Posterior Locking Plate Fixation of Bartoníček Type IV Posterior Malleolar Fracture: A Focus on Die-Punch Fragment Size

Chunguang Sun, MD1,2, Zhengguo Fei, MS2, Xiaoliang Peng, MS2, Cheng Li, MS2, Qijia Zhou, MS2, Qirong Dong, MD1, Wei Xu, MD1

1 Surgeon, Department of Orthopaedics, Second Affiliated Hospital of Soochow University, Jiangsu, China
2 Surgeon, Department of Orthopaedics, Funing People’s Hospital, Jiangsu, China

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ABSTRACT

Die-punch fragments refer to articular cartilage and subchondral bone embedded in cancellous bone as part of an intra-articular fracture. Bartoníček type IV posterior malleolar fractures with associated die-punch fragments are rare, and the appropriate surgical approach remains unclear. We determined outcomes, and the effect of die-punch fragment size on outcomes, for 32 patients with Bartoníček type IV posterior malleolar fractures with die-punch fragments between January 2015 and December 2017. Mean follow-up for all patients was 23.8 (range 20.0-30.0) months. At the final follow-up visit, mean ankle dorsiflexion was 24.6° and plantar flexion was 40.0°; American Orthopaedic Foot and Ankle Society ankle-hindfoot score was 88.6 ± 4.3; visual analog scale weightbearing pain score was 1.5 ± 0.6; and Bargon traumatic arthritis score was 0.8 ± 0.4. There were no severe complications. We divided patients into a small-fragment (<3 mm) group (n = 12) and large-fragment (>3 mm) group (n = 20). The Bargon scores at final follow-up were 0.5 and 1, respectively (P = 0.02). There were no statistically significant differences between the 2 groups for the other outcome scores at various time intervals. The posterolateral approach with distal locking plate internal fixation for Bartoníček type IV posterior malleolar fractures with die-punch fragments can result in excellent anatomical reduction of the collapsed articular surface and the displaced fragment from the tibial plafond, recovery of articular surface congruity, and maintenance of joint stability. Die-punch fragment size may not impact clinical and functional outcomes but may contribute to post-traumatic arthritis.

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Conflict of Interest: We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We understand that the corresponding author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the corresponding author and which has been configured to accept email from JFAS.

Address correspondence to: Wei Xu, MD, Department of Orthopaedics, Second Affiliated Hospital of Soochow University, No. 1055, Sanxiang Road, Suzhou, Jiangsu 215004, China.
E-mail address: 13962157016@139.com (W. Xu).

Posterior malleolar fractures (PMFs) occur as part of more than 40% of ankle fractures (1). It is generally acknowledged that patients with ankle fractures that include a posterior malleolar fragment have inferior outcomes to those with other types of ankle fractures (2). The recovery of ankle function after PMFs is substantially influenced by whether anatomical fixation of the posterior malleolar fragment is performed (3). In the past, indirect reduction and percutaneous fixation with cannulated screws placed from anterior to posterior were used to treat PMFs (4,5). In recent years, better results have been obtained with the use of reduction under direct vision and internal fixation with a plate and screws through a posterolateral approach (6,7).

In theory, fracture classification systems are intended to help guide clinical management. However, many of the current PMF classifications are based on fracture line morphology, and few of them provide effective guidance when choosing treatment. In 2015, Bartoníček et al. proposed an innovative PMF classification system, based on the results of computed tomography (CT) rather than plain radiography, which can be used to determine optimal surgical approaches, including whether internal fixation is indicated (8). A Bartoníček type I PMF has an
extracapsular fragment with an intact fibular notch, type II has a poste- 
rolateral fragment extending into the fibular notch, and type III has a 
posteromedial 2-part fragment involving the medial malleolus.

A Bartoníček type IV PMF is characterized by a large triangular frag-
ment on the posterolateral side of distal tibia, with a fracture line that 
usually extends to the posterior colliculus of the medial malleolus. In 
our experience, these fractures can occur with die-punch fragments. 
These are fragments that occur as part of an intra-articular fracture, 
formed when the articular cartilage and subchondral bone are embed-
ded in the cancellous bone, and patients with die-punch fragments 
tend to have a poor prognosis (9,10). Reports suggest that it is not 
unusual for Bartoníček type II and III PMFs to occur with die-punch 
fragments (8,11), but we were unable to identify studies concerning the 
management of Bartoníček type IV PMFs with die-punch fragments.

The aim of this study was to summarize our experience with 32 
patients who had Bartoníček type IV PMFs with die-punch fragments, 
and who were treated according to the Bartoníček classification system 
recommendations, using distal locking plate internal fixation with a 
posterolateral approach. We were also interested in determining 
whether the size of the die-punch fragments had any influence on the 
clinical outcomes of these patients.

Patients and Methods

This study was performed in accordance with the ethical standards of the 1964 Decla-
ration of Helsinki and was approved and supervised by the Ethics Committee of Funing 
People’s Hospital (No. 2019003).

Patient Cohort

From January 2015 to December 2017, we retrospectively identified a total of 32 con-
secutive patients with 32 Bartoníček type IV PMFs who underwent surgery at our facility.
Inclusion criteria: (1) age >18 years and <75 years; (2) new closed posterior malleolus 
fracture; (3) follow-up duration of at least 12 months; (4) fracture involving large internal 
posterior triangular fragment combined with die-punch fragment. Exclusion criteria: (1) 
old or pathological fracture; (2) Gustilo type II or III open fracture; (3) fracture combined 
with vascular or nerve injury; (4) incomplete cooperation with follow-up.

After admission, anteroposterior (AP) and lateral plain radiographs (Fig. 1) and com-
puted tomography (CT) scans with 3-dimensional reconstruction of the involved ankle 
joins were performed. All patients underwent surgery after local swelling had resolved, 
blisters had healed, and skin had softened. They remained in the hospital with limb eleva-
tion during this waiting period. The mean waiting time from injury to surgery was 8.5 
(range 1-10) days.

For each patient, we obtained data about age, gender, side of fracture, body mass 
index (BMI), mechanism of injury, associated injuries, and maximum diameter of the die-
punch fragment, which we designated “fi”. We categorized the fractures using both the 
Haraguchi (12) and Mason (13) classifications systems.

Surgical Technique

All surgeries were done by the same surgical team. General anesthesia was used 
for all surgeries. A first generation cephalosporin was given a half hour before sur-
gery and continued for 24 hours postoperatively. Patients whose fractures included 
the medial malleolus were first placed in the prone position and then in the supine 
position, whereas those without medial malleolar fractures were only placed in the 
prone position.

A longitudinal posterolateral incision was made along a line extending from the lat-
eral edge of the Achilles tendon to the posterior border of the fibula. The distal end of the 
incision extended just beyond the tip of the lateral malleolus. Skin, subcutaneous tissue 
and deep fascia were divided by their anatomical levels to protect significant structures, 
including the small saphenous vein and the sural nerve. The fibula was exposed at the 
front edge of peroneal longus and brevis muscles, seeking to identify one end of the frac-
ture. Care was taken to preserve the peristome, while any hematoma and incarcerated 
soft tissue were cleared.

The lateral malleolar fracture was reduced and fixed. In keeping with the osteosyn-
thesis principle of Traditional Chinese Medicine, this included reverse folding (reduction 
opposing the stress mechanism that caused the fracture), tracting (reduction opposing 
deforinites caused by local muscle contraction) and poking (reduction of smaller areas of 
placement with insertion of a Kirschner [K]-wire). The anatomical lateral plate of the 
distal fibula was appropriately positioned and then fixed to the lateral aspect of the lower 
part of the fibula, through the same posterolateral incision.

A gap was created between the peroneal longus and brevis muscles and the flexor 
hallucis longus tendon, through which a periosteal elevator was used to strip the poste-
rior peristome of the tibia. A Hoffman pull hook was placed into the posterior colliculus 
of the medial malleolus, allowing visualization of the posterior ankle and exploration of 
the integrity of the posterior tibiofibular ligament. The posterior malleolar fragment was
lifted laterally and distally, using a K-wire if necessary, as if “opening a book”, to allow further exploration of the posterior articular surface of the distal tibia. The posterior tibiofibular ligament and the periosteum to which it was attached were protected. Residual bone and cartilage debris were then removed using joint cavity flushing. Once the posterior articular surface of the distal tibia was exposed, any compressed die-punch fragments were reset. Die-punch fragments were excised if too small for fixation (which occurred in a small number of patients). Once the integrity of the articular surface was restored, the PMF was reduced, as if “closing a book.” If necessary, autologous or allogeneic bone grafting was used to provide additional support. K-wires were used for temporary fixation, to allow anatomical positioning of the proximal, medial, and lateral surfaces of the posterior malleolar fragment. Screws were placed and then the K-wires were removed. The successful anatomical reduction of both the die-punch fragment and the PMF, and the integrity of the articular surface, was confirmed using C-arm fluoroscopy.

Then, a distal locking plate was placed, in an upside down fashion, for support and fixation (Figs. 2 and 3). We chose a distal locking plate over a 1/3 tubular plate for fixation. Whereas the tubular plate can be used in young patients with satisfactory results, for most patients, particularly those who are elderly or have osteoporosis, we favor the locking plate, because it provides an anti-glide effect and supports the die-punch fragment with locking screws.

The plate was placed to include the distal end of the tibial plafond, in order to secure the reduction of the die-punch fragment, and short locking screws were used to avoid the articular surface. The height of the plate and the length of the distal short locking screws were determined based on the location of the die-punch fragment as seen on preoperative CT scans. Finally, a Cotton test was performed to detect lower tibiofibular joint stability, with the plan to insert a lower tibiofibular lag screw for fixation if necessary. However, none of the patients in this study had lower tibiofibular joint instability. The incision was closed in layers.

The medial malleolar fracture was then exposed using a second longitudinal incision directly over the medial malleolus, and the hematoma and soft tissue in the area were cleared. Reduction and fixation were done with priority placed on creating a smooth con-
Postoperative Care and Follow-Up

For deep venous thrombosis prophylaxis, caregivers were instructed to passively flex and extend the affected ankle joint and to intermittently massage the muscles of the affected limb in the recovery room (sequential compression devices were not used routinely for ankle fractures at our facility for cost reasons). All patients were encouraged to begin gradually moving their toes and ankle joints, to do range of motion (ROM) exercises as soon as possible, and to be up and out of bed beginning 3 days after surgery. Patients were asked to be non-weightbearing for 6 weeks after surgery, and then they were allowed to begin weightbearing with the help of crutches. No formal physical therapy was done.

No K-wires were left in after surgery. Sutures were removed 2 weeks after surgery. Plain AP and lateral radiographs were performed at visits in the 1st, 2nd, 3rd, 6th, and 12th months after discharge from the hospital, then every 6 months after that as needed. In addition, the outcome measures described below were assessed at each of these visits, though only those done preoperatively, postoperatively (one week after surgery), and at the final follow-up visit were analyzed for this study. The final follow-up visit was defined as the last time the patient came back after the 12th month. All functional and radiographic outcomes were assessed by a single surgeon who had not been part of the surgical team.

Outcomes

Complications were recorded. The time intervals from surgery to fracture healing and to full weightbearing were each recorded. Dorsal extension and plantar flexion ROM were measured from neutral and recorded at the final follow-up visit for each patient. Functional outcomes were assessed using the preoperative, postoperative, and final follow-up visit American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot scores (16,14-16). At each visit, ROM and AOFAS measurements were done 3 times, and the mean was calculated and ultimately used as the result for that visit. Ankle pain in the resting state was determined at similar time intervals using a 10-point visual analogue (VAS) scale (17). Ankle pain was also assessed for non-weightbearing activity, both postoperatively and at the final follow-up visit, and for weightbearing walking at the final follow-up visit. The Bargon criteria were used to grade post-traumatic arthrosis of the ankle joint based on plain radiographs done at the final follow-up visit (18).

Statistical Methods

All descriptive data are presented as means ± standard deviations (SD) or frequencies and proportions. To assess the impact of die-punch fragment size, we compared the clinical and radiologic outcomes of patients with ϕ ≤ 3 mm to those with ϕ > 3 mm. We also compared outcomes at 3 specific time intervals in the care process: preoperative, postoperative (one week after surgery), and at the final follow-up visit. Comparisons of the means of 2 groups were performed using the Student’s t test, and comparisons of the means of more than 2 groups were done using the one-way ANOVA and Tukey post hoc test. We defined statistical significance at the 5% (p ≤ .05) level. Data analysis was performed using GraphPad Prism software version 8.0 (GraphPad, San Diego, CA).

Results

Of the 32 patients in the study, 11 were male and 21 were female, and the mean age was 45.6 ± 6.3 (range 32-59) years (Table 1). The most common mechanism of injury was motor vehicle accident (22 patients). There were 20 patients with Haraguchi type I and 12 patients with Haraguchi type II fractures. There were 10 patients with Mason type IIA and 22 patients with Mason type III fractures. All 32 patients had die-punch fragments, of whom 12 were in the small-fragment (ϕ ≤ 3 mm) group and 20 were in the large-fragment (ϕ > 3 mm) group. All 32 patients had fractures of the distal ipsilateral fibula, 30 patients had ipsilateral malleolar fractures, and 5 patients had distal tibial anterior margin fractures. Associated injuries included spinal fracture in 1 patient, lung contusions in 2 patients, and mild cranio-cerebral injury in 1 patient.

Table 1 Demographic and clinical characteristics of 32 consecutive patients with 32 Bartoníček type IV posterior malleolar fractures with die-punch fragments, January 2015 to December 2017

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Patients Mean ± SD or n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>45.6 ± 6.3</td>
</tr>
<tr>
<td>Sex</td>
<td>11 (34.4)</td>
</tr>
<tr>
<td>Male</td>
<td>11 (34.4)</td>
</tr>
<tr>
<td>Male</td>
<td>21 (65.6)</td>
</tr>
<tr>
<td>Female</td>
<td>15 (46.9)</td>
</tr>
<tr>
<td>Right</td>
<td>17 (53.1)</td>
</tr>
<tr>
<td>Left</td>
<td>15 (46.9)</td>
</tr>
<tr>
<td>Body mass index (BMI), kg/m²</td>
<td>25.5 ± 2.6</td>
</tr>
<tr>
<td>Mechanism of injury</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>9 (28.1)</td>
</tr>
<tr>
<td>Motor vehicle accident</td>
<td>22 (68.8)</td>
</tr>
<tr>
<td>Sports injury</td>
<td>1 (3.1)</td>
</tr>
<tr>
<td>Haraguchi classification</td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td>20 (62.5)</td>
</tr>
<tr>
<td>Type II</td>
<td>12 (37.5)</td>
</tr>
<tr>
<td>Mason classification</td>
<td></td>
</tr>
<tr>
<td>Type IIA</td>
<td>10 (31.2)</td>
</tr>
<tr>
<td>Type III</td>
<td>22 (68.8)</td>
</tr>
<tr>
<td>Maximum die-punch fragment diameter, mm</td>
<td>12 (37.5)</td>
</tr>
<tr>
<td>≤ 3</td>
<td>3 (9.4)</td>
</tr>
<tr>
<td>≥ 4</td>
<td>20 (62.5)</td>
</tr>
</tbody>
</table>

Abbreviation: SD, standard deviation.

1 Bartoníček type IV posterior malleolar fracture characterized by large triangular fragment involving posterolateral side of distal tibia with fracture line usually extending to posterior calciculus of medial malleolus (8).

2 Die-punch fragments occur in intra-articular fractures and refer to articular cartilage and/or subchondral bone that has been embedded in cancellous bone.

3 Haraguchi classification is a 2-dimensional computed tomography (CT)-based system used to categorize posterior malleolar fractures and includes type I (posterolateral-oblique), type II (medial-extension), and type III (small-shell) (12).

4 Mason classification used to categorize primary posterior malleolar fracture fragments and includes type I (small extra-articular primary fragment), type IIA (primary fragment of postero lateral triangle of tibia [Volkmann area] extending into the incisura), type IIB (same as IIA with secondary fragment posterosmedial aspect of tibia, usually at 45° angle to primary fragment), and type III (primary fragment of coronal plane fracture line involving entire posterior plafond) (13).

5 Maximum diameter of die-punch fragment (ϕ) of posterior malleolar fracture, as measured on axial view of computed tomography (CT) scan.

Outcomes

The mean follow-up for all patients was 23.8 (range 20.0-30.0) months (small-fragment group, 22.5 [range 20.0-27.0] months; large-fragment group, 24.8 [range 22.0-30.0] months). The surgical incisions in all patients healed well, without any deep infections or skin necrosis. At 1 month after surgery, 30 patients had radiographic confirmation of satisfactory anatomical reduction of fractures, and 2 patients had evidence of a 1 mm displacement of the posterior articular surface (Fig. 4). During the follow-up period, none of patients had evidence of fracture dislocation or failure of internal fixation (Figs. 5 and 6). The only complication recorded was a superficial infection in 1 patient.

Fracture healing time and full weightbearing time for the entire study population were 13.1 (range 11.5-15.0) weeks and 15.6 (range 13.0-18.0) weeks, respectively (Table 2). At the final follow-up visit, ankle ROM mean values were 24.6° (range 20.0°-28.0°) for dorsal extension and 40.0° (range 38.0°-43.0°) for plantar flexion. In addition, the mean AOFAS was 88.6 ± 4.3, and VAS weightbearing pain score was 1.5 ± 0.6, and Bargon score was 0.8 ± 0.4.

In the small-fragment (ϕ ≤ 3 mm) group, the mean AOFAS score at final follow-up of 88.0 ± 2.2 was significantly higher than the preoperative score of 18.0 ± 1.5 (p < .003 and p = .02, respectively; Table 3). The resting state mean VAS score at final follow-up was 0.5 ± 0.6, which was significantly better than the preoperative score of 8.0 ± 0.8 and the postoperative score of
3.8 ± 1.0 (p = .006 and p < .001, respectively). The final follow-up mean VAS scores for non-weightbearing activity and weightbearing walking were 1.3 ± 0.5 and 1.5 ± 0.6, respectively.

In the large-fragment (φ > 3 mm) group, the mean AOFAS score at final follow-up of 89.0 ± 4.0 was significantly higher than the preoperative score of 18.8 ± 2.8 and the postoperative score of 62.7 ± 7.4 (p = .02 and p = .009, respectively; Table 3). The resting state mean VAS score at final follow-up was 0.7 ± 0.7, which was significantly better than the preoperative score of 7.3 ± 1.4 and the postoperative score of 3.1 ± 0.8 (p = .007 and p = .03, respectively). The final follow-up mean VAS scores for non-weightbearing activity and weightbearing walking were 1.0 ± 0.9 and 1.6 ± 0.9, respectively.

The mean Bargon score at the final follow-up visit was significantly lower for the small-fragment group (0.5 ± 0.6) than for the large-fragment group (1.0 ± 0.9) (p = .02; Table 3). Other than that, when comparing the small- and large-fragment groups, no other significant differences between the specific outcome scores at each particular time interval were identified (all p > .05).

Discussion

In this study, we report on the outcomes for 32 patients with Bartoniček type IV PMFs with die-punch fragments, who were treated with open reduction and distal locking plate internal fixation, using a
postero-lateral approach. We found that, on average, patients in this population had fractures that healed in just over 13 weeks; were able to achieve full weightbearing in just less than 16 weeks; had dorsal extension and plantar flexion ranges of motion at the final follow-up visit that were 25° and 40°, respectively; and, had AOFAS, weightbearing VAS, and Bargon scores at the final follow-up visit that were 88.5, 1.6, and 0.8, respectively.

Others have used some of the same outcome measures to assess ankle function recovery after surgery for PMFs. For example, Gao et al reported on patients who underwent a postero-lateral approach to reduction and plate fixation of posterior pilon fractures (19). They used the AOFAS score to assess ankle function recovery in 23 patients, and they found it to be 82.3 (range 44–97). Evers et al published their experience with 42 patients with trimalleolar fractures, many of whom had PMFs fixed by osteosynthesis (20). They found a mean postoperative AOFAS score around 74 to 75 and a mean Bargon score around 1.5. Somewhat paradoxically, when they divided their patients into 2 groups, they found that the group with a worse mean Bargon score had a better mean AOFAS score. The AOFAS scores in our patients appear to have been better, possibly with a narrower dispersion as well, and the Bargon scores seemed to be better than in these 2 other studies as well. It may be that these differences were in part due to the differing types fractures in these groups and the fact that the fractures in our group were all Bartonícek type IV fractures with die-punch fragments.

In 2015, Bartonícek et al reported on 141 consecutive patients with ankle fractures or a Weber type B or C fracture-dislocations with evidence of a posterior tibial fragment on standard radiographs (8). They used CT scans and 3-dimensional CT reconstructions to supplement their understanding of the fracture anatomy, and particularly to evaluate the fibular notch, shape and size of posterior tibial fragments, and stability of the tibiotaral joint. Based on their CT observations, they proposed classifying PMFs into 4 or 5 types, each having consistent pathoanatomical features. As part of their report, they noted that die-punch fragments were often present with type II fractures, but they did not mention die-punch fragments occurring with type IV fractures. More recently, Sultan et al published a retrospective study of patients with 247 PMFs, and found that up to 70% of Bartonícek type III PMFs had die-punch fragments measuring between 2 mm and 5 mm (11). In our practice, however, we have noted that die-punch fragments occurred in patients with not only Bartonícek type II and III PMFs, but also in a moderate number of those with Bartonícek type IV PMFs.

Die-punch fragments occur in intra-articular fractures, and they represent articular cartilage and subchondral bone that is embedded in the cancellous bone (9,10). They have been described as also occurring in fractures in other areas of the body, including the distal radius, tibial plateau, and calcaneus (9,10). We have previously reported on our experience with calcaneal fractures with die-punch fragments (21). In that report, we noted the importance during open reduction and internal fixation of obtaining anatomic reduction of the die-punch fragments so that the of the articular surface involving no more than 1 mm of displacement, in order to achieve optimal functional results.

We sought and were unable to find reports about the evaluation or treatment of Bartonícek type IV PMFs that are associated with die-punch fragments. We agree with Bartonícek et al that plain radiography does not provide enough information on which to base treatment decisions for these particular fractures (8). Instead, we have found that CT scans with 3-dimensional reconstructions are needed to fully understand the size and morphology of these fractures, allow their accurate classification, and determine whether or not they are associated with die-punch fragments or tendon incarcerations in the fracture gap. Ultimately, these scans can provide the surgeon with the information necessary to render more precise surgical treatment.

Nevertheless, unlike for patients with ankle fractures involving only the lateral malleolus or medial malleolus, the optimal management approach for patients with ankle fractures involving the posterior malleolus remains unclear. Historically, surgical fixation of PMFs was recommended primarily when more than 25% of the articular surface was involved on the lateral radiograph (22). However, more recent indications for surgical fixation vary and include PMFs involving more than 25% to 33% of the articular surface, displacement of more than 2 mm, ankle instability with concomitant syndesmotic injury, and persistent posterior subluxation of the talus (6,23). That said, in a review article, Bartonícek et al argue that the 3-dimensional outline of the fragments as reflected by CT classification, involvement of the fibular notch, and

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**Table 2**

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Patients Mean ± SD</th>
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<tbody>
<tr>
<td>Fracture healing time, weeks</td>
<td>13.1 ± 0.9</td>
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<tr>
<td>Full weightbearing time, weeks</td>
<td>15.6 ± 1.5</td>
</tr>
<tr>
<td>Range of motion †, §</td>
<td></td>
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<tr>
<td>Dorsal extension</td>
<td>24.6 ± 1.7</td>
</tr>
<tr>
<td>Plantar flexion</td>
<td>40.0 ± 1.8</td>
</tr>
<tr>
<td>AOFAS score†</td>
<td>88.6 ± 4.3</td>
</tr>
<tr>
<td>VAS weightbearing pain score ‡</td>
<td>1.5 ± 0.6</td>
</tr>
<tr>
<td>Bargon score ‡</td>
<td>0.8 ± 0.4</td>
</tr>
</tbody>
</table>

Abbreviation: SD, standard deviation.

* Bartonícek type IV posterior malleolar fracture characterized by large triangular fragment in postero-lateral side of distal tibia with fracture line usually extending to posteri- collum of medial malleolus (8).
* Die-punch fragments occur in intra-articular fractures and refer to articular cartilage and/or subchondral bone that has been embedded in cancellous bone.
§ Dorsal extension was measured from neutral and assessed at the final follow-up visit.
† Range of motion (ROM) was measured from neutral and assessed at the final follow-up visit (15,16).
‡ The 10-point Visual Analog Scale (VAS) score for pain was determined for weightbearing walking at the final follow-up visit (17).
§ The Bargon criteria were used to assign a score, ranging from 0 to 3, to assess the level of post-traumatic arthritis of the ankle joint, based on plain radiographs done at the final follow-up visit. The Bargon scores were 0 in 10 patients, 1 in 19 patients, 2 in 3 patients, and 3 in 0 patients (19).
Die-punch fragments occur in intra-articular fractures and refer to articular cartilage and/or subchondral bone that has been embedded in cancellous bone. When comparing the $\varphi \leq 3$ mm and $\varphi > 3$ mm groups, no significant differences between the specific outcome scores at each particular time interval were identified (all $p > .05$), other than for the Bargon score.

Comparisons of the means of 2 groups were performed using the Student’s $t$ test, and comparisons of the means of more than 2 groups were done using the one-way ANOVA and Tukey post hoc test.

Postoperative assessments were done at the time of discharge from the hospital, which was one week after surgery.

The American Orthopedic Foot and Ankle Society (AOFAS) ankle-hindfoot score is a measure of functional outcomes. In the $\varphi \leq 3$ mm group, the final follow-up score was significantly higher than the preoperative and postoperative scores ($p = .003$ and $p = .02$, respectively). In the $\varphi > 3$ mm group, the final follow-up score was significantly higher than the preoperative and postoperative scores ($p = .02$ and $p = .009$, respectively) (15,16).

The 10-point Visual Analog Scale (VAS) score is a measure of pain. In the $\varphi \leq 3$ mm group, the resting state final follow-up score was significantly better than the preoperative and postoperative scores ($p = .006$ and $p < .001$, respectively), and the non-weightbearing state final follow-up score was significantly better than the postoperative score ($p = .001$). In the $\varphi > 3$ mm group, the resting state final follow-up score was significantly better than the preoperative and postoperative scores ($p = .007$ and $p = .03$, respectively), and the non-weightbearing state final follow-up score was significantly better than the postoperative score ($p = .01$) (17).

The Bargon criteria were used to assess the level of post-traumatic arthrosis of the ankle joint based on plain radiographs. The final follow-up Bargon scores for the $\varphi \leq 3$ mm and $\varphi > 3$ mm groups were significantly different ($p = .02$) (18).

Table 3

| Time Interval | Die-Punch Fragment Diameter, mm | AOFAS Score$^a$ | Outcomes Mean $\pm$ SD | Bargon Score$^b$
<table>
<thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Resting State</td>
<td>Non-weightbearing Activity</td>
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<tr>
<td>Preoperative</td>
<td>$\leq 3$</td>
<td>18.0 ± 3.4</td>
<td>8.0 ± 0.8</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>$&gt;3$</td>
<td>18.8 ± 2.8</td>
<td>7.3 ± 1.4</td>
<td>—</td>
</tr>
<tr>
<td>Postoperative</td>
<td>$\leq 3$</td>
<td>63.5 ± 8.7</td>
<td>3.8 ± 1.0</td>
<td>4.8 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>$&gt;3$</td>
<td>62.7 ± 7.4</td>
<td>3.1 ± 0.8</td>
<td>4.2 ± 1.4</td>
</tr>
<tr>
<td>Final follow-up</td>
<td>$\leq 3$</td>
<td>88.0 ± 2.2</td>
<td>0.3 ± 0.6</td>
<td>1.3 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>$&gt;3$</td>
<td>89.0 ± 4.0</td>
<td>0.7 ± 0.7</td>
<td>1.0 ± 0.9</td>
</tr>
</tbody>
</table>

Abbreviation: SD, standard deviation.

$^a$ Bartoníček type IV posterior malleolar fracture characterized by large triangular fragment in posterolateral side of distal tibia with fracture line usually extending to posterior colliculus of medial malleolus (4).

$^b$ Die-punch fragments are one of the most important factors for these injuries, and that it also allows the use of posterior fibular soft tissue to reduce the risk of exposure of a lateral malleolar plate. On the other hand, we acknowledge that with this approach, there is risk of damage to the sural nerve or posterior tibial vascular bundle. Also, we have observed that later removal of internal fixation hardware, when the

presence of intercalary fragments are of greater therapeutic relevance than the amount of articular surface involved (24).

Whereas in that same review Bartoníček et al also suggested that the size of the fracture fragments was not particularly relevant for treatment choice (24), a secondary aim of our study was to determine whether the size of die-punch fragments had any influence on patient outcomes. We divided our study population into 2 groups based on the maximum diameter of the die-punch fragments, and we found no significant differences in AOFAS or VAS scores between the groups at any point in time. The only significant difference was that the group of patients with smaller die-punch fragments had lower Bargon scores (less radiographic arthrosis) than the group with larger fragments. It is possible that the amount of cystic change and sclerosis after local fracture healing was higher when the die-punch fragments were larger. We are, of course, unable to say whether the radiologic arthrosis will evolve into symptomatic arthritis for either group in the longer-term future.

Despite the fact that we identified limited differences between the functional outcomes in those with small and large die-punch fragments, we still believe that preoperative evaluation of die-punch fragment size is important when anticipating treatment with posterior locking plate fixation. The size of the fragment impacts the process of restoration of the articular surface. Our findings suggest that no matter the size of the die-punch fragment, if it is handled carefully during surgery, the postoperative functional prognosis can be excellent. Careful handling includes a focus on exposing both the posterior tibial die-punch fragment and the incarcerated tissue between the bone fragments, which we believe was a key to successful surgery and good functional results.

A recent systematic review of clinical and biomechanical studies has identified a number of factors that may potentially impact outcomes and prognoses in patients with PMFs (25). Based on that review, the 3 items proposed as the most important prognostic factors for these injuries were presence of residual talus subluxation, fracture dislocation, and articular surface congruity. Anatomically, the posterolateral region is the attachment point of the lower tibiofibular posterior ligament to the tibia. If the surgeon does not pay attention to the treatment of this area, subluxation of the talus can occur, which can certainly have a negative impact on prognosis. To address the issues of fracture dislocation and articular surface congruity in our patients with Bartoníček IV PMFs with die-punch fragments, we used a distal T-shaped locking plate and multiple screws. The plate and screws supported the subchondral bone, particularly that which was part of the die-punch fragments. We believe that this is the most likely reason that none of the patients in our study experienced internal fixation failure or fracture displacement.

Based on our experience, we agree with others that it may be preferable to perform fixation for all PMFs, including those with die-punch fragments, and to do so through a posterolateral approach. Erdem et al have suggested that in these fractures, fixation of the posterior malleolar fragment results in regaining 70% of normal lower tibiofibular function, whereas fixation with just a lower tibiofibular screw results in regaining only 40% of normal function (26). In addition, they noted that lower tibiofibular joint stability tended to be restored after fixation of the posterior malleolus. Miller et al found that posterior malleolar fixation was equivalent to fixation with syndesmotic screws or combined posterior malleolar and syndesmotic screw fixation, and they suggested that in a situation where the fracture involved ligamentous damage, even a small die-punch fragment should be repaired (27). Others have emphasized the importance of taking the posterolateral approach to these fractures, because it allows direct examination of the amount of compressive injury sustained by the cartilage as well as the reduction of the posterior malleolar fracture under direct vision (28,29). In addition, we have observed that the posterolateral approach allows the same incision to be used to address both a PMF and a lateral malleolar fracture, and that it also allows the use of posterior fibular soft tissue to reduce the risk of exposure of a lateral malleolar plate. On the other hand, we acknowledge that with this approach, there is risk of damage to the sural nerve or posterior tibial vascular bundle.
posterolateral approach for fixation was taken, can be challenging, especially for inexperienced surgeons.

We recognize that there are some limitations in our study. The relatively small sample sizes in the small- and large-fragment groups may have limited our ability to demonstrate statistically significant differences between them for some of the outcomes. In addition, the mean follow-up times for the small- and large-fragment groups differed, which may have impacted some of the results, though the difference was only about 2 months. Also, we did not have 2 surgeons assess outcomes at each visit, because it was impractical, so this may have impacted our results. Nevertheless, the different surgeons who assessed outcomes did so independent of the surgeons who were part of the surgical team, so it is unlikely that interviewer bias had a substantial impact on our results.

In conclusion, this study may represent the first description of outcomes specifically pertaining to the surgical treatment of Bartoníček type IV PMFs with die-punch fragments. So, despite our appreciation of the limitations of our investigation, we believe that the observations from and the results of this study could be useful to surgeons treating patients with this specific type of fracture. We also submit that the information from this study could potentially be used in the future development of prospective cohort studies or randomized controlled trials that focus on comparing different treatments of Bartoníček type IV PMFs with die-punch fragments or on determining long-term outcomes, particularly regarding symptomatic traumatic arthritis.

Authors’ Contributions

CS, ZF and XP assessed outcomes and collected clinical data. CL and QZ performed statistical analyses and were members of the surgical team. CS wrote the manuscript. QD contributed to the literature search and manuscript revision. WX designed the study and revised the manuscript. All authors read and approved the final manuscript.

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