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Original Research

Anatomic Locking Plate for Displaced Intraarticular Calcaneal Fracture: Design and Application

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A R T I C L E I N F O

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A B S T R A C T

Calcaneal fracture can lead to long-term disability and have a considerable economic effect. Most calcaneal fractures are intraarticular fractures involving the posterior facet of the subtalar joint. Treating displaced intraarticular calcaneal fractures is complicated because of the lack of an optimal treatment option. Internal fixation typically involves screw-and-plate implants, which can be unfavorable owing to the lack of an anatomic design and the intraoperative bending required for the plate to contour to the irregular surface of the calcaneus. We assessed the outcomes of 30 patients treated using innovative, anatomically designed calcaneal locking plates and the perceived advantages for surgeons. Postoperative computed tomography images of the affected feet were obtained, and the functional performance was recorded. The mean average Böhler angle had increased significantly from 16.8° ± 14.9° to 28.5° ± 9.4° ($p < .001$). The mean average maximal fracture gap and maximal step-off in the posterior facet of the subtalar joint in the coronal computed tomography images also decreased significantly from 2.8 ± 3.7 mm to 0.8 ± 1.3 mm ($p < .01$) and from 3.3 ± 2.8 mm to 0.8 ± 1.2 mm ($p < .001$), respectively. The mean average American Orthopaedic Foot and Ankle Ankle-Hindfoot scale score was 93.9 ± 7.1 at the final follow-up visit. In addition, the surgical time was reduced because bending the plate was not required and the quality of reduction could be assessed easily by examining the gap between the cortex and the plate. The results were promising, revealing that the anatomic locking plate can be used effectively in the treatment of displaced intraarticular calcaneal fractures using simple reduction techniques with a potentially shortened operating time.

Calcaneal fracture accounts for 2% of all fractures (1). Many fracture patients are young athletes or laborers of working age. Some of these patients can experience persisting disability for several years, resulting in a delay in resuming work and causing considerable economic impact. Many calcaneal fractures are intraarticular, involving the posterior facet of the subtalar joint, which is the major weight-bearing surface of the human heel.

The optimal treatment of displaced intraarticular calcaneal fractures (DIACFs) remains unclear because the currently available evidence has failed to demonstrate substantial benefits for any single treatment option. The risk of requiring subtalar arthrodesis is substantially lower when DIACFs are treated surgically (2). A recent systematic review revealed that in 84% of patients receiving open reduction and internal fixation for calcaneal fractures, screw-and-plate implants were used (3). Contemporary screw-and-plate implants for calcaneus fractures have several disadvantages, including the lack of anatomic design and the subsequent need to bend intraoperatively the plate to fit the irregular surface of the calcaneus. We designed an anatomically shaped calcaneal locking plates with several innovative features for DIACFs and reported the clinical experience of 30 patients with DIACFs from March 2012 to May 2014. The primary aim of the present study was to determine the clinical effect of the anatomic locking plate for fractures of the calcaneus, and the secondary aim was to explore the current clinical problems associated with the treatment of DICAFs.

Patients and Methods

The institutional review board of our institution approved and monitored the present study.

Designs, Features, and Mechanical Properties

The plates were made of a Ti-6Al-4V alloy and were anatomically based using a database of computed tomography (CT) images of 100 Asian patients (4). The plates

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were manufactured using the 5-axis milling technique (5), a computerized numerical controlled milling technique that adds 2 axes to the existing 3 normal axes (XYZ) to cut plates from alloy blocks. This manufacturing method prevents the notch effect and residual stress caused by traditional forging or casting manufacturing. The implant was manufactured by APlus Biotechnology Co., Ltd. (New Taipei City, Taiwan, Republic of China). The plates were 1.5-mm thick and were available in 3 sizes ranging from 58 to 71.4 mm long. Three fins were specifically designed to facilitate fracture reduction: the Achilles, sulcus calcaneus, and plantar fins. Moreover, 15 to 19 locking screws are provided, according to the size chosen, with the configuration predesigned to support the posterior facet of the subtalar joint, to hold the tongue-type fragment, and to hold the sustentaculum tali (Fig. 1) (6).

To further prove the concept of the plate, finite element analysis was performed under the assumption of a reduced comminuted calcaneal fracture with a 0.5-mm gap between fragments. The cortex was 0.5-mm thick, and a friction coefficient of 0.2 was assigned between the fractured segments. After completely constraining the posterior end of the calcaneus (7), a 400-N compressive load was vertically exerted on the subtalar joint to evaluate the biomechanical responses of the fixation plates (8). The finite element model comprised 76,109 elements (Fig. 2), as determined by a convergence test of the total strain energy. The maximal vertical displacement of the model under the 400-N compressive load was 0.72 mm; thus, the calculated structural stiffness of the stabilized calcaneal fracture model was 555.5 N/mm. Furthermore, the stress was concentrated on the calcaneal plate where the plate bridged the fractured bone fragments in the anteroposterior direction (Fig. 3). The magnitude of the concentrated von Mises stress was 733.6 MPa, which was lower than the yielding stress of the titanium alloy (approximately 760 to 795 MPa).

Demographic Data

From March 2012 to May 2014, 30 consecutive patients with DIACFs were treated and included in the present study (C.H.C., Y.Y.C.). All patients were recruited from the emergency department and outpatient department from a single institution. Of the 30 patients, 25 (83%) were male and 5 (17%) were female, with a mean average age of 44.8 (range 20 to 59) years. The cause of the factures was vehicle collision for 7 (23%) and falls for 23 (77%). The mean average interval from injury to surgery was 1.5 (range 0.25 to 10) days, and no patient had concurrent lumbar or thoracic spine injuries. Frontal, lateral, and calcaneal axial radiographs were obtained for the affected feet of all patients. CT images in the horizontal and coronal planes for the affected feet were also obtained.

Surgical Procedures

The surgeries were performed by the first and second authors (C.H.C., Y.Y.C.). The patients were administered spinal anesthesia and were placed in the lateral decubitus position with the affected limb facing upward. A standard L-shaped skin incision was made, and the extensile lateral approach was used to expose the fracture. The subtalar joint was reduced under direct visualization after transecting the calcaneofibular ligament. Furthermore, the calcaneal length and inclination were reduced and temporarily fixed using Kirschner wires. The quality of reduction was assessed from the findings on the lateral, calcaneal axial, and Broden's views (9), using a C-arm fluoroscope. If the reduction was satisfactory, an appropriate-size anatomic locking plate was applied to the lateral calcaneus wall and fixed using 3 or 4 lag screws to achieve a favorable contact between the calcaneus and the plate (Fig. 4). After reassessing the reduction and implant position using C-arm fluoroscopy, appropriate locking screws were used according to fracture patterns and comminution. The incision was closed in layers with or without a drainage device at the surgeon's discretion and was covered with a compressive dressing. The patients were instructed to perform active toe and ankle exercises 24 hours after surgery, partial weightbearing ambulation using the forefoot for 4 to 6 weeks postoperatively, and full weightbearing ambulation using the entire foot after 6 weeks postoperatively.

The implants were removed from all patients ≥1 year after surgery because it is popular to remove metallic implants in our country (as well as in other countries).

Fig. 1. The anatomic locking plate for calcaneus fractures. The left side of the plate is for the posterior calcaneus and the right is for the anterior calcaneus process. *A* indicates the Achilles fin, *B*, the sulcus calcaneus fin, and *C*, the plantar fin. The 2 red screws are designed for tongue-type fractures and sustentaculum tali, respectively.

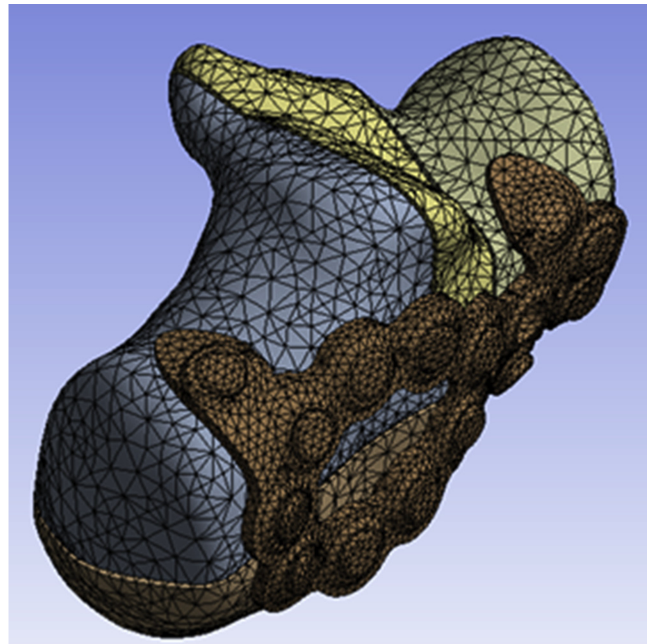

Fig. 2. Finite element model of the calcaneal fracture model fixed with an anatomic locking plate for calcaneus.

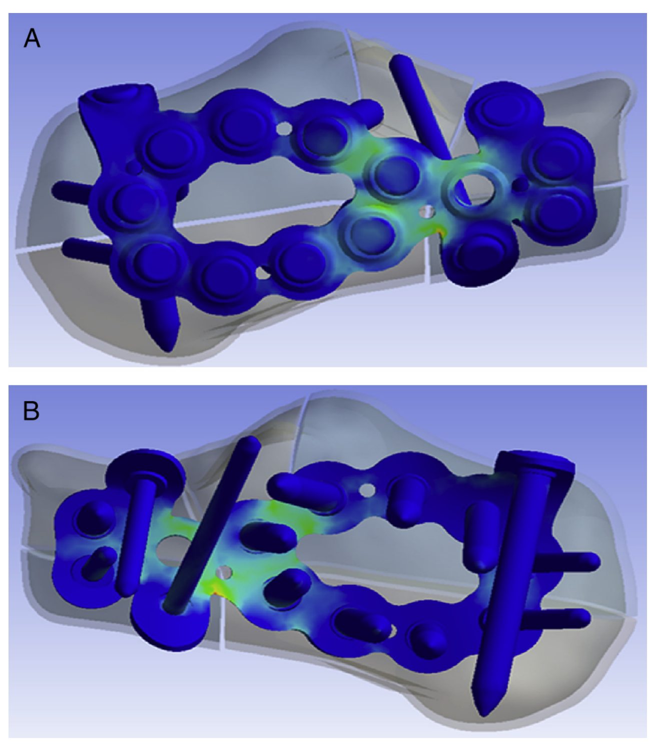

Fig. 3. Illustration of maximal von Mises stress distribution: (*A*) lateral view and (*B*) medial view.