postoperative day (step-off < 2 mm); b2: 2 years after surgery.
may help to assess the reduction while decreasing radiation exposure to the surgeon, other healthcare personnel, and patient.

Our results confirm that additional fixation is unnecessary. The bone cements used ensured excellent osteo-articular stability until fracture healing, with no loss of reduction and with sufficient resistance to pressure to allow rapid resumption of weight bearing. However, one year after kyphoplasty, Maestretti et al. observed Ca-Pc cracks and lacunae around the cement on all follow-up CT scans, in the absence of further trauma and without corresponding clinical manifestations [2] The cracks tend to develop within the first postoperative week and may be due to incorrect cement application responsible for disturbances in the crystallisation process that change the intrinsic properties of the cement. Scrupulous adherence to post-cementoplasty recommendations is clearly indispensable. An animal experiment by Verlaan et al. confirmed that neither PMMA nor Ca-Pc carried a risk of subchondral bone degeneration, even when the bone was fractured [17]. Years of research in spine, trauma, and tumour surgery have established that both types of cement can be used safely in these fields.

As the intervertebral discs act as shock-absorbers, allowing resumption of the erect position after 24 h, we felt that weight-bearing elimination until fracture healing was a sensible precaution. Nevertheless, earlier weight bearing may be safe: several patients resumed weight bearing early after surgery of their own accord, with no adverse consequences. We used PMMAc in the 2 patients older than 65 years, as adherence to immediate postoperative recommendations may be more challenging in the elderly.

Two recent studies performed at the same time as ours evaluated the same method in 4 and 3 patients, respectively [18,19]. In one, PMMAc was used in all four patients, K-wires were inserted above the fractured inferior cortex to support the balloon, and a clamp was used to compress the thalamus and avoid its widening during balloon inflation [18]. In the other study, the three patients were selected based on less than 5° of varus, and Ca-Pc was used [19]. We believe that trans-calcaneal traction is crucial to achieve reduction and expands the range of indications of the technique. Although all our patients had one or two secondary fracture lines into the inferior cortex, destabilisation did not occur during balloon inflation. A clamp for lateral compression should not be used routinely, as intra-thalamic diastasis is inconsistently present and clamp application carries a risk of skin complications. Intra-operative compression between the thumb and forefinger followed by joint remodelling induced by mobilisation is sufficient. In neither of the two earlier studies were any complications recorded, and the postoperative outcomes were excellent after 3 years and 1 year of follow-up, respectively. Similarly, good anatomic reduction in our patients was consistently associated with good functional outcomes. This correlation between anatomic and functional outcomes was previously demonstrated by Rammelt et al. [7].

The treatment of intra-articular calcaneal fractures in elderly patients with osteoporosis remains highly controversial. Non-operative management is widely used but is associated with numerous complications. The paucity of published data is in striking contrast to the many fixation techniques designed to expedite rehabilitation after other fractures of the limbs or spine. Surgery may be considered but requires careful patient selection [20]. Our results in two patients with osteoporosis are extremely encouraging, with an uneventful postoperative course and rapid resumption of self-sufficiency.

The cost of the material has decreased since we first asked Medtronic to produce “extremity kits” (ETL153A, Medtronic) containing a single manometric syringe and modified balloons. However, the kit still costs three times more than a screw-plate. Nevertheless, the cost/benefit ratio may be favourable: the median hospital stay length and need for local care were diminished, no complications occurred, no secondary surgery to remove material was needed, and times to weight-bearing and to work resumption were shorter. A medico-economic study to assess this point would be of interest.

Conclusion

Our preliminary results support the continued use of minimally invasive balloon reduction and cementoplasty to treat intra-articular calcaneal fractures. They confirm our hypothesis: the quality of the reduction is excellent, the fracture site remains stable until full healing is achieved, and the good functional outcomes allow the patients to rapidly recover their self-sufficiency. This technique seems to hold considerable promise, particularly for patients with osteoporosis.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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