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ORIGINAL PAPER

Is the occurrence of extra-articular calcaneal fractures of the joint depression type related to osteoporosis and aging?

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Abstract

Purpose The authors experienced several cases of extra-articular calcaneal fracture accompanied by joint depression involving the entire posterior facet without joint involvement. This type of fracture and its characteristics and treatment outcomes have not been previously reported. The study was performed to analyze the characteristics of extra-articular calcaneal fractures of the joint depression type and their postoperative clinical and radiographic results and complications.

Methods Between February 2013 and March 2021, 23 extra-articular calcaneal fractures of the joint depression type were consecutively treated by a single surgeon. Relationships between fracture characteristics and patient demographics were assessed. Clinical results were quantified using visual analog scale, American Orthopaedic Foot and Ankle Society ankle-hindfoot scale, and Foot Function Index, radiographic results were evaluated using Böhler's angles, and calcaneal widths were determined using calcaneal axial and lateral radiographs obtained preoperatively and at last follow-up.

Results Twenty (87%) of the 23 cases occurred in women, and the mean age of all patients was 65.8 years (43–90). The three men were older than 65. Five (21.7%) patients had osteopenia, and 12 (52.2%) had osteoporosis. Bone mineral density testing could not be performed in the other six patients. Clinical and radiographic results were significantly improved after surgery.

Conclusion Extra-articular calcaneal fractures of the joint depression type are much more common in women and occur at an older age than calcaneal fractures commonly occur. These fractures are also more common in patients with a low bone mineral density.

Level of evidence Level IV. Case series.

Keywords Calcaneus · Fracture · Joint depression · Osteoporosis

Introduction

Calcaneal fractures are devastating injuries of the lower extremity and are typically the result of axial loading during high-energy incidents, such as falls or motor vehicle accidents [1, 2]. Of these fractures, approximately 75% are intra-articular and primarily involve the posterior facet of the calcaneus [3], and the management of these fractures poses numerous challenges to surgeons in terms of early and late complications [2, 4–8]. Therefore, a significant proportion of the literature on calcaneal fractures is devoted to intra-articular fractures, and extra-articular fractures have received comparatively little attention [9].

Due to the unique anatomy of the calcaneus, calcaneal fractures occur in various forms, and therefore, a simple division into intra-articular and extra-articular fractures inadequately addresses all fracture types [9]. Calcaneal fractures are four to five times more common in men than women [5], and most are caused by major trauma, such as a fall. Thus, most calcaneal fractures occur in physically active men [10]. However, several recent studies have suggested that microarchitectural disruption may be a risk factor for

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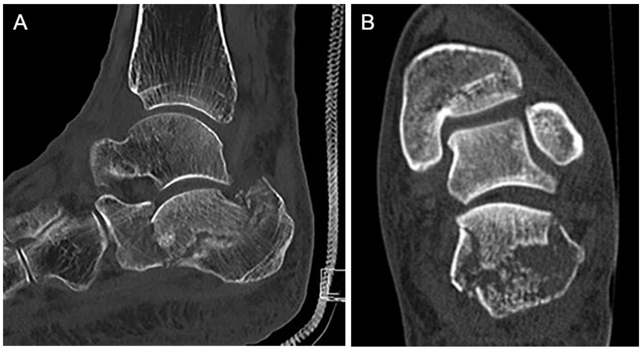

Fig. 1 Sagittal (**A**) and coronal (**B**) CT images showing extra-articular calcaneal fractures of the joint depression type with depression of the entire posterior articular surface without joint involvement

calcaneal fractures [11–13]. In men, calcaneal fractures are most common in the 30s and 40s, whereas in women, they are most common in the 65–70 age group, when osteoporosis develops [14, 15].

The primary tensile and secondary compressive trabeculae that support the posterior articular surface of the calcaneus are the first to be lost during aging [16], and as osteoporosis progresses, only the primary compressive trabeculae that directly support the posterior articular surface are retained [16]. A study on calcaneal bone microarchitecture concluded that greatest microarchitectural loss occurs in the thalamic portion below the posterior articular surface in individuals over 60 years of age [11]. Therefore, with age or bone weakening, joint depression fractures may occur due to weakening of bone around the posterior articular surface and resulting depression of the entire posterior articular surface (Fig. 1). This type of depression differs from the joint depression associated with intra-articular fractures, and its associated fractures are more difficult to reduce and fix using conventional methods. In addition, extra-articular calcaneal fractures of the joint depression type have a higher risk of recurrence of posterior facet depression after surgery. However, this type of fracture has not been reported previously, and neither have its characteristics or treatment outcomes.

The authors experienced several extra-articular calcaneal fractures of the joint depression type in which the entire posterior articular surface was depressed in elderly patients or patients with osteoporosis. Good results were obtained by reducing the depressed posterior facet using a sinus tarsi approach and additional screw fixation to support the reduced posterior facet directly.

This study was undertaken to document the characteristics of extra-articular calcaneal fractures of the joint depression type, in which the entire posterior articular surface is depressed, and to analyze postoperative clinical and radiographic results and complications.

Table 1 Inclusion and exclusion criteria

Inclusion criteria
Adult patient (age ≥ 18 years)
Extra-articular calcaneal fracture
Fracture of joint depression type
Exclusion criteria
Intra-articular calcaneal fracture
Fracture involving calcaneocuboid joint
Patients with a followed-up period of less than 24 months

Table 2 Demographics and baseline data

Parameters	*n* (%)	Mean (range)
Gender		
Male	3 (13)	
Female	20 (87)	
Age (years)		65.8 (48 ~ 90)
Body mass index (kg/m^2)		22.7 (16.3 ~ 30.4)
Follow-up periods (months)		37.7 (24 ~ 50)
Smoker	0 (0)	
Diabetes	6 (26.1)	
Chronic kidney disease	2 (8.7)	
Bone mineral density		
No evaluation	6 (26.1)	
Osteopenia	5 (21.7)	
Osteoporosis	12 (52.2)	

Methods

Patients

This study was reviewed and approved by the Institutional Review Board of our hospital, which waived the requirement for informed consent due to its retrospective design. Between February 2013 and March 2021, 152 displaced calcaneal fractures with joint depression were consecutively treated by a single surgeon. The study inclusion and exclusion criteria are shown in Table 1. Patients were followed for more than 24 months after surgery, and 129 intra-articular calcaneal fractures were excluded. Finally, the remaining 23 cases (3 males and 20 females) were included in the study. Demographic and baseline characteristics are described in Table 2.

Clinical evaluation

Relationships between fracture characteristics and demographics, including gender, age, medical history, and osteoporosis, were analyzed by chart review. Clinical results were evaluated using visual analog scale (VAS), American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale [17], and Foot Function Index (FFI) [18], which were assessed at last follow-up. An independent nurse, not part of the surgical team, performed the clinical evaluations to avoid potential bias. Subtalar ranges of motion (ROMs), including inversion and eversion, were measured at last follow-up. Measured ROMs of injured feet were compared with those of corresponding uninjured feet and expressed as ratios. Postoperative complications were evaluated during regular follow-up visits.

Radiographic evaluations

Radiographs of injured and uninjured limbs were obtained at the same institution using the same protocol. Radiographs were retrieved using a picture archiving and communication system (PACS) (IMPAX; Agfa Healthcare, Mortsel, Belgium), and radiographic measurements were performed by an observer independent of the surgical team using PACS software. Radiographic evaluations were performed using calcaneus lateral and axial radiographs. Lateral and axial radiographs were obtained at regular follow-up visits. In addition, Böhler's angles and calcaneal widths were measured preoperatively, immediately after surgery, and at last follow-up.

Operative technique

Surgery was performed under spinal anesthesia in the lateral decubitus position, with the leg exsanguinated using an elastic bandage and a tourniquet applied to the thigh.

A 5-mm Schanz pin was inserted into the calcaneal tuberosity prior to skin incision as close to the centre of the tuberosity fragment as possible to allow it to be used later as a screw insertion point (Fig. 2A). Manual varus and valgus distraction were applied to reduce the length and height of the calcaneus. A 4-cm incision was then made along the tarsal sinus from the tip of the lateral malleolus to the calcaneocuboid joint along the tarsal sinus. Careful dissection was performed between the peroneal tendons and the sinus fat pad to preserve the sural nerve (Fig. 2B).

After exposing the fracture site, bone fragments and hematoma were removed using a curette and suction. A small curette or lamina spreader was then inserted into the fracture site to elevate the depressed posterior facet fragment and restore calcaneal height, and calcaneal alignment was restored using a pre-inserted Schanz pin (Fig. 2C). After reducing the posterior facet fragment, one or two Kirschner wires were temporarily fixed through the subtalar joint in

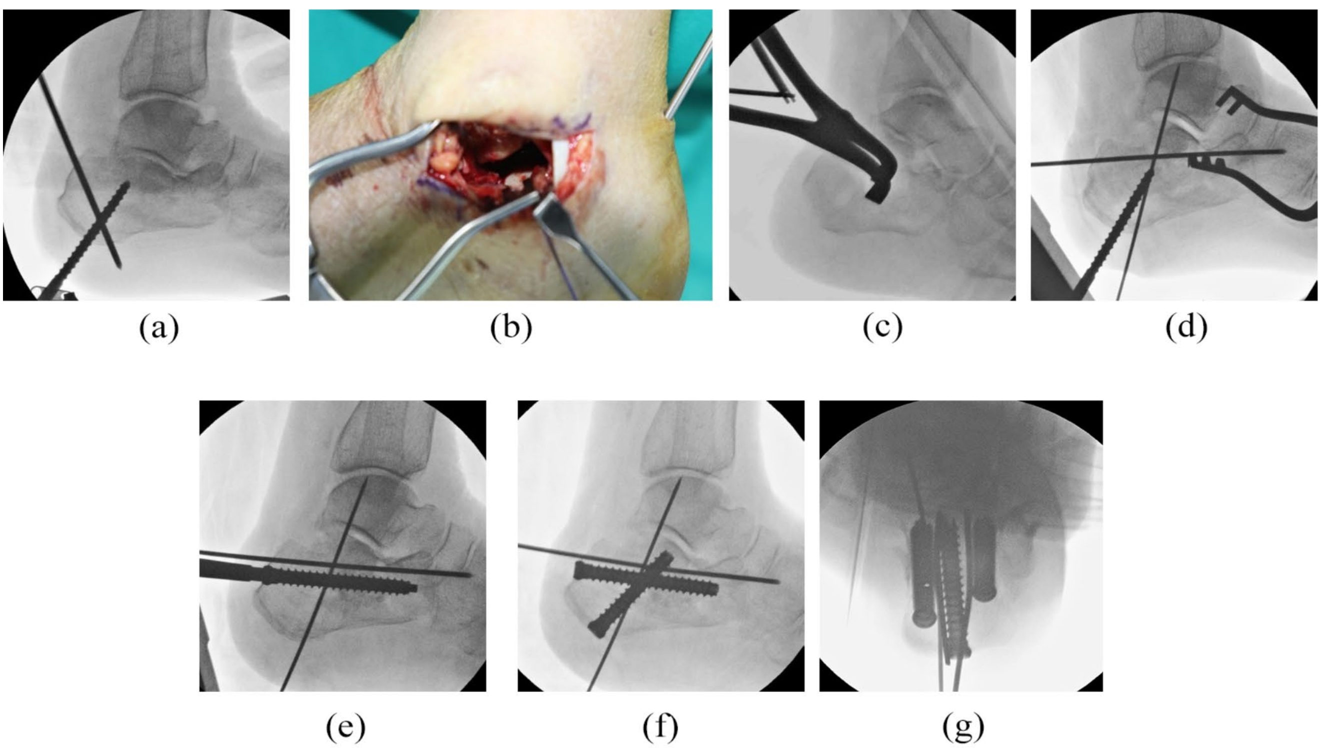

Fig. 2 (**A**) A 5-mm Schanz pin was inserted into the calcaneal tuberosity prior to skin incision. (**B**) The fracture site was exposed through a sinus tarsi approach, and the depressed posterior articular surface was identified. (**C**) A lamina spreader was inserted into the fracture site to elevate the depressed posterior facet fragment. (**D**) After reduction of the posterior facet fragment, a Kirschner wire was inserted through the subtalar joint in the tuberosity fragment to the posterior facet fragment direction. (**E**) A 2.4-mm Steinmann pin was inserted between the anterior process and posterior facet fragments as close as possible to the bottom of the posterior facet. (**F**) A 7.0-mm cannulated screw was inserted from the tuberosity fragment below the posterior facet fragment to provide a buttressing effect. (**G**) This screw was positioned at the site of the Schanz pin insertion to pass between the two previously inserted 7.0 mm cannulated screws

the tuberosity fragment in the direction of the posterior facet fragment (Fig. 2D). These wires were left in place in cases of poor bone quality. Calcaneal height reductions and alignments were confirmed by C-arm fluoroscopy.

In addition, the void under the posterior facet fragment was checked, and bone grafting with allograft bone was performed if necessary. Grafting with allograft bone was performed in seven cases. Finally, calcaneal width was restored by lateral heel compression.

Depending on bone quality, 7.0-mm cannulated screws or a 2.4-mm Steinmann pin were inserted between the anterior process and posterior facet fragments as close to the bottom of the posterior facet as possible (Fig. 2E). In addition, a 7.0-mm cannulated screw was inserted from the tuberosity fragment below the posterior facet fragment to provide a buttressing effect (Fig. 2F). This screw was fixed at the site of the Schanz pin insertion and positioned to pass between the two previously inserted 7.0 mm cannulated screws (Fig. 2G). The reduction, hindfoot alignment, and screw positions were finally confirmed using C-arm fluoroscopy, and the wound was closed using interrupted sutures.

Postoperative care

Patients were placed in short leg splints for six weeks postoperatively, and passive and active motion exercises of the ankle and subtalar joint were started the day after surgery without weightbearing. Patients remained non-weightbearing for eight to 12 weeks, depending on bone quality and fracture type, and this was followed by gradual, protected weightbearing.

Statistical analysis

All dependent variables were tested for distribution normality and equality of variances. Paired t test was used to determine the significances of differences between preoperative and postoperative radiographic results because the variables showed normal distribution. $P<0.05$ was considered significant for all tests. Statistical analysis was performed using SPSS software, version 12.0 (SPSS Inc., Chicago, IL).

Table 3 Radiographic results after surgery

	Preoperation (range)	Immediate postoperation (range)	Last follow-up (range)
Böhler angle (°)	-1.3 (-33～21)	22.3 (14～37)	18.5 (-26～36)
P-value		$<0.001^*$	$0.053^\dagger$
Calcaneal width (mm)	45.9 (36～65)	39.0 (32～47)	40.1 (32～49)
P-value		$<0.001^*$	$0.002^\dagger$

*Comparison of values between preoperation and immediate postoperation

†Comparison of values between immediate postoperation and last follow-up

Results

Twenty (87%) of the 23 patients were women, and the mean age of all patients was 65.8 (43–90) years. The three men were over 65 years old, which is greater than the peak age for male calcaneal fractures. Five (21.7%) patients had osteopenia, and 12 (52.2%) had osteoporosis; bone mineral density testing could not be performed on the other six. In addition, six (26.1%) patients had diabetes, and two (8.7%) were on dialysis for chronic renal failure.

At last follow-up, mean VAS, AOFAS, and FFI were 2.3 (0–6), 84.2 (65–100), and 21.5 (16.3–53.2), respectively, and mean subtalar joint ROM of injured feet was 73.3% (60–90) of that of uninjured feet.

Böhler angles ($P<0.001$) and calcaneal widths ($P<0.001$) were significantly improved after surgery (Table 3). No significant difference was observed between Böhler angles ($P=0.053$) during the immediate postoperative period and last follow-up, but heel widths ($P=0.002$) were significantly wider at last follow-up (Table 3).

No sural nerve injury or wound problem occurred in any case. However, in one case, radiographs taken immediately after surgery showed a slight lack of restoration of Böhler angle due to insufficient descent of the tuberosity fragment (Fig. 3A). Radiographs taken 2 months after surgery showed failure of reduction (Fig. 3B). As the patient did not want additional surgery, follow-up was continued, and bone union was achieved with no further loss of reduction one year after surgery (Fig. 3C).

Discussion

In this study, we analyzed the characteristics of extra-articular calcaneal fractures of the joint depression type involving the entire posterior articular surface, and evaluated treatment results. This type of fracture can occur in elderly patients and patients with osteoporosis or underlying conditions that might lead to osteoporosis. Buttressing screw fixation of the posterior articular surface produced good clinical and radiographic results for this type of fracture.

Calcaneal fractures are much more common in men than in women and are usually caused by strong external forces [5]. These fractures are usually encountered in active men in their 30–40 s, whereas in women they usually occur in the 60s and 65s with the emergence of osteoporosis [14, 15]. Recently the calcaneus has been used as a reference site for the diagnosis of osteoporosis [12, 19–21], which raises

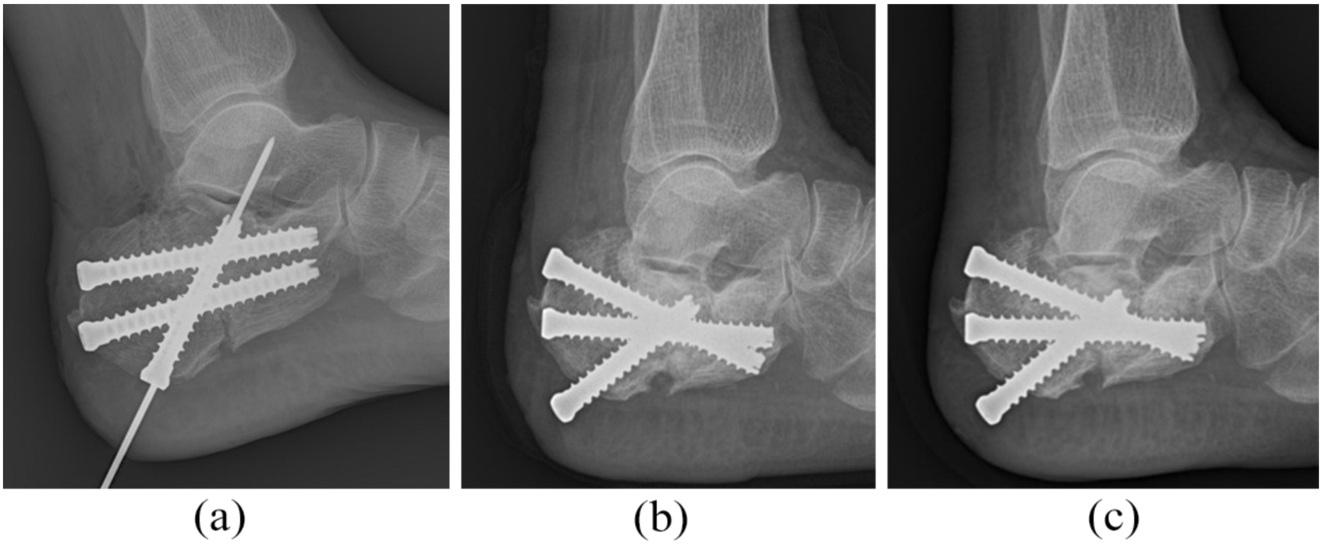

Fig. 3 (**A**) Radiographs taken immediately postoperatively showing a slight lack of restoration of Böhler angle due to insufficient descent of the tuberosity fragment. (**B**) Radiographs taken 2 months after surgery showing reduction failure. (**C**) One year after surgery, bone union was achieved with no further loss of reduction

suspicion that the calcaneus is subject to age- and osteoporosis-related bone loss and a structural risk factor for fracture. Furthermore, prospective population studies conducted in the 2000s independently suggested that the calcaneus is a skeletal element prone to osteoporotic changes [13]. We speculate that age-dependent bone strength differences influence calcaneal fracture types, but this has not been studied.

In the case of intra-articular calcaneal fractures, compression forces create a primary fracture line at the neutral triangle, where the bone is relatively weak [5]. And if this energy is not completely dissipated after the primary fracture line has formed, a secondary fracture line is created at the posterior facet [22]. As a result, trabeculae condense because the thalamic portion below the posterior articular surface is surrounded by primary and secondary compression trabeculae and primary tensile trabeculae. Therefore, secondary fracture lines generally occur as intra-articular fractures involving the posterior facet [23]. However, the trabeculae of the thalamic portion are rapidly lost with age, and especially in cases of osteoporosis, primary tensile and secondary compression trabeculae are lost, resulting in a significant loss of bone density around the posterior facet. Therefore, the secondary fracture line does not impact the posterior facet, but rather lies posterior to the posterior facet where the bone is relatively weak, which can result in an extra-articular fracture of the joint depression type with depression of the entire posterior articular surface.

In the present study, 20 (87%) of the 23 cases of extra-articular calcaneal fractures with joint depression type occurred in women, and the mean age of all patients was 65.7 years. The three men were older than 65, which is older than previously reported mean patient ages (40–46 years) [2, 4, 24–27]. In addition, the youngest patient in this study, a 43-year-old woman, had diabetes, was on dialysis for chronic renal failure, and had severe osteoporosis with a T-score of -3 or less. These results suggested that extra-articular calcaneal fractures of the joint depression type with depression of the entire posterior facet are associated with osteoporosis and the aging process.

Recently, several studies have analyzed intra-articular calcaneal fractures using 3D-mapping technology, which allows for visualization of the calcaneal fracture pattern [28–33]. These studies have shown that the fracture lines of a simple joint-depression fracture on the medial wall are closer to the anterior than those of the tongue-type fracture. And compared to the comminuted fractures, simple fractures showed less involvement of fracture lines on the lateral side of the anterior process extending forward to the calcaneocuboid joint [28–30]. The results of this study also showed a similar fracture pattern to the 3D-mapping studies. The osteoporotic fracture of the calcaneus showed a simple joint depression fracture without comminution, and the fracture line was placed anterior to the posterior facet without involving the posterior facet and calcaneocuboid joint.

Surgical treatments of intra-articular calcaneal fractures are performed in the following order [10, 34]: reduction of the collapsed lateral articular fragment, fixation to a stable medial articular fragment, and fixation of the anterior and posterior bone fragments. However, this sequence cannot be used if the entire posterior articular surface is depressed. To treat this type of fracture, the entire depressed posterior

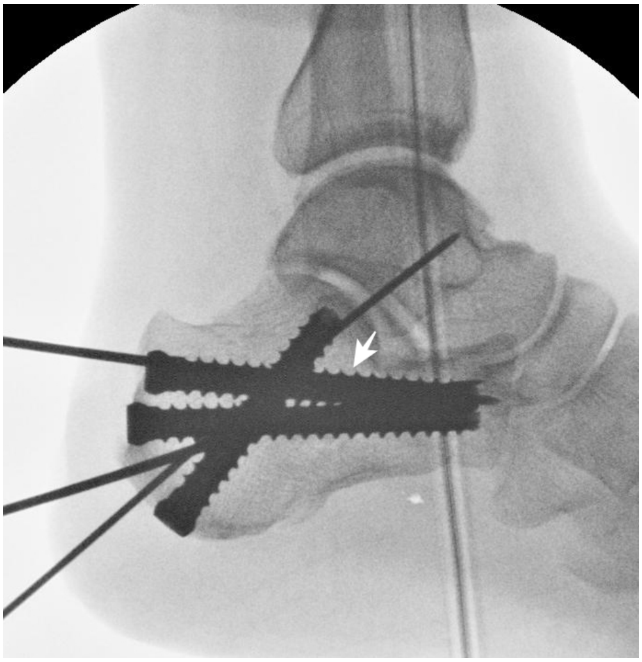

Fig. 4 Screws (arrow) securing the anterior and posterior fragments were inserted as close as possible to the posterior articular surface to support the reduced posterior facet

Fig. 5 Radiograph taken immediately after surgery, the tuberosity fragment (dotted line) did not descend far enough so that the posterior aspect of the posterior facet fragment (line) was positioned below the tuberosity fragment

facet is reduced using the subtalar articular surface as a template and then fixed. However, a void may be created under the posterior facet after reduction, and this may cause the reduced posterior facet to collapse again. In addition, when osteoporosis is present, strong fixation cannot be achieved using conventional fixation methods, and there is a risk of fixation failure. Therefore, an extensile lateral approach with plate fixation is preferred because it can achieve strong fixation [35]. However, we prefer the sinus tarsi approach to avoid the risk of wound problems caused by extensive incision and soft tissue dissection [36].

When the sinus tarsi approach is used, bone grafting is performed simultaneously, and screws that fix the anterior and posterior fragments are inserted as close to the posterior articular surface as possible to support the reduced posterior facet and increase fixation stability (Fig. 4). However, in cases with osteoporosis, fixation strength may be insufficient if this method is used alone. Therefore, we suggest that direct support by additional screw fixation under the depressed posterior facet should be considered to increase fixation strength. Thus, we attempted to place screws holding the anterior and posterior fragments as close to the posterior articular surface as possible. When a large space was created under the reduced posterior facet, bone grafting was also performed, and a 7.0 mm cannulated screw was placed directly under the posterior facet to provide a buttressing effect. In addition, anatomical locking plates for the tarsal sinus approach have recently been developed and are becoming more widely used. In the tarsal sinus approach, anatomical locking plate fixation facilitates accurate buttressing under the depressed posterior facet. Therefore, it may be a good option for osteoporotic calcaneal fractures.

In one case, loss of reduction occurred after surgery. In this case, a radiograph taken immediately after surgery showed the Böhler angle had recovered, but the tuberosity fragment did not descend sufficiently such that the posterior aspect of the posterior facet fragment was positioned below the tuberosity fragment (Fig. 5). We believe that direct weightbearing on the posterior facet fragment caused this reduction loss, which cautions that when reducing this type of fracture, it is important to elevate the posterior facet fragment sufficiently and lower the tuberosity fragment sufficiently to ensure that the posterior aspect of the posterior facet fragment is above the tuberosity fragment to prevent reduction loss. Bone union was achieved in all cases, and no patient required additional surgery for traumatic arthritis. Mean Böhler angle immediately after surgery was 22° and this decreased to 18° at last follow-up. However, with the exception of one case in which reduction failure occurred, the Böhler angle was well maintained at 21° at last follow-up.

The limitations of this study include its retrospective nature and the small number of subjects. Little is known about the incidence of calcaneal fractures associated with depression of the entire posterior facet because the low incidence of this type of fracture preempts studies on large numbers of patients at a single institution. Therefore, we suggest a well-designed multicenter prospective study be conducted on a large number of patients as a follow-up to this study.

Conclusion

Extra-articular calcaneal fractures of the joint depression type are much more common in women and occur at an older age than when calcaneal fractures commonly occur. In addition, they are also more common in patients with decreased bone mineral density. Therefore, a fixation method that firmly supports the depressed posterior articular surface is required, and we suggest the support of a 7.0-mm cannulated screw under the posterior facet may provide a good treatment option.

Author contributions The design of the study was performed by CHP. And gathering and analyzing the data were performed by IHW, KHP. Writing the initial draft was performed by CHP. And IHW and HDN took part in the ensuring the accuracy of the data and analysis.

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Data availability All the data and materials are available upon requests from the corresponding author.

Declarations

Informed consent Informed consent was waived due to its retrospective design.

Conflict of interest The authors declare that they have no conflict of interest

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