Original Article
Abductor digiti minimi muscle flap transfer to prevent wound healing complications after ORIF of calcaneal fractures

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Abstract: Objectives: To examine the transfer of abductor digiti minimi (ADM) muscle flaps as a method for preventing wound healing complications in cases of closed calcaneal fractures treated with open reduction and internal fixation (ORIF). Method: Design: Retrospective review. Patients: Twenty-six cases of acute closed calcaneal fracture in patients at risk for serious wound complications or with serious fractures. Intervention: During the ORIF surgery, an ADM muscle flap was removed and used to cover the plate, filling the gap between the plate and skin. Main Outcome Measures: Wound healing rates, postoperative complications, and time to heal. Results: All wounds healed uneventfully, except for one case of minor superficial epithelial necrosis during the early postoperative period, which was treated conservatively. All patients regained ambulatory status with regular foot apparel. At last follow-up, the patients presented no clinical, laboratory, or radiological signs of complications. Conclusions: This ADM muscle flap transfer technique appeared to successfully prevent wound healing complications among patients undergoing ORIF for closed calcaneal fractures. This method offers a promising treatment option for calcaneal fractures in patients at high risk for serious wound complications, and future studies with greater numbers of cases are needed to further investigate its clinical application.

Keywords: Calcaneal fractures, open reduction and internal fixation, abductor digiti minimi muscle flap, wound complications

Introduction
The calcaneus has long been the most frequently injured tarsal bone. Since the 1950s, calcaneal fractures have been estimated to represent approximately 2% of all fractures, and 75% of calcaneal fractures involve intra-articular fracture [1, 2]. Calcaneal fractures are among the most difficult articular fractures to treat and can lead to significant disability. In fact, the most appropriate treatment for displaced intra-articular calcaneal fractures remains controversial. Generally, surgical fixation has been applied in the treatment of displaced intra-articular calcaneal fractures that would likely develop posttraumatic arthritis if left untreated.

Currently, open reduction and internal fixation (ORIF) is widely used in the surgical treatment of calcaneal fractures [3]. Because varying degrees of comminution, articular displacement, and soft tissue trauma can accompany calcaneal fractures, the availability of a variety of treatment methods is advantageous in the balance between minimizing the risks of wound complications and obtaining the best reduction possible. The extensile lateral approach to the calcaneus provides direct exposure of the calcaneal body and the articular surface, which allow lag screw fixation through the lateral plate into the medial sustentacular fragment to achieve fixation of the body reduction [4-7].

Many previous studies have examined wound healing complications that can occur after ORIF of calcaneal fractures, such as wound edge necrosis, hematoma, dehiscence or separation, and soft tissue infection, and 10-20% cases of calcaneal fractures after ORIF are complicated by superficial skin infection or wound dehiscence [8, 9]. The largest prospective, randomized, multicenter study published by Buckley et
ADM muscle flap transfer with calcaneal fracture repair

Table 1. Distribution of patients’ risk factors

<table>
<thead>
<tr>
<th>Patients’ characteristic</th>
<th>Sanders’ type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sanders II</td>
</tr>
<tr>
<td>Fractures</td>
<td>26</td>
</tr>
<tr>
<td>Gender, No. males</td>
<td>19</td>
</tr>
<tr>
<td>Age, years (range)</td>
<td>38 (21-59)</td>
</tr>
<tr>
<td>Right side</td>
<td>15</td>
</tr>
<tr>
<td>Result of fall</td>
<td>21</td>
</tr>
<tr>
<td>Result of motor vehicle accident</td>
<td>5</td>
</tr>
<tr>
<td>Medical history</td>
<td></td>
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<tr>
<td>Smoking history</td>
<td>26</td>
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<tr>
<td>Obesity*</td>
<td>25</td>
</tr>
<tr>
<td>Diabetes</td>
<td>22</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>19</td>
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</tbody>
</table>

Operative characteristics

<table>
<thead>
<tr>
<th></th>
<th>Sanders’ type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time from injury to surgery, days</td>
<td>9.16±3.14</td>
</tr>
<tr>
<td>Hospital stay, days</td>
<td>16.17±2.25</td>
</tr>
<tr>
<td>Estimated blood loss, mL</td>
<td>188.87±18.34</td>
</tr>
</tbody>
</table>

Note: *Obesity was defined as BMI ≥28 kg/m². Values for operative characteristics are given as the mean ± standard deviation.

Figure 1. A closed calcaneal fracture in a 52-year-old man prior to use of a standard L-shaped lateral approach to the calcaneus.

al [10] in 2002 reported rates as high as 17% for superficial infection and wound complication and 5% for deep infection after ORIF of calcaneal fractures. In cases of deep infection, because of poor local vascularization within a compromised soft tissue envelope, osteomyelitis often represents the worst outcome [11]. Most wound healing complications following ORIF occur within 1 month after surgery, and overall, the risk of serious wound healing complications is a major drawback of ORIF, as these complications can require treatment with a soft tissue flap or even in rare cases below the knee amputation [12, 13].

Our goal was to investigate the use of the abductor digiti minimi (ADM) muscle flap as a muscular plug between the wound and the plate after ORIF of calcaneus fractures. We hypothesized that muscle flaps would eliminate the dead space to prevent hematoma and provide coverage of plates to help prevent wound edge necrosis, dehiscence, or separation.

Materials and methods

Cases of calcaneal fracture

We performed ADM muscle flap transfers in 26 acute cases of closed calcaneal fracture between February 2007 and January 2013. Patients were chosen at the discretion and according to a higher than normal risk for wound healing complications associated with diabetes, a high body mass index (BMI), and smoking, or serious fractures that could be treated using a lateral approach. The details of the included cases are listed in Table 1. Patient age ranged from 21-59 years, and the ratio of male to female patients was 19/7. ORIF with
plates and screws was performed in all cases. The causes of injury included 21 falls and 5 motor vehicle accidents. Associated injuries involving vertebra, the tibia, the femur, and pelvic fractures were identified in nine patients (34%). The mean follow-up period was 31 months (range, 6-72 months). The fractures were evaluated by means of radiographic and computed tomography imaging, and they were classified according to Sanders’ classification system [7]. Patients were treated according to a standard protocol established by the senior author. All patients were admitted to the hospital for foot elevation. Once swelling had subsided so that wrinkles in the skin were visible, surgery was performed.

**Surgical technique**

Patients were positioned in a full lateral position with a hip bump. Each case used the standard L-shaped lateral approach to the calcaneus (Figure 1). Subperiosteal dissection was performed to expose the lateral aspect of the calcaneus, and a full-thickness soft tissue flap was created. A “no-touch” technique was applied to protect the flap. Kirschner wires were placed in the talus, fibula, and cuboid for flap retraction. Standard techniques were used to achieve stabilization, and low profile plates and screws were used as described by Benirschke and Sangeorzan [3]. Autogenous bone graft was used in all cases. With sharp dissection, the ADM muscle was exposed from the insertion site of the proximal phalanx of the fifth toe and the muscle belly. A part of ADM muscle was transected at its insertion. Dissection commenced from the distal to the proximal end to expose the body of the muscle (Figure 2A). During this dissection, several minor pedicles were encountered along the middle and distal one-third of the muscle. These pedicles were carefully ligated and divided in order to achieve adequate mobility of the flap. Muscle flap size was 1.5 cm×1.5 cm×5.5 cm.

The major pedicle that extends approximately 2 cm proximally from the styloid process of the fifth metatarsal bone was identified. The dissection was stopped and preserved medially to the proximal one-third of the muscle. The nerve of the muscle that passes along with the artery should be preserved to minimize muscle atrophy. During dissection, the major pedicle did not need to be skeletonized. For increased mobility, the muscle was freed from its origin sufficiently to permit arc of rotation of the flap. The muscle flap was then carefully rotated into the corner of the incision to avoid kinking or stretching of the dominant pedicle. After ensur-

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**Figure 2.** ADM muscle flap transfer. A. Dissection of the ADM muscle flap (black arrow). B. Covering of the plate with the ADM muscle flap (black arrow).
ADM muscle flap transfer with calcaneal fracture repair

Postoperative treatment

The length of postoperative hospital stay depended on standard medical practice at that time, patients’ comorbidities, and the patients’ ambulatory status. The average hospital stay is currently 16 days. After hospital discharge, the patients were instructed to not place any weight on their operated foot for 3-weeks and were given ambulatory assist devices (e.g., wheelchair, walker, crutches, or cane). For additional protection, the leg of the operated foot was placed in either a short-leg cast or postoperative splint. Once healed, an orthotic or a molded shoe was used for the patients if necessary. Follow-up of the patients spanned 6-72 months. Outcome analysis included wound healing rates, postoperative complications, time to heal, limb salvage, the time that the wound remained healthy, and patient survival. Telephone surveys assessed patient satisfaction and ambulatory status. Once the incision was well healed and the sutures were removed 2-3 weeks after operation, the patients initiated motion. The affected feet remained non-weight bearing for 10-12 weeks.

Results

All operations, wound management, and follow-up examinations were performed by the senior plastic surgeon. All transferred flaps were precisely integrated between the skin and plate. The blood supply of the ADM muscle flap was evident by gross inspection in grafted cases. Primary wound healing was achieved by the third postoperative week (Figure 3). In one patient, delayed healing was observed with superficial epithelial necrosis during the early postoperative period, but complete healing was achieved within 3-6 weeks with active local wound care and without surgical intervention. Patients did not complain of any significant donor-site problems. By the fourteenth or sixteenth postoperative week, all patients achieved full weight-bearing ambulation. At the 2-month follow-up, CT of the calcaneus showed that the gray scale intensity of the ADM muscle flap on the plate was similar to that of the remnant ADM (Figure 4). The average length of follow-up was 19 months (range, 2-41 months). Postoperative measurements of Gissane’s angle averaged 132° (range, 122-150°), and those of Böhler’s angle averaged 29° (range, 25-36°). These angles were in the

Figure 3. CT imaging of the same patient at 2-month follow-up showing that the gray scale intensity of the ADM muscle flap on the plate (white arrow) appears similar to that of the remnant ADM (black arrow).

Figure 4. Wound healing at 3-week follow-up.
normal ranges. All patients were able to regain ambulatory status with regular foot apparel. At last follow-up, patients showed no clinical, laboratory, or radiological signs of complications. In all cases, no effect on the functionality of toe abduction.

Discussion

Despite ongoing debate regarding the best treatment plan for displaced intra-articular fractures of the calcaneus, ORIF can offer good functional outcome with anatomical restoration of the joint, and thus, has been the classical treatment for these fractures for almost 20 years [14]. Surgical treatment of calcaneal fractures aims to achieve optimal articular surface reduction and to restore the structure of the non-articular parts of the bone and requires that the reduction be held with stable internal fixation [7]. However, the risk of wound healing complications must also be considered during ORIF of calcaneal fractures.

Among several surgical approaches that have been investigated for calcaneal fracture repair, the extended lateral approach is most widely applied for ORIF [5] and generally provides excellent visualization. However, high rates of complications in wound healing also have been reported [15, 16]. Superficial epithelial necrosis, full-thickness skin sloughing, deep purulent infection, and osteomyelitis are typical adverse reactions that occur following ORIF of calcaneal fractures. In a retrospective study, Abidi et al [15] concluded that risk factors for wound healing complications include single-layer closure, high BMI, smoking, and extended time between injury surgeries. Folk et al [13] reported that diabetes, smoking, and open fractures all are associated with an increased risk of profound wound healing complications and that their effects are cumulative.

After the L-shaped lateral incision is made to expose the calcaneus, the corner of the incision is the most likely site of wound healing complications, such as necrosis. Skin necrosis, wound dehiscence, and plate exposure most often appear in this area, because there is less subcutaneous tissue under the lateral calcaneal flap. Moreover, the skin suture of the incision is performed as a monolayer, which increases the risks for subcutaneous hematoma and wound infection. Blood flow to the lateral calcaneal flap is primarily supplied by the lateral calcaneal artery (LCA), and complications in wound healing, such as ischemia of the lateral calcaneal flap, can arise from damage to the LCA. Borrelli et al [17] concluded that based on the position of the LCA, it is vulnerable to injury from the vertical incision in the lateral approach.

Ger [18] first reported the use of the local pedicle muscle flaps in the repair of foot defects. The ADM muscle originates from the lateral and medial processes of the calcaneal tuberosity and extends into the lateral base of the proximal phalanx of the fifth toe [19]. Both the blood supply and motor innervation of the ADM muscle are derived from the lateral plantar neurovascular bundle. Specifically, the lateral plantar artery runs along a groove between the ADM and the flexor digitorum brevis. The ADM muscle extends proximally and stops at the fifth metatarsal tuberosity. Approximately 1-2 cm proximally from the styloid process of the fifth metatarsal bone, the terminal branches of the lateral calcaneal branch of the lateral plantar artery perforate the ADM muscle, thus providing the vascular supply [20]. Dissection of the ADM muscle is relatively straightforward, but considering the immediate blood supply, care must be taken to preserve the main vascular pedicle during the procedure. Also, before suturing the muscle flap, transposition of the muscle flap is necessary to avoid venous congestion and ischemia.

In this study, the transferred muscle tissue eliminated the void space between the inserted plate and the debrided wound cavity and provided vascularized tissue under the skin. The removal of a portion of the ADM muscle had no effect on the function of the ADM muscle remnant. Furthermore, the average time for flap transfer was approximately 5 minutes, and thus, this step did not considerably affect the length of the operation. In general, the use of microsurgical flaps is associated with high success rates, and such techniques are relatively straightforward and thus often the preferred reconstructive option when ORIF is performed. In conclusion, the outcomes of the cases described in the present study support the use of ADM muscle flap transfer during surgical treatment of displaced intra-articular fractures of the calcaneus with ORIF.
Disclosure of conflict of interest

None.

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