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Calcaneal insufficiency fractures following total knee arthroplasty: Classification and clinical findings

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ABSTRACT

Background: Calcaneal insufficiency fracture (IF) following total knee arthroplasty (TKA) is a rare disorder. This study aimed to examine the prevalence and clinical findings of calcaneal IF following TKA.
Methods: We retrospectively reviewed 3,585 consecutive patients undergoing primary TKA between 2012 and 2017 in four hospitals. Calcaneal IF following TKA was diagnosed by plain radiography or magnetic resonance imaging. First, we investigated the prevalence and clinical findings of calcaneal IF following TKA. Second, we classified calcaneal IF into three types based on its location: type 1, fracture by traction force around the Achilles tendon insertion; type 2, compression fracture around the posterior subtalar joint; and type 3, fracture by ground reaction force at the bottom of the calcaneus. Finally, we compared the clinical findings between calcaneal IF with and without TKA.
Results: Calcaneal IF following TKA was seen in 17 (0.5%) of the 3,585 patients undergoing primary TKA. All patients were female, with a mean age of 76.5 ± 5.9 years, relatively high body mass index (BMI), and osteoporosis. All fractures achieved bone union with conservative treatment. Type 1 fractures were the most common. Calcaneal IFs following TKA were significantly shorter in height and the patients had higher BMI than those without TKA. The locations of calcaneal IF following TKA varied, while only type 1 calcaneal IFs were seen in cases without TKA. However, there were no significant differences with regard to the bone union period or malunion between the two groups.
Conclusions: Calcaneal IF should be suspected in patients presenting with ipsilateral foot pain following TKA, particularly in female patients with a relatively high BMI and osteoporosis. Calcaneal IF can be classified into three types based on the fracture location. These variations in calcaneal IF may be due to differences in conditions and changes in mechanical loading of the lower extremity and bone quality following TKA.

Introduction

Insufficiency fracture (IF) occurs during normal activity as a result of repetitive accumulation of mild stresses on abnormal bones with decreased mineralisation [1]. IF differs from fatigue fracture, which occurs in normal bone as a result of excessive loading, in the category of stress fractures.

IF after ipsilateral total knee arthroplasty (TKA) can occur due to increased weightbearing after postoperative improvement of knee pain [2], or due to changes in the mechanical axis following TKA after correction of knee deformities [3,4], mainly at the femoral neck [4,5]. Calcaneal IF following TKA is a rare disorder, with only five cases reported in the English literature to date, including a previous case series [6,7]. Only limited information is available regarding its prevalence, morphological abnormalities, and clinical findings diagnosed via plain radiography or magnetic resonance imaging (MRI).

This study was performed to (1) investigate the prevalence and clinical findings of calcaneal IF following TKA in a multicentre study, (2) present a classification of calcaneal IF based on plain

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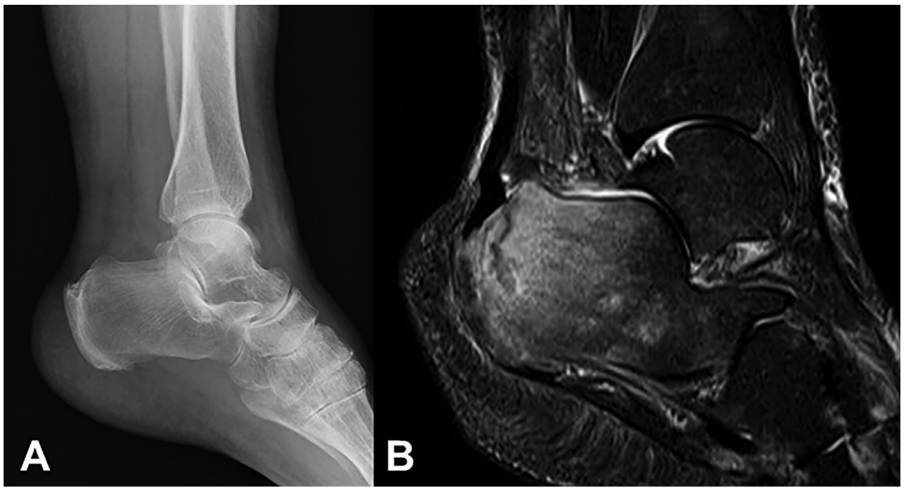

Fig. 1. Type 1 calcaneal insufficiency fracture. (**A)** Lateral plain radiograph showing no fracture line. (**B)** Sagittal views on fat-suppression T2-weighted images. The fracture line, i.e., the low-intensity line surrounded by bone marrow oedema, was irregular from the insertion of the Achilles tendon to the bottom, perpendicular to the posterior calcaneal trabecular line.

radiography or MRI, and (3) compare clinical findings between calcaneal IF with and without TKA.

Patients and methods

Setting

This retrospective multicentre study was performed at four general hospitals in Japan. The study protocol was approved by the ethics committees, and patients provided written informed consent.

Participants

All 3585 consecutive patients who underwent primary TKA at the four participating hospitals between 2012 and 2017 were included in the study. During the study period, patients with foot or ankle pain after TKA were evaluated by plain radiography based on clinical history and physical examination. In addition, they were diagnosed via MRI when a diagnosis could not be confirmed, and calcaneal IF was suspected. All plain radiographs and MRI data for the diagnosis were re-evaluated by two orthopaedic surgeons.

Calcaneal IF was defined as a fracture occurring during normal activity or physiological stress in day-to-day activities [1]. The day of onset of foot pain was deemed to be the day of the fracture. Patients with any trauma, including falls, malignancy, infection, neurological deficit [8], such as Charcot foot [9], or prior calcaneal fractures, were excluded. The treatment strategy was left to the discretion of the attending physician. The patients were followed up until healing of the calcaneal IF clinically and radiologically.

We reviewed medical records to assess demographic data, including age, sex, height, weight, body mass index (BMI), and dual-energy X-ray absorptiometry T-score values at the total hip and lumbar spine. Clinical data on the knee that was scheduled for TKA were noted on diagnosis of the knee, including preoperative and postoperative range of motion (ROM), knee scoring system of the Japan Orthopaedic Association (JOA) [10], and hip-knee-ankle angle. The JOA knee score comprised pain during walking, pain while ascending and descending the stairs, ROM, and joint effusion, which are rated with maximum scores of 30, 25, 35, and 10 points, respectively. A positive hip-knee-ankle angle represented the varus alignment of the knee. In addition, ipsilateral ankle osteoarthritis was evaluated with standing full-length radiographs of the lower limb. Clinical data on calcaneal IFs regarding the period from the onset of foot pain to diagnosis, fracture location at the calcaneus bone, and the period of bone union were noted. Medical records and follow-up radiographs were reviewed to evaluate bone union. Bone union was defined by pain-free gait or sclerosis on radiographs.

Classification of calcaneal insufficiency fractures

Calcaneal IFs were classified into three types based on the location of the fracture in the calcaneus, determined on lateral plain radiograph or in the sagittal plane on MRI (Figs. 1–3): type 1, fractures by traction force around the Achilles tendon insertion, and with a fracture line perpendicular to the posterior calcaneal trabecular line; type 2, compression fractures around the posterior subtalar joint, and with a fracture line parallel to the posterior subtalar joint line; and type 3, fractures due to ground reaction force at the bottom of the calcaneus, mainly the anterior lip of the calcaneal tubercle, which is the insertion of the plantar aponeurosis and flexor brevis muscles. In addition, calcaneal IFs without TKA during the same period at the four hospitals were reviewed, and their clinical data were compared with those of calcaneal IFs with TKA.

Statistical analysis

Data are expressed as the mean and standard deviation. The Student *t*-test was used for continuous numeric data. The chi-square or Fisher exact test was used to analyse categorical variables, as appropriate. All tests were two-sided, and $P < 0.05$ was considered significant. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan).

Results

Prevalence and clinical findings of calcaneal insufficiency fractures following total knee arthroplasty

Calcaneal IF following TKA was noted in 17 (0.5%) of the 3585 patients who underwent primary TKA at the four participating hospitals over the 6-year study period. The prevalence rates (calcaneal IF following TKA/primary TKA cases) were 5/341 (1.5%), 5/1,858 (0.3%), 1/561 (0.2%), and 6/825 (0.7%) at the four hospitals, respectively.

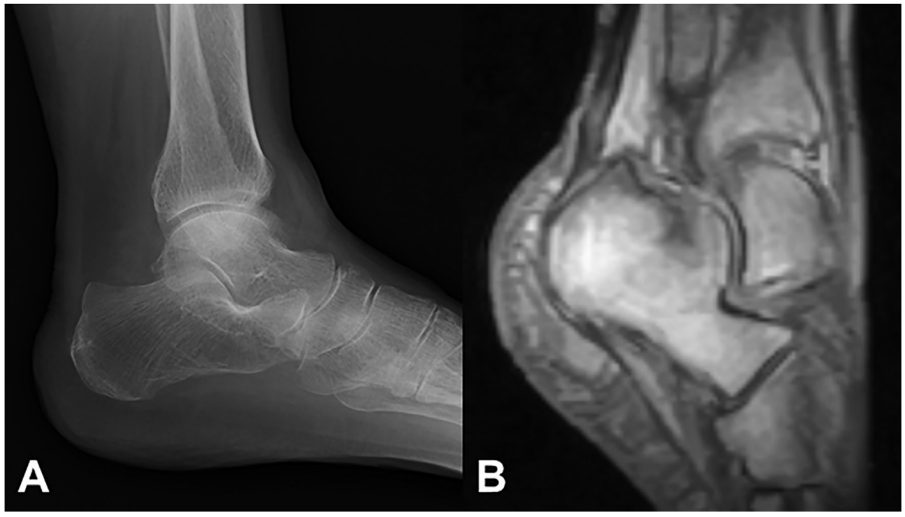

Fig. 2. Type 2 calcaneal insufficiency fracture. (**A)** Lateral plain radiograph showing no fracture line. (**B)** Sagittal T1-weighted image showing the fracture line, which was parallel to the posterior subtalar joint line.

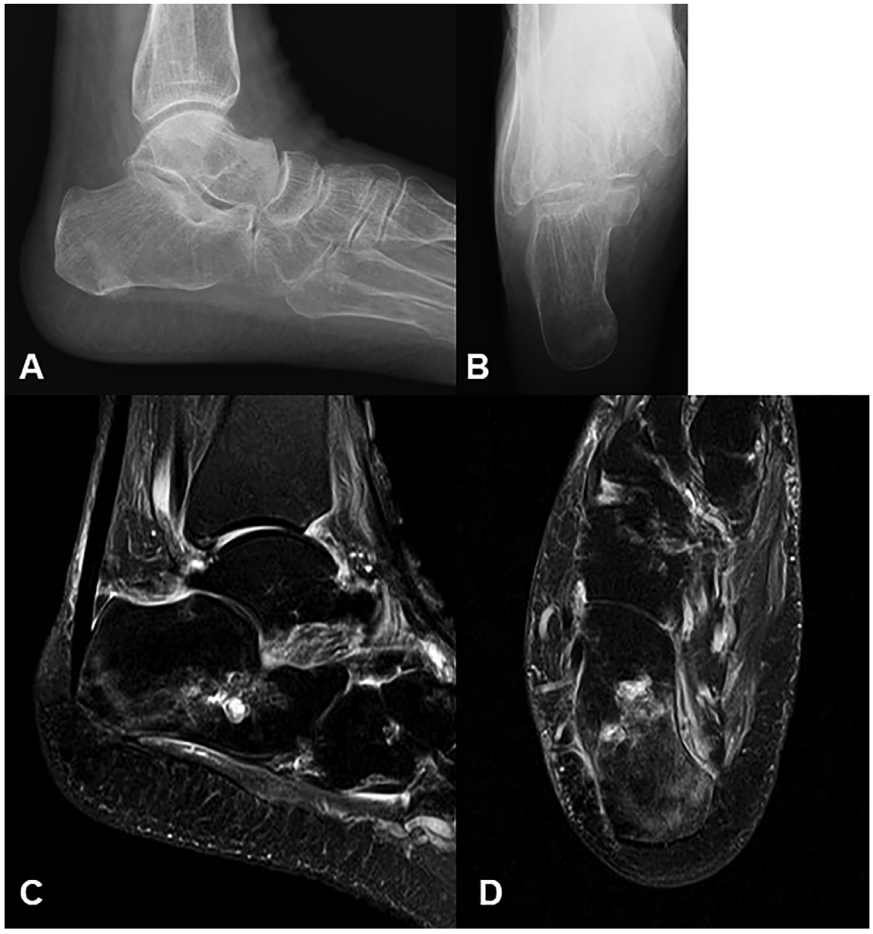

Fig. 3. Type 3 calcaneal insufficiency fracture. (**A)** Lateral and (**B)** axial plain radiographs showing a subtle irregular sclerotic line around the calcaneal tuberosity. **(C)** Sagittal and (**D)** axial fat-suppression T2-weighted images showing diffuse bone marrow oedema.

The baseline characteristics and clinical outcomes of calcaneal IF following TKA are summarised in Table 1. All patients were female, with a mean age of 76.5 ± 5.9 years, and had a relatively high BMI and osteoporosis. The diagnosis in all cases scheduled for primary TKA was osteoarthritis. There were no cases of ankle osteoarthritis before the TKA procedure. All patients showed improvements in knee ROM and the JOA knee score following correction of varus knee alignment after TKA. IF was not detected on plain radiographs, but was detected by MRI in eight (47%) of the 17 patients. Only one IF occurred on the contralateral side, while the others occurred on the same side as the knee undergoing TKA. All fractures achieved bone union with conservative treatment,

Table 1
Baseline characteristics and clinical findings of calcaneal insufficiency fractures following TKA according to fracture location classification

	All patients (n = 17)	Type 1: Achilles tendon insertion (n = 12)	Type 2: Posterior subtalar joint (n = 4)	Type 3: Bottom (n = 2)
Age (years)	76.5 ± 5.9	76.2 ± 6.1	77.3 ± 5.9	74.0 ± 8.5
Sex (female/male)	17/0	12/0	4/0	2/0
Height (cm)	144.0 ± 6.3	144.3 ± 5.2	146.5 ± 6.6	138.8 ± 11.6
BMI (kg/m^2)	24.3 ± 2.8	24.3 ± 3.2	24.0 ± 2.2	25.3 ± 1.5
T-score at total hip	−2.8 ± 0.9	−2.7 ± 0.9	−3.1 ± 0.8	−2.5*
T-score at lumbar spine	−2.0 ± 1.4	−1.9 ± 1.4	−2.3 ± 1.7	−1.1*
Preoperative HKA angle (degrees)	18.2 ± 6.7	18.3 ± 7.5	15.5 ± 6.6	18.0 ± 5.7
Postoperative HKA angle (degrees)	1.5 ± 2.1	1.8 ± 2.3	0*	1.0*
Preoperative knee extension/flexion (degrees)	−14 ± 11/ 124 ± 23	−2 ± 12/ 124 ± 21	−14 ± 9/128 ± 16	−5 ± 7/113 ± 53
Postoperative knee extension/flexion (degrees)	−4 ± 6/129 ± 16	−4 ± 6/126 ± 19	−1 ± 3/133 ± 10	−3 ± 4/135 ± 0
Preoperative JOA	54.4 ± 13.6	54.8 ± 16.9	55.0 ± 4.1	55*
Postoperative JOA	81.6 ± 3.9	79.9 ± 2.7	85.0 ± 4.1	80*
Duration from TKA operation to fracture (weeks)	11.5 ± 9.9	12.6 ± 11.5	7.3 ± 1.0	11.5 ± 6.4
Duration from onset of fracture to diagnosis (weeks)	1.4 ± 1.5	1.6 ± 1.7	1.3 ± 0.5	0.5 ± 0.7
Definitive diagnosis with MRI	8 (47)	5 (42)	2 (50)	1 (50)
Bone union (weeks)	5.7 ± 2.4	5.9 ± 2.5	9.0 ± 1.4	3.5 ± 0.7
Malunion	2 (12)	2 (17)	0 (0)	0 (0)

Values are presented as means ± SD or as count (%). * SD was not available due to missing data. One case with multiple fractures (a type 1 fracture that occurred after bone union of a type 2 fracture) was included in type 1 and type 2.
HKA = hip-knee-ankle; JOA = Japan Orthopaedic Association.

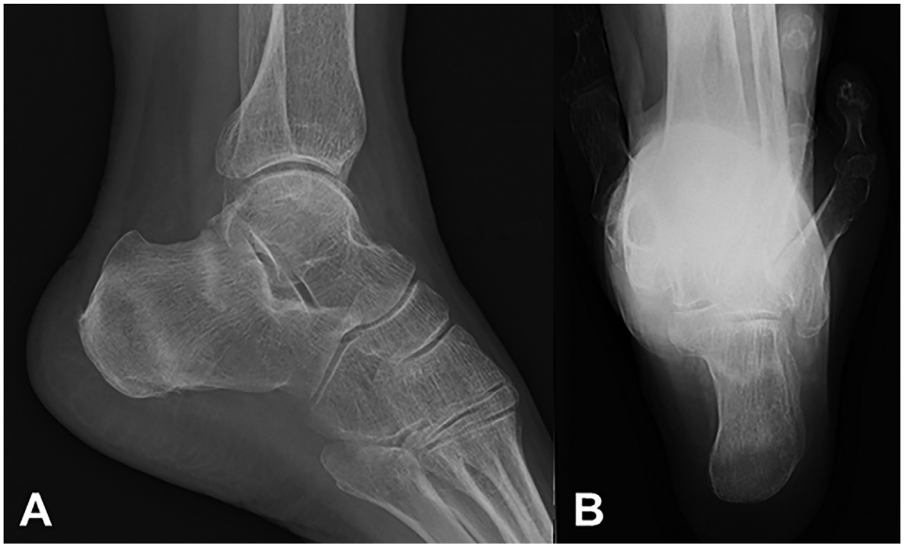

Fig. 4. Multiple calcaneal insufficiency fractures. **(A)** Lateral and (**B**) axial plain radiographs. A type 1 fracture with a radio-opaque irregular line occurred after bone union of the type 2 fracture with a sclerotic line.

including activity restriction, use of a heel-pad insert, or protected weightbearing for a short period of time.

Classification of calcaneal insufficiency fractures

The baseline characteristics and clinical outcomes of calcaneal IF are summarised in Table 1. Type 1 was the most common type of calcaneal IF following TKA (12 cases of type 1 vs. four cases of type 2 and two cases of type 3). Multiple fractures at the same calcaneus (type 1 fracture occurring soon after bone union of a type 2 fracture) occurred in only one case (Fig. 4). The period from TKA operation to fracture was shorter for type 2 IF than for the other types (7.3 ± 1.0 weeks for type 2 vs. 12.6 ± 11.5 weeks for type 1 and 11.5 ± 6.4 weeks for type 3). The bone union period was shorter for type 3 IF than for the other types (3.5 ± 0.7 weeks for type 3 vs. 5.9 ± 2.5 weeks for type 1 and 9.0 ± 1.4 weeks for type 2). Malunion after conservative treatment occurred only in cases of type 1 IF.

Comparison of calcaneal insufficiency fractures with and without total knee arthroplasty

The results of the comparison of calcaneal IF with and without TKA are summarised in Table 2. Calcaneal IF without TKA occurred in 10 cases at the four hospitals during the study period, and all of these fractures achieved bone union with conservative treatment. The prevalence of calcaneal IF following TKA was higher than that of calcaneal IF without TKA (17 cases vs. 10 cases, respectively).

Patients with calcaneal IF following TKA had a significantly shorter height (144.0 ± 6.3 vs. 151.8 ± 13.0, P = 0.04) and higher BMI (24.3 ± 2.8 vs. 21.1 ± 2.5, P = 0.006) than those without TKA. With regard to fracture type, the location of calcaneal IF following TKA varied, while only type 1 fractures were seen in patients without TKA. However, there were no significant differences in bone union period and incidence of malunion between cases of calcaneal IF with and without TKA.

Table 2
Comparison of calcaneal insufficiency fractures with and without TKA

	Calcaneal insufficiency fractures following TKA (n = 17)	Calcaneal insufficiency fractures without TKA (n = 10)	P-value
Age (years)	76.5 ± 5.9	79.1 ± 14.1	0.51
Gender (female/male)	17/0	8/2	0.12
Height (cm)	144.0 ± 6.3	151.8 ± 13.0	0.04
BMI (kg/m^2)	24.3 ± 2.8	21.1 ± 2.5	0.006
T-score at femoral neck	−2.8 ± 0.9	−3.4 ± 0.7	0.16
T-score at lumbar spine	−2.0 ± 1.4	−2.9 ± 1.6	0.21
Period from onset of fracture to diagnosis (weeks)	1.4 ± 1.5	2.2 ± 2.9	0.36
Detected with MRI (%)	8 (47)	7 (70)	0.25
Fracture type	Type 1: 12, type 2: 4, type 3: 2	Type 1: 10	0.12
Bone union (weeks)	5.7 ± 2.4	5.0 ± 2.4	0.53
Malunion	2	1	0.89

Values are presented as means ± SD or as count (%). One case with multiple calcaneal insufficiency fractures following TKA (a type 1 fracture that occurred after bone union of a type 2 fracture) was included in type 1 and type 2.

Discussion

Our study is the largest retrospective case series of calcaneal IF following TKA diagnosed by plain radiography or MRI; calcaneal IF was detected in 17 of 3,585 patients undergoing primary TKA, representing a prevalence rate of 0.5%. Patients with calcaneal IF following TKA had a high BMI and osteoporosis. These patients were significantly shorter and had a significantly higher BMI than calcaneal IF patients without TKA. However, there were no significant differences in bone union period or incidence of malunion between the two groups.

Prevalence

With a growing geriatric population and increasing rates of TKA procedures, the incidence of calcaneal IF will rise with the improved recognition of the possibility of such fractures. Calcaneal IF can be easily overlooked due to its similarity to plantar fasciitis, Baxter nerve entrapment, insertional Achilles tendonitis, atrophic heel pad, and retrocalcaneal bursitis [11].

Prevalence rates varied between prefectures in this study. Similarly, there are also regional differences in the incidence of hip fracture in Japan [12]. This may explain some of the regional differences in nutrient intake levels [12], osteoporosis management, and living environment, even in a single country (i.e. Japan).

Pathogenesis

The causes of this rare complication are multifactorial, and include osteoporosis, changes in knee alignment, and increased activity after TKA [9,13].

Osteoporosis and rheumatoid arthritis are the most common underlying conditions in patients with IF of the foot and ankle [14]. Osteoporosis includes both generalised osteoporosis and disuse focal osteoporosis. Brief periods of non-weightbearing lead to significant bone loss affecting the trabecular and cortical regions of the tibia after hip joint surgery [15]. This previous study also showed that a period of 1–1.5 years was required for the baseline bone mineral density (BMD) to recover. These findings are particularly relevant to the calcaneus before TKA because patients with knee osteoarthritis are relatively immobile and lose the beneficial effects of weightbearing on BMD. Increase in activity after TKA may result in an improvement of bone quality at the calcaneus equivalent to that of age-matched normal controls [16]. However, calcaneal IF occurred at about 3 months postoperatively in the present study, suggesting that increased weight loading and altered biomechanical forces exceeded the threshold level of calcaneal bone resistance over time, and contributed to the development of IF.

The ankle-subtalar joint in patients with knee osteoarthritis significantly reduces anterior and posterior ankle displacement, and inversion/eversion rotation [13]. TKA restores knee alignment in the coronal, sagittal, and axial planes. Hindfoot alignment has been shown to adapt to knee alignment within the range of compensation ability [17]. However, the compensation ability is lost in cases of hindfoot varus deformity before TKA [18]. Improvements in knee pain, ROM, and alignment affect the gait pattern, with a change from the forefoot strike gait to the heel strike gait. In addition, the changes in direction and strength on mechanical loading are likely to correspond to the fracture pattern. In this study, calcaneal IF following TKA occurred in various locations, although all knees undergoing TKA had varus deformity, while only type 1 fractures were noted in cases without TKA.

Diagnosis

It is important to perform a physical examination and understand the condition of the ankle and foot before TKA as well as the condition of the knee. Standard radiographs of the calcaneus usually cannot detect IF in the early phase [19]. Therefore, the attending physician should request appropriate radiological investigation, and if this is not clear, MRI should be performed to promptly diagnose these fractures [20]. MRI may be useful for detecting calcaneal stress fractures, as only 15% of radiographs show evidence of fracture [21]. In this study, 15 (56%) of 27 calcaneal IFs required MRI for detection, while MRI was required to detect six (86%) of seven calcaneal IFs in a previous report [20]. A delay in the diagnosis of calcaneal IF would limit gait due to the deformity of the calcaneus arising from fracture displacement and late complication of compartment syndrome [8], although these are low-risk fractures [22,23].

Classification

No calcaneal IF classification focusing on fracture location has been reported previously. We reviewed the pertinent literature regarding calcaneal IF, with a focus on fracture location in this study. There have been some reviews regarding calcaneal IF cases in which the diagnosis was clearly described and radiological images were reported (Table 3) [3,8,9,20,24-30]. The classification into three groups used in this study was shown to be comprehensive through a literature review. However, the anterior part of the calcaneus was not involved in IFs, although 26% of stress calcaneal fractures are located in this region [9].

One patient had two IFs of the same calcaneus in this study. It is notably rare for a second IF to occur in a different location on the same side after the healing of the first calcaneal IF. To our knowledge, this is only the second report in the literature of such

Table 3
Brief summary of calcaneal insufficiency fractures with literature review

Authors	Age (years), gender	Height (cm)	BMI (kg/m^2)	Medical information	Fracture location	Definitive diagnosis	Treatment	Bone union
Ha et al. [26]	72, F	NA	NA	RA, OP	Type 1, 2	MRI	Conservative treatment	NA
Spina et al. [30]	78, F	NA	NA	RA	Type 2, talus	Plain radiograph	Conservative treatment	NA
Ito et al. [28]	65, F	149.4	22.0	OP	Right: Type 2 Left: Type 1, 2	MRI	Conservative treatment	8 weeks
Ito et al. [28]	78, F	148	18.7	OP	Type 2	MRI	Conservative treatment	8 weeks
Lui et al. [8]	75, F	NA	NA	Neurological disorder due to cauda equine impingement	Type 1	Plain radiograph	Conservative treatment	NA (malunion with claw toe deformity)
Jeong et al. [4]	80, F	153	19.4	OP, ipsilateral heel pain three months later after TKA	Type 1, 2	Plain radiograph	Conservative treatment	2 months
Takai et al. [9]	73, M	NA	19.6	Charcot joint due to syphilis, ipsilateral heel pain four weeks later after TKA	Type 1	Plain radiograph	Open reduction and internal fixation	6 months
Alonso et al. [20]	69, F	NA	NA	Classic polyarthritis nodosa, OP, Vertebral fracture	Type 1	MRI	Conservative treatment	NA
Charles et al. [24]	26, F	NA	NA	OP, Diamond-Blackfan anemia	Type 1 bilaterally	MRI	Conservative treatment	6 weeks
Arni et al. [3]	83, F	NA	NA	OP	Type 1	MRI	Conservative treatment	NA
Kose et al. [19]	33, F	NA	NA	Osteomalacia, Celiac disease	Type 2	MRI	Conservative treatment	3 months
Imerci et al. [27]	44, F	NA	22.6	Non RA, non OP	Type 2 bilaterally	MRI	Conservative treatment	8 weeks
Godavitarne et al. [25]	82, M	NA	NA	RA, OP	Type 1, 2	MRI	Cement calcaneoplasty	6 months

*F = female; M = male; NA = not available; RA = rheumatoid arthritis; OP = osteoporosis; TKA = total knee arthroplasty.

a case [31], although there have been reports of two calcaneal IFs occurring at the same time [4,28].

Treatment

In most cases, calcaneal IF has a good prognosis with conservative treatment [20]. A literature review regarding conservative treatment indicated that most authors selected therapeutic regimens that limited activity or protected the heel from weight-bearing activity [31]. In this study, all fractures achieved bone union with conservative treatment, while care was required for type 1 fractures to avoid fracture displacement. It is important to promptly diagnose and recognise such fractures. In addition, we recommend the assessment of osteoporosis and obesity before TKA to prevent calcaneal IF.

This study had several limitations. First, the number of calcaneal IFs in this study was small, and therefore our study was not sufficiently powered to detect differences in factors among the groups. However, our study represents the largest reported case series of calcaneal IF following TKA to date. In addition, coexisting factors other than the factors evaluated in this study may affect calcaneal IF because it has multiple causes rather than a single aetiology. Second, there was also a lack of consistency in clinical management due to the retrospective nature of the study, and the different hospitals had various management protocols. However, the involvement of many surgeons suggests that these results are generalisable to the orthopaedic community. Third, there were some missing data, and no medical records and assessments focused on the ankle and foot before TKA. We may underestimate the number of the calcaneal IF cases due to underdiagnosis. Despite these limitations, this study provided important information for the clinical management of calcaneal IF.

Conclusions

It is important to suspect calcaneal IF in patients presenting with ipsilateral foot pain following TKA, particularly in patients with relatively high BMI and osteoporosis. Calcaneal IF can be classified into three types based on the fracture location. These variations in calcaneal IF following TKA may be due to differences in conditions and changes following TKA on mechanical loading of the lower extremity and bone quality.

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