Update 2020

The Proceedings of the Annual Meeting of the Podiatry Institute
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The transmetatarsal amputation (TMA) is an aggressive amputation that eliminates a large amount of diseased tissue but allows for a functional foot that does not require a prosthetic or specialized shoe. Although the foot is functional, some activities such as running or walking for long periods of time may not be possible. The biggest complications with TMA are related to the pathology that originally necessitated the need for the amputation such as poor circulation, chronic ulcers in a neuropathic patient, or simply osteomyelitis. The best way to mitigate these complications is to work extensively to treat these pathologies at the time of the amputation. There are, however, complications that can arise from the procedure itself. Therefore, simplifying the procedure and shortening the procedure time can minimize these risks.

INDICATIONS FOR THE PROCEDURE

The author has found that the most common reason for performing the amputation is because of loss of soft tissue associated with chronic ulcers or infection. At some point the foot is more salvageable with an amputation then it is with either massive soft tissue necrosis that is unlikely to heal, or such a small amount of remaining forefoot (i.e., 1 or 2 metatarsals) In either case, enough blood flow must be present for the operative site to heal. The amputation is usually done in an inpatient setting, which allows for the use of the intravenous (IV) antibiotics to fight infection. The hospital setting also gives the opportunity to work in conjunction with a vascular team to both improve blood flow and if the procedure does not work to convert to a more proximal amputation.

Work with rehabilitation or physical therapy is also important to help the patient to remain off the foot during the immediate postoperative time and to help make the transition to ambulation after the foot has healed.

CHALLENGES

There are challenges associated with the TMA procedure such as poor patient selection, too much stress on the soft tissue at the time of closure, and blood loss due to the length of operative time. When considering TMA, it is important to verify that enough viable soft tissue is available to cover the amputation site at closing. If the plantar flap is pulled too tight, it can result in necrosis at the closure site. If there is not enough soft tissue, the surgeon may need to remove more bone in order to close the wound, and this may impact the patient’s ability to ambulate.

Procedure time should be minimized to limit blood loss. Use of a tourniquet in patients with compromised blood flow may cause damage and should be avoided if possible. If a tourniquet must be used, it is preferable to place it on the thigh where more soft tissue is present. In a patient with marginal circulation, most of the disease will occur below the knee and cannot tolerate the pressure from a tourniquet in this area.

When the amputation is being performed to remove infected tissue and a suspicion of proximal bone infection exists, it is important to obtain a bone specimen for analysis by the pathologist. When the amputated tissue is submitted in several specimens, it can be hard for the pathologist to determine which bone was located in which section of which metatarsal. A single specimen sent to the pathologist eliminates questions about orientation and there is no doubt as to the identification of the metatarsals. Simple modifications of the traditional TMA can minimize the risk by speeding up the procedure, sending a single intact specimen, and maximizing soft tissue preservation.

STEPS TO PERFORM THE EASY TMA

First, identify the amputation boundaries. Preserve as much of the soft tissue as possible for the flap and remove as little bone as possible (Figure 1). If necessary, extra soft tissue can be removed when it is time to close the flap. Next, identify the individual metatarsals at the level of the amputation site and draw a short line for the incision in line with the long axis of the metatarsal (Figure 2). Make short incisions over the metatarsals down to bone. These incisions should be approximately 1 centimeter or less (Figure 3). Use a mini Hohmann retractor and push the soft tissue away from the metatarsal and hook the end of the retractors under the metatarsals to expose the bone. A power saw is then used to cut the bones perpendicular to the long axis of the bone (Figure 4).

The next step is to perform the amputation. The amputation is done as a full-thickness cut and follows the outline already drawn earlier (Figure 5). The idea is to make a single long cut that produces a single specimen. Once this is completed, any bleeding vessels are tied off or cauterized and the tissue is irrigated. Careful inspection is done to be sure that no pockets of infection are present (Figure 6). The...
plantar flap is then pulled over the end of the amputation site and sutured in place (Figure 7). The flap needs to be loose enough to have a short cap refill time but be tight enough to not have a pocket that allows blood to pool. If needed, the soft tissue can be trimmed to fit. A monofilament suture should be used due to the threat of possible infection. Absorbable suture should be avoided to reduce inflammation at the amputation site. The sutures should be in long enough for the amputation site to heal.

**POSTOPERATIVE COURSE**

The immediate issue is to deal with any pending infection. When diffuse osteomyelitis is present, 6 weeks of IV antibiotics are needed to eliminate any residual infection.

The patient needs to be non-weighbearing until the surgical site is healed. Options for offloading include, walker, crutches, knee scooter, or wheelchair. If the patient ambulates on the foot, healing will be compromised and a chronic wound or procedure failure could possibly be the result.

Figure 1A. Boundary for the dorsal incision.

Figure 1B. Boundary for the plantar incision.

Figure 2. Identify the metatarsals at the level of the amputation site.

Figure 3. Use of retractors to isolate the metatarsals.
CHAPTER 1

Figure 4. Use a saw for the osteotomy.

Figure 5A. Start the amputation on the dorsum of the foot.

Figure 5B. Continue the amputation in a single incision to the bottom of the plantar aspect of the foot.

Figure 5C. Post amputation specimen to be sent to pathologist.
Figure 6. Open amputation site to be inspected and flushed.

Figure 7. Closure of the flap.
INTRODUCTION

After patients have failed conservative treatment for a Haglund’s deformity, surgery may alleviate their pain. Since Patrick Haglund first described this condition, there have been many approaches to surgical treatment. There are many thought processes and opinions from the incision to resection of the Achilles tendon. Incisional approaches include a straight midline, a J incision, an L incision, a lateral incision, and a modified S incision. Some surgeons have even performed a medial incisional approach. There has also been debate as to how to work around the Achilles tendon when resecting the Haglund’s deformity. Some surgeons will split the tendon as described by Xia et al (1). Advocates for this approach state that it provides good visualization and that patients return to normal function earlier than those whose tendons were resected with a posterolateral approach (2). Some surgeons will transect the Achilles tendon in a U fashion while others will use a lateral approach. Each one of these approaches has their advantages and disadvantages. The authors advocate a technique that provides the best of all surgical approaches in regard to visualization, access, and healing.

TECHNIQUE

The patient is placed in a prone position. A modified S incision, step down incision, or double L incision is mapped out on the posterior aspect of the heel. The central line should be made in line with relaxed skin tension lines of the posterior heel (Figure 1). Dissection is carried out down through the subcutaneous tissue. With the double L incision, the surgeon can create a superior and inferior flap. The medial and lateral borders of the Achilles tendon are identified (Figure 2). Dissection is continued at the lateral border of the Achilles tendon with the surgeon starting anterior to the tendon and carrying the dissection inferiorly.

The lateral aspect of the Achilles tendon is carefully dissected off the Haglund’s deformity and off of the insertion. Care is taken to only dissect off the lateral 35-50% of the Achilles tendon insertion. An osteotome is used to resect the bony prominence (Figure 3 and Figure 4). In this case a straight osteotome was used but one may use a curved osteotome if the situation dictates. The surgeon carefully removes the piece of the bone from the remaining attached...
Achilles tendon (Figure 5). After resection, the surgeon uses a reciprocating rasp to smooth off any remaining prominent edges (Figure 6). Next, any diseased tendon is debrided and positioning of the anchor is determined (Figure 7). The authors prefer a Mytek anchor to secure the tendon back to the calcaneus with a Krakow stitch (Figure 8). It should be noted that a Kirschner wire is used to drill a guide hole for the anchor. The strength of the Achilles is checked after the anchor is secured. The surgical site is irrigated, followed by use of 3-0 Vicryl to secure the tendon to the surrounding fibers (Figure 9), 4-0 Vicryl is used for the subcutaneous layer, and 5-0 Vicryl is used for the skin layer.
POSTOPERATIVE COURSE

A posterior splint is applied after the procedure (Figure 10 and Figure 11). The patient remains in the posterior splint until 1 week follow-up after surgery. At the initial follow-up, the patient is placed in a cast for an additional 2 weeks. The patient is placed in the splint and casted in a plantarflexed position and will remain non-weightbearing. After 3 weeks of non-weightbearing, the patient is transitioned into a walking boot in neutral position for an additional 3 weeks. After the walking boot, the patient is transitioned to supportive shoe gear and is allowed to gradually increase activity.
DISCUSSION

The advantages of utilizing this technique are primarily two-fold. The first advantage is seen with the step down, double L type, or modified S incision. The incision will avoid vital neurovascular structures such as the sural nerve. In the experience of the authors, it also reduces the chance of wound dehiscence and allows for optimal visualization of the entire posterior aspect of the heel, especially when it comes to accessing the medial and lateral aspects. This is especially beneficial when it comes to resecting and rasping the exostosis. This is not the case if one decides to use a more lateral incisional approach.

The second advantage comes by dissecting the Achilles off its insertion starting from the lateral aspect. The reason for dissecting the lateral aspect of the tendon versus other approaches is to keep the central integrity of the tendon. In the experience of the authors, this technique maintains the central strength of the tendon in comparison to other approaches. It should be noted that dissecting only a portion of the lateral aspect of the Achilles tendon will provide enough access for resection and tendon debridement. It has been reported in the literature by Kolodziej et al (3) and others (4,5) that less than 50 percent of the Achilles can be resected safely before there is failure within the strength of the tendon. Besides maintaining the central strength of the tendon, the lateral approach will help preserve the paratenon and by extension the blood supply of the tendon in comparison to other approaches of tendon resection. With this approach to working around the Achilles tendon healing potential is increased. This approach to the Haglund’s removal attempts to capture the most efficacious skin incision and dissection of the Achilles tendon and will provide surgeons with adequate access, visualization, and healing potential when performing a Haglund’s removal.

REFERENCES


Figure 11. Postoperative radiograph of resected bone and anchor.
INTRODUCTION

Periarticular osseous defects pose a significant challenge when considering arthrodesis in foot and ankle surgery for limb or ray salvage. Resection of large amounts of bone is often necessary during revision procedures or treatment of certain pathologies. Clinical scenarios in which these defects might be encountered include avascular necrosis, osteomyelitis, non-union, post-traumatic deformity, and Charcot neuroarthropathy. Osseous defects may also be encountered when a joint prosthesis is removed and arthrodesis is being performed as a salvage procedure (1-8). These defects often require some type of structural support to restore length, cubic content of bone, and alignment. Failure to restore anatomic length and alignment transfers pressures to adjacent joints, altering biomechanics, which causes compensatory gait disturbances, placing stresses on proximal joints such as the hip, knee, and spine (9-13).

Options for surgical management of these clinical scenarios include end-to-end arthrodesis, arthrodesis with interpositional autogenous or allogenic bone graft, bone transport utilizing an external fixator, Masquelet’s induced membrane technique, osteomyocutaneous flaps of the fibula, or amputation (1,8,14-20). Each of these techniques has their disadvantages, including high nonunion rates and an increased incidence of revision surgery, as well as prolonged requirement for external fixation (21).

The process of 3-dimensional (3-D) printing is based on the concept of additive manufacturing, or manufacturing structures by depositing materials in a layer by layer fashion. This concept is in contrast to customary techniques, which produce constructs by cutting, molding, or manipulating raw materials (22). The use of 3-D printing, or any technique utilized to manufacture physical objects from graphic computer data, has revolutionized musculoskeletal surgery (23). For example, custom total arthroplasty components are now manufactured based on the patient’s preoperative computed tomography (CT) scans (24). Additional uses of 3-D printing are virtual surgical planning and training purposes (23). The use of 3-D printed titanium implants has the potential benefits of unlimited geometry, increased size options over allografts and autografts, and no donor site morbidity (22). Furthermore, these implants maintain structure, limiting concerns such as graft collapse or bone resorption (21).

So et al published a case series of 3 patients who underwent implantation of custom titanium trusses after failed elective surgery with 100% success rate for limb or ray salvage (8). In another case series, Dekker et al retrospectively reviewed 15 patients who underwent tibia, ankle or hindfoot reconstructive procedures with a patient-specific 3-D printed titanium truss, with an 87% success rate (21). Aside from these case series and single patient case reports, the use of titanium trusses has not been widely studied in the literature. None of the case series examined the use of off-label prefabricated, manufacturer trusses. The primary objective of this study was to report the rates of limb and ray salvage utilizing customized, patient-specific 3-D printed and prefabricated titanium trusses for arthrodesis procedures in cases of osseous defects or malalignment involving the foot and ankle. The secondary objective of this study was to report the incidence of radiographic union based on postoperative CT and weight-bearing plain film radiographs.

PATIENTS AND METHODS

A total 12 consecutive patients who underwent revision arthrodesis or arthrodesis for a severe underlying deformity with 3-D printed patient-specific or prefabricated titanium trusses were retrospectively reviewed at our institution between 2016 and 2019 by a single surgeon. A minimum follow-up of 6 months was required to be included in this case series. The mean follow-up was 14 months (range 6 to 22 months). A total of 10 females and 2 males were included in the study, with an average age of 49.3 years (range 33 to 61 years). Patient demographics, initial failed index procedures (if applicable), revision procedures, ray/limb salvage, complications, postoperative CT time frame and interpretation, and type of truss are listed in Table 1.

The primary objective of this study was successful limb or ray salvage. Successful limb salvage was determined by whether or not a proximal amputation was performed (below-knee amputation or above knee amputation). Successful ray salvage was determined by whether or not a digital amputation or ray resection was performed. The secondary objective of this study was to determine whether
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<th>Complications</th>
<th>Post operative CT scan (read)</th>
<th>Postoperative CT scan (months status post-surgery)</th>
<th>Fixation</th>
<th>Truss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>Male</td>
<td>Tibiototalocalcaneal arthrodesis</td>
<td>Tibiototalocalcaneal arthrodesis</td>
<td>22</td>
<td>No</td>
<td>-Non-union of ankle and subtalar joints, hardware failure with break-down of Truss (14 months status post-surgery) BKA (25 months status post-surgery)</td>
<td>First: Complete union of ankle and subtalar joints Second: Non-union of ankle and subtalar joints, hardware failure with break-down of Truss</td>
<td>First: 3.5 months Second: 14 months</td>
<td>11 x 200-mm retrograde IM nail</td>
<td>4WEB custom rectangular truss</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>Female</td>
<td>First metatarsal phalangeal joint arthrodesis</td>
<td>First metatarsal phalangeal joint arthrodesis</td>
<td>21.5</td>
<td>Yes</td>
<td>None</td>
<td>Partial fusion of first metatarsal phalangeal joint</td>
<td>1 month</td>
<td>Locking plate</td>
<td>4WEB custom peg in hold shaped truss</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>Female</td>
<td>None</td>
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<td>14</td>
<td>Yes</td>
<td>None</td>
<td>None</td>
<td>N/A</td>
<td>7.3 mm partially threaded compression screws x 2</td>
<td>4WEB prefabricated 12 mm wedge</td>
</tr>
<tr>
<td>4</td>
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<td>Tibiototalocalcaneal arthrodesis</td>
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<td>Yes</td>
<td>-Midfoot osteotomy for malalignment with planterflexed forefoot on hindfoot (14 months status post-surgery)</td>
<td>Complete fusion of the ankle and subtalar joints</td>
<td>2 months</td>
<td>11.5 x 250-mm retrograde IM nail</td>
<td>4WEB custom spherical truss</td>
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<td>5</td>
<td>46</td>
<td>Female</td>
<td>Total ankle arthroplasty</td>
<td>Tibiototalocalcaneal arthrodesis</td>
<td>14</td>
<td>Yes</td>
<td>None</td>
<td>75% fusion of tibia-truss interface, 50% fusion talus-truss interface</td>
<td>2 months</td>
<td>10 x 150-mm retrograde IM nail</td>
<td>4WEB custom rectangular truss</td>
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<td>6</td>
<td>60</td>
<td>Male</td>
<td>Treated conservatively with cast immobilization</td>
<td>Subtalar joint arthrodesis</td>
<td>19</td>
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<td>None</td>
<td>N/A</td>
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<tr>
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<td>Yes</td>
<td>None</td>
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<td>3 months</td>
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<td>4WEB prefabricated 12 mm wedge</td>
</tr>
<tr>
<td>8</td>
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<td>First tarsal metatarsal joint arthrodesis</td>
<td>9.5</td>
<td>Yes</td>
<td>None</td>
<td>Complete fusion of first tarsal metatarsal joint</td>
<td>2 months</td>
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<td>4WEB prefabricated 12 mm wedge</td>
</tr>
<tr>
<td>9</td>
<td>57</td>
<td>Female</td>
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<td>First metatarsal phalangeal joint arthrodesis</td>
<td>8</td>
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<td>None</td>
<td>None</td>
<td>N/A</td>
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<td>Yes</td>
<td>None</td>
<td>Partial fusion of first metatarsal phalangeal joint</td>
<td>4 months</td>
<td>4-hole claw plate</td>
<td>4WEB custom peg in hold shaped truss</td>
</tr>
<tr>
<td>11</td>
<td>61</td>
<td>Female</td>
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<td>First metatarsal phalangeal joint arthrodesis</td>
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<td>Yes</td>
<td>None</td>
<td>None</td>
<td>N/A</td>
<td>7.3 mm partially threaded compression screws x 2</td>
<td>4WEB prefabricated 12 mm wedge</td>
</tr>
<tr>
<td>12</td>
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<td>Female</td>
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<td>First tarsal metatarsal joint arthrodesis</td>
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<td>None</td>
<td>None</td>
<td>N/A</td>
<td>7.3 mm partially threaded compression screws x 2</td>
<td>4WEB prefabricated 12 mm wedge</td>
</tr>
</tbody>
</table>
successful radiographic union was demonstrated by CT or plain film radiographs. Radiographic consolidation was determined on CT by an independent fellowship-trained musculoskeletal radiologist and confirmed by the surgeon. Radiographic consolidation was determined on plain film radiographs by >50% osseous bridging at all boney-truss interfaces by the surgeon.

All patients had previously undergone an elective procedure resulting in malalignment, malunion, or nonunion, or had a severe acquired deformity that required arthrodesis. The authors considered these cases complex since failure would likely result in limb loss or ray resection. All 12 patients were counseled preoperatively regarding their reconstructive options. They were given the choice of structural bone graft, below-knee amputation or ray resection, or titanium trusses as surgical alternatives. If infection was suspected prior to the definitive procedures, the hardware was removed, affected bone was debrided and bone cultures were obtained prior to the definitive operation. Patients were placed on culture-directed antibiotics when indicated and antibiotic loaded spacers were placed in the interim until the definitive procedure was performed.

A total of 7 of 12 patients (Patients 1,2,4,5,10,11, and 12) underwent implantation of a customized, patient-specific titanium trusses (Table 1). The preoperative CT scans were provided to the manufacturer where a customized titanium truss was then developed and fabricated based on CT scan results, incorporating surgeon input. The surgeon communicated with an engineer and discussed factors such as desired amount of correction, acceptable amount of shortening, and fixation options. Additionally, the surgeon took into account factors unique to the patient such as the quality of soft tissue envelope and biomechanic issues that could affect the design of the implant. Schematic illustrations were sent to the surgeon for final approval. After final approval was obtained and manufacturing complete, the titanium implant as well as ancillary materials such as trial-sizing implants and guides, were sent to the healthcare institution. The remaining 5 of the 12 patients (Patients 3,6,7,8,9) underwent implantation of a prefabricated titanium truss. The prefabricated trusses are available in a wide range of shapes and sizes. The decision to use a prefabricated versus customized truss was based on the patient’s specific needs. A prefabricated truss was selected when the available shapes and sizes were suitable to address the specific anatomic considerations. Due to the relatively high cost of customized implants, a prefabricated, manufacturer truss was utilized instead of a customized truss whenever feasible.

The preoperative diagnoses included 1 patient with a non-union and failed tibiotalocalcaneal (TTC) arthrodesis with avascular necrosis of the talus (Patient 1), 2 patients who had undergone previous first metatarsophalangeal (MTP) fusions with subsequent malunion and shortening (Patients 2 and 9), 1 patient with a shortened and elevated first metatarsal with advanced osteoarthritis of the first tarsometatarsal (TMT) joint (Patient 3), 1 patient with combined nonunion and malunion of a TTC arthrodesis resulting in a plantarflexed and varus malalignment (Patient 4), 1 patient with stiffness following total ankle arthrodesis in a fixed plantarflexed position (Patient 5), 1 patient with a nonunion after 2 previous attempts at isolated subtalar arthrodesis with a subsequent horizontal talus resulting in equinus with anterior impingement of the ankle (Patient 6), 1 patient with a horizontal talus and severe posttraumatic osteoarthritis involving the subtalar joint following nonoperative treatment of a joint depression fracture of the calcaneus (Patient 7), 2 patients with nonunion and malunion of the first TMT joint after arthrodesis for hallux valgus reconstruction (Patients 8 and 12), 1 patient with a failed first MTP joint prosthesis (Patient 10), and 1 patient with necrosis and shortening of the metatarsal head secondary to a giant cell tumor (Patient 11).

All patients received preoperative antibiotics prior to the procedure in accordance with SCIP protocol. The patients were brought to the operating room and positioned on the operating table in a supine fashion. All patients underwent general anesthesia. The surgical extremity was prepped and scrubbed in the typical sterile manner.

Three patients (Patient 1, Patient 4, and Patient 5) underwent implantation of a custom, patient-specific titanium truss at the level of the ankle joint (Figure 1, Figure 2, and Figure 3). Preoperative diagnoses included 1 patient with a non-union and failed TTC arthrodesis with avascular necrosis of the talus (Patient 1), 1 patient with combined nonunion and malunion of a TTC arthrodesis resulting in a plantarflexed and varus malalignment (Patient 4), and 1 patient with stiffness following total ankle arthroplasty in a plantarflexed position (Patient 5). Prior to the procedure, bone marrow aspirate harvested from the ipsilateral tibial tuberosity was spun down and later mixed with either stem cells or bone morphogenic protein (BMP) and autogenous bone harvested from the fibula. A lateral incisional approach overlying the fibula was used in these 3 cases. The distal fibula was osteotomized to access the

![Figure 1. Patient 1. (A) sagittal (B) coronal and (C) axial views of preoperative computed tomography scan of patient with nonunion of tibiotalocalcaneal arthrodesis 4 months following the index procedure.](image-url)
ankle and subtalar joints for resection and preparation. The fibula was morselized in a bone mill and mixed with bone marrow aspirate, stem cells or BMA, and 0.5 milligrams of vancomycin powder, which was then packed into the truss. If greater volume was necessary, more bone was harvested from the remaining portion of fibula or frozen allograft bone was utilized. Joint surfaces were then resected or remodeled based on the deformity and a healthy cancellous substrate was developed for arthrodesis. In cases requiring a customized truss, the manufacturer provided 3 sizes of trusses, based on preoperative CT scans and discussions with the surgeon. Customized sizers were placed and evaluated under image intensification to ascertain the most appropriate size truss. The selected truss was then packed with the bone graft material and delivered into the defect.

An intramedullary nail was used for fixation through the truss in all 3 cases, which was incorporated into the design during the preoperative design process. The intramedullary nail was delivered through the plantar aspect of the heel and fixated in standard fashion. Patients were immobilized in a short-leg cast and kept non-weightbearing for 8-16 weeks. They were transitioned from a short-leg cast to a weight-bearing fracture brace and eventually into standard footwear. The decision to transition to weigh bearing was based on radiographs and CT scans.

Two patients (Patient 6 and Patient 7) had standard prefabricated titanium trusses implanted for posttraumatic osteoarthritis and malunion of the subtalar joint. Preoperative diagnoses included 1 patient with a nonunion after 2 previous attempts at isolated subtalar arthrodesis (Patient 6) (Figure 4) and 1 patient with severe posttraumatic osteoarthritis involving the subtalar joint following a joint depression fracture of the calcaneus (Patient 7). Both patients had a horizontal talus with anterior impingement at the ankle during gait. Autogenous bone graft was obtained from the distal tibial metaphysis in both cases. A standard posterolateral incision was utilized between the Achilles tendon and the fibula. The subtalar joint was prepared for arthrodesis by removing articular cartilage, subchondral drilling, and fish scaling, until a healthy cancellous substrate was developed. Prefabricated trapezoid wedges were implanted into the subtalar joint. The appropriate size titanium truss was determined by using a lamina spreader to distract the subtalar joint under image intensification. Different sized implants were trialed. Restoration of calcaneal height and reduction of Bohler’s angle were evaluated under fluoroscopy on lateral radiographs to determine the degree of correction and size of implant that was most appropriate. Autogenous bone graft and allograft stem cells were packed into the titanium truss. Prior to insertion of the truss, bone
graft was packed into the anterior aspect of the subtalar joint. The prefabricated titanium truss was then placed into the posterior aspect of the subtalar joint. The subtalar joint was then fixated using 7.5 mm partial-threaded cancellous screws placed in a lag fashion adjacent to the implant. Patients were immobilized in a short leg cast for 8-12 weeks and thereafter transitioned into a weight-bearing fracture brace. The decision to transition to weightbearing was based on radiographs and CT scans.

Four patients underwent implantation of titanium trusses at the first MTP joint. Preoperative diagnoses included 2 patients who had undergone previous first MTP fusions with subsequent nonunion, malunion, and shortening (Patient 2 and Patient 9), 1 patient with pain and lateral forefoot overload following first MTP joint prosthesis (Patient 10), and 1 patient with necrosis and shortening of the metatarsal head secondary to a giant cell tumor (Patient 11). A patient-specific, customized titanium truss was used in 2 patients (Patient 2 and Patient 10) (Figure 5). A patient-specific, customized titanium truss was used in 1 patient. One patient (Patient 9) underwent conversion from a joint prosthesis to first MTP arthrodesis with a prefabricated titanium truss. Dorsal extensile incisions were used in all patients. A lengthening of the extensor hallucis longus was performed to address the contracted tendon and permit access to the joint. Bone graft was harvested from the proximal tibial metaphysis or calcaneus. All retained hardware was removed. Devitalized bone from the base of the proximal phalanx and the first metatarsal head was resected. The joint surfaces were remodeled based on the customized or prefabricated truss sizes. Optimal sizing and position were confirmed under image intensification. The custom titanium truss was packed with autogenous bone graft and allograft with stem cells or BMP. The truss was placed into the defect and secured using a dorsal locking plate.

One patient (Patient 3) underwent a first TMT arthrodesis for a shortened and elevated first ray, with end-stage arthritis (Figure 6). One patient (Patient 8) underwent the same procedure for a nonunion after an attempted first TMT joint arthrodesis procedure as part of hallux valgus reconstruction. Both patients underwent implantation of prefabricated trusses into the first TMT articulation. One patient underwent implantation of a customized titanium truss for shortening and nonunion following 2 previous attempts at a first TMT joint arthrodesis. A linear incision was performed along the medial aspect of the midfoot. The joints were then prepared in standard fashion until a healthy cancellous substrate was developed. Trial sizers were evaluated under image intensification to ascertain the appropriate size. The trusses were then packed with autogenous bone graft harvested from the ipsilateral calcaneus, frozen cancellous allograft, and stem cells. The titanium trusses were then placed, and fixation was accomplished with a medially placed locking plate. Fully-threaded cortical screws were delivered from the base of the first metatarsal to the base of the second metatarsal and from the medial to lateral cuneiforms to impart stability.

RESULTS

Successful limb or ray salvage was achieved in 11 of the 12 patients (91.7%). One patient (Patient 1) did not achieve successful limb salvage (Figure 7). A CT was performed 3.5 months status post revision TTC arthrodesis using a customized titanium truss. The CT demonstrated near complete consolidation at both the tibial-truss and the calcaneal-truss interfaces. The patient began partial weightbearing in a CAM boot at that time, and gradually transitioned to supportive footwear with a customized gauntlet brace. At 14 months after surgery, a CT scan demonstrated non-union of both the tibial-truss and the calcaneal-truss interfaces, with lucency and collapse.
surrounding the intramedullary nail, metallic truss, and distal interlocking screws. The patient eventually developed a hardware infection and elected to have a below-knee amputation performed. Another patient (Patient 4) developed difficulty getting her heel to the ground, as the patient’s forefoot was rigidly plantarflexed in relation to the hindfoot. She underwent a dorsally based midfoot wedge ostectomy with complete alleviation of her symptoms. Six of the 7 patients (85.7%) who had a postoperative CT scan performed went on to complete radiographic consolidation across the arthrodesis sites, as determined by an independently trained musculoskeletal radiologist. The remaining 5 patients showed complete consolidation across the arthrodesis sites on radiographs as demonstrated by >50% osseous bridging across all bony-truss interfaces, as determined by the senior author.

**DISCUSSION**

Traditional surgical treatments for large osseous defects and deformities include end-to-end arthrodesis, arthrodesis with interpositional autogenous or allogenic bone grafts, bone transport utilizing an external fixator, Masquelet’s induced membrane technique, osteomyocutaneous flaps of the fibula, and amputation.

End-to-end arthrodesis procedures have higher documented fusion rates compared to arthrodesis with interpositional autogenous or allogenic bone grafts, as it has fewer bone interfaces required to heal. However, it does not restore anatomic length, causing indirect effects such as decreased skin tension and destruction of normal musculotendinous function (1). An average limb length discrepancy of 1.5 to 3.5 cm has been reported following tibiocalcaneal arthrodesis after takedown without structural interpositional grafts (1). Substantial shortening can alter gait mechanics, and place stresses upon proximal joints (9-13). Additionally, studies have shown that there is an increase in oxygen consumption, along with patient perceived exertion with limb length discrepancies greater than 2.0 cm in adults (25,26).

In contrast, arthrodesis procedures with interpositional structural bone grafts restore anatomic length. However, disadvantages include variable fusion rates ranging from 58% to 93%, additional bone interfaces necessary to heal, slow graft incorporation, and the potential for delayed graft collapse (1,14,27,28). Both autograft and allograft bone have been utilized for interpositional structural grafting and each has distinct advantages and disadvantages.

Autogenous structural bone graft is considered to be the gold standard in bone substitution as it is both osteoinductive and osteoconductive, containing growth factors and osteogenic cells, making it ideal for arthrodesis procedures (29-31). Autogenous bone graft is most commonly harvested from the iliac crest (32). A study by Takemoto et al demonstrated that autogenous bone graft taken from the iliac crest showed increased expression of BMPs, BMP receptors, and other growth factors when compared to the proximal tibia or humerus (33,34). Autograft is also considered to be both histocompatible and nonimmunogenic, diminishing the chances of host rejection and disease transmission (29,32). However, it is associated with increased donor site morbidity and complications, especially in cases where a large volume of bone is required (29,31,32,34-36). The most common complications include infection, hematoma, fracture, nerve and vascular injuries, and donor site pain (31,33,34). In a systematic review by Dimitriou et al, 1,249 of 6,449 patients who underwent autologous bone graft harvesting from the iliac crest noted complications, with an overall morbidity rate of 19.37% (32). Along with patient morbidity, studies have shown that autografts lead to increased time in the operating room, and increased hospital stay (34,37,38).

While allograft eliminates donor site morbidity, it is only weakly osteoinductive and possesses the risk of disease transmission (29,32,33). Compared to autogenous bone, allografts have been found to have a higher incidence of non-union, with slower incorporation and re-vascularization, along with the potential for late structural collapse (1,14). In a study by McGarvey et al, 37 patients underwent 41 arthrodesis procedures of a single or multiple joints of the tarsal complex with use of either structural autograft or allograft. They encountered 4 nonunions, 3 of which utilized allograft bone substitute (39). Slow incorporation and revascularization are also an issue with interpositional allografts (28). In a study by Delloye et al, allograft incorporation for ankle fusions following tumor resection was studied. Graft incorporation was evaluated utilizing bone scintimetry with isotope uptake superior to controls 15 years after the initial surgery by microradiographic analysis. However, slow revascularization with creeping substitution was noted, with incomplete osteons noted at 2-3 years after surgery (28). Clifford et al studied 32 patients who underwent a TTC arthrodesis with bulk femoral head allograft with complete...
consolidation at the fusion site noted in 16 of the 32 patients (50%) (1). The authors also noted an average height loss of 3.6 mm over the average 41-month follow-up period (1). Additionally, 19% of the patients went on to require a below-knee amputation (1).

Bone transport employing external fixation, or distraction osteogenesis, has proven to be effective, as it utilizes the body’s intrinsic healing potential inducing de novo bone and soft tissue formation to lengthen bone without the need for interpositional grafts (40-43). However, complications have been reported throughout the literature, including non-union, stress reaction and re-fracture at the docking site, pin-tract infection, and osteopenia secondary to extended periods of non-weightbearing (40-44). In a study by Paley et al, the authors found that 1 cm of regenerated bone takes approximately 1 month to consolidate, with distal consolidation occurring after 6 months between the distal and transported fragments (44). In addition, patients often find it cumbersome to maintain an external fixator for the required time frame often necessitated by bone transport, which may be a limiting factor in patient compliance (44).

Masquelet’s induced membrane technique is a staged technique that utilizes the surrounding soft tissues and their membrane as a biologic chamber. In the first stage, radical debridement is performed, with insertion of a cement spacer into the defect, and soft tissue repair by flaps if needed. The second stage is performed 6-8 weeks later after the soft tissues have healed. At that time, the spacer is removed, but the membrane induced by the cement is left in place. The defect is then filled with cancellous bone. The membrane prevents resorption of the cancellous bone placed in a richly vascular muscular environment, which promotes vascularization and corticalization of the cancellous bone (20,45-47). However, similar to bone transport or distraction osteogenesis, an external fixator must be used for prolonged periods of time, making it a burdensome option for the patient, and limiting compliance. The induced membrane technique has had mixed results and complications associated with it. In a study by Barakat et al, 17 patients underwent induced membrane technique of the tibia and femur, with a mean osseous defect of 7 cm secondary to infected non-union (12 cases) and osteomyelitis (5 cases). Osseous union occurred in 14 of the 17 patients. However, further complications that were encountered included, graft non-union (5 cases), failure of graft maturation (2 cases) reactivation of infection (2 cases), and refracture after removal of the frame (1 case) (47).

Osteomyocutaneous free vascularized fibular flaps were first described by Yoshimura et al (48). They allow for concurrent reconstruction of osseous and soft tissue defects (48). This technique has been utilized successfully in maxillofacial surgery for mandibular reconstruction following tumors and trauma (49,50). Osteomyocutaneous free vascularized fibular flaps have also been used for posttraumatic defects of the foot. However, it has been limited to several case series, which have been localized to the metatarsal and pre-tibial regions (50). The harvesting of an osteomyocutaneous free vascularized flap is technically challenging and must be performed by a plastic surgeon with microvascular training (10,48-51).

Proximal amputations remain a treatment option for severe deformities, infections, chronic pain, and congenital defects. However, studies have demonstrated that lifetime costs associated with amputation compared to limb salvage are significant. A study by MacKenzie et al demonstrated that the mean lifetime cost associated with amputation is $500,000 compared to limb salvage, which is approximately $160,000 (52).

This study demonstrates the use of 3-D printed titanium trusses for patients who had previously undergone an elective procedure resulting in malalignment, malunion, nonunion, a large osseous defect or had a severe acquired deformity that required arthrodesis. The technique of 3-D printing is different from typical manufacturing techniques and has been applied in the medical community for greater than 10 years. It is founded on the principle of additive manufacturing, or depositing materials layer by layer based on the 3-D reconstruction of the patient’s MRI and CT scans (24). This has been applied in orthopedic surgery for surgical planning, manufacturing of patient specific surgical guides and implants, and the production of bioscaffolds (24). The technique of 3-D printing has been utilized for surgical planning in complicated cases. Based on patients’ preoperative imaging, 3-D printing provides accurate anatomic models, to assist in surgical planning and diagnosis, and can provide a surgical simulation. This can theoretically reduce the risk of intra-operative complications, along with decreasing operating times (53,54). Another use of 3-D printing in orthopedic surgery is in the manufacturing of patient-specific implants. For example, patient-specific guides and implants have been utilized during total joint arthroplasty (24). Additionally, 3-D printing can be used for bioscaffold production, providing a structural scaffold, which also allows for cell attachment and proliferation with subsequent bone formation in vivo (24,53). By the custom-nature of 3-D printing, surgeons can tailor the fabrication to an individual patient’s patho-anatomy, theoretically restoring joint congruity with concomitant structural integrity, promoting successful osseous consolidation (55,56).

The principle of a structural scaffold has been applied to titanium inter-body spinal trusses packed with bone graft, which is considered to be the gold standard for treatment of severe spinal degenerative disc disease, functioning by restoring anatomic alignment and disc height (56). This same principle can be applied to surgical treatment of the foot and ankle by using standard or custom titanium trusses to fill voids of large segmental osseous defects. From a
biomechanical or engineering standpoint, the configurations of trusses provide the most strength with the least mass (23). When considering the shape of a patient-specific customized truss, mechanical, anatomical, and functional criteria must be considered, as well as potential fixation options. The general shape, size, and contours must closely match the original bone, to allow stability and osseous consolidation to occur (23). The anatomy and previous implants must also be taken into consideration to allow for adequate surgical exposure. The implant must be designed with holes and voids incorporated into the construct to accommodate traversing hardware and fixation (23). Mechanically, inherent stability is provided by the titanium struts, which are rough and aid in resisting torsional forces (23). To increase the rotational stability, trusses can be augmented with miniature spikes or cleats added to the struts (23).

Prior to use of titanium trusses, several case studies evaluated tantalum in foot and ankle surgery for large osseous defects. Tantalum is a trabecular metal that resembles bone in its microstructure (56-59). It is osteoconductive and is considered biocompatible. Tantalum also possesses a compressive strength and elasticity similar to bone, which prevents stress shielding in adjacent bone in structural orthopedic applications (56-59). Sagherian et al documented a case series of 25 patients, who underwent arthrodesis of the foot and ankle using a tantalum in place of a structural autograft or allograft; 4 in the ankle, 17 in the hindfoot, and 6 in the midfoot (59). The clinical indications for use of tantalum included failed total ankle arthroplasty, post-traumatic ankle arthritis, a giant cell tumor in the distal tibia, post-traumatic hindfoot arthritis, hindfoot arthritis secondary to posterior tibial tendon dysfunction, subtalar arthritis secondary to rheumatoid arthritis, and midfoot arthritis (59). The mean American Orthopedic Foot and Ankle Society (AOFAS) hindfoot/midfoot scores improved from 40.6 preoperatively to 86.3 postoperatively (59). The authors found tantalum to be a viable alternative to structural allograft or autograft (59). Frigg et al retrospectively reviewed 9 patients who underwent arthrodesis of the foot and ankle using a tantalum spacer. Indications included a failed total ankle replacement, osteonecrosis of the talus, a subtalar joint nonunion after pantalar arthrodesis, severe flatfoot deformities on chronic pes planus, and patients with morbid obesity used to prevent loss of correction (57). At 1 and 2-year follow-up, all 9 patients had consolidated at the arthrodesis site, with no loss of correction (57). While tantalum spacers can be manufactured to a patient’s specific anatomy using preoperative CT scans, it cannot be customized to accommodate traversing hardware (4).

There have been several reports describing use of titanium trusses in foot and ankle surgery. Dekker et al published a case series of 15 patients with osseous defects and severe deformity that required arthrodesis procedures who underwent reconstruction of the ankle or tibia with custom 3-D printed titanium trusses. Procedures included 11 TTC fusions, 2 tibial osteotomies, 1 ankle fusion, and 1 tibial spanning procedure. Consolidation across the arthrodesis sites was demonstrated on CT scan in 13 of 15 patients (87%), with an average time to arthrodesis of 5 months. There were 2 failures, which resulted in 2 trans-tibial amputations. The mean AOFAS and Foot and Ankle Ability Measure Activities of Daily Living scores improved from 28.4 to 64.8 and 23.5 to 62.8, respectively. The authors concluded that 3-D printed titanium trusses can be utilized in complex ankle and tibial deformities and osseous defects (21). So et al published a case study of 3 patients, who underwent implantation of custom titanium trusses for failed elective procedures of the foot and ankle. Preoperative diagnoses included 1 failed total ankle replacement, 1 septic nonunion of Lapidus bunionectomy, and 1 nonunion of an Evans calcaneal osteotomy. Successful limb and ray salvage occurred in all 3 patients. Radiographic union was achieved in all 3 patients, as demonstrated by >50% osseous bridging across all bone-truss interfaces at 6 months postoperatively (8).

This case series showed successful limb or ray salvage using either custom 3-D printed, or prefabricated manufacturer trusses for arthrodesis. Our results were consistent with previous case series that demonstrated successful limb and ray salvage utilizing custom, 3-D printed titanium trusses. However, this case series also demonstrated successful consolidation and ray or limb salvage using prefabricated manufacturer titanium trusses. There appears to be potential to produce prefabricated trusses made for specific joints such as the first MTP joint, first tarsal TMT joint, and subtalar joint.

Our study had several limitations. First, the number of patients included in the study was small. A larger sample size is necessary to determine the long-term efficacy of titanium trusses as a viable treatment alternative compared to traditional techniques for osseous defects. Second, postoperative CT scans were only utilized in 7 of the 12 patients included in the study. While 5 of the patients demonstrated consolidation as seen on radiographs, CT scans would have been ideal to determine union at the arthrodesis site. Also, the quality of images on the postoperative CT scans was somewhat obscured by artifact. Third, as patient follow-up was limited, the long-term results are unknown. Comparative trials are needed to assess the value of titanium trusses versus traditional techniques such as end-to-end arthrodesis, arthrodesis with interpositional autogenous or allogenic bone graft, bone transport utilizing an external fixator, Masquelet’s induced membrane technique, osteomyocutaneous flaps of the fibula, or amputation.

In conclusion, 91.7% of the patients in this review demonstrated successful arthrodesis with use of both customized, patient-specific 3-D printed and prefabricated
CHAPTER 3

17

titanium trusses. This study offers an alternative to traditional methods of arthrodesis for large osseous defects. Additionally, this study shows the successful use of prefabricated trusses. This appears to be a reasonable option for patients at risk for limb loss or ray amputation.

REFERENCES


INTRODUCTION

Heterotopic or ectopic ossification (HO) is the formation of lamellar bone in soft tissues such as muscles, tendons, or other nonskeletal structures where bone does not normally occur. HO can either be inherited or acquired. Inherited conditions include fibrodysplasia ossificans progressiva (FOP) in which HO occurs in addition to skeletal abnormalities due to a missense mutation of a bone morphogenic protein receptor. This condition is rare and generally presents itself during infancy. FOP HO is generally preceded by painful soft tissue inflammation termed flare-ups, which is often accompanied by fever, more inflammation and a loss of mobility. Depression and anxiety are also experienced, which only increases pain perception (1,2). Other inherited forms include Albright inherited osteodystrophy, a syndrome with a variety of manifestations including obesity, short stature, round face, shortening and widening of long bones in the hands and feet, and subcutaneous ossifications.

Acquired HO conditions are far more common than inherited conditions and are often the result of musculoskeletal trauma, surgery, amputations, spinal cord injuries, brain trauma, or burns. Genetic HO generally results from minor inflammatory flare-ups often nontraumatic in nature such as vaccination whereas non-genetic is generally the result of a more traumatic event. In addition, HO can occur as a result of autoimmune diseases such as tetanus, polio, sickle cell anemia, or even idiopathically (1,3). The incidence of heterotopic ossification varies widely and is dependent on the cause. Inherited conditions such as FOP are rarely reported with only 800 documented in the literature. Postsurgical incidence can reach up to 40% after elbow fractures (4). Total hip arthroplasties are also a common cause of HO ranging from 5.2% to 61.3% following surgery. Even higher rates are associated with revisions of total hip arthroplasties (5). People who experience traumatic brain injury or spinal cord injury have a significantly higher risk of developing HO if limb fracture is also present (4). HO can present shortly after or years after the original injury.

PATHOGENESIS

Although the biochemical mechanism of HO and the cellular origin is unknown at this time, most authors agree that 3 factors must be present for HO to occur: the presence of osteogenic precursor cells, an inducing event, and the proper environment. This environment is provided by the inflammatory process as a result of the inducing event such as trauma or neurogenic injury. Inflammatory cells in the presence of tissue hypoxia and cellular damage lead to recruitment and proliferation of undifferentiated progenitor and stem cells. Several signaling pathways play crucial roles in the differentiation of these cells into osteogenic cells although this process is not well understood at this time. Similarities for all types of HO regardless of the cause is increased bone morphogenic protein following inflammation, which promotes bone formation (1).

SYMPTOMS

HO can be hard to diagnose in the early stages. Patients often report pain, swelling, erythema, stiff joints, and even fever. However, as time goes on, individuals experience soft tissue loss, joint contractures, increased stiffness, chronic pain, and loss of mobility. Fusions of joints, nerve entrapment, and pressure ulcers may also occur. Moreover, HO can result in neurologic symptoms including the loss of sensation and strength. HO can reduce the quality of life and increases expenses due to ongoing medical treatments and need for further surgery especially if the condition is due to brain or spinal cord injuries or significant limb fracture. Although almost 80% of HO is relatively benign, 10-20% often results in loss of motion (3,4).

TREATMENT AND DIAGNOSIS

HO can initially be treated prophylactically with nonsteroidal anti-inflammatory drugs (NSAIDs) and radiotherapy. NSAIDs help to prevent or reduce the inflammatory phase of HO. Post surgically, NSAIDs inhibit prostaglandin-
mediated bone remodeling, decrease callus formation, and change the haversian canals used in fracture healing. Radiotherapy on the other hand prevents the differentiation of mesenchymal stem cells into osteogenic cells. Therefore, abnormal bone growth is inhibited. Both methods have not been shown to be effective once heterotrophic bone has already formed. Many surgeons use radiotherapy and NSAIDs prior to and after surgery. Other treatments include bisphosphonates and glucocorticoids. Once bone formation has occurred in the extra skeletal region, the only treatment option is surgical excision. Diagnosis includes plain film radiographs, magnetic resonance imaging (MRI), and computed tomography (CT) scans (7).

**CASE REPORT**

A 73-year-old man presented with right Achilles tendon pain. The patient stated that he was able to ambulate but feels soreness and discomfort. The patient reported that 5 years ago, his chiropractor informed him that his Achilles tendon was ossifying, but he only started to have pain a few months prior to presentation. The patient had a significant traumatic incident 55 years ago, when he had a Go Kart accident and lacerated the right Achilles tendon requiring surgery. The patient stated that he healed uneventfully and denied any pain until just prior to his presentation to clinic. The patient was applying voltaren gel with mild relief of his pain.

On physical examination, the neurovascular status was intact and there were no open wounds or lesion noted. The patient had 5/5 muscle strength crossing the ankle joint. A significant palpable mass was noted along the entire Achilles tendon extending approximately 8 cm from its insertion (Figure 1). The right lower extremity was noted to be shorter than the left. Radiographs revealed ossification of the Achilles tendon measuring 18.5 cm (Figure 2). The patient declined a CAM boot at the time; but agreed to wear heel lifts, stop high-impact activity, and continue to use voltaren gel. The patient returned to the clinic 3 weeks later with no pain and stated he was able to go on a long walk with his friends without issues. The patient was seen again in the clinic 14 months later and was able to perform activities of daily living without any issues.

**DISCUSSION**

HO of the Achilles tendon is a rare condition, has an unknown incidence, and generally occurs in males twice as often as females. All the literature reports to date are case studies and case reports. Achilles tendon ossification is generally preceded by trauma or surgery. Other factors can include metabolic conditions such as Wilson’s disease, DISH, seronegative/crystal arthropathies, neoplasm, chronic infection, renal disease, reactive arthritis disease, and repetitive microtrauma (7). A few case studies also report instances of idiopathic causes. Sizes of the ossification have ranged from small, discrete masses to up to 12.5 cm.
of the tendon ossified. Patients generally present with pain, swelling, or erythema. Often, the pain is caused by a fracture to the ossific site. A decrease of range of motion is often encountered. Many patients do not experience pain until the ossification is fractured. Surgical treatment includes the excision of the ossification and repair of the Achilles tendon (8). Surgical treatment has been documented throughout the literature. Brotherton et al reported a 12.5 cm mass that fractured in a patient. The mass was repaired using figure 8 wire. Osseous union was observed 4 months postoperatively (9). Ishikura removed bone, which left a 12.0 cm defect. The ipsilateral semi-tendinosus and gracilis tendon were harvested and used to repair the defect. A gastrocnemius flap was then turned down to reinforce the repair (10). Other forms of repair include a V-Y lengthening and an FHL transfer to bridge a 10 cm gap following excision (7). Conservative treatment options include cast immobilization for several weeks with serial radiographs taken to monitor the healing progress (11). Some people heal with the use of heal lifts and decrease in activity as in the case above.

HO can affect several areas of the body whether acquired or genetic. Traumatic injuries of the Achilles tendon can result in ossification of the tendon within weeks or even years later. Most cases of HO are often benign and do not cause symptoms. If symptoms arise, Achilles tendon pathology can be treated conservatively as in the case presented above. Surgical treatment is warranted if conservative care fails, and several options are available depending on the defect size.

REFERENCES

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Calaj-Tavaf-Moon-Merrill Classification System of Pes Planus: A Novel Classification Describes the Six Types of Pes Planus

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Zohaib Moon
Misha Tavaf
Thomas Merrill, DPM

INTRODUCTION

Pes planus, commonly referred to as flatfoot, is a common deformity seen in patients of all ages. While pes planus commonly tends to be asymptomatic, it can potentially have severely debilitating effects on functionality and quality of life. Generally, it is characterized by abnormal subtalar joint pronation (1). While reviewing the current literature on pes planus, there is a lack of information on the varieties that can be seen in individuals and in how they can be properly identified and differentiated. The authors propose that there are six variations of pes planus based on age and flexibility. This will aid clinicians in the recognition and appropriate treatment.

Recognizing age and flexibility will allow physicians to accurately diagnose and propose various treatment modalities towards pes planus deformities. Currently, there is no pes planus classification system to distinguish between the etiologic and progressive variations seen in flatfoot deformities. We propose an applicable classification system providing physicians with a guideline towards the diagnosis and treatment of a pes planus foot type. Initial patient and pedal evaluation must be considered, specifically the clinical and radiographic findings.

The Calaj-Tavaf-Moon-Merrill (CTMM) Classification System of pes planus is stratified from child, teenage, and mature based on the patient’s age, with subcategories Type 1 and 2 based on the flexibility of the deformity. Type C is the child, at the time of birth. Type T is the teenager age group, typically ranging from ages 10-24 years. Type M is the mature adult age group, representing fully developed and ossified primary and secondary centers, as seen radiographically. Subcategory Type 1 reflects a flexible foot type, while Type 2 reflects a rigid foot type. There are six possible diagnoses based on the CTMM classification system. This classification should be implemented both clinically, in the diagnoses and treatment, and academically, providing stratification of a rather complex disorder (Table 1 and Table 2).

Congenital calcaneovalgus (CCV), is a common birth finding believed to be obtained secondary to intrauterine mispositioning in which the dorsum of the foot is elevated toward the anterior aspect of the leg, at times contacting the tibia (2,3). CCV is most often confused with CCPPV (congenital convex pes plano valgus). CCV immediately manifests itself on the newborn’s foot, with an estimated incidence of 0.4-1.0 in 1,000 live births (4). There is notable dorsiflexion and eversion of the calcaneus, restricted plantarflexion, and common peroneal tendon subluxation. A hallmark finding in the diagnosis of CCV is the absence of any equinus involvement, rather it is accompanied by a long and relaxed Achilles tendon. A practitioner will encounter the ankle in a dorsiflexed position, often to the extent to where the first metatarsal is pushing against the tibia. Tightness may be noted to the extensor retinaculum along the deep creases to the dorsum of the foot. Contrasting CCPPV, the deformity is flexible and absent of any tarsal dislocations or subluxations (3). Clinicians should utilize lateral stress radiographs.

Table 1. CTMM CLASSIFICATION SYSTEM OF PES PLANUS

<table>
<thead>
<tr>
<th>AGE</th>
<th>FLEXIBLE (1)</th>
<th>RIGID (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHILD (C)</td>
<td>C1: CCV</td>
<td>C2: CCPPV</td>
</tr>
<tr>
<td>TEENAGER (T)</td>
<td>T1: FFF</td>
<td>T2: TC</td>
</tr>
<tr>
<td>MATURE (M)</td>
<td>M1: PTTD</td>
<td>M2: PTTD</td>
</tr>
</tbody>
</table>

W/ DJD

Table 2. CTMM CLASSIFICATION SYSTEM OF PES PLANUS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Congenital Calcaneovalgus</td>
</tr>
<tr>
<td>C2</td>
<td>Congenital Convex Pes Planovalgus</td>
</tr>
<tr>
<td>T1</td>
<td>Flexible Flatfoot</td>
</tr>
<tr>
<td>T2</td>
<td>Tarsal Coalition</td>
</tr>
<tr>
<td>M1</td>
<td>Posterior Tibial Tendon Dysfunction</td>
</tr>
<tr>
<td>M2</td>
<td>Posterior Tibial Tendon Dysfunction with Degenerative Joint Disease</td>
</tr>
</tbody>
</table>
Only a few radiographs have been taken regarding the present material, all confirming normal findings (5). Many authors agree that this is essentially a benign condition that can be followed clinically and does not require radiographic evaluation or active treatment (6). However as mentioned, there will be no luxation found implying that no secondary adaptive bone changes or hypoplasia are found at the time of birth. Such findings are determined radiographically (7).

CCPPV is commonly referred to as vertical talus or rocker bottom flatfoot (8) and is a pronation dislocation of the talonavicular joint. The rigidity of the deformity is the hallmark to differentiating between vertical talus and a CCV foot. Vertical talus clinically manifests on newborn feet with plantar flexion of the hindfoot and ankle, also known as equinus. Furthermore, forefoot dorsiflexion is present and the heel is in a valgus position. It is important to note deep creases on the dorsum of the feet, and the absence of creases on the plantar aspect of the feet due to the excessive dorsiflexion of the forefoot and midfoot (9,10). If hindfoot equinus is not clinically featured, then the deformity is not vertical talus and is likely positional in nature (11). Vertical talus should be detected immediately after birth, as it may be associated with genetic syndromes (12). There are four clinical patterns currently associated with vertical talus: arthrogryposis, spina bifida, NF, and isolated congenital defect (50%) (13). CCPPV has an incidence of 1 in 10,000 and affects males and females equally (14).

The radiographic anatomy associated with CCPPV has been poorly defined, with many variations in findings. Nevertheless, lateral stress radiographs (the Eyre-Brook) should be obtained to address the deformity and rule out other pathologies. CCPPV will present as a non-reducible rigid deformity (8). The most common findings and measurements noted in evaluation of CCPPV include Kohler-like changes as the navicular ossifies, a wedged shaped navicular, calcaneocuboid diastasis, elevated first metatarsal, flexion contracture of the first MPJ, and lastly an hourglass talus. The talus will present parallel to the tibia and the calcaneus will be fixed in an equinus position. The normal value of the talocalcaneal angle should measure between 25-40 degrees, an increase in this measurement will suggest excessive pronation in the rearfoot (15). A deviation of greater than 40 degrees is noted in patients with CCPPV. Another angle of deviation is the calcaneal inclination angle (CIA), which is used to differentiate between equinus, cavus, and planus deformities. The normal measurement for a CIA is 15 degrees (15). A lateral weight-bearing radiograph will demonstrate a negative CIA, a hallmark feature of CCPPV.

Flexible flatfoot is one of the most common deformities to present itself to the lower extremity, most commonly presenting as a collapse of the medial arch typically presenting in the adolescent age group. Flatfoot in general, flexible or rigid may present as isolated congenital defects, or from other underlying abnormalities and disorders (16). Idiopathic flexible flatfoot is the most common form (17). Flexible flatfoot may present as either asymptomatic or symptomatic. There are no distinct criteria to distinguish between the two, as symptoms are uniquely based on lifestyle. (18). A hallmark feature of flexible flatfoot is a collapsing medial arch that is only present when the patient is weightbearing. This medial arch collapse is a static anatomic comparison of the height of the arch compared to the normal population (16,19). According to Mosca (19), the flexibility of the flatfoot refers to the range of motion of the subtalar joint.

Radiographic evaluation of flexible flatfoot utilizes anteroposterior and lateral weight bearing views of the foot. Non-weightbearing views tend to be insufficient and tend to misrepresent the true clinical deformities associated with flexible flatfoot (19). Three angles are of primary interest when diagnosing flexible flatfoot: the talar declination angle (TDA), CIA, and talus-first metatarsal angle (Meary’s angle). A TDA greater than 24 degrees correlates with the plantar flexion of the talus as seen in flexible flatfoot, and a CIA less than 18 degrees is consistent with flexible flatfoot calcaneal plantar flexion (20). Meary’s angle is useful in defining a normal longitudinal arch by drawing two lines through the mid-axis of the first metatarsal and mid axis of the talus. Normally the two form a continuous and parallel line (0 degrees), however in flatfoot, Meary (21) defined it as greater than 4 degrees with a plantar sag in which those two lines intersect. An increased TFM angle is an important correlation in symptomatic versus asymptomatic patients with flexible flatfoot (18). An anteroposterior radiograph can additionally be used to evaluate the relationship between the talus and first metatarsal. On both anteroposterior and lateral radiographs it is critical to note the center of rotation of angulation (CORA) as applied to the foot, indicating the true etiologic site of deformity, differentiating between flexible flatfoot and skewfoot, and assisting in proper surgical implications (19).

Tarsal coalition is the most common cause of juvenile or adolescent rigid flatfoot (22). A tarsal coalition is an unwanted union of two tarsal bones at a joint, therefore restricting motion in the foot. These deformities lead to stiff feet usually accompanied by chronic pain and spastic peroneal muscles. The cause of a tarsal coalition is unknown but could be acquired or congenital. It is commonly due to accessory ossicles fusing two tarsal bones or genetic mutations (10). There are three common coalitions seen in adolescent feet: talocalcaneal, talonavicular, and calcaneonavicular. Talocalcaneal and calcaneonavicular coalitions tend to be the most common, accounting for more than 90% of all coalitions (23). In talocalcaneal coalitions the middle and sometimes anterior facets will fuse. Talocalcaneal coalitions often ossify in children ages 12-16 years (23). Talocalcaneal
coalition will lead to increased trabecular patterns in the cortical bone due to compressive forces on the subtalar joint.

On radiographs, increased trabecular bone shown in a circular ring pattern is referred to as the C-sign or halo sign (23). Talar beaking can also be noted on lateral radiographs. In the case of a calcaneonavicular coalition, elongation and blunting of the tip of the anterior process of the calcaneus is seen on lateral radiographs (24). This finding is known as an anteater sign and is pathognomonic in diagnosing a calcaneonavicular coalition. When these signs are present, a tarsal coalition can be confirmed and treatment options to correct a rigid adolescent flatfoot should be considered.

Posterior tibial tendon dysfunction (PTTD) is the most common etiology of an adult acquired flatfoot deformity (15). The average age of PTTD presentation is around 40 years old and is most prevalent in women (25). The tibialis posterior muscle is a key structure involved in maintaining the integrity of the medial arch of the foot, crucially firing throughout the gait cycle. As the posterior tibial tendon loosens, there is resultant pressure on the spring ligament, forcing the ligament to stretch. The spring ligament is the primary structure holding the navicular head in place in an attempt to avoid medial arch collapse.

The etiology of PTTD can be acute or chronic. Acutely, although rare, PTTD may occur due to trauma, falls, or sudden movements that lead to tendon tear. More commonly, PTTD is caused by chronic injuries, which result from overuse or high impact sports. The medial longitudinal arch of the foot is supported by the posterior tibial tendon, along with the spring ligament, which supports the head of the talus from the inferomedial side. Impingement of the posterior tibial tendon at the fibro-osseous groove behind the medial malleolus is the most common etiology of PTTD. It has been noted that the prevalence of PTTD increases if an accessory navicular is present (25). The dysfunction can also be due to tendonitis and degenerative changes at the point of insertion. Signs and symptoms of PTTD can present as swelling around the medial malleolus and pain upon palpation on the posterior aspect of the medial malleolus. PTTD results in inflammation or tearing of the posterior tibial tendon and as a result, the tendon is unable to support the arch of the foot.

During midstance the foot maximally pronates to absorb shock, resulting in adduction and plantarflexion of the talus, as well as forward movement of the Cyma line. On radiographic imaging, a decrease of the CIA and increased talocalcaneal and Meary’s angle can be noted. When the CIA drops down, the lateral process of the body of the talus moves forward until it contacts the calcaneus and floor of sinus tarsi. If the CIA can be corrected with stress supination, this would represent a flexible flatfoot, which can be seen when comparing lateral radiographs of the patient standing normally to those with the patient standing with a block under the medial side of the heel (26). If there is some correction of the CIA noted on the stress radiograph, the flatfoot is considered flexible and the treatments will usually be conservative.

PTTD with degenerative joint disease rigid flatfeet in the adult are mostly due to degenerative changes in the joints secondary to posterior tibial tendon dysfunction. As the adult acquired flatfoot progresses, ankle valgus will increase and eventually rigidity and arthritic changes will be observed. In these progressed situations, the patient will gradually lose normal function and will have alterations in the shape of the feet (27). As explained above, due to stretching of the spring ligament after posterior tibial tendon loosening, the medial arch will collapse due to subluxation and the secondary changes will lead to rigid flatfeet in adults.

End-stage PTTD leads to subtalar joint dislocation with the calcaneus completely pronated and lateral process of the talus in contact with the floor of the sinus tarsi. This position of the subtalar joint is the maximum amount of pronation tolerable prior to fracturing the lateral process of the talus. The bodyweight force on the maximally pronated subtalar joint is a continuous compression that will lead to arthritic changes. This will lead to decreased range of motion, rigidity, and can be extremely painful (25). In this position, the posterior process of the talus is medial to the calcaneus and the middle facet of the talocalcaneal joint cannot be seen on radiographs. If in a lateral radiograph taken with stress supination, the middle facet cannot be observed and there is no correction in the CIA, treating the flatfoot as a rigid pes planus should be considered.

**DISCUSSION**

As with the CTMM, exceptions are of the nature of many universally accepted classification systems. An example can be seen in the Danis-Weber system, which completely overlooks the medial side of the ankle, and has been shown to only predict outcomes for uni-malleolar ankle fractures (28). Another renowned classification system is the Lauge-Hansen, which does not apply to isolated ankle fractures of the posterior tibial margin and fails to define all possible fracture patterns (28,29). In the CTMM, although extremely rare, one can see anomalies of flatfoot in different ages, such as PTTD in children rather than as expected in adults. However, after considering the various clinical and radiographic findings, the proper underlying etiology is assured.

In conclusion the complexity of pes planus in its diagnosis and treatment has impacted practicing physicians internationally. The multitude of underlying issues that can present as flatfoot are numerous and their treatments can vary substantially. The premise of the CTMM Classification...
System of pes planus is reliant on two variables: age and flexibility. The simplicity of the CTMM Classification system is evident and its use is fundamental. The CTMM system provides physicians with a guide to narrow down the potential etiologies and target the underlying disease behind the flatfoot. The CTMM explains the 6 types of pes planus clinical presentations. The idea of clinical functional classification can also be applied to cavus foot deformities.

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Subtalar Realignment Arthrodesis in the Mid-Stage Neurogenic Cavovarus Foot

Daniel J. Hatch, DPM
Aniela Cordoba, DPM
Meghan M. Hurley, DPM
Abigail M. Smith, DPM

INTRODUCTION

A common etiology of cavus foot is an underlying neuromuscular disorder. Brewerton found that 66% of his cavus patients had a neuromuscular pathology, and of those, more than 50% had Charcot-Marie-Tooth disease (CMT) (1). In 1968, work by Dyck and Lambert classified this disease process as a hereditary sensory motor neuropathy (2,3). Presently, there are several subtypes described, with CMT type 1 being the most common form (4). CMT is a progressive disease that usually involves an imbalance of the antagonistic muscles inserting into the foot after loss of intrinsic musculature, resulting in a complex cavovarus deformity. The peroneus longus overpowers the tibialis anterior. In a similar fashion, the tibialis posterior vanquishes the peroneus brevis. This muscular asymmetry leads to an inverted rearfoot with plantar deviated first rays. Due to these progressive imbalances, the timing of surgical intervention is paramount in the decision-making process. Our surgical examples include patients with mid- to long-standing cavus deformity with variable signs of arthrosis and/or instability.

CASE REPORTS

Patient 1 is a 37-year-old man with CMT who presented with significant weakness and gait instability. He was not able to wear ankle foot orthoses (AFO) due to the amount of deformity and subsequent abrasions. Clinical evaluation revealed bilateral severe hammertoe deformities, plantarly deviated first rays, and varus heel positions. To address the right foot deformity, the following procedures were performed: Jones tenosuspension with hallux interphalangeal joint fusion, dorsiflexory first tarso-metatarsal joint arthrodesis, hammertoe repair by fusion of the proximal interphalangeal joint, tibialis posterior tendon transfer, subtalar joint realignment arthrodesis, and tendo-Achilles lengthening (Figure 1 and Figure 2). Note the improvement in Kite’s angle on the anteroposterior and lateral radiographs of the right foot versus the left. Additionally, note the significantly improved calcaneal alignment in the postoperative long leg axial views.

Patient 2 is a 53-year-old man with CMT presenting with bilateral cavovarus foot deformities (Figure 3). He was concerned with the recurrent instability of the left ankle. Dynamic evaluation with fluoroscopy demonstrated significant subtalar joint instability (Figure 4). Therefore, subtalar realignment arthrodesis was performed along with first tarsometatarsal joint dorsiflexory arthrodesis; tibialis posterior tendon transfer, plantar fascial release and tendo-Achilles lengthening bilaterally (Figure 5).

Patient 3 is a 29-year-old man who also developed bilateral cavovarus foot deformities secondary to CMT (Figure 6). In order to correct the left foot, we performed a tibialis posterior tendon transfer, Dwyer calcaneal

Figure 1. Preoperative radiographs of the right foot of patient 1.
Figure 2. Postoperative radiographs of the right foot of patient 1.
osteotomy, peroneus longus to brevis tendon transfer, plantar fasciotomy, and gastrocnemius recession (Figure 7). Note in the postoperative anteroposterior projection the poor alignment of the talo calcaneal joint (Kite’s angle). Additionally, note the lack of calcaneal alignment to the distal tibial axis in the axial views.

**CASE SUMMARY**

All three patients related good functional outcomes and increased stability after a minimum 5-year follow-up. However, the patients who underwent subtalar realignment had the best long-term alignment of the rearfoot complex. Additionally, they were able to return to regular shoe wear with minimal use of their AFO bracing. Patient 2 had the most improvement with his left side subtalar instability treated by realignment arthrodesis of the subtalar joint. Conversely, patient 3 had the poorest result with his joint-preserving osteotomies not employing the subtalar joint realignment. The joint sparing approach was chosen because of his younger age. Improvements could have been made in the osteotomy, incorporating more lateral translation in addition to the Dwyer procedure. Also note that with the calcaneal osteotomy there was little change in the anteroposterior Kite’s angle.
DISCUSSION

A thorough evaluation of the neurogenic cavus foot type is imperative to elucidate the best surgical options for the patient in establishing a plantigrade foot (5). Radiographic assessment is also imperative with the long leg axial view providing critical information (6-9). Neuromuscular assessment allows physicians to determine which muscle groups are deforming vectors and which groups are paretic. Quite often in CMT, the primary deforming force is the dominating strength of the TP and PL over their weak antagonists. Subsequently this results in a complex, progressive cavovarus foot type (10,11). All of these factors substantiate that timing of the intervention is a critical factor in the decision-making process. Historically, triple arthrodesis for this condition has been advocated by many authors for best long-term results (12-17). However, more recent literature favors joint preserving osteotomies, especially in younger patients (9,18-22).

Some authors even advocate earlier surgical intervention by tendon rebalancing with the hopes of avoiding any form of surgical arthrodesis later in life (9,21,23). Mosca proposed an individualized staged approach, with early intervention involving tendon transfers and osteotomies and end-stage treatment incorporating triple arthrodesis (24). Mosca reiterates that timing of the surgical procedures is very important in the decision-making process. Our cases involved patients who displayed mid- to late-stage cavovarus deformities without evidence of secondary arthritic involvement.

The consideration of the subtalar joint realignment arthrodesis is multifactorial. While all joints are involved in the rearfoot complex in CMT, we advocate that arthrodesis of the subtalar joint offers an ideal apex from which to address the triplane deformity while preserving some midtarsal joint motion (25,26). In order to appropriately correct a deformity, the authors support Paley’s theory of a 3-dimensional approach that allows for correction at the center of rotational angulation (27). In this case, we are addressing the mechanical axis of the subtalar joint. Most studies evaluate this condition in 2 dimensions therefore a common recommendation to address heel varus (in 2-D) is a calcaneal osteotomy (Dwyer) with or without lateral displacement (28,29). Even the Coleman-Chesnut block test only evaluates the heel in the coronal plane (30). Although we acknowledge that a wedge calcaneal osteotomy helps align the heel to the tibia in the coronal plane, it does not provide improvement of Kite’s angle or address instability of the subtalar joint (31). A recent 3-D study by Pfeffer et al acknowledged the lack of correction in all 3 planes with a Dwyer, oblique osteotomy, and the more technical Z-osteotomy (32). The calcaneus does not solely move in the frontal plane by inverting the posterior tuber. It is a triplane deformity with its axis through the subtalar joint that can be best appreciated on CT studies (33) (Figure 8). The varus heel position commonly seen in CMT patients is notably similar to the calcaneal position in patients with clubfoot deformity. With this in mind, when we apply the biomechanical principles as advocated by Ponseti, the deformity will reduce during surgical repair (34-36). His evaluation of the mechanics of the subtalar joint was inspired by the findings of Huson (37) and Farabeuf (38).

During subtalar realignment, the beak of the calcaneus is abducted, dorsiflexed and rotated about the subtalar axis.

Figure 8A. 3-D Computed tomography of cavus foot in the same patient. Note the curved medial border of heel suggesting a Dwyer type procedure.

Figure 8B. Computed tomography view of the same foot and patient that was rotated eliminating the perceived curved border. This illustrates that the varus heel is positional versus structural.
producing a valgus positioning of the calcaneal tuber along with improvement of Kite’s angle (Figure 9).

When addressing rearfoot malalignments, especially in patients with CMT, it is important to understand the complex biomechanical axes of the rearfoot. The calcaneus moves in a triplanar fashion about the subtalar joint axis. A cavovarus deformity develops from the underlying neuromuscular imbalances. After addressing these imbalances usually with tendon transfers; care should be taken to evaluate for any arthrosis, instability and malposition of the calcaneus. We have found that realignment arthrodesis of the subtalar joint offers improved talocalcaneal alignment, calcaneal repositioning and stability in the mid- to late-stage CMT patient.

Figure 9. In cavus/clubfoot, the anterior process of the calcaneus is under the talar head, yielding a varus and slight equinus deformity of the calcaneus. Lateral displacement of the anterior process will correct the heel varus.

REFERENCES

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INTRODUCTION

Complex regional pain syndrome (CRPS) is an uncommon and poorly understood debilitating condition that has been described in both the podiatric and general medical literature. CRPS is a painful neurological condition that is associated with progressively worsening spontaneous regional pain. There is no dermatomal distribution. CRPS has now replaced other terms such as Sudeck’s atrophy, reflex sympathetic dystrophy, algodystrophy, fracture disease, and causalgia. CRPS can develop after major trauma or surgery and has a variable course progression that can sometimes be self-limiting with mild symptoms or can develop into chronic disease. Future research is needed to further understand CRPS.

EPIDEMIOLOGY AND PATHOPHYSIOLOGY

The incidence of CRPS is approximately 20-26 per 100,000 people annually and can occur within a few months of any extremity injury or surgical procedure (1). The incidence disparity between women and men is as high as 71% and 29%, respectively (2). The peak age at onset is between 45 and 55 years (3). Patients with asthma, osteoporosis, migraines, or hematological disorders are at a higher risk due to the fact they take angiotensin-converting enzyme (ACE) inhibitors (1). Other population variables associated with CRPS include Caucasian race, higher median income, and a history of depression, headache, or drug abuse. Patients with hypothyroidism, or who are diabetic or obese have lower rates of CRPS (3).

CRPS is thought to be caused by post-traumatic hyperactivation of small nerve fibers. This abnormal nerve fiber activation leads to central sensitization, which is a process where the central nervous system increases any peripheral impulses (1). Studies have shown that low-dose ketamine treatments can downregulate central sensitization, which leads to a reduction of CRPS pain (4). Now it is clear that the nerve fiber hyperactivation is caused by immune processes in patients (1). Most CRPS patients have autoantibodies that are specific in their serum. Studies have demonstrated that when the autoantibody is transferred to mice, it elicits a CRPS picture that has been restricted to the paw, which confirms an autoimmune origin (3). The exact pathogenesis of why CRPS patients produce these autoantibodies is still unknown, but there has been some progress in identifying genotypes that convey that vulnerability (1).

DIAGNOSIS

There is no diagnostic gold standard for CRPS, however a thorough history and physical examination are critical for appropriate diagnosis and management of these patients. Currently, the new International Association for the Study of Pain (IASP) criteria are the most frequently used clinical diagnostic criteria for CRPS. The IASP criteria are based on clinical as well as patient-reported signs and symptoms. (5). CRPS can be differentiated between CRPS type I (without an obvious nerve lesion) and CRPS type II (with a verifiable nerve lesion). At first presentation, approximately 70% of patients report a warm subtype with an increased skin temperature at symptom onset, whereas the remaining 30% report a cold subtype. Trauma typically precedes clinical symptoms. Table 1 shows the Budapest diagnostic criteria, which present clinical diagnostic criteria to help identify patients with CRPS.

Instrument-based investigation may be beneficial if there are doubts concerning the differential. These include repeated measurements of skin temperature, magnetic resonance imaging and radiographs of each extremity, and 3-phase bone technetium scintigraphy in acute CRPS. Quantitative sensory testing (QST) is not suited for CRPS diagnosis because it primarily describes pain symptoms, which are not specific. A typical QST pattern (thermhypaesthesia, mechanical hyperalgesia, and pressure hyperalgesia) may support a CRPS diagnosis, particularly in the distal joints that were not affected directly by trauma and are sensitive to pressure pain. The CRPS severity score can also be utilized to grade the severity of CRPS and help monitor the disease course (Table 2) (6).

Pain is the most important clinical symptom. The pain can be permanent or fluctuating and most often occurs in the deep tissue. This pain symptom increases through movements and during temperature changes. In chronic and severe cases of CRPS, allodyna is a hallmark feature. Sensory deficits include hypoesthesia and impairment of thermal perception in a glove or stocking-like pattern. All patients have decreased muscle strength and most have
movement-induced pain. Contractures can develop fairly quickly. Trophic changes may be found on the skin (ulcers), nails, and hair. In chronic cases, patients have reported that their extremity feels thicker. All patients display a change in their skin color that varies from reddish in patients with warm CRPS, to a blueish color in those with cold CRPS (6).

**TREATMENT AND MANAGEMENT**

A multidisciplinary approach is recommended for the management of CRPS. The main goals of therapy are to restore function to the affected limb, decrease pain and disability, and improve the quality of life while minimizing side effects and toxicities. Treatment is more effective when started early in the course of disease. Referral to a pain management specialist with experience in CRPS management is appropriate in patients with progressive symptoms and signs of CRPS, as well as patients with chronic/severe forms. Initial management of CRPS includes patient education, physical and occupational therapy, a psychosocial assessment, and symptomatic pain management, typically beginning with low-risk pharmacotherapy.

<table>
<thead>
<tr>
<th>Table 1. Budapest Diagnostic Criteria For CRPS</th>
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<tbody>
<tr>
<td>Clinical diagnostic criteria for CRPS</td>
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<tr>
<td>• Continuing pain, which is disproportionate to any inciting event</td>
</tr>
<tr>
<td>• Must report at least 1 symptom in 3 of the 4 following categories:</td>
</tr>
<tr>
<td>• Sensory: Reports of hyperalgesia and/or allodynia</td>
</tr>
<tr>
<td>• Vasomotor: Reports of temperature asymmetry and/or skin color changes and/or skin color asymmetry</td>
</tr>
<tr>
<td>• Sudomotor/Edema: Reports of edema and/or sweating changes and/or sweating asymmetry</td>
</tr>
<tr>
<td>• Motor/Trophic: Reports of decreased range of motion and/or motor dysfunction (weakness, tremor and dystonia) and/or trophic changes (hair, nails, and skin)</td>
</tr>
<tr>
<td>• Must display at least 1 sign at the time of evaluation in 2 or more of the following categories:</td>
</tr>
<tr>
<td>• Sensory: Evidence of hyperalgesia (to pinprick) and/or allodynia (to light touch and/or deep somatic pressure and/or joint movement)</td>
</tr>
<tr>
<td>• Vasomotor: Evidence of temperature asymmetry and/or skin color changes and/or asymmetry</td>
</tr>
<tr>
<td>• Sudomotor/Edema: Evidence of edema and/or sweating changes and/or sweating asymmetry</td>
</tr>
<tr>
<td>• Motor/Trophic: Evidence of decreased range of motion and/or motor dysfunction (weakness, tremor, and dystonia) and/or trophic changes (hair, nails, and skin)</td>
</tr>
<tr>
<td>There is no other diagnosis that better explains the signs and symptoms</td>
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Adapted from reference 8.

<table>
<thead>
<tr>
<th>Table 2. CRPS severity score CSS</th>
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<tr>
<td><strong>Self-reported symptoms</strong></td>
</tr>
<tr>
<td>Continuing disproportionate pain</td>
</tr>
<tr>
<td>Allodynia or hyperalgesia</td>
</tr>
<tr>
<td>Temperature asymmetry</td>
</tr>
<tr>
<td>Skin color asymmetry</td>
</tr>
<tr>
<td>Sweating asymmetry</td>
</tr>
<tr>
<td>Asymmetric edema</td>
</tr>
<tr>
<td>Trophic changes</td>
</tr>
<tr>
<td>Motor changes</td>
</tr>
<tr>
<td><strong>Signs observed on examination</strong></td>
</tr>
<tr>
<td>Hyperalgesia to pinprick</td>
</tr>
<tr>
<td>Allodynia</td>
</tr>
<tr>
<td>Temperature asymmetry</td>
</tr>
<tr>
<td>Skin color asymmetry</td>
</tr>
<tr>
<td>Sweating asymmetry</td>
</tr>
<tr>
<td>Asymmetric edema</td>
</tr>
<tr>
<td>Trophic changes</td>
</tr>
<tr>
<td>Motor changes</td>
</tr>
</tbody>
</table>

Adapted from reference 8.

Participating in physical and occupational therapy can be facilitated by explaining that CRPS-associated pain symptoms does not indicate tissue damage in the hyperalgesic area but arises from an unknown cause. It is important to stress the importance of working to regain use of the affected limb while also recognizing the difficulty of doing so due to ongoing pain. Physical and occupational therapy is considered to be the first line treatment for CRPS. Physical therapy can be performed twice daily at home for patients in all stages of CRPS. This should ideally begin before limitation of movement occurs in order to maintain the patient’s current range of motion and prevent any contractures from arising. Resting splints can be utilized to prevent progressive joint contractures. General therapeutic methods of physical and occupational therapy include general exercise/strengthening, gait retraining, transcutaneous electrical nerve stimulation, hydrotherapy, edema control strategies, and relaxation techniques.

Psychosocial and behavioral therapy can be used in CRPS patients. A clinical psychologist should be consulted if a patient has CRPS longer than 2 months duration at presentation, insufficient response to a treatment, or if a patient has a suspected comorbid psychological or psychiatric disorder. The goals of psychosocial and behavior management include identifying any psychological factors contributing to a patient’s pain and disability, treating anxiety/depression, considering needs to family and caregivers, identifying and addressing internal factors (counter-productive behavior patterns) or external influences (family dynamic), and providing a problem-
solving and goal-oriented approach to reduce barriers and promote healthy functioning. A skilled hypnotherapist can also be helpful for patients with heightened arousal and in whom exercise is otherwise impossible.

In terms of the pharmacologic approach, the goals of pain management are to allow active participation in a rehabilitation program and to restore both motion and strength of the affected extremity. The key to success is to use whatever works to reduce pain so patients can tolerate physical therapy. For patients with early CRPS, this approach encompasses one or more of the following agents: an NSAID such as ibuprofen or naproxen, neuropathic pain medications such as gabapentin or pregabalin, a course of bisphosphonate treatments, and/or topical lidocaine or capsaicin cream. The total duration of pharmacotherapy is individualized. Pharmacotherapy is generally continued as long as patients have a significant symptom burden, do not have intolerable side effects and appear to be deriving a symptomatic benefit.

In patients with refractory pain, there are a few interventional options. Interventional procedures for the treatment of pain related to CRPS include trigger and tender point injections, regional sympathetic nerve blocks, spinal stimulation, epidural clonidine, and chemical/mechanical sympathectomy. Patients who are receiving noninvasive therapy and are not improving are candidates for increasingly invasive treatment, allowing 2 weeks for improvement before proceeding to the next treatment (7). Amputation in patients with CRPS may be indicated due to chronic/severe pain, extremity dysfunction, gangrene, infections, or ulcers. A majority of patients will report a reduction in pain along with improvements in mobility and sleep following amputation of the affected limb. Many patients will still exhibit pain and symptom recurrence in the residual extremity (8).

**FUTURE TREATMENT AND MANAGEMENT**

The scope of finding new or existing agents to target the different disease mechanisms of CRPS will continue to grow, as our understanding of CRPS pathophysiology develops.

There are several emerging treatments for the future of CRPS patients. Certain cancer drugs possess anti-inflammatory and immunomodulatory effects that have shown promise in alleviating CRPS since many of these patients display systemic elevation of proinflammatory cytokines. Hyperbaric oxygen therapy has also been thought to be useful due to its antinociceptive effect. Botulinum toxin A can provide pain relief in neuropathic pain. Although there has yet to be a currently successful or gold standard treatment for patients with CRPS, years of research has provided the field of medicine many valuable lessons. Given the complex nature of this syndrome, the future of CRPS treatment may lie in combination therapy along with a multidisciplinary approach (8).

**REFERENCES**

Comparison of Tests

<table>
<thead>
<tr>
<th></th>
<th>Culture</th>
<th>Histopathology</th>
<th>KOH (fungal)</th>
<th>Web Space DNA Test</th>
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<tbody>
<tr>
<td>Turnaround Time</td>
<td>2-28 days</td>
<td>2-3 days</td>
<td>Same day</td>
<td>1-2 days</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>50-75%</td>
<td>85-90%</td>
<td>73-91%</td>
<td>92-100%</td>
</tr>
<tr>
<td>Specificity</td>
<td>100%</td>
<td>72%</td>
<td>42-91%</td>
<td>97-100%</td>
</tr>
</tbody>
</table>

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- Tinea pedis
- Candida intertrigo
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3 Internal validation study compared to NYS Dermatophyte, NYS Candida, and Sanger DNA sequencing.
Pediatric Perioperative Pain Management

*Caitlyn Lee, DPM*

*Chandler Ligas, DPM*

**INTRODUCTION**

Each physician has their preferred postoperative pain management regimen for their adult patients, however, managing pediatric perioperative pain is not as simple as lowering the adult dosage. Historically, there has been a misconception among health professionals that children experience less severe pain than adults, which has led to their undertreatment of postoperative pain. Therefore, it is paramount to take a multimodal approach to perioperative pain management including regional anesthesia, appropriate pain assessment, opioid and nonopioid analgesics, and nonpharmacologic methods, (Figure 1). Using these strategies, the goal is to achieve proactive symptom relief that will allow them to return to daily activities and rehabilitation while minimizing adverse effects such as respiratory depression. We will discuss multiple options for pediatric perioperative pain management and dosage guidelines for analgesics commonly used in podiatric surgery.

![Figure 1. Pain management strategy.](image-url)
PAIN ASSESSMENT

Behavioral and physiological signs, in conjunction with a child’s self-report of pain are necessary for accurate pain assessment as well as using an age and context appropriate pain assessment tool. Due to potential under-evaluation it is important to give the analgesic on a scheduled time frame in order to stay ahead of the pain and diminish the child’s ability to feel severe pain. It has been made increasingly clear that early life pain and surgery can produce long-term changes in sensory processing and future pain responses. At all ages, effective analgesic management needs to extend beyond the immediate perioperative period and should also include pain management at home. With reports that despite the fact that most children receive postoperative analgesic, they still report moderate to severe levels of pain, therefore an aggressive and proactive pain management plan is necessary to overcome the historic undertreatment of pain. This plan should include a multi-modal approach including regional anesthesia, nonpharmacologic interventions, and pharmacologic interventions.

REGIONAL ANESTHESIA

Up to 75% of pediatric patients who underwent outpatient procedures reported inadequate analgesia. Therefore, regional anesthesia becomes paramount in immediate postoperative pain management. If left untreated, pain can cause physiological, psychological, and financial tolls. Regional blocks are an attractive option because they maintain normal ventilatory control during surgery, furthermore they are safe and effective. One main concern for regional anesthesia is its safety in the pediatric population, however, this concern has faded with the results of multiple large-scale studies showing no instances of total paralysis or other major complications. Polaner et al found no instances of death or sequelae over 3-months from complications based on over 90,000 peripheral nerve blocks recorded in the Pediatric Regional Anesthesia Network (PRAN) database (1). The PRAN database is the first internet-based continuous audit of practice trends and complication rates in children. From the information derived from this database, Taenzner et al went on to conclude that the placement of blocks under general anesthesia is as safe as placement while children are sedated or awake (1).

Caudal Neuraxial Blockade

The caudal neuraxial blockade is the gold standard for regional anesthesia in children due to its ease of mastery and reliability for subumbilical surgery. The inherent concerns for this type of blockade are the incidence of increased intracranial pressure. Keplinger et al found that caudal blocks can be performed safely in larger children (30-50 kg) with the stipulation that the local anesthetic must have a suboptimal plasma concentration (2).

Continuous Peripheral Nerve Blocks (CPNB)

CPNB are used for patients who are expected to undergo an inordinate amount of postoperative pain, have painful physical therapy sessions or have complex regional pain syndrome. CPNBs are performed by inserting a perineural catheter, which significantly extends the block duration compared to peripheral nerve block alone. Until recently, CPNBs have been avoided in children due to the risk of neuraxial damage, however, the feasibility has been tested and found that children experienced lower pain scores and required less opioids in the recovery setting (3). With the utilization of ultrasonography the reliability of CPNBs has become mainstream, however, the complication rates prove to be their downfall. Therefore, CPNBs should not be the only line of attack on pediatric pain management.

Proximal Sciatic Nerve Block

The landmarks for locating the sciatic nerve extend from the apex of the popliteal triangle and are joined at the midpoint of the line joining the greater trochanter and the ischial tuberosity. This is divided into 3 equal parts. The junction of the proximal two-thirds with the distal one-third of this line represents the middle of the biceps femoris muscle. A Touhy needle is introduced at the point perpendicular to the thigh with the bevel pointing proximally. This block can also be performed with the patient supine after the front of the thigh is painted and draped. The block is performed 1 cm lateral and below the femoral pulsations felt below the inguinal ligament. Usually this type of blockade is performed in children under the age of 5. Lakshmi et al studied physiological response during surgery by measuring heart rate, response to tourniquet pressure and incision during surgery. They found that less than 2% of subjects out of 131 had an elevated heart rate, no patients responded to the tourniquet and about 11% of children responded to a medial ankle incision. They concluded that this type of nerve block is efficacious and safe to administer in children (3).

Popliteal Fossa Nerve Block

The block is placed approximately 1-2 cm superior from where the sciatic nerve splits into the common peroneal nerve and the tibial nerve. A needle is placed in the same plane as the transducer of an ultrasound, the needle should enter the skin at a 45 to 60 degree angle with the skin surface (4). The sciatic nerve can be located just medial to the biceps femoris fascial sheath and local anesthetic can be infiltrated in this area. The biceps femoris tendon is an excellent anatomic landmark for the infiltration of regional anesthesia for the sciatic nerve. It has been published that the use of popliteal nerve blocks can decrease the amount of
narcotic administration, decrease postoperative nausea, and decrease the length of hospital stays for pain management following foot and ankle surgeries.

**PHARMACOLOGIC MANAGEMENT**

Pharmacologic management has historically been the mainstay of postoperative pain management and can be in the form of non-opioid analgesics, opioid analgesics and anti-inflammatory drugs. Typically used analgesics for the pediatric postoperative patient are listed in Table 1.

**Non-Opioid Analgesics**

Acetaminophen is an antipyretic medication with a weak analgesic effect by blocking central prostaglandin synthesis, reducing substance P-induced hyperalgesia, and modulating the production of hyperalgesic nitric oxide in the spinal cord. This medication can be administered safely with a dose of 15 mg/kg for children every 4-6 hours without exceeding a maximum dose of 100 mg/kg for children; 75 mg/kg for infants; and 60 mg/kg for term and preterm neonates.

Acetaminophen has been used successfully in children in the perioperative timeframe and may be just as effective than opioids. Swanson et al retrospectively evaluated 217 children with a mean age of 5.37 years who underwent supracondylar fracture surgery who were either given acetaminophen or narcotics. They found no significant difference between pain scores of the 2 cohorts, and noted narcotics were associated with more side effects than acetaminophen. They concluded that acetaminophen should exclusively be used for pain control after supracondylar fracture surgery in children (6). It has yet to be tested whether this study’s findings can be extrapolated to podiatric surgery; however the results show that narcotics are no better than acetaminophen alone in managing surgical pain in the pediatric population.

Nonsteroidal anti-inflammatory drugs (NSAIDs) have

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dosing</th>
<th>Major Formulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaminophen</td>
<td>10-15 mg/kg/dose every 4-6 hours as needed (max = 75 mg/kg/day up to 4 g in 24 hrs)</td>
<td>Chewable Tablet (80 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oral Disintegrating Tablet (80 mg, 160 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solution (160 mg/mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suppository (80 mg, 120 mg, 325 mg, 650 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tablet (325 mg, 500 mg)</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>4-10 mg/kg/dose every 6-8 hrs as needed (max is 400 mg/dose and 40 mg/kg/day up to 1600 mg/day)</td>
<td>Capsule (200 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chewable Tablet (100 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suspension (100 mg/5 mL)</td>
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<tr>
<td></td>
<td></td>
<td>Tablet (100 mg, 200 mg, 400 mg)</td>
</tr>
<tr>
<td>Codeine</td>
<td>0.5 – 1.0 mg/kg/dose every 4-6 hours as needed (Max = 60 mg/dose)</td>
<td>Codeine Sulfate Tab (15 mg, 30 mg, 60 mg)</td>
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<td></td>
<td></td>
<td>Codeine/Acetaminophen Tab (15 mg/300 mg, 30 mg/300 mg, 60 mg/300mg)</td>
</tr>
<tr>
<td>Hydrocodone/Acetaminophen</td>
<td>&lt;50 kg: 0.1-0.2 mg/kg/dose every 4-6 hours as needed</td>
<td>Elixir (10-300 mg/15 mL)</td>
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<tr>
<td></td>
<td>&gt;50 kg: 5-10 mg every 4-6 hours as needed</td>
<td>Solution (7.5-325 mg/15 mL)</td>
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<tr>
<td></td>
<td></td>
<td>Tablet (5-325 mg, 7.5-325 mg, 10-325 mg)</td>
</tr>
<tr>
<td>Oxycodone</td>
<td>&lt;50 kg: 0.1-0.2 mg/kg/dose every 4-6 hours as needed (Max = 5-10 mg/dose)</td>
<td>Capsule (5 mg)</td>
</tr>
<tr>
<td></td>
<td>&gt;50 kg: 5-10 mg every 4-6 hours as needed</td>
<td>Solution (5 mg/5 mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tablet (5 mg, 10 mg)</td>
</tr>
<tr>
<td>Tramadol</td>
<td>1-2 mg/kg/dose every 4-6 hours as needed (Max = 100 mg/dose)</td>
<td>Tablet (50 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suspension (10 mg/mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tramadol w/ Acetaminophen Tab: 37.5 mg/325 mg)</td>
</tr>
</tbody>
</table>
been widely used to reduce pediatric postoperative pain. NSAIDs work by inhibiting cyclooxygenase, thus reducing the production of prostaglandins at the site of tissue injury and diminishing the inflammatory cascade. Specifically speaking the COX-1 enzyme is present in the brain, gastrointestinal tract, kidneys, and platelets; it preserves the gastric mucosal integrity, results in platelet aggregation, and helps with renal perfusion. If this enzyme is blocked it may cause injury to the gastric mucosa, a decrease in renal perfusion, and result in platelet dysfunction. It has been postulated that selective COX-2 inhibitors have less of an effect on the gastric mucosal function and fewer effects on platelet aggregation and would be a better option in the pediatric population. Diclofenac is therefore an excellent option in the pediatric patient population with a pediatric dose of 1 mg/kg every 8 hours orally, rectally, or intravenously. Ketorolac is the only intravenous formulation of an NSAID in the US and can be used in the pediatric population at a dosage of 0.5 mg/kg. The practitioner should be aware that the onset of action takes 20-30 minutes. Caution should be used when prescribing Ketorolac with any boney procedure as decreased bone repair is a side effect.

**Opioids**

Opioids are the typical analgesic choice for moderate to severe postoperative pain. Opioid tolerance and physiologic dependence are unusual in short-term postoperative use in opioid naive patients, therefore, can be safely administered to pediatric patients under the correct dosing and management. Dose can vary greatly among individuals due to the inherent nature of individuals having a different pain perceptions; however, can be simplified in the pediatric population by utilizing the current standards for weight-based dosing if the child weighs less than 50 kg. If a child weighs more than 50 kg then the individual is given pain medications that are dosed appropriately to that of the adult formulation. The most common opioids used in pediatric pediatric surgery are hydrocodone, oxycodone, and acetaminophen with codeine.

Codeine, oxycodone, and hydrocodone are used when parenteral opioids need to be converted to enteral ones. These have a 60% bioavailability after oral ingestion and the analgesic effects occur 20 minutes after ingestion and reach a maximum effect by 60–120 minutes. Only 10% of the codeine is metabolized into morphine, which is responsible for the analgesic effect of codeine. The usual dosage is 0.5-1 mg/kg of codeine. However, codeine has fallen out of favor in the pediatric population due to some patients being ultra-convertors of codeine to its active metabolite, producing side effects and increased risk of respiratory depression.

Oxycodone is used for moderate to severe pain and is used in pediatric patients with dosages starting at 0.2 mg/kg every 3-4 hours if the patient weighs less than 50 kg and up to 10 mg every 4-6 hours in pediatric patients that weigh more than 50 kg. Oxycodone becomes an excellent option in the pediatric patient when osteotomies have been performed and it has been shown to have comparable analgesia to morphine (2).

Hydrocodone is another opioid used for moderate to severe pain in pediatric patients with dosages starting at 0.2 mg/kg every 3-4 hours for pediatric patients weighing less than 50 kg, and 10 mg every 4-6 hours in pediatric patients weighing more than 50 kg. There have been multiple studies reporting that hydrocodone and oxycodone provide similar analgesic effects, however, hydrocodone can result in an increase incidence in constipation. This should be taken into consideration when the pediatric patient has any gastrointestinal conditions.

Tramadol is a synthetic analog of codeine with analgesic effects of medium potency. It has 2 complementary mechanisms of action, one of which is a weak affinity for the opioid receptors and those inhibiting pain. The other is inhibition of the reuptake of neurotransmitters norepinephrine and serotonin. Tramadol in pediatric dose has a dose ranging effect, essentially if you increase the dose of tramadol you will have less need for rescue analgesia.

**NONPHARMACOLOGIC**

There have been reports of particular awareness to pediatric pain management due to the developmental differences in their experiences and expression of pain. The emotional component of pain is particularly strong in infants and children because in their short life they may not have experienced such a strong pain reaction before. Absence of their parents, security objects, and familiar surroundings may cause as much distress as the surgical incision. It is important to allow the child their comfort objects in the perioperative setting. Additionally, nonpharmacologic techniques for diminishing pain response such as elevation of the legs following foot and ankle surgery should be an important piece of patient education following surgery.

Observational research shows significant increases in opioid prescriptions for pediatric populations from 2001 to 2010. Adolescents who misuse opioid pain medication often misuse medications from their own previous prescriptions, with an estimated 20% of adolescents with currently prescribed opioid medications reporting using them intentionally to get high or increase the effects of alcohol or other drugs. Misuse of opioid pain medications in adolescence strongly predicts later onset of heroin use. Therefore, with the multimodal approach to pediatric pain management, opioids should be used with caution.
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Pain management during the perioperative phase should be multimodal to help decrease the amount of opioids that we are prescribing. These modalities are divided into pharmacologic and non-pharmacologic techniques. Popliteal blocks have been a safe, effective, and useful adjunctive to minimize postoperative opioid consumption (1). This update will review the anatomy of the popliteal fossa, review the optimal placement of local anesthetic and utilization of ultrasound versus nerve stimulation when performing a popliteal block, and describe how opioid consumption is reduced perioperatively with popliteal blocks.

ANATOMY OF THE POPLITEAL FOSSA

An understanding of the anatomy and spatial relationships of the structures of the popliteal fossa are essential for an effective and safe block. The popliteal fossa is a rhomboid-shaped depression posterior to the knee joint defined by muscular borders (2). Its superior borders consist of the biceps femoris laterally and the semi-membranosus and semi-tendinosus medially. Inferior borders include the medial and lateral heads of the gastrocnemius. The major neurovascular structures that supply the lower leg and foot are found within these boundaries. The deepest of the neurovascular structures is the popliteal artery, which is located medially along the femur. The popliteal vein is relatively superficial and lateral to this with the popliteal nerve being the most superficial and lateral of the structures. An understanding of this multiplanar relationship is essential when attempting to target the nerve during the popliteal block. Although they take distinct paths distally, the common peroneal nerve and tibial nerve share a common epineural sheath (3-5) (Figure 1 and Figure 2).

OPTIMAL PLACEMENT OF LOCAL ANESTHETIC

Many studies have investigated the optimal anatomic location for local anesthesia placement around the nerve itself when performing a popliteal block. With the increased use of ultrasound, the anatomy of the connective tissue layers enveloping the nerves has been the subject of research over the past decade. Several human cadaver studies have investigated the anatomy of the sciatic nerve by both dissection and histologic methods (3,5). These studies have...
shown that as the tibial nerve and common peroneal nerve course down the thigh, they each have their own epineurium and are also surrounded by an additional connective tissue layer termed the “paraneural sheath, intra-epineural, subepineural” (5). This sheath has been described as virtual space between the perineurium and epineurium, which acts as a physical barrier by trapping local anesthesia and increasing exposure to local anesthetic molecules. Researchers have suggested that injection through this paraneural sheath results in extensive, contained spread of local anesthetic making it an ideal location for anesthetic deposition (6). Perlas et al (5) performed a prospective randomized trial on 89 patients undergoing an ultrasound-guided popliteal block for foot and ankle surgery. Patients were randomized to receive a single injection of local anesthesia at the site of bifurcation through a common paraneural sheath (group 1) or 2 separate circumferential injections of the tibial and common peroneal nerves (group 2). Patients in group 1 had a 30% shorter onset time of both sensory and motor block (5). Some authors argue that identification of these separate fascial layers is beyond the scope of clinical ultrasound machines.

Karmakar and colleagues (7) demonstrated the “paraneural sheath” and its fascial compartments using high-definition ultrasound. Their results aligned with the cumulative evidence that suggests the benefit of paraneural sheath injection, however, because of the complex fascial compartments, they questioned to what extent this injection can be safely and reliably performed with lower resolution ultrasound imaging. Missair and colleagues (8) also used 3-D ultrasound to compare the effects of injection outside the paraneural sheath to within the sheath. They found that injection within the sheath results in typical laminar pattern spread of local anesthesia with greater volume coming in direct contact with the nerve, also a longer-acting block. However, patients receiving a block within the paraneural sheath reported a higher incidence of transient paresthesia (9). While evidence is that a paraneural sheath block is desirable, more research is needed to develop a safe, simple, and objective method for performing this method of popliteal nerve block.

**ULTRASOUND VERSUS NERVE STIMULATOR**

The use of ultrasound guided peripheral nerve blocks has increased dramatically over the past decade (1). Many surgeons and anesthesiologists rely on anatomic landmarks and electrical nerve stimulation in order to place the needle in close proximity to the target nerve, however, the probe may be intra-vascular, intra-neural, or on the other side of the fascia (10). Moreover, in some patients it is not possible to elicit muscle twitches even with high currents. Ultrasound offers a real-time visualization of the anatomy and has been shown to decrease necessary local anesthetic dose, onset time, increased block quality, and patient satisfaction (1) (Figure 3 and Figure 4).

In a prospective randomized study by Geffen et al (10) of 40 patients receiving sciatic nerve blocks, they found they were able to use approximately 50% less local anesthetic to effectively block the sciatic nerve. Ultrasound also has the benefit of visualizing where the sciatic nerve bifurcates into its tibial and common peroneal nerve components. Patients with a block distal to the bifurcation exhibit faster time to complete the block than a proximal block (1). However, the research has shown some synergistic effect of ultrasound and neurostimulation used together. Dufour et al (11) showed in his prospective randomized study of 60 patients that there was a 65% success of sensorimotor block with both techniques and only 16% when using neurostimulation alone at 30 minutes.
REDUCTION IN PERIOPERATIVE OPIOID USE

According to the National Institute on Drug Abuse (12), everyday more than 130 people in the US die from opioid overdose. The total economic burden of prescription opioid misuse alone in the US is 78.5 billion a year according to the Centers for Disease Control and Prevention (12). These alarming statistics demonstrate the fact that opioid abuse is a national epidemic and the spotlight for a solution is on physicians. As podiatrists, we should be considering multimodal approaches to help minimize the amount of opioids our surgical patients take postoperatively. Fortunately, medical advances and anesthesia techniques continue to evolve and may help further reduce the need for opioids.

Popliteal blocks have been shown to reduce the amount of perioperative opioid consumption. This in turn has the beneficial effect of limiting opioid related side-effects including nausea and vomiting, constipation, respiratory depression, and abuse of opioids. A meta-analysis performed by Richman (13) investigated the ability of popliteal blocks to reduce patient opioid consumption. His team reviewed 19 articles with a total of 603 patients and found that perineural analgesia provided better postoperative analgesia compared to opioids at 24, 48, and 72 hours. White (14) performed a randomized, double-blind, placebo-controlled study, with a continuous popliteal sciatic nerve block with either 0.25% bupivacaine or saline (control group) in patients undergoing foot or ankle surgery. Patients in the bupivacaine group required 70% less PCA morphine than those in the control group. Also, 40% of patients in the bupivacaine group versus 0% in the control group were able to be discharged home on the day of surgery.

In conclusion, popliteal blocks provide a safe and effective form of analgesia during the perioperative course of foot and ankle surgery. Research over the past decade has focused on the most efficacious techniques to perform popliteal block based on the anatomy of the connective tissue surrounding the nerves themselves. It has been shown that ultrasound guidance has many benefits and will continue to be useful as technology evolves and 3-D ultrasound becomes more common in the clinical setting. Lastly, popliteal blocks have been shown to help reduce the amount of opioids consumed and can help reduce the length of hospital stay postoperatively.

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INTRODUCTION

Fall risk prevention continues to be an important topic of discussion because falls are common and costly, especially in the American population ages 65 years and older (1). According to the Centers for Disease Control and Prevention, it is estimated that 30 million older American adults fall each year resulting in approximately 30,000 deaths secondary to their injuries and co-morbidities. One out of every 5 falls result in serious injury, most commonly head injuries and/or hip fractures. With current high medical costs for hospitalization and associated procedures, it is estimated that falls in America in 2015 alone cost >$50 billion dollars.

There are a variety of intrinsic and extrinsic factors that increase an older adult’s risk of falling. Intrinsic factors include but are not limited to associated medical conditions such as diabetic polyneuropathy, hypertension, cardiac history, psychiatric disorders, neurologic conditions, impaired vision and or hearing, and age-related changes in neuromuscular function, gait, and postural reflexes (2). Extrinsic factors include but are not limited to unsafe home/environmental hazards such as uneven inclines or stairs, improper use of assistive devices such as a walker or wheelchair, and various medications that can cause side effects of imbalance, dizziness, and/or fatigue. Regarding the field of podiatry, various foot and ankle conditions increase the fall risk of elderly adults such as reduced ankle flexibility, unstable lateral column with associated pronated/valgus rearfoot, supinated/varus rearfoot, decreased tactile sensitivity, decreased lower extremity strength, and foot and ankle pain (3).

Annually, it is recommended that elderly adults ages 65 years or older or at high risk for falls be assessed and screened by their primary care doctor to reduce their risk of falls (4). Podiatrists serve as another key provider in reducing fall risk by performing detailed lower extremity musculoskeletal examinations and prescribing protective bracing such as ankle foot orthoses and/or assisted devices when indicated. Ankle foot orthoses (AFOs) have been debated in literature to their utility in reducing fall risk in the high risk population. AFOs are designed with the goals to support ankle joint and foot stabilization, decrease postural sway, decrease foot pain, increase proprioception, and potentially increase confidence in gait. Recent studies comparing AFOs to shoes alone or barefoot suggest that AFOs reduce fall risk by reducing postural sway quantitatively measured with an F-scan device (Tekscan) (5,6).

In our study, we seek to confirm if prescribing AFOs in a high fall-risk population results in reduced postural sway measured through the F-scan device (7). Secondarily, we will compare the number of falls before and after AFO application and the compliance of wear time of the AFOs. We hypothesize that AFOs will reduce postural sway and significantly reduce the number of falls with increased compliance in daily wear of the AFOs.

MATERIALS AND METHODS

The Moore Balance Brace (MBB) was chosen as the AFO similar to previous studies (5,6). The MBB is an AFO with a fixed ankle hinge that the authors believe offers more rigid support in the high fall risk population than a free ankle hinged AFO such as the Richie Brace although this is debated and not thoroughly studied in current literature. We decided to modify the brace to increase compliance of daily AFO wear that we believe would correlate with a decreased number of falls. The brace was modified in 3 ways: the plantar foot arch support was cut on the edges
and smoothed to better fit in shoes, the medial and lateral solid ankle hinges were beveled to also better fit in shoes, the interior of the brace was cushioned with P-cell material for extra support and comfort (Figure 1) (8,9).

Our study was a prospective, non-blinded study involving 43 patients that met our inclusion criteria in a private practice clinic in Dallas, Texas followed for a total of 1 year. Inclusion criteria were those that were deemed high fall risk if scoring ≥4 or answering yes to the associated key questions on the Medicare fall risk assessment questionnaire. Exclusion criteria were patients with previous spine surgery, foot/ankle surgery, or a primary neurologic deficit.

Primary outcome measures were pre- and post-postural sway data obtained from the F-scan after application of the Modified Moore Balance AFO on day 1 of wear. Postural sway data were collected in the anterior and posterior sway in the sagittal plane and medial and lateral sway in the coronal plane. Secondary outcomes measured included the average time (0-4 hours, 4-8 hour, 8+ hours) patients wore their AFOs and the number of pre versus post falls and lower extremity injuries after wearing AFOs over a time period of 1 year.

Statistical analysis performed included paired t-tests comparing pre- and post-treatment with AFO, with P < 0.5 considered statistically significant. Normal distribution was assumed given an adequate n value of 43 patients.

RESULTS

The results are shown in Tables 1-5.

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>P value &lt; 0.1678. Decrease in anterior-posterior postural sway by 0.21.</th>
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<th>P value &lt; 0.6749. Increase in medial to lateral postural sway by 0.21.</th>
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<td>SD</td>
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<th>Table 3.</th>
<th>P value &lt; 0.001, statistically significant with average 1.72 falls pre AFO application and 0 falls post AFO 1 year follow-up.</th>
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<tr>
<td>Group</td>
<td>Pre AFO Fall #</td>
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<td>SD</td>
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<td>SEM</td>
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<th>Table 4.</th>
<th>P value &lt; 0.001, statistically significant with average 1.35 injuries to lower extremities pre AFO application and 0 falls post AFO 1 year follow-up.</th>
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<tr>
<td>Group</td>
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<th>Table 5.</th>
<th>Total n = 43 with majority of patients showing increased compliance daily wear with Modified Moore Balance brace.</th>
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<tr>
<td>Compliance Daily Wear</td>
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<tr>
<td>N = 5 (12%) &lt;4 hrs</td>
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<tr>
<td>N = 7 (16%) 4-8 hrs</td>
<td></td>
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<tr>
<td>N = 31 (72%) 8+ hrs</td>
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**DISCUSSION**

AFOs have been suggested to reduce fall risk by reducing postural sway (5,6). In our study, although we did not find a statistical difference in initial reduction of postural sway after application of AFOs, all patients in our study had no falls or injuries one year from dispensing AFOs (Table 3 and 4). There was a slight decrease in postural sway of 0.21 (Table 1) in the anterior-posterior direction, while a not surprising slight increase in left to right postural sway of 0.21 (Table 2). We believe the slight increase in the left to right postural sway was due to the modification of the brace in loss of medial and lateral ankle support at the cost of comfort and fitting better in shoe gear that patients would tolerate. The slight decrease in anterior to posterior sway can be attributed to the increased surface area contact in the posterior leg that offers increased proprioception and balance.

With modification of the Moore Balance brace, we believe this led to increased compliance with 31 out of our 43 subjects having 8+ hours of wear time daily. Although no statistical analyses were able to correlate increased daily AFO wear time with decrease in falls, we believe this correlation is a significant factor in aiding reduce fall risk. From the authors’ own clinical practice and other practices, there is a general complaint of AFOs not fitting well into shoes that unfortunately leads patients to then wear the supportive bracing less often than optimal to help reduce fall risk. We believe the key to reducing fall risk is finding a balance between AFO modifications for patient comfort while not completely sacrificing the AFOs important qualities of foot and ankle postural and biomechanical support.

While not performed in this study, a limitation of the F-scan is for the study of peak plantar pressures during active running as suggested by Kong et al (10), which showed healthy runners having increased stride frequency and decreased stride length when wearing the F-scan device. Another potential limitation is noted in the pediatric population that those weighing less than 100 pounds did not show accurate F-scan readings according to D’Amico et al (11). The F-scan otherwise in normal gait and walking has shown to be effective in measuring postural sway and peak plantar pressures (5-9,12).

A limitation of our study is that to our knowledge this is the first study modifying the MBB to increase patient compliance and therefore no direct comparative studies can be made. Although we were able to obtain F-scan results on day 1 pre versus post AFO wear, we would have ideally wanted a 6 month and 1 year F-scan result to see any differences in postural sway compared to baseline but this was not achieved given patients were unable to be followed up. Another limitation is that for the number of falls 1 year after wearing the AFO, this was performed by questionnaire in person or by phone and not completely reliable versus direct monitoring of AFO compliance wear. Further randomized control studies are required to validate the use of specific AFOs on the market in proving their effectiveness in reducing fall risk and postural sway.

In conclusion, we believe that our study adds to current literature in suggesting that AFOs have a role in reducing fall risk in the high risk population when indicated. Podiatrists play a key role in correctly prescribing and/or fitting AFOs in patients that are at high risk secondary to unstable lower extremity mechanics and pathologies.

**REFERENCES**

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Elongation of the Proximal Phalanx With External Fixation After Correction of Bilateral Fourth Brachymetatarsia

Christopher Galli, DPM
Brittany Rice, DPM
Donald Green, DPM

INTRODUCTION
Brachymetatarsia is a disorder in which there is early closure of one or more of the metatarsal growth plates secondary to acquired or congenital conditions. Acquired etiologies include idiopathic, trauma involving metatarsal physeal fractures, iatrogenic, infection, inflammation secondary to juvenile rheumatoid arthritis, or polio (1). More commonly, brachymetatarsia is caused by congenital deformities such as family history, brachiodactyly, Down’s Syndrome, and pseudohypoparathyroidism (2). These congenital deformities tend to present with bilateral shortening. On an anteroposterior (AP) radiographic view, this condition can be diagnosed when 1 metatarsal ends 5 mm or more proximal to the parabolic arc (2). Females have a higher prevalence of brachymetatarsia than males 10-25:1.

Patients often present reporting the affected foot is cosmetically displeasing, metatarsalgia pain, in overlaping cock-up toe, or plantar callosities. However, patients most commonly present with skin irritation and pain with shoe wear (1,3). Often these patients are interested in surgical correction. The goal of brachymetatarsia surgery is to restore normal weight-bearing alignment and a functional metatarsal parabola. However, the toe length of these patients must be taken into consideration as well (4).

Many techniques for surgical correction have been reported in the literature, which include slide osteotomy transpositional osteotomy, scarf osteotomy, and syndactylization (5). Recently the 2 most utilized techniques include elongation of the metatarsal utilizing bone graft in a single-stage technique, or with distraction osteogenesis with use of external fixators. Benefits to single-stage lengthening procedures include shorter time to bony union, and better patient compliance. However, disadvantages include the inability to perform if length needed is greater than 10 mm, donor site morbidity, and neurovascular impairment due to tension on soft tissues (2,3,5-11).

Callus distraction utilizing external fixation is performed by placing a fixator on half-pins that are on either side of the proximal metaphysis diaphysis osteotomy and then distracting the bone to promote growth. This technique does not require bone grafting, early weightbearing can be performed, and gradual lengthening can achieve greater length gain while allowing the soft tissues to adapt (10). Postoperative AOFAS scores reported in studies by Kim et al, Oh et al, and Lee et al were 80%, 89%, and 95% good or excellent results, respectively, for fourth brachymetatarsia utilizing distraction osteogenesis (4,9,11). The disadvantages to this technique include metatarsophangeal joint (MPJ) stiffness, a short proximal phalanx affecting the overall toe length, and greater time to bony union (3,4,11).

Lamm (7) published a case where percutaneous external fixation technique for distraction osteogenesis was utilized to limit devascularization and preserve peristemeum. At the same time, he tried to prevent the most common complication of MPJ stiffness by placing an additional half-pin with clamp in the proximal phalanx to distract the MPJ at the same time as the metatarsal (7).

Many surgical techniques have been described to treat brachymetatarsia, however, there are few recommendations in treatment of the shortened phalanx, which can affect the toe-tip parabola. We present a case where lengthening of a shortened proximal phalanx via external fixation was performed after correction of bilateral fourth brachymetatarsia.

CASE REPORT
A 32-year-old woman presented with bilateral foot pain secondary to bilateral fourth metatarsal brachymetatarsia diagnosed by radiographic imaging and clinical examination. Despite modifications in shoe gear, she continued to have pain with ambulation. The patient refused to wear sandals as this was a cosmetic “psychological” deformity. The patient was interested in surgery.

Physical examination revealed bilateral shortened and elevated fourth toes (Figure 1) with painful range of motion (ROM) of the fourth MPJ. There was no tenderness to palpation of the fourth metatarsal head bilaterally, however, the patient did have generalized metatarsalgia to the forefoot. In addition, the forefoot was everted relative to the rearfoot in neutral calcaneal stance position, bilaterally. There was no ankle joint ROM limitation with the knee extended, bilaterally. There was adequate pain-free ROM of the ankle, subtalar, midtarsal joint, bilaterally. In gait, the patient pronated throughout without resupination.
The patient underwent bilateral open external fixation callus distraction technique utilizing half-pin and clamp in the proximal phalanx as described by Lamm (7) (Figure 2 and Figure 3). Postoperatively, there was a latent period of approximately 7 days with 1 mm lengthening by 0.25 mm turns 4 times per day. On the left side, the patient distracted the metatarsal and joint for 8 weeks and the external fixator remained on the foot for an additional 13 weeks. The patient was allowed to be immediate weightbearing in a postoperative shoe where the fourth metatarsal was offloaded utilizing cork, bilaterally (Figure 4).

At 3.5 weeks postoperatively, the patient presented to the clinic where postoperative radiographs were taken. The left foot images revealed adequate spacing between the distal portion of the fourth metatarsal and the proximal portion, as well as between the proximal phalanx and the metatarsal head. On the right foot, there was distraction significant at the MPJ, however, the metatarsal osteotomy had consolidated. This required an additional osteotomy to allow for distraction. The patient distracted the external fixator on the left foot for approximately 5.5 weeks and it remained on the extremity for 11.5 weeks. The osteotomies and lengthening of bilateral fourth metatarsal went on to heal successfully.

At 11 months postoperatively, the patient returned to the clinic. Physical examination revealed residual fourth toe
stiffness, bilaterally. The toes did not purchase the ground. The left fourth toe was slightly dorsiflexed and adducted. There was pain when the toe was placed in an abduced and plantarflexed position on the MPJ. In addition, there was tenderness to palpation sub fourth metatarsal head, distal fourth toe, and fourth distal interphalangeal joint (DIPJ). Radiographs showed a long fourth metatarsal, which violated the metatarsal parabola with a fourth proximal phalanx that was short. The fourth toe proximal phalanx measured approximately 15.43 mm, whereas the fifth toe proximal phalanx measured 19.54 mm and the fourth measured 21.36 mm (Figure 5 and 6). However, due to the overcompensation of the metatarsal length, the fourth toe was clinically of appropriate length.

The right fourth toe was slightly dorsiflexed and semi-reducible (Figure 7). There was tenderness with palpation to the plantar aspect of the fourth metatarsal head. On the right foot, the AP radiograph showed a newly elongated fourth metatarsal, which was slightly shorter than the third metatarsal. The metatarsal was in the appropriate position within the metatarsal parabola. The fourth proximal phalanx was significantly short. It measured 15.67 mm compared to the third proximal phalanx at 20.69 mm and the fifth proximal phalanx 22.27 mm (Figure 8). This toe was clinically much shorter than the third toe, and slightly longer than the fifth toe. The metatarsal head was painful, and the toe continued to be cosmetically displeasing to the patient.
The left fourth toe was dorsally deviated on an over-lengthened metatarsal. The right fourth toe had similar length to the right fifth digit, and the fourth metatarsal length was appropriate. In addition, retrograde buckling of the dorsal deviated digits caused fourth metatarsal head pain, bilaterally. Further surgical intervention was warranted. The patient underwent left-sided extensor digitorum longus (EDL) lengthening of the fourth toe, and release of the medial interossei with MPJ capsulotomy (Figure 9). On the right side, EDL lengthening and release of the fourth MPJ along with osteotomy of the fourth proximal phalanx with application of an external fixator was performed.

A mini-rail was applied to the right fourth toe proximal phalanx by placing three half pins in the proximal phalanx and two pins in the metatarsal head. The osteotomy was created in the proximal phalanx and the external fixator was applied. There was a latency period of 5 days. The patient performed 0.25 mm turns 4 times per day for a total of 6 weeks (Figure 10, Figure 11, and Figure 12).
LITERATURE REVIEW

Brachymetatarsia correction has been discussed extensively in the literature and we were able to correct the metatarsals utilizing external fixation for callus distraction. On the other hand, we realized that the proximal phalanges of the fourth digits were shortened. The right foot fourth toe needed to be corrected as there was continued pain and the toe was still clinically displeasing. However, few articles suggest treatment for a short proximal phalanx.

Kim et al (4) reminded us that the correction of the metatarsal parabola is important for weight-bearing function, however, they state that the toe-tip parabola is important for the cosmetic component. They recognized that a short proximal phalanx can create an inadequate toe parabola. Therefore, Kim et al corrected brachymetatarsia and/or shortened proximal phalanges by lengthening or shortening adjacent metatarsals or phalanges with single stage lengthening or external fixation application (4). This technique, in our opinion increases the risk of morbidity and complication.

Song et al state that MPJ stiffness is the most common complication when metatarsal length gained is >40% (3). Masada et al states that with >40% length gain there is a large decrease in ROM (12). Song believes that excessive lengthening of the metatarsal is performed as compensation of a short proximal phalanx. When extrapolating data, 59% of feet with brachymetatarsia had a short proximal phalanx in their report and 11/13 of patients (85%) with a short proximal phalanx had an over-lengthened metatarsal. A total of 7/11 (64%) of these patients with an over-lengthened metatarsal had a complication: 5 with subluxation (total or partial stiff joint), 1 with pin tract infection, and 1 with angulation.

Song et al would obtain preoperative AP radiographs to measure the metatarsal and proximal phalanx length. If the assumed length to gain was greater than 40%, they would simply inform the patient that the outcome of the final result may not be as expected (3). Meaning the metatarsal may be out to the appropriate length, but the toe clinically will not be at its correct position in the toe parabola.

Oh and Sharma (11) classified two groups: short metatarsals with or those without an associated short proximal phalanx. They found that the lengthening percentage was larger (39.6%) and mean AOFAS score was lower (81.7) in the short proximal phalanx group compared to the normal proximal phalanx group (28.7%, AOFAS 88.9). However, no procedure was performed to address the short proximal phalanx (11).

RESULTS

At final follow-up examination, the patient had no residual pain and was happy with the results. On musculoskeletal physical examination, the left fourth toe was rectus with the fourth metatarsal. However, there was minimal dorsiflexion on the MPJ, but the toe length was appropriate. No tenderness was apparent with palpation of the sub fourth metatarsal head, distal fourth toe, and fourth DIPJ. AP radiographs again showed an over-lengthened metatarsal disrupting the metatarsal parabola along with a short proximal phalanx (Figure 13).

The right fourth toe was rectus on the MPJ with ability to dorsiflex the right fourth toe. The toe length
was appropriate with no tenderness on palpation to the plantar aspect of the fourth metatarsal head. AP radiographs showed a metatarsal lengthened to its appropriate position in the parabolic arch. In addition, the proximal phalanx was successfully lengthened as well (Figure 14).

Overall, we were able to successfully lengthen the metatarsals and the right fourth proximal phalanx. Table 1 lists the lengths preoperatively, postoperatively, and final percentage length gained of each bone.

**DISCUSSION**

Several complications arose during the treatment of this patient. Three-and-a-half weeks after the initial surgery, the osteotomy of the right fourth metatarsal had consolidated. This required an additional osteotomy. At the 11-month follow-up, it appeared that the metatarsals were out to length. However, the left fourth metatarsal appeared to disrupt the metatarsal parabola, the left fourth proximal phalanx was short, and the fourth toe was dorsally deviated on the metatarsal head (Figure 15). Clinically, the fourth toe was within the appropriate toe parabola position as the over lengthened metatarsal compensated for the short proximal phalanx. Soft tissue surgery was able to successfully bring the toe down. On final examination, there was minimal dorsiflexion at the left fourth MPJ as a result of over-lengthening the metatarsal, but there was no residual pain to the left foot.

At the 11-month follow-up, the right fourth metatarsal was positioned appropriately within the parabolic arc. The fourth proximal phalanx was short and because this metatarsal was not over lengthened the fourth toe clinically appeared short of the toe parabola. In addition, the fourth toe remained dorsiflexed and there was pain at the fourth metatarsal head at this time.

It has been documented in the literature that a short proximal phalanx plays a role in brachymetatarsia correction. According to Song et al (3), 59% of patients with brachymetatarsia also had an associated short proximal phalanx. Oh et al (11) recognized this phenomena as well, however, other than soft tissue correction neither groups performed osseous correction directly to the proximal phalanx. Kim et al (4) mentioned that the metatarsal and toe parabola are very important for successful surgery. To achieve their goal, extensive surgery was performed on the forefoot, but we believe this increases the risk for complications.

Our patient continued to have right forefoot pain and the toe was cosmetically unsatisfactory. Therefore, further surgery was warranted. We were able to successfully utilize a mini-rail external fixator on the right fourth toe proximal phalanx to perform callus distraction and lengthen the toe to its appropriate toe parabola position (Figure 16).

We were able to lengthen the fourth metatarsals and

<table>
<thead>
<tr>
<th></th>
<th>Preoperative length</th>
<th>Postoperative length</th>
<th>Length gained</th>
</tr>
</thead>
<tbody>
<tr>
<td>R Proximal Phalanx</td>
<td>15.67 mm</td>
<td>18.60 mm</td>
<td>18.7%</td>
</tr>
<tr>
<td>R 4th metatarsal</td>
<td>47.07 mm</td>
<td>72.84 mm</td>
<td>54.7%</td>
</tr>
<tr>
<td>L 4th metatarsal</td>
<td>50.30 mm</td>
<td>74.55 mm</td>
<td>48.2%</td>
</tr>
</tbody>
</table>

Figure 15. Right fourth metatarsal violates metatarsal parabola.

Figure 16. Right fourth metatarsal length appropriate. Lengthen fourth proximal phalanx.
CHAPTER 11

In conclusion, we were able to successfully lengthen the proximal phalanx of the right fourth toe by utilizing external fixation and callus distraction after correction of bilateral brachymetatarsia. With this case report, we are able to suggest a technique to perform lengthening of the proximal phalanx and make certain a toe is in its appropriate position in the toe parabola without having to disrupt the metatarsal parabola by overcompensation (Figure 17).

REFERENCES


Figure 17. Final clinical follow-up of bilateral feet.

the right fourth toe proximal phalanx to relieve the forefoot pain, as well as satisfy the patient’s cosmetic psychological deformity. The bilateral brachymetatarsia correction was achieved with slightly different results and because of this we now have a better understanding of the appropriate surgical technique.

Song et al state that MPJ stiffness is the most common complication when metatarsal length gained is >40%. On the right side, we had an overall length gain of 54.7% and on the left side, 48.2%. On the left side, residual stiffness at the MPJ did occur and we did violate the metatarsal parabola while lengthening. However, due to over-lengthening the right fourth toe was in its appropriate toe parabola position. The right fourth metatarsal was at the appropriate metatarsal parabola position on final radiographs and MPJ stiffness was not present with ROM. Therefore, we believe that it is imperative to closely follow a patient’s progress of lengthening with serial radiographs to ensure the metatarsal does not violate the metatarsal parabola.
TOPHI ARE A SIGN OF UNCONTROLLED GOUT

Gout is the most common form of inflammatory arthritis.\textsuperscript{1,2} Most gout patients have significant urate burden which can result in visible and/or nonvisible tophi, which may put them at risk for joint damage and disease progression.\textsuperscript{1,3,4,5}


**References**


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Elongating Osteotomy of the Short First Metatarsal in Non-Iatrogenic Deformities: A Case Series

Alan S. Banks, DPM
Lauren E. Kuenzi, DPM

INTRODUCTION
Plantar second metatarsal pain, capsulitis, and predislocation syndrome are common ailments for which second metatarsal osteotomies are performed when surgical treatment is needed. Surgeons often refer to patients as possessing a long second metatarsal as part of the underlying pathology. However, often the structural problem is a short first metatarsal, and the relationship between the remaining metatarsals is normal. This study demonstrates the effectiveness of relieving second metatarsal pain by elongating the short first metatarsal and correcting the abnormal metatarsal parabola.

LITERATURE REVIEW
Treatment for congenitally short first metatarsals are not well documented. It is more common to see discussions of correction regarding iatrogenic shortening (1,2). Regardless of the etiology, a short first metatarsal may lead to second metatarsal capsulitis. Classically, the surgical management has focused on procedures of the second metatarsal (3). Other options discussed for iatrogenic shortening of the first metatarsal have included lengthening osteotomies as well as first metatarsophalangeal joint (MPJ) fusions with bone grafting (1,4). When first MPJ fusion is avoided, distraction Scarf lengthening and Sagittal Z lengthening seem to be the primary choices described (2,5,6). In this study, we will describe the use of the Z lengthening in dealing with a congenitally shortened first metatarsal in patients with second ray metatarsalgia (Figure 1).

CASE SERIES/PROCEDURE
We present a case series of 3 patients, all with the chief symptom of second metatarsal capsulitis or metatarsalgia. Each of these patients had a shortened first metatarsal when evaluating the overall metatarsal parabola. We utilized an elongating Z osteotomy to lengthen the first metatarsal 5 to 7 mm in order to correctly realign the metatarsal parabola and restore more normal weight-bearing to the forefoot (Figure 2, Figure 3, Figure 4).

The patient is placed in the supine position. Hemostasis may be achieved with either a tourniquet or local anesthesia with epinephrine. A linear incision is made over the first metatarsal from the metatarsal cuneiform joint to the first MPJ area. After dissection through the subcutaneous tissues, the periosteal incision is made longitudinally along the first metatarsal. The periosteum is reflected, and the first metatarsal-cuneiform joint and the first MPJs are both identified. Two 0.045 Kirschner wires are employed as axis guides. The distal osteotomy should avoid the sesamoids, proximally the axis is 1 cm distal to the metatarsal cuneiform.
joint. An elongating Z osteotomy is then performed using power instrumentation. The distal portion of the osteotomy is then distracted to the desired length. Temporary fixation is applied and fluoroscopy used to check for approximate length gain. Typically 5 to 7 mm of length is gained at this point from distraction. Temporary fixation is replaced with two screws. The sizes of the screws depend on the individual patient anatomy. Freeze-dried tricortical iliac bone graft is then cut and shaped to fit into the gaps created from distraction of the osteotomy. The grafts are secured with two 2.0 mm cortical screws. Layer closure is then performed. A below-knee Jones compression cast is applied to the lower extremity. The patient will remain non-weightbearing for 6 weeks until they can be transitioned to a surgical shoe and eventually to a regular shoe (Figure 5, Figure 6, Figure 7).
DISCUSSION

Assessing the metatarsal parabola is an important tool for proper surgical planning in patients with chronic lesser metatarsal symptoms. It has been the experience of the authors that when there is structural aberration of the metatarsal parabola, often the relationship between the second and fifth metatarsals is normal and it is the first metatarsal that is short as opposed to a long second metatarsal. In this case study, 3 patients, all with a chief complaint of second metatarsal capsulitis or metatarsalgia, underwent a lengthening Z osteotomy. Each patient gained 5 to 7 mm of length at the first metatarsal. Lengthening the first metatarsal via osteotomy corrected the problem of the short first metatarsal and eliminated the symptoms of metatarsalgia. This study demonstrates the importance of recognizing the malalignment of the parabola by correcting the true structural deformity.

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Suturedesis: Technique for Hammertoe Repair

Gregory Alvarez, DPM  
Trent Lott, DPM

INTRODUCTION

Hammertoe deformities are among the most common conditions treated by foot and ankle surgeons. Many techniques have been explored in order to adequately address the pathology. One of the most common techniques is pinning with Kirschner wires, which has proven to be reliable with good outcomes (1). Other techniques include implants, absorbable pins, buried pins, screws, and two-pin fixation. Each of these techniques has pros and cons. Some common disadvantages include pin tract infection, pin pistoning, patient anxiety with pins, hardware failure, and marrow edema.

One of the more challenging disadvantages to address is stability in the frontal, transverse, and sagittal planes. Harris et al (2) describe a technique utilizing stainless steel suture that provides stability and eliminates complications that may be seen with other techniques such as pinning. The technique involves using guide holes drilled with a Kirschner wire and passing stainless steel suture through the guide holes to bring stability to the fusion site. There are not many descriptions of similar techniques reported in the literature. These authors use a similar approach with some modifications. The suturedesis technique used will be described.

SURGICAL TECHNIQUE

Anatomic dissection is performed through the skin down to the subcutaneous tissue. This layer is then brushed away from the deep fascia layer (Figure 1). Once you are down to the deep fascia, the extensor tendon is identified, followed by identification of the PIPJ. An extensor tenotomy is performed transversely. It should be noted that the tenotomy is performed proximal to the flare of the head of the proximal phalanx (Figure 2 and Figure 3). This allows the surgeon to more readily retract for greater distraction during dissection and suture the 2 ends back together. It also allows for proper placement of the guide holes, which will be discussed later.

Following the tenotomy, the extensor tendon is reflected off the dorsal aspect of the proximal phalanx. Reflection of the tendon only needs to be carried out proximally in a minimalistic fashion unless procedures are required at the metatarsophalangeal joint (MPJ), then reflection of the tendon can be carried out to the level of the MPJ. After dissection, the head of the proximal phalanx is resected with a saw. The cut is made distal to the flare of the proximal phalanx head with care being taken to not over shorten the phalanx. The cut is angled slightly from dorsal-distal to...
plantar-proximal (Figure 4). Cutting the proximal phalanx first will make it easier to dissect the middle phalanx.

Attention is then directed to the base of the middle phalanx. Care is taken to circumferential dissect tissue off the base of the middle phalanx (Figure 5). This will allow for proper placement of the guide holes and allow for proper passing of the suture. Next, the base of the middle phalanx is resected using a saw. Only a small amount of bone needs to be resected off the middle phalanx. The surgeon may use Adson Brown forceps to hold the middle phalanx, in order to gain more control for this resection. The cut is made with a slight proximal-dorsal to plantar-distal angle. One can imagine the orientations of the cuts on the proximal phalanx and middle phalanx making a triangle with the fulcrum at the dorsal aspect. The reason that these cuts are made in this manner is to provide the digit with a natural curl appearance at the end of the procedure. After resection of the middle phalanx the plantar plate of the PIPJ is sharply dissected out and discarded (Figure 6). This is done to prevent any soft tissue from preventing arthrodesis and to eliminate the contraction created by the flexors. At this point in the procedure positioning and alignment of the joint is re-evaluated.

Once alignment and positioning of the PIPJ is adequate, the surgeon will take a 0.045 Kirschner wire and drill a pilot hole centrally in the proximal phalanx. From this central pilot hole, the surgeon will angulate the Kirschner wire in a dorsal-lateral fashion. The exit point of this guide hole is just distal to the flare and on the dorsal-lateral aspect of the proximal phalanx (Figure 7 and Figure 8). Next, another guide hole is drilled from the central pilot hole and will exit just distal to the flare and on the dorsal medial aspect of the proximal phalanx. After the guide holes are placed in the proximal phalanx, attention is then directed to the middle phalanx. The same sequence is carried out with a central pilot hole in the middle phalanx being drilled first (Figure 9 and Figure 10). Then in similar fashion, the exit points will be to the dorsal medial and the dorsal lateral aspect of the middle phalanx.

Once the guide holes are placed, 3-0 stainless steel on a curved needle or small half circle needle is passed through the holes (Figure 11). The suture is passed through the 2
medial guide holes first. Care must be taken to not bend or kink the stainless steel as it is passed through each set of guide holes. The stainless steel is then cut in a manner that will leave an adequate amount of tail for cinching down of the suture. Next, another 3-0 stainless steel suture is passed through the lateral guide holes, and the suture is then cut as to leave enough tail for tightening. At this time, the PIPJ can again be re-evaluated for positioning and alignment. The sutures are then tightened down starting with the medial or lateral side. The surgeon does 2 throws in total. The first throw will re-approximate and tighten the 2 joint ends and the second throw will keep the construct in place. After this is performed, the stainless steel is cut and the ends are tamped down towards the midline of the proximal phalanx. This will allow the extensor tendon to lie off the stainless steel, which will minimize any prominent suture material. At this point the surgical site is washed out and closure begins with re-approximating the extensor tendon with 3-0 vicryl. The subcutaneous layer and skin are closed with 4-0 and 5-0 vicryl, respectively.
DISCUSSION

This surgical technique may initially take a surgeon more time to perform (at least until it becomes more familiar) but it still has its advantages. Stability is one of the more advantageous aspects of this procedure. When pins are used, the digit still lacks rotational stability (1). The suturedesis technique with 3-0 stainless steel suture provides rotational stability because of the 2 guide holes that are being used. Some surgeons will keep as much soft tissue intact as possible in order to give the joint more stability especially within the sagittal and transverse planes. Suturedesis provides stability despite the surrounding soft tissue being disrupted. The 2 guide holes essentially take the place of surrounding soft tissue attachments and will prevent drifting within the sagittal and transverse planes at the level of the PIPJ.

A second advantage to this technique is that the suturedesis will provide compression at the fusion site. Pins may piston, which will lead to a lack of compression. This lack of adequately-coapted bone ends may lead to a higher rate of pseudo arthrodesis (3). Using 2 stainless steel sutures will adequately compress the joint and provide stability. Although suturedesis provides greater compression, future research is needed to determine if higher rates of fusion are seen in suturedesis compared to pinning or other techniques.

Some disadvantages to consider when performing this procedure include increased time to perform the suturedesis and possible removal of the sutures themselves. In regard to timing, with more experience the surgeon will become more efficient. The learning curve to this procedure is not terribly steep. There may also be times (such as infection or pain) in which the sutures must be removed. The author has not found removal of the sutures to be difficult. Out of the thousands of suturedesis procedures that have been performed the author has only needed to remove a handful.

In conclusion, suturedesis of the PIPJ when addressing hammertoe deformities is a very viable option. It should especially be considered with mild to moderate deformities that will not require pinning across the MPJ. Despite some of the disadvantages that naturally exist with this procedure, the advantages make a strong argument in the case of utilizing this procedure. Suturedesis provides rotational stability where pinning fails, brings stability to the transverse and sagittal plane even in the absence of functioning soft tissue, and may be associated with higher fusion rates.

REFERENCES

Weil Osteotomy With Plantar Plate Repair: Tips for Success

Thomas A. Brosky, II, DPM
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Jeanne Mirbey, DPM

INTRODUCTION

The Weil osteotomy is an established and effective osteotomy that is used for both the treatment of lesser metatarsalgia, and to aid in the reconstruction of lesser metatarsophalangeal joint (MPJ) subluxation or dislocation. The Weil osteotomy is particularly indicated in cases of relatively long or plantarflexed metatarsals. Additionally, the procedure is useful in managing cross-over and subluxed or dislocated hammertoe and can be used in a translation fashion to realign the MPJ. The procedure has been popularized due to its simple technique, ability for stable fixation, excellent union rates, and predictable results (1). More recently, this osteotomy has been used in conjunction with repair of the plantar plate. Postoperative complications after a Weil osteotomy can be minimized with appropriate surgical technique (2). The authors will demonstrate that the Weil osteotomy, when used in conjunction with repair of the plantar plate has manageable side effects and allows for excellent reproducible results.

BACKGROUND

The pathomechanics of the plantar plate degeneration and/or rupture involve increased plantar plate pressure due to hallux valgus, first ray insufficiency, hammertoe deformity, elongated lesser metatarsal, and gastrocnemius equinus. One or a combination of these deformities can lead to increased load at the lesser metatarsal head, particularly at the second metatarsal due to its increased length in the typical foot (2). This increased load leads to joint effusion and increased stress on the plantar plate, thus leading to degeneration or rupture. Other cases involve repetitive or acute trauma from an injury or increase in activity (3).

Clinically, patients with plantar plate pathology present with dorsiflexion or dorsal dislocation at the MPJ, often with an accompanying hammered digit. Pain can often be localized to the distal-planter aspect of the MPJ. Some cases present with additional medial or lateral deviation of the proximal phalanx due to more medial or lateral degeneration of the plate (Figure 1).

WEIL OSTEOTOMY WITH DIRECT PLANTAR PLATE REPAIR

The original description of the Weil osteotomy involves an oblique osteotomy cut within the metatarsal neck, originating within the dorsal one-quarter of the articular cartilage. The osteotomy should be parallel to the weight-bearing surface of the foot, approximately 15° to 20° relative to the long axis of the metatarsal, thereby creating a large area of bone-to-bone contact, which can be easily fixated (4). This long osteotomy also prevents plantarflexion of the capital fragment, which aids in reducing the incidence of a floating toe phenomenon (4). Performing a double cut or wafer cut osteotomy, which can be accomplished using 2 blades on the same saw or by making 2 separate saw cuts, allows for elevation of the head and further aids in the prevention of floating toe phenomenon. Shortening of the capital fragment should be 1-3 mm to prevent over-shortening and again, to prevent floating toe.

When performing this osteotomy in conjunction with plantar plate repair, the capital fragment can be proximally...
translated for easy visualization of the plantar plate, thus allowing for a direct repair technique. Numerous techniques have been published that involve direct repair of the plantar plate without the Weil osteotomy including the Arthrex Complete Plantar Plate Repair System and Smith & Nephew HAT-Trick Lesser Toe Repair System. Recently, the plantar plate has been implicated as an important stabilizer of the MPJ. In the past, some procedures attempted the joint repair without direct plantar plate repair. These procedures involved stabilizing the MPJ with a Kirschner wire (K-wire) in an attempt to allow fibrosis to occur and thereby stabilize the joint. This technique typically resulted in a stiff digit and often led to a recurrent hammertoe deformity. Plantar plate repair using a direct plantar approach has been performed in the past, however numerous complications including painful scarring and prolonged immobilization have caused this technique to fall out of favor.

Some proponents of direct plantar plate repair techniques argue that the Weil osteotomy is not necessary due to its relative complications. The osteotomy is associated with various complications including floating toe (36%), recurrence (12.5%), and transfer metatarsalgia (7%) (5). Other complications associated with the Weil include delayed union, non-union, and malunion, which account for 3% of cases overall and are most often associated with significant comorbidities (5). The complication of floating toe is increased when concurrent proximal interphalangeal joint (PIPJ) arthrodesis is performed.

In a study by Migues et al, floating toe occurred 15% of the time without concurrent PIPJ arthroplasty and increased to 50% when the Weil osteotomy was performed with a concurrent PIPJ arthroplasty (7). Floating toe can also be prevented by avoiding plantarflexion of the metatarsal head by ensuring the osteotomy is parallel to the weight-bearing surface, or by using a wafer cut method with parallel osteotomies to achieve more shortening from the osteotomy with minimal capital fragment proximal-plantar translation and therefore plantarflexion of the metatarsal head (5). It should also be noted that while floating toe is a common complication associated with the Weil osteotomy, only a fraction of patients with this complication state that they are unhappy with the results (10% in 1 study) (6). There is an inverse relationship noted between recurrence of symptoms in the second digit Weil and simultaneous first ray procedures, indicating a potential need for correction of asymptomatic hallux valgus in the presence of subluxed second MPJ (8). Transfer metatarsalgia has been noted to be a result of excessive shortening. In a retrospective review of the Weil metatarsal osteotomy, transfer metatarsalgia was reduced to 1.1% by simply determining the amount of shortening necessary preoperatively using anterior-posterior radiographs to ensure proper metatarsal parabola (9).

**TECHNIQUE DESCRIPTION**

A longitudinal skin incision is made over the dorsal aspect of the involved digit, from just proximal to the MPJ and extending distal to the PIPJ. Following anatomic dissection, sharp or blunt dissection is carried down to the deep fascia where any crossing vessels should be carefully ligated and divided. A transverse extensor tendon tenotomy is performed at the PIPJ and the tendon is reflected proximally, and a medial and lateral capsulotomy is performed allowing for exposure of the MPJ.

The double cut osteotomy can be performed using 2 blades on the same saw or by making two separate saw cuts. If the surgeon wishes to perform the joystick method for fixation, a K-wire is inserted into the capital fragment prior to the osteotomy. If 2 separate cuts are performed for the double cut osteotomy, the first cut is made at the metatarsal head, parallel to the longitudinal axis of the bone. The capital fragment is then retracted plantarly using a thin osteotome in preparation for the double cut osteotomy. The second cut is oriented slightly distal-dorsal to proximal-plantar, creating a thin wedge-like fragment allowing for dorsiflexion of the capital fragment upon fixation. At this time the wedge-like fragment is removed and the capital fragment is ready for fixation.

Mobilization and fixation of the capital fragment using the joystick technique can now be performed. The joystick method uses the K-wire driven into the capital fragment, prior to osteotomy. This can be used to aid in appropriate positioning of the capital fragment in both the transverse (medial and lateral translocation) or longitudinal (lengthening or shortening) planes. This also aids in compression at the osteotomy site during temporary fixation with a vertical K-wire. Two screws can then be used for fixation of the capilar fragment.

Exposure of the MPJ space is excellent and allows for good exposure of the plantar plate. The plantar plate can be carefully inspected and repaired primarily using 2-0 Ethibond suture. Additional procedures can then be performed including an PIPJ arthrodesis. The extensor tendon can be lengthened as needed and should be repaired distally. The subcutaneous and skin layers are then closed.

**CASES**

Three cases are presented, which highlight the double cut or wafer cut technique, along with the joystick technique and adequate visualization for a direct plantar plate repair. These techniques can be used to aid in better control of osseous position and fixation and help reduce postoperative complications.
Case 1.
An illustration of the double cut osteotomy is shown in Figures 2-8.

Figure 2. Clinical presentation of a hammer toe with plantar plate degeneration with cross over second digit.

Figure 3. Radiograph of same patient showing medial dislocation of the second metatarsophalangeal joint.

Figure 4. Saw placement for the Weil osteotomy after joint exposure.

Figure 5. Retraction of the capital fragment in preparation for a double cut osteotomy with an osteotome.
Case 2.
An illustration of the joystick method with K-wire is shown in Figures 9-15.

Figure 6. Double cut osteotomy used for dorsiflexion of the capital fragment and prevention of a floating toe.

Figure 7. The double osteotomy fragment.

Figure 8. Segment of bone removed from the double osteotomy.

Figure 9. Preoperative radiograph showing the medially dislocated second digit.
Figure 10. Dissection to the metatarsophalangeal joint with Kirschner wire used for the joystick method. Insertion into the capital fragment prior to the osteotomy.

Figure 11. Saw placement for osteotomy with Kirschner wire in place.

Figure 12. Medial translation of the capital fragment with Kirschner wire.

Figure 13. Kirschner wire used for compression with temporary fixation in place.
Case 3.
Illustration of excellent plantar plate exposure for direct repair after a double cut Weil osteotomy is shown in Figures 16-19.

Figure 14. Screw fixation with two screws.

Figure 15. Preoperative and postoperative radiographs with congruent second metatarsophalangeal joint. Note that a second proximal interphalangeal joint arthrodesis along with a first metatarsophalangeal joint arthrodesis were also performed.

Figure 16. Excellent exposure of the plantar plate is achieved after the double cut Weil osteotomy.

Figure 17. After adequate exposure, the plantar plate can be carefully inspected and primarily repaired or tightened as needed.
DISCUSSION

The authors believe that the complications previously mentioned are of little significance if managed appropriately and intraoperatively. Additionally, it is believed that excellent results can be obtained by combining a Weil osteotomy with direct plantar plate repair. In a 2007 study by Gregg et al, 95% of patients with concomitant plantar plate repair and a Weil osteotomy demonstrated no or only mild pain postoperatively (10). In 2011, Weil and colleagues demonstrated that combined plantar plate repair and a Weil osteotomy reduced the visual analog pain scale scores from 7.3 preoperatively to 1.7 postoperatively (11).

From a review of the literature and the authors’ personal experience, it can be concluded that direct plantar plate repair combined with a Weil osteotomy gives patients the best result in terms of treatment of the rupture and correction of the osseous deformity.

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Interpositional Arthroplasty with Acellular Dermal Matrix Allograft: Two Applications

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Thomas A. Brosky, II, DPM  
Adam Port, DPM  
Navita Khatri, DPM  
Chandler Ligas, DPM

INTRODUCTION

Sigvard Hansen differentiates the joints of the foot into 3 categories: essential, nonessential but useful, and unnecessary (1). When considering surgical treatment options for recalcitrant arthritis, arthrodesis of essential joints should be avoided when possible due to increased stress and strain applied to the surrounding joints increasing the likelihood of arthritis in these joints. The ankle, subtalar, talonavicular, and the 2-5 metatarsophalangeal joints (MPJ) are essential joints in the foot. The nonessential but useful joints for normal ambulation are the first MPJ and the fourth and fifth tarsometatarsal joints (TMTJ) (1). Clinical and patient factors may preclude arthrodesis for useful and nonessential joints. These factors include patient refusal, infection, poor bone quality, demanding postoperative regimen, and other patient comorbidities (2,3). Alternatives to arthrodesis for essential and useful joints should be considered when these factors are at play. Interpositional arthroplasty for useful joints is a viable alternative to arthrodesis (2,3). Interpositional arthroplasty diminishes the stress applied to surrounding joints by allowing continued motion at the arthroplasty site (2).

Options for interpositional arthroplasty include autograft from surrounding muscle and tendon including the EDB for the fourth and fifth TMTJ and adductor tendon for the first MPJ (2-6). An autograft is a viable option for interposition using intrinsic structures of the foot; but there are negatives to this method including longer operating room times, further anatomic disruption, and loss of function of the sacrificed intrinsic structure (2,3). Other options include capsular interposition utilizing a purse-string technique, or alternative allografts (2). Various allograft options have been used historically and continue to be utilized. These include autogenous fascia lata, gracilis autograft, tendon allograft, amniotic membrane graft, collagenous tissue matrix, and meniscal allograft (6-8). All of these options report favorable outcomes, however, interpretation of this is limited due to the nonuniformity of outcome measures (6-8). To date, there are no high-quality level 1 studies describing outcomes of interposition arthroplasty (6-8). A recent evidence-based literature review found no consistent findings in comparative studies, that are properly powered with validated/appropriate outcome measures to allow any definitive conclusions on which procedure is best (9,10).

ACELULAR DERMAL MATRIX

Acellular dermal matrix (ADM), specifically GraftJacket (Wright Medical Group) is a viable allograft option. ADM is comprised of a human dermal collagen matrix that undergoes a patented process, which renders the material essentially acellular (11). The matrix provides a scaffold for host cell repopulation, revascularization, and ultimately the ability to convert into host tissue (11). For use in interpositional arthroplasty, this characteristic is useful due to host remodeling of the graft with durable fibrotic tissue (11). ADM has been used successfully in the ankle joint for interpositional arthroplasty due to its versatility and reliability (3,12,13). This material has been shown to be a successful option for interposition in the ankle joint, the fourth and fifth TMTJ, the first MPJ, and particularly useful as an option when there is an infection involved (3,12,13). Previous studies show improved AOFAS scores and high patient satisfaction with the interposition of the ankle joint with ADM (3,12,13). Two cases that will be presented that utilize ADM for interpositional arthroplasty in both nonessential but useful joints of the foot.

CASE REPORTS

Interpositional ADM Allograft Following Failed Hemi-Implant With Infection in the First MPJ

A 64-year-old man presented for 6-month follow-up after a right first MPJ hemi-implant with an edematous and erythematous right hallux. Upon radiographic evaluation, there was increased lucency and subsidence noted surrounding the implant (Figure 1 and Figure 2).
Surgical intervention was deemed necessary due to concern for infection versus implant reaction. Arthrodesis and arthroplasty options were discussed with the patient. The patient, along with the surgical team, chose arthroplasty due to concern with retained hardware in a possibly infected area, and patient concern for the loss of mobility of the digit. During the procedure, purulence was expressed along with deep necrotic tissue and bone to the proximal phalanx of the hallux with subsidence of the hemi-implant (Figure 3). Additionally, necrosis of the metatarsal head was noted. Intraoperative cultures were obtained and the implant was removed along with all necrotic and infected soft tissue and bone including the EHL, a large portion of the proximal phalanx of the hallux, and a portion of the metatarsal head.

Intraoperative options were to utilize the adductor tendon or to use ADM for interposition. It was determined that due to the infected tissue, the ADM along with antibiotic powder would be the superior option. This decision was solidified due to no contraindications of using ADM in the presence of infection. When the intraoperative decision was made, the first metatarsal head was measured (Figure 4). The corresponding measurements were translated to
the ADM and then cut for proper fit overlying the first metatarsal head (Figure 5). Utilizing a 0.062 Kirschner wire, 2 holes were made in the first metatarsal neck to suture anchor the allograft in place; one from the dorsal-medial to lateral-plantar aspect, and the other from the dorsal-lateral to plantar medial aspect, just proximal to the sesamoid apparatus (Figure 6). Next, 2-0 monocryl (Ethicon) was sutured in place to 2 corners of the ADM on one side (Figure 7). The tails were then passed through the anchor holes from plantar to dorsal, utilizing a suture passer and allowing the graft to be interposed plantar to the metatarsal head between the head and the sesamoid apparatus (Figure 8). The ADM was then draped over the distal and dorsal metatarsal head and was secured in place with the suture tails (Figure 9). This fixation method ensures the graft will stay in place around the distal aspect of the joint. The joint was manipulated intraoperatively and noted to be adequate in dorsiflexion and plantarflexion range of motion.

Prior to incision closure, the wound was irrigated with copious amounts of saline and then supplemented with vancomycin powder. Postoperative radiographs were taken following the procedure (Figure 10).
of intraoperative infection discovered, the patient was discharged on oral antibiotics (doxycycline) and infectious disease was consulted. Following intraoperative culture results of methicillin-resistant Staphylococcus aureus susceptible to doxycycline and vancomycin, the patient was converted to intravenous vancomycin via peripherally inserted central line for 4 weeks. The patient is doing well at 2 months postoperatively, off of antibiotics, with no further signs of infection and ambulating with no pain.

Fourth and Fifth TMTJ Interpositional Arthroplasty With Acellular Dermal Matrix Allograft

A healthy, active, 41-year-old man presented with a chief report of pain at his fourth and fifth TMTJ, which had progressively gotten worse over the last 3 years despite conservative treatment including corticosteroid injections, orthotics, and over-the-counter anti-inflammatories. He stated that the pain had limited his activity and lead to weight gain. Preoperative radiographs showed loss of joint space and osteophyte formation to the fourth and fifth TMTJs (Figure 11).
After exhausting conservative treatment, the patient elected for surgical intervention. Exposure of the joints showed extensive osteophyte formation in both joints (Figure 12). All dorsal osteophytes were resected revealing more defined joint spaces (Figure 13). Next, the joints were distracted and the plantar osteophytes were resected. Damaged and synovitic tissue was resected. A single piece of ADM was interposed into both joints after length and depth were measured (Figure 14). The ADM was sutured in place dorsally to help prevent displacement of the graft (Figure 15). Intraoperative fluoroscopy was used to ensure that all osteophytes were resected. Preoperative and postoperative radiograph comparison shows the removal of osteophytes, and adequate joint space preserved by the allograft (Figure 16 and Figure 17).
DISCUSSION

With the prevalence of hallux rigidus being the highest incidence of osteoarthritis in the foot, a multitude of treatment options can be utilized depending on the grade of severity of the condition (3,7,8). The gold standard for advanced-stage hallux rigidus is arthrodesis, but this requires joint destruction, which is not an attractive option for some patients. There is increasing popularity for joint replacement surgery throughout the entire body including the first MPJ (14). Therefore, to determine the success of implant arthroplasty of the first MPJ, Salonga et al produced a retrospective review outlining the incidence of pertinent clinical data (15). Their results included 11 with antalgic gait (13.92%), 74 with normal hallux purchase (93.67%), 49 with satisfaction with the appearance of the great toe (62.03%), 42 with the ability to wear conventional shoes (53.16%); 45 with freedom from pain (56.96%), and 68 with satisfaction or high level of satisfaction with the outcome (86.08%). Other reports showcase that the first MPJ implants have an overall satisfaction rate of around 85% (15,16). These reports of satisfaction are similar to the results seen with first MPJ arthrodesis (9). Thus, both surgical procedures prove the variability of procedure selection for end-stage hallux limitus.

The most confounding evidence against the first MPJ implants is the failure rate and long-term outcomes (16). Konkel published long term results of the hemi-implant of the great toe joint and found that subsidence and lucency in all 9 patients and a painful fracture in 1 patient (16,17). They went on to conclude that the ultimate longevity of the implant should be questioned. These complications become especially troubling when there is associated infection with the failure of the first MPJ implant. While this complication is rare, it can lead to devastating consequences including ray resection and thus provoke the necessity for a salvage procedure. One option that the senior author would suggest is the interpositional arthroplasty for failed first MPJ implant. Khoury et al published a case report utilizing ADM for first MPJ interpositional arthroplasty following the failure of the first MPJ implant due to infection (18). These authors went on to discuss that bone block arthrodesis may be the more permanent option for this type of failure. However, in the setting of acute infection, ADM for interposition diminishes the risk of further hardware infection and is a viable option for some patients. ADM has also been used when there is not an infection present, as published by Berlet et al (19). A total of 9 patients with grade 3 hallux rigidus were treated with interpositional arthroplasty involving ADM. The authors found no complications at a 12-month follow up and found significant improvements in the AOFAS score with a mean improvement of 25.4 points comparing preoperative AOFAS to most recent clinical follow-up AOFAS scores (19). The mean AOFAS score postoperatively was 87.9, which is comparable to a published postoperative AOFAS score for first MPJ arthrodesis (9). Therefore, if a practitioner is faced with the intraoperative finding of infection, ADM may be used either temporarily until the infection is eradicated, or as a long-term alternative to arthrodesis. Intraoperative cultures should be taken in the setting of infection and infectious disease consultation should be utilized to adequately target antibiotic therapy. At approximately 6 weeks postoperatively, our patient is ambulating in a postoperative shoe and is finishing his last 2 weeks of intravenous antibiotics. The patient is satisfied with the result thus far. Longer-term follow up will be required to determine the overall success of this method.

Fourth and fifth tarsometatarsal arthritis is a condition that is relatively common and surgical options are limited. The most common cause of midfoot arthritis is trauma (20). Mann et al suggest that atraumatic arthrosis in this area is more common in the neutral or supinated foot (20). The tarsometatarsal joints have been demonstrated to show a critical role in load transfer during the gait cycle and in regulating contact pressures of the midfoot (4,20). The longitudinal arch derives its stability primarily from the second metatarsal base, functioning as a keystone. It is generally accepted that while the 3 medial rays are relatively immobile, the fourth and fifth ray are mobile and function as a unit about an independent axis (4,20). As mentioned above, the fourth and fifth TMTJ are nonessential, but useful joints (1).

Currently, there are two main categories of surgical options: motion-preserving and motion eliminating (4,5). The motion preserving category includes ceramic interpositional arthroplasty, resection arthroplasty, and tendon interposition procedures (4,5). Motion eliminating
includes arthrodesis by various fixation types. Shawn et al did a study with 11 patients who underwent resection arthroplasty of the base of the fourth or fifth metatarsals with ceramic ball interposition. These patients had an improvement of AOFAS and visual analog scale scores postoperatively. However, no formal postoperative measurement data were given to support maintenance of the motion in the lateral midfoot following this procedure (21). Also, there are no long-term studies to show the long-term reliability of ceramic ball interposition or the life-span of the ceramic balls.

Additional risks include joint and implant dislocation. Berlet et al showed 12 patients who had an improvement of AOFAS scores postoperatively following resection arthroplasty and tendon interposition (6). However, again, no formal documentation of pre- or postoperative range of motion of the fourth and fifth TMTJ was made, nor was there any documentation of pre- or postoperative pain reduction. Complications of arthrodesis include non-union, mal-union, broken hardware, stress fractures, foot stiffness, abnormal loading, and arthrosis in adjacent joints particularly the calcaneocuboid joint (21,22). Arthrodesis on these joints can lead to increased pain and iatrogenic dysfunction (23). We believe that utilizing ADM as an interposition for arthroplasty helps reduce pain postoperatively and maintains motion at the fourth and fifth TMTJ. Also, it does not compromise any intrinsic structures. The patient is doing well postoperatively and is satisfied.

In conclusion, ADM is a product that has the potential to be used in a variety of surgical cases. These 2 unique cases represent the versatility of using ADM for interpositional arthroplasty, along with the other applications discussed above. Interpositional arthroplasty is a good alternative to arthrodesis because it does not damage intrinsic muscle functions, does not damage joints and maintains joint mobility. This is especially important because the first MPJ and the fourth, fifth TMTJs are nonessential but useful joints in the foot. Eliminating motion at these joints can lead to complications with gait and ambulation. Additionally, the ability to use this product when infection is present increases its versatility and gives the surgeon the option to avoid amputation in some cases. ADM is a versatile product and a useful tool for surgeons to prevent unnecessary arthrodesis and amputation in the foot.

**REFERENCES**

INDICATION
JUBLIA (efinaconazole) topical solution, 10% is indicated for the topical treatment of onychomycosis (tinea unguium) of the toenail(s) due to Trichophyton rubrum and Trichophyton mentagrophytes.

IMPORTANT SAFETY INFORMATION
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• Patients should be instructed to contact their health care professional if a reaction suggesting sensitivity or severe irritation occurs.

The most common adverse reactions (incidence >1%) were (vs vehicle): ingrown toenail (2.3% vs 0.7%), application-site dermatitis (2.2% vs 0.2%), application-site vesicles (1.6% vs 0%), and application-site pain (1.1% vs 0.2%).

JUBLIA should be used during pregnancy only if the potential benefit justifies the potential risk to the fetus, and should be used with caution in nursing women. The safety and effectiveness in pediatric patients have not been established.

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INTRODUCTION

Posterior malleolar fractures are an often overlooked but potentially serious aspect of any traumatic injury to the ankle joint. Posterior malleolar fractures occur most frequently in males with one case series showing a mean age of 31.5 years (1). While typically associated with more complicated injuries, including both soft tissue and osseous, posterior malleolar fractures also occur approximately 4% of the time in an isolated fashion (1). These isolated injuries often occur with a direct axial loading force on the ankle when in a plantarflexed position. The more complex injuries involving other ankle joint structures most often occur in a more rotational fashion. When the ankle is in a plantarflexed position, up to 40% of the total traumatic force can be transmitted through the posterior malleolus alone (2).

Regardless of the mechanism of injury, the talus is forced into the tibia fracturing off the posterior malleolus in varying sizes. These fractures have important long-term implications in these patients, specifically relating to stability of the joint and post traumatic arthritic changes. Posterior malleolar fractures due to their rarity and perceived unimportance, are often misdiagnosed or neglected. Knowledge and understanding of these traumatic injuries and their impact on both osseous and soft tissue components of the ankle joint is paramount. This knowledge should be applied in the decision-making process when deciding if advanced imaging modalities are warranted for surgical planning. In patients with continued pain following diagnosed ankle sprains or ankle fractures with no posterior malleolar fracture noted on plain film radiographs, the modality of choice is often a magnetic resonance image (MRI) to include both soft tissue and osseous examinations. However, if there is a high suspicion for posterior malleolar fracture based on mechanism of injury, a computed tomography scan of the ankle is a more appropriate modality for surgical planning. Either way, the goal of the surgeon should be to fully evaluate these often severe injuries.

CURRENT TECHNIQUES

There have been many different opinions when dealing with how to treat posterior malleolar fractures. Unlike medial and lateral malleolar fractures, there is currently no gold standard for the treatment of posterior malleolar fractures. The debate on when to switch from conservative treatment to surgical management is widely contested. In most of the literature, treatment is determined by the size and displacement of the fracture fragment (3). This is usually defined by the involvement of the articular surface of the distal tibia. The generally accepted algorithm is that if the articular surface is affected by 25% or larger, then the fragment should be treated with fixation. If smaller than 25%, conservative management is typically the treatment of choice (4). In the original study by Nelson and Jensen, posterior malleolar fractures were divided by the size of the fragment determined by radiologic evidence. Determining the size of the posterior malleolar fragment appears to be less and less of a metric used to determine whether fixation is required. Using fragment size alone is too simple of a measurement when evaluating these complex injuries. Many surgeons are now primarily taking into consideration the morphology and presentation of the fracture pattern itself. Those fracture patterns with more medial extensions and more proximal extension are known to have a worse outcome long term and require more aggressive fixation (5).

Most current evidence suggests that fragments larger than 25% are best treated by considering the other aspects of the injury and how those relate to the overall stability of the joint. There are however many other studies that outline when surgical treatment is warranted. Other studies have suggested determining stability of the talus and if stable, then surgical treatment is not needed. If the medial and lateral malleoli are intact or fixated with the talus stable, then the posterior fragment should not affect the stability of the joint. Others have taken the Vassal principle into account stating that if the lateral malleolus is anatomically reduced then the posterior malleolus will heal into place with immobilization. However, fixing the posterior malleolus also leads to greater
syndesmotic stability and thus a more stable ankle joint (4). Yet another study indicates that in the treatment algorithm of posterior malleolar fractures the main consideration should be not the size of the malleolar fracture but instead whether or not a “step off” exists following reduction of any other potential injuries to the joint (6).

CASE STUDY

A 27-year-old man presented to the office for treatment options for a left ankle fracture that occurred approximately 7 months prior to presentation. The patient stated he was riding a motorcycle when he lost control, causing the vehicle to fall onto his plantarflexed and inverted ankle at a moderate speed. He was evaluated and treated at a local emergency department and was placed in a cast and told to follow up with the on-call physician. This physician decided to treat this injury conservatively believing that the fractures would heal effectively without intervention despite MRI and computed tomography (CT) showing a fibular fracture (Figure 1), posterior malleolar fracture (Figure 2), talar dome osteochondral defect, deltoid rupture (Figure 3), and posterior tibial tendon rupture. The patient continued to have pain once he was cleared for weightbearing 8 weeks later and was unable to work or perform daily activities for several months despite bracing. The patient was then referred to the senior authors for treatment. It was decided that a staged procedure was in the patient’s best interest to facilitate healing and prevent future pathologies.

Approximately 8 months following the initial injury, the patient was taken to the operating room for the initial procedure to repair his posterior malleolar fracture. An incision was made just lateral to the Achilles tendon and carried down to expose the fibular fracture paying close attention to and being sure not to violate the peroneal tendons and the neurovascular structures in this area. It was noted that there was a posterior fragmentation that was loosely adhered to the fibula via fibrous scar tissue. This was completely excised from the surgical site and prominent edges resected using a power rasp. At this time the ankle joint itself was exposed via a posterior capsular incision and inspected and noted to have unusually excessive amounts of chronic inflammatory adhesions and synovitis, which were evacuated from the joint. Attention was then directed to the previously seen talar cyst at the posterolateral aspect of the talus, which was drilled in a retrograde fashion and then packed with allograft to repair the defect.

At this time, the focus was shifted to the posterior malleolar fracture. An osteotome was used to recreate the fracture line of the previous injury. The fracture site was opened and noted to not only be a nonunion but also was noted to have intervening soft tissue preventing any true healing of the fracture. The edges of the fracture were freshened up to allow for a restart of the acute healing phases following removal of all soft tissue at the fracture site. Once healthy bleeding tissue was seen and all inter-positional soft tissue was removed, the posterior malleolus was temporary fixated in place before two 4.0 mm cannulated screws were inserted across the fracture site using a modified AO technique. The screws were oriented perpendicular to the fracture itself from posterior to anterior. Proper reduction and fixation were confirmed intraoperatively using C-arm.

Figure 1. Magnetic resonance image showing distal fibular fracture with minimal displacement.

Figure 2. Magnetic resonance image showing posterior malleolar fracture occupying approximately 30% of the articular surface of the ankle joint.
CHAPTER 16

The patient was placed in a posterior splint and instructed to remain strictly non-weightbearing.

The patient was seen 2 times prior to the second staged procedure. Patient reported good compliance with non-weightbearing status and was kept in a posterior splint. There were no significant postoperative complications. Approximately 6 weeks following stage 1 of the staged procedures the patient was taken back to the operating room for further correction of the left ankle joint involving soft tissue repair. An 8 cm incision was made from the medial tibia to the plantar aspect of the navicular tuberosity. Dissection was carried down through the ankle capsule and the deltoid ligament was exposed. Prior to the procedure, the patient had significant instability to the ankle with a positive talar tilt test. The deltoid ligament was noted to have severe degenerative changes with the remaining healthy ligamentous tissue noted to be quite thin. The healthy remaining tissue was primarily repaired using 3-0 Vicryl and the Arthrex Internal Brace system was used to reinforce the deltoid ligament with anchors in the calcaneus, talus, and medial malleolus. Intraoperatively, the ligament and internal brace were stressed and noted to have reduced eversion with significantly increased stability seen. Lastly, the posterior tibial tendon was noted to be lax with chronic degenerative changes. The redundancy of the posterior tibial tendon was measured to be about 1.5 cm. The tendon was advanced 1.5 cm and anchored into the navicular with fiberwire securing the tendon to the anchor. The patient was again placed into a posterior splint and was instructed to remain non-weightbearing.

The patient remained in the posterior splint for 3 weeks following the second procedure and was then transferred into a CAM boot with progressive weightbearing using his crutches for assistance. No postoperative complications were reported. The patient has progressed to full weightbearing and returned to full time work utilizing only an ASO brace. Follow-up radiographs show excellent healing of the ankle joint, with continued stability of the left ankle and subtalar joint clinically seen. The rapid improvement in pain and function of this patient shows the importance of proficiency in identifying and treating these complicated injuries (Figure 4 and Figure 5).

REFERENCES

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INTRODUCTION

The Achilles tendon, also known as the calcaneal tendon, unites 2 calf muscles into a single parallel-fiber dense connective tissue of great tensile strength. With a strength of approximately 50-100 N/mm², the Achilles tendon is the strongest tendon in the body. Despite its strength, the Achilles tendon is one of the most commonly ruptured tendons (1). More than 20% of acute Achilles tendon injuries are misdiagnosed (2). This misdiagnosis often leads to chronic Achilles tendon ruptures, which tend to occur within 4 to 6 weeks after the initial injury (3).

Chronic Achilles tendon ruptures may lead to retraction of the tendon, which results in an inadequate healing process, which will require a method of repair that calls for surgical augmentation. Due to the advantages of elastic strain modulus, reproducibility in technique, and the consistency of results without significant complications, when repairing chronic Achilles tendon ruptures, autografts offer the more reliable and successful method of augmentation when compared to other grafts (4). Ultimately, surgical repair of an Achilles rupture continues to be the gold standard of treatment. Surgical repair has consistently proven to decrease re-rupture rates, which along with the risk of infection are the primary concerns in the first 2 years after surgery (5).

CASE REPORT

On August of 2019, a 55-year-old woman with an unremarkable medical and surgical history presented to the office with chronic pain in the posterior aspect of the right foot and ankle. She had been referred by her primary care physician. The patient reported that the pain began 3 years before, one morning when she got out of bed. The patient said the pain began suddenly and she does not remember any trauma to the area. A magnetic resonance image (MRI) report, brought in by the patient indicated a partial tendo-Achilles rupture with extensive inflammation. Treatment options and their risks and benefits were discussed, and the patient gave consent for surgical correction. Preoperative evaluations were performed and she was taken to surgery.

A 10-centimeter incision was placed on the posterior right ankle along the Achilles tendon. However, after observing the extensive damage present, the incision was lengthened to approximately 15 centimeters. There was significant tenosynovitis present that needed to be debrided (Figure 1). Once the affected area was debrided, the extent of the rupture was better visualized (Figure 2), and it was
noted that the rupture was almost complete, and fat and synovitic infiltration within the tendon had occurred.

After evaluating the damage present, the tendon was released from the insertion and 6 centimeters of distal Achilles tendon was removed (Figure 3). The affected section was removed, the remaining distal edge was debrided, and the gap was measured in preparation for an aponeurosis autograft (Figure 4). Once measured, the required length of the aponeurosis was incised down to half-way depth (Figure 5) and reflected down (Figure 6).

Once the autograft was flapped down and it was confirmed to have the right length, it was anchored down to the posterior calcaneus using Arthrex Speed Bridge Anchors. In order to reinforce the autograft, the tendon was then grafted with a Matrix HD allograft (Figure 7). The incision site was closed with 3-0 nylon and the patient recovered from anesthesia without incident.

The patient spent 2 days in the hospital and experienced moderate pain at the surgical site. A 24-hour course of intravenous dilaudid and percocet were prescribed. The dilaudid was discontinued after 24 hours, and the percocet
after 48. The patient was then discharged home with a prescription for Tramadol to be taken 2-3 times per day (for 3 days) and a Duloxetine to help control nerve pain and sensitivity in the surgical area. The patient was followed-up in the office at 1 week.

**DISCUSSION**

Treating chronic tendo-Achilles ruptures can be challenging due to the extensive damage and inflammation that can be present. In this case, because the patient did not remember any trauma, she thought the pain would eventually disappear on its own. The patient also reported that eventually she became worried that a malignancy was present, and that led to further delay in treatment. Once the pain interfered with her daily activities, she sought help with her primary care physician, who ordered an MRI and then referred her to a podiatric surgeon.

After the surgery, most of the pain was localized at the level of the insertion, where the anchors were placed. The sutures stayed in place for 3 weeks without any incidents. The sutures were removed, and the patient was placed in a CAM walker for 2 additional weeks, after which the patient the patient will have 3-6 weeks of physical therapy. It is important to note that the left Achilles tendon is also currently being evaluated due to moderate pain. Tenosynovitis was diagnosed via ultrasound and it will be treated in physical therapy as well. If symptoms do not improve with physical therapy, endoscopic synovitis debridement will be considered.

**REFERENCES**

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Giant Cell Tumor of Soft Tissue: A Case Report and Review of a Rare Lesion

Scott Bird, DPM

INTRODUCTION

Giant cell tumor of soft tissue, also known as soft tissue giant cell tumor of low malignant potential (GCT-ST LMP) is a rare soft tissue tumor found most frequently in the extremities (1,2). GCT-ST LMP is distinct from other giant cell entities such as giant cell tumor of tendon sheath and more aggressive lesions such as malignant fibrous histiocytoma-giant cell type, although it does have an aggressive sibling lesion known as malignant giant cell tumor of soft tissue (2). It is histologically identical to osseous giant cell tumor and has the same remote chance of distant metastasis on occasion, with the main difference being its location within the soft tissues rather than in bone (3). Histologically, the GCT-ST LMP is characterized by the presence of osteoclast-like multinucleated giant cells and nodules of mononuclear histiocytoid cells without any evidence of atypia or pleomorphism, however a brisk mitotic rate and occasional vascular invasion can be observed. Tumors can present in the deep or superficial soft tissues and have no bony or tendinous attachments (4). Here we present a case of GCT-ST LMP that was located on the plantar surface of the foot.

CASE STUDY

A 31-year-old male athlete with no significant medical history presented for evaluation of a left foot lesion that was causing pain and disability. He had been seen by another provider and had undergone a marginal excision attempt with rapid recurrence within 1 month. The initial appearance of the lesion when the patient was evaluated by the other provider is shown in Figure 1A. A radiopaque nodule was seen within the soft tissues on the initial radiograph prior to presentation in our clinic, with no evidence of osseous involvement (Figure 2). After initial excision, the pathology assessment identified the lesion as a giant cell tumor of tendon sheath.

The lesion rapidly recurred, and the patient was referred to our clinic. At presentation, an ulcerated and hypertrophic nodule was noted on the plantar aspect of the foot (Figure 1B). Due to the aggressive recurrence, a magnetic resonance image was obtained. The pathology report identified the lesion as a “soft tissue mass in the plantar soft tissues superficial to the head of the first metatarsal and flexor tendon. The mass appears to be separate from the flexor tendon. The mass measures 3.9 x 2.4 x 4.9 cm and demonstrates T1 hypointensity and mildly increased signal intensity on the proton density weighted and STIR images…”

Based on this information from the pathologist, it was determined that a second excision attempt would be necessary, this time with a modified wide local excision. However, due to the plantar nature of the mass and the patient’s active lifestyle, there was concern over removing too much of his weight-bearing fat pad. There was low suspicion for malignancy, so the second excision attempt was made without the use of frozen section. Intra-operatively,
the lesion was shelled out in marginal fashion, followed by removal of a large amount of surrounding tissue that was normal in appearance. The lesion was sent for pathologic analysis and it was determined that it appeared different than a tenosynovial giant cell tumor. Therefore, expert consultation at Harvard Medical School was requested. Expert review at Harvard determined that the lesion was consistent with a giant cell tumor of soft tissue because it contained “multiple lobules consisting of relatively uniform mononuclear histiocytoid cells with palely eosinophilic cytoplasm admixed with numerous osteoclastic giant cells... (with) no evidence of malignancy, but the tumor is multifocally present at excision margins and there is therefore a distinct risk of local recurrence.”

The patient was informed of the results as well as the possibility of recurrence. He initially did well and the incision healed except for a small nodule that was appreciated at the midline. The small nodule proceeded to dehisce and have the appearance of a very small ulcer. Recurrence was suspected and, due to the locally aggressive nature of the tumor, orthopedic oncology consultation was requested. Unfortunately, the patient was lost to follow-up despite ongoing requests to communicate with him.

**DISCUSSION**

In 1972, two separate case series were published describing the behavior of soft tissue tumors that were characterized by giant cells and were found in the soft tissues (Figure 3). Guccion and Enzinger described 32 cases of giant cell tumor of soft parts, over half of which behaved very aggressively and caused death in their patients (5). They regarded the lesion as a high-grade sarcoma. That same year however, Salm and Sissons also published a case series of 12 cases of what they also called giant cell tumor of soft tissue. In contrast to Guccion and Enzinger, their series described a lesion with a benign clinical course that was treated well with excision but had the potential for local recurrence if not resected entirely. They concluded that this newly recognized entity was a relative of osseous giant cell tumor occurring primarily in the soft tissues (6).

Over the next few decades, GCT-ST was regarded as a malignant sarcoma in the pathology world. However, in 1999, Folpe et al published a series of 31 cases and asserted that giant cell tumors of soft tissue could be split into two groups: those with malignant potential and those with low malignant potential (2). He re-examined the work of Guccion and Enzinger and also reasserted the claim of Salm and Sissons in 1972 that GCT-ST LMP actually reflected a soft tissue version of bony giant cell tumor, which usually follows a benign clinical course. This was confirmed by other case series in the following years (4,7). Accordingly, a separate entity was recognized as malignant giant cell tumor of soft tissue, with the main differences between the two being the presence of atypia and pleomorphism in the malignant group.

Here we present a case of GCT-ST LMP. To our knowledge, ours is the first reported case of a GCT-ST LMP occurring on the plantar surface of the foot. In 2003, Kim and Han reported a case of GCT-ST LMP that occurred near the malleoli in a patient that they diagnosed using fine needle aspiration (8). Previous publications regarding GCT-ST LMP have reported the majority of these tumors occur in the extremities, but have not recorded their frequency in the acral region (1,2,4,7). There have been case reports of GCT-ST LMP being found in the head and neck and mediastinum as well (9,10). In contrast, giant cell tumor of tendon sheath has been reportedly found on the plantar surface of the foot (11,12). For example, Zhang and Huang reported 20 cases of giant cell tumor of tendon sheath in the foot and ankle and 3 of the cases were noted to be present on the plantar surface of the foot (13). While giant cell tumor of tendon sheath is associated with a tendon sheath or joint capsule, our case is unique in that imaging evidence revealed that there was no clear association with the flexor tendon sheath. Rather, the tumor originated in the soft tissues of the foot just superficial to the tendon.

Our case highlights the importance of obtaining clear margins when resecting a giant cell tumor of soft tissue. In this instance, it was felt that overaggressive resection might lead to the inability to bear weight on the foot in the future, making a wide resection difficult. The majority of case series and case reports have noted a very low recurrence rate when tumor resection margins were negative (2,4,7), but it is often noted that local recurrence is common if clear margins are not achieved. The best method to prevent recurrence is complete resection without leaving any neoplastic cells near the tumor site. This usually requires a wide resection. The use of intra-operative frozen section could be of use to determine during surgery if clear margins have been achieved, however this may not be available in all geographic areas. There have been reports of using

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Figure 3. Pathologic appearance.
radiotherapy postoperatively in an attempt to eradicate any remaining tumor cells if clear margins were not achieved (7), but the effectiveness of this technique is unknown as of yet.

The histologic findings of the tumor in our case are consistent with those described in the literature. The basic features of GCT-ST LMP are the presence of osteoclastic multinucleated giant cells surrounded by a background of uniform mononuclear cells with some sources also noting the presence of spindle-shaped cells (2,4,6,7). In addition, the key findings that distinguish a GCT-ST LMP from its malignant counterpart is the lack of any atypical mitoses or pleomorphism. GCT-ST LMP can, however, display a brisk mitotic rate and local vascular invasion (7). GCT-ST LMP can be differentiated from tenosynovial giant cell tumors by the lack of a dense hyaline stroma, which can be found in the latter (2). In addition, tenosynovial giant cell tumors usually have a clear connection to an underlying tendon. Giant cell tumor of bone has been described as having much the same features and behavior of GCT-ST LMP. Some sources cite the incidence of pulmonary metastasis in giant cell tumor of bone at between 1% and 9% of all tumors (14). GCT-ST LMP has also shown the ability to occasionally cause pulmonary metastasis, and thus the lesion should be treated with caution (15).

In conclusion, GCT-ST LMP is a primary soft tissue tumor that usually follows a benign clinical course, although it can rarely cause pulmonary metastasis. It is histologically and clinically similar to giant cell tumor of bone and is best treated by surgical resection. Our case highlights the difficulty of treating this lesion on the plantar surface of the foot, and the importance of obtaining clear surgical margins to ensure no local recurrence. Moreover, frozen section may be of benefit to the foot and ankle surgeon when approaching a suspected case of GCT-ST LMP.

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Intra-Articular Osteochondroma of the Ankle Joint: A Case Report

Kelly Brennan, DPM
Alan Banks, DPM

BACKGROUND

Osteochondromas are among the most common benign bone tumors, although they are not reported as such in the feet. They typically affect those ages 10 to 25 years with a higher incidence in males compared to females (1). However, extraskeletal osteochondromas are usually seen in those in the third through sixth decade of life (2).

Osteochondromas may present as either solitary or multiple lesions. Multiple lesions include a hereditary component and have a higher rate of malignant transformation than solitary tumors. Solitary tumors have a malignant transformation rate of only 1% (1). They are commonly found in the metaphysis of long bones, such as the distal femur and proximal tibia, as they originate from distal epiphyseal plates (3,4). Due to its origination pattern, osteochondromas are not considered to be true neoplasms.

Milgram suggested a three-stage evolution of osteochondromas. The first pathologic abnormality to occur is sub-synovial cartilage hyperplasia. This is followed by synovial hyperplasia and the production of round cartilaginous nodules, or chondromas (5). These chondromas continue to grow as they are nourished in synovial fluid. Once calcified, they become known as osteochondromas. Gross examination of these specimens reveals a shiny, cartilaginous cap with cauliflower-like appearance with magnetic resonance imaging (MRI) findings of a hyaline cartilage cap characteristic of this bone tumor (6).

Maurice et al noted the recurrence rate of osteochondromas to be 11.5% after surgical intervention, and a prevalence of less than 5% of all cases occurring in the ankle joint is reported by Robinson et al (7,8). Cromer describes a case report where a synovial osteochondroma was seen in a relatively short time frame after an incidence of traumatic injury. He theorized that trauma may play a role in the dysplasia of chondrocytes and initiation of an osteochondroma (9).

Associated complications for osteochondromas involve osseous deformities, fractures, bursa formation, vascular compromise, and neurologic symptoms (10). In this case report, the authors illustrate an intra-articular osteochondroma of the ankle joint sustained 10 years after traumatic injury.

CASE REPORT

A 64-year-old woman presented to the senior author’s clinic with left ankle pain after sustaining an ankle sprain in 2007. She related that she has had anterior and lateral ankle pain ever since that initial injury with difficulty ambulating in recent years. A fine-needle aspiration was performed of the anterior left ankle mass and revealed an intra-articular osteochondroma after MRI showed a large mass.

In perioperative discussion, there was a question as to whether the mass extended into the subtalar joint. Figures 1-3 show the expansiveness of the anterior ankle mass from
Figure 3. Magnetic resonance image of the lateral aspect of the left ankle.

Figure 4. Tumor exposed after ankle joint incision and periosteal reflection.

Figure 5. Separation seen between the ankle joint and tumor.

Figure 6. Tumor seen cleanly reflected from underlying ankle joint articulation.

Figure 7. Excision of the tumor in total measuring approximately 4 cm in width.

Figure 8. Osteochondral defect seen in the talus after removal of the tumor.
medial to lateral. Figure 2 illustrates the mass at its widest anterior to posterior portion measuring 17.9 mm.

Surgical exposure was achieved through an incision at the medial aspect of the ankle between the medial malleolus and tibialis anterior tendon. Dissection was carried down to the subcutaneous tissue, and superficial fascia was dissected from underlying deep fascia. The medial ankle capsule and periosteum were incised, and the anterior ankle tumor was readily exposed. An obvious separation was seen between the cortex of the anterior tibia and the intra-articular tumor. Careful dissection was then used to remove the approximately 4 centimeter wide mass in total where some extension to the lateral ankle joint was noted, however, no communication into the inferior subtalar joint was found. Further inspection into the ankle joint revealed damage to the dorsal aspect of the talus and anterior tibia secondary to the mass. This anterior tibial lip was remodeled with hand resection, and improvement of ankle passive range of motion was noted.

The ankle joint was flushed copiously with normal saline, layered closure was performed, and the patient was placed in a below-knee fiberglass cast. The specimen was sent to the pathology department and was identified as a solitary synovial osteochondroma. The patient went on to heal uneventfully.

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Malignant Melanoma Masquerading as Ganglion Cyst

Ryan Bangart, DPM
William D. Fishco, DPM

INTRODUCTION

Soft tissue masses in the lower extremity are commonly seen in the office setting. The most common pathologies include ganglion cyst, lipoma, fibroma, synovial cysts, giant cell tumor of tendon sheath, and rheumatoid nodules. Although benign tumors of the lower extremity outnumber malignant primary tumors by up to five times (1), an unexpected result can leave physicians unsure of what steps to take. This case report highlights the case workup after an unexpected result of a soft tissue mass excision.

CASE PRESENTATION

A 34-year-old man presented with a 5-month history of a mass at the right ankle (Figure 1, Figure 2, Figure 3). There was no pain with direct or side-to-side palpation of the mass. The mass would swell at the end of the day and cause local irritation and irritation of the sural nerve. The patient denied any inciting event. His medical history was unremarkable. He reported bilateral foot surgery as a child for “intoeing” and his social history was positive for smoking one-half pack a day. The patient denied any systemic symptoms such as night sweats, weight gain, or weight loss. He related that the mass had been progressively increasing in size. Prior treatment included an aspiration of the mass at an outside facility with removal of “bloody drainage” (as reported by the patient).

Physical examination revealed palpable pulses rated 2/4 to the DP and PT arteries, bilaterally. The capillary refill was immediate to the level of the distal toes and pedal hair was present. Epicritic sensation was intact to the level of the toes. A soft tissue mass was noted on the lateral right ankle just distal to the sinus tarsi. A negative Tinel’s sign was noted with percussion of the soft tissue mass. The mass measured approximately 3.5 cm in diameter with accentuated skin lines overlying it. The mass was slightly mobile, nonfluctuant, and firm. There was no pain with direct palpation of the mass and there was no skin discoloration. Orthopedic examination revealed no limitation or crepitus with range of motion of the subtalar, ankle, or midtarsal joints.
Ancillary studies included plain film radiographs and ultrasound. Radiographs showed diffuse lateral foot swelling and a small radiopaque area in the center of the mass (Figure 4). No osseous abnormality was noted in the area of the mass. Ultrasound showed a multilobular, hypoechoic lesion in the subcutaneous fat (Figure 5 and Figure 6). No involvement of the skin or underlying muscle was noted. The lesion was avascular on Doppler studies. The radiologist’s interpretation of the ultrasound was suggestive of a ganglion cyst.

Due to the increasing size, failed aspiration, and radiographic findings, magnetic resonance imaging (MRI) was obtained to rule out a ganglion cyst and for surgical planning (Figure 7, Figure 8, Figure 9). T2-weighted MRI showed a multi-lobulated hyperintense signal with surrounding edema. Additionally, bone marrow edema was seen adjacent to the mass with no obvious communication. The radiologist’s interpretation of the MRI was ganglion cyst with lateral calcaneal bone marrow edema.

The decision was made to proceed with surgical excision.
of the soft tissue mass. A lateral incision was made over the mass and dissection was carried down to the peroneal tendon sheath. The sural nerve and peroneal tendons were identified and protected. Intraoperative findings included a firm, semi-mobile mass that was partially incorporated into the peroneal tendon sheath. There was an identifiable stalk attached to the subtalar joint. Biopsies of the mass were taken at 12, 3, 6, and 9 o’clock around the lesion as well as centrally over the stalk to the level of the joint. The mass was approximately 5 cm in diameter (Figure 10 and Figure 11). The pathology results were consistent with malignant melanoma. The pathologist dictated the following, “sections show a frankly malignant spindle and epithelioid cell neoplasm with focal arrangement of tumor cells in nests. Constituent cells focally show rhabdoid cytomeiology, grow in a perithelial pattern with surrounding necrosis, and show frequent nuclear pseudoinclusions” (Figure 12, Figure 13, Figure 14). Stains were positive for S100, SOX10, and focally positive for melan-A. Stains were negative for HMB45, desmin, SMA, CD34, and pancytokeratin. Biopsy of the stalk was also consistent with melanoma, suggesting retained tumor.

At his first postoperative appointment, the patient was found to have routine healing of the surgical site. With the assistance of a general surgeon, a full body skin assessment was performed of the patient to determine if there was a primary skin lesion. No lesions were identified. The patient also noted a new swelling in his right shoulder. The patient was seen by an oncologist who recommended a PET scan and computed tomography (CT) for tumor staging and possible identification of primary tumor (Figure 15, Figure 16, Figure 17). The patient had focal lesions identified to the right shoulder and right lateral femoral condyle. There was an area of increased uptake at the gastro-esophageal
junction that was difficult to distinguish between anatomic variant or possible primary source. Ultrasound guided aspiration of right shoulder lesions was identified as spindle cell neoplasm. Biopsies of the gastro-esophageal junction were negative for neoplastic cells.

The patient was started on chemotherapy at 3 months postoperative with a regimen of Iplimumab/Nivolumab. After three rounds of chemotherapy, the patient complained of lethargy and persistent headaches. MRI of the brain was obtained to evaluate for metastases to the brain, which was negative. Laboratory values revealed a low free T4 and elevated TSH, consistent with hypothyroidism, which is a known complication of this particular chemotherapy regimen.

A repeat PET/CT scan was ordered to evaluate the patient’s response to chemotherapy. The right shoulder and knee nodules were found to have no change. The right foot showed increased uptake in the calcaneus, suggesting local spread of the cancer to the calcaneus. The patient is currently scheduled for excision of right shoulder lesion. No plans for the lesion on right knee have been made at this point, and further evaluation by oncology is underway.

**DISCUSSION**

Malignant melanoma is relatively rare, accounting for approximately 4% of all skin cancers (2). In this case report, it was unclear whether this tumor was a primary or a secondary tumor of unknown source. There are case reports of melanoma with a primary lesion of the calcaneus (3) as well as metastatic cancer of an unknown primary lesion (4). This presentation is unusual because it is highly unlikely that a primary tumor would metastasize to the lateral foot. This would lead one to believe that this is a primary tumor.

It should be noted that this presentation is different than clear cell sarcoma (CCS) (5-7). CCS, is also called
malignant melanoma of soft tissue and is similar in histologic appearance to melanoma. Many stains are similar, but there are different morphologic characteristics (8). The survival rate of CCS is poor, with estimated 5-year survival at 67%, 10 year at 33%, and 20 year at 10% (5). The survival rate of metastatic melanoma for 5 years is extremely low at 5-19% (9). Results of a 2-year study by Sandru et al showed that 80.6% of patients who developed metastases, died. The tumor has a high likelihood of metastases to lung, brain, and visceral organs.

When primary surgical excision is possible, margins of 2 cm are recommended after initial staging. Using Breslow classification, tumors greater than 2 mm thickness are associated with poor prognosis. A study by Thomas et al showed that there was no difference in the survival rates between those who had 1 cm surgical margins and those with 3 cm surgical margins. When primary excision is not possible, aggressive treatment via below knee amputation is a viable option (10).

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Introducing the Enhanced Recovery After Surgery Approach

Jared Cicero, DPM
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Enhanced recovery after surgery (ERAS) is a set of guidelines aimed to standardize perioperative care in an attempt to minimize variability, reduce errors, decrease postoperative pain, decrease length of hospital stay, and save healthcare dollars. ERAS protocols have been formulated for numerous specialties. Initially, ERAS was defined for patients undergoing colonic surgery but have evolved to meet demands of other surgical patients. The ERAS guidelines tie together results and recommendations of high-level literature and over time have gained popularity as results demonstrate clinical outcome advantages. Key perioperative categories that ERAS aim to improve and standardize include prophylactic use against thromboembolic events, postoperative fluid therapy, perioperative nutritional care, prevention of postoperative ileus, postoperative glucose control, and postoperative analgesia management.

Given the current opioid crisis, perioperative pain management practices have recently been more strictly regulated by the Drug Enforcement Administration, insurance companies, and healthcare providers. The use of opioid alternatives is a topic of growing interest. Mitigating the effects of opioid addiction starts with prevention. In an effort to decrease opioid use, the ERAS approach utilizes adjunct medications and a multi-modal approach to minimize opioid needs. This area of research is not just clinically significant but crucial for the welfare of society. According to the Centers for Disease Control and Prevention, drug overdose deaths from prescription opioids quadrupled between 1999 and 2014 (1). In 2018, 42,000 deaths were reported to be related to opioid overdoses (2).

Despite the worsening opioid epidemic, opioids are still the most frequently prescribed postoperative medication for the management of pain following orthopedic surgeries. Different patients have various pain tolerances and anticipated pain levels depending on the extent of the surgery. It is ultimately the prescribing physician’s responsibility to select the most appropriate drugs, their dose, the quantity prescribed, and to regulate the duration of refills.

Opioid dependence and addiction affect individuals differently and the length of time it takes to become dependent or addicted also differ, but there has been substantial evidence showing that the longer time that individuals take opioids, the greater their risk of developing physical dependence (3). Opioid addiction and physical dependence can lead to worsening substance abuse of harder drugs such as heroin, exponentially worsening the situation (3).

To minimize opioid demands, ERAS uses adjunct medications and a multi-modal approach. Acetaminophen (Tylenol), gabapentin (Neurontin), celecoxib (Celebrex) and regional nerve blocks have been found to synergistically reduce postoperative pain and thus opioid needs. The regional block provides a pre-analgesic effect and continues to provide anesthesia and control pain for hours following surgery. The 3 adjunct medications have different mechanisms of action to target different intermediate steps along the complex pain pathways, which link the peripheral and central nervous systems (4) (Figure 1).

Several publications have shown that gabapentin, as a solo adjunct, decreases postoperative pain. Gabapentin is a synthetic analogue of g-amino butyric acid. It reduces neuron excitability and inhibits pain transmission through the spinal cord. A study published in 2015, reported that preoperative gabapentin resulted in opioid and pain reduction 24-hours postoperatively in lower extremity orthopedic surgery (5). Although gabapentin recently has been designated a controlled substance, the risk of abuse and dependency is significantly less compared to opioids (5).

Inflammation plays a necessary role in healing,
However, excessive inflammation following surgery is a large contributor to postoperative pain. Inflammation can be controlled with icing and elevating the extremity but even more so via the use of nonsteroidal anti-inflammatory drugs (NSAIDs). NSAIDs inhibit the rate-limiting cyclooxygenase (COX) enzyme in prostaglandin synthesis, which is a major precursor of inflammatory signaling. Although there has historically been some question as to whether NSAIDs influence bone healing, there has been no compelling evidence to substantiate those concerns, especially when considering prescribing only a 3-day oral NSAID course. Celebrex, an NSAID with COX-2 specific inhibition, has been reported to be a reliable NSAID for postoperative pain control (6). A 2017 report demonstrated that preoperative administration of Celebrex significantly improved pain control 12 and 24 hours after surgery (4).

Acetaminophen (Tylenol), is a very weak anti-inflammatory but offers analgesic and anti-pyretic effects. It has also been found beneficial in postoperative pain management. The mechanism of action of acetaminophen is not fully understood but it is believed that it has a central and peripheral site of action. In 2017, Yang reported a significant reduction in pain and opioid usage with the use of intravenous acetaminophen (Ofirmev) after total hip arthroplasty. This significant pain reduction had its effect for 3 days postoperatively, presumably when the pain would be the worst following surgery. The effect of route of administration of acetaminophen (oral versus intravenous) has not been shown to have an impact on efficacy (7), however, oral administration is certainly less expensive. These areas have not been studied specifically following foot and ankle surgery but we assume the conclusions can be generalized to other orthopedic surgeries.

The ERAS protocol also guides peri-operative nutrition supplementation with the use of nutrition shakes, specifically Ensure (Mountain View, CA) at our institution. Traditionally, decreased oral intake prior to surgery, tissue injury during surgery, and pain following surgery result in relative insulin resistance and subsequently a hyperglycemic state. Nutritional shakes provide carbohydrate loading and reduce insulin-resistance. In reducing the postoperative hyperglycemic state, there have been reported decreased lengths of hospital stays, fewer wound healing complications, and lower infection rates (8). Reduction in insulin resistance also results in better postoperative pain control (8). Recommendations have differed on the number of shakes preoperatively and postoperatively but a mainstay recommendation is to ingest 1 protein shake 2 hours prior to surgery.

As discussed, the ERAS protocol is not a set of absolute mandates but merely an evidence-based guide that can be customized for each specific patient. There may be contraindications to medications and clinical scenarios where the ERAS approach may not be best. Patients who have a known allergy to any of the adjunct medications should obviously have the protocol altered to avoid that medication. Also, specific considerations must be taken when dealing with pediatric, elderly, or pregnant patients, patients with liver or kidney disease, those with GERD or a history of stomach ulcers, patients with sensory neuropathy, or patients taking non-compatible medications, etc. The effects of ERAS have not been specifically studied in the pain management patient population.

Currently, there are no published ERAS guidelines specific for foot and ankle surgery. Compelled by ERAS outcome studies in other areas of orthopedic surgery, the senior author adopted a modified ERAS protocol and found excellent anecdotal results with decreased pain reported from his surgical patients (Table 1). Many patients who previously had contralateral foot/ankle surgery reported less pain with the ERAS approach. Several patients even called the office for refills of the adjunct medications after they completed the 3-day postoperative adjunct course because they reported that pain increased at postoperative day 4 when the adjunctive medication prescriptions were completed (Table 2). Patients receive education of the ERAS approach in the office during their surgical consultation. Preoperative medication doses are ordered to be administered by the hospital when the patient is in the preoperative unit. Not all patients elect to purchase the nutritional drinks so this may

### Table 1. ERAS guidelines adopted for our foot and ankle surgery patients

Preoperative doses of the following:
- Tylenol 1000 mg PO, given 1 hour prior to surgery
- Celebrex 200 mg PO, given 1 hour prior to surgery
- Gabapentin 600 mg PO, given 1 hour prior to surgery
- Nutritional drinks (Ensure shakes). It is suggested that patients drink 2 nutritional drinks daily for 3 days prior to surgery, one nutritional drink 2 hours prior to surgery and 2 nutritional drinks daily for the 3 days following surgery.

### Table 2. Discharge medication prescriptions

- Acetaminophen 500mg #18, two PO taken every 8 hours x 3 days
- Celebrex 200mg #6, one PO, taken every 12 hours x 3 days
- Gabapentin 600mg #6, one PO taken every 12 hours x 3 days
- Opioid of choice (Oxycodone or Hydrocodone)
be a limitation. Although we understand the rationale for how nutritional drinks can help our foot and ankle surgery patients, we also realize that the nutrition shakes may also have a greater impact in other surgery patients (colonic surgery, etc.).

Our hospital institution and the anesthesia department broadly utilize the ERAS approach and supports it (including drinking a nutritional shake 2 hours prior to surgery). We have not experienced any anesthesia events or aspiration episodes related to pre-operative shake consumption. A large review study from Brady et al in 2003 assessed 22 randomized control trials and concluded that there was no evidence to suggest shortened fluid fasts result in an increased risk of aspiration (9). This is also our experience.

The authors present this update as an introduction to the ERAS approach, which we believe will be adopted by other podiatric surgeons, providers, and healthcare systems in the future. If the reader approaches this concept with an open mind, we believe the patient outcomes will be convincing enough to adopt this approach and ERAS will continue to benefit our patients, our healthcare systems, and society. Next, the authors will prepare a prospective, randomized clinical study to objectively assess the influence that the ERAS approach has on postoperative pain levels and opioid demands following foot and ankle surgery.

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INTRODUCTION

In the field of podiatric medicine, a vast majority of injuries to the feet are observed but the link between a patient’s dominant foot and the injuries they are prone to is still premature. Having a dominant foot is derived from the concept of laterality. Laterality is a term used to designate the asymmetrical use of limbs or sensory organs (1). The human body is characterized by asymmetrical dominance pertaining to the majority of its components. A person’s laterality is influenced by the physical development and changes induced by cultural and environmental factors (2) making it an important aspect of human development and function. It is not solely a trait specific to humans but has been recognized among other species. Recent evidence shows that nearly 70% of nonhuman vertebrates have exhibited limb preferences (3).

The notion of laterality is mostly familiar to the public based on the concept of having a dominant hand. Having a dominant hand is understood globally and culturally and is gaining more traction towards being utilized in research. In 2013, a study conducted by Marcinowski et al, predicted that infants with a hand preference would develop cognitive skills earlier, and found that a hand preference did relate to earlier development of object stacking skills (4). In humans, handedness is the most-widely studied lateral preference, but a similar asymmetrical use has been described for other paired organs such as feet, eyes, and ears (1). The results of a study conducted by Tran and Coracek in 2016, reported that footedness is a more relevant predictor of motor abilities and sporting performance than handedness, and is less subjected to cultural biases (5). Handedness has always been considered a reliable predictor for language dominance, but subsequent findings stress a close relation between language dominance and footedness, suggesting foot preference may be a superior indicator for language laterality (3). These findings illustrate the importance of studying laterality as it pertains to the lower extremity, particularly the foot. Various studies have already been conducted in trying to understand the effects of foot dominance across the board ranging from the effect it has on playing sports to the effects displayed when evaluating musculoskeletal disorders. However, there is still a need for a podiatric focused study regarding the dominant foot as it pertains to the biomechanic, pathologic, and neurologic aspects of patients.

METHODS

We decided to focus on 2 studies conducted in 2019 that focused on foot dominance and its effects on playing sports and musculoskeletal disorders, specifically The Evaluation of Musculoskeletal Disorders Seen in Footballers with Regard to Dominant Foot Preference (6) and The Effect of Unilateral and Bilateral Foot Dominance on Sprinting Speed of Young Athletes (7).

Tanir et al (6) utilized primary research in the form of questionnaires to collect data. Their research sample consisted of 40 male football players, age range 14-18 years from the Aydin Incirliova Sport High School in the school year of 2018-2019. The Waterloo Handedness Questionnaire created by Elias et al was utilized to determine the dominant foot. The Cornell Musculoskeletal Disorders Questionnaire was implemented in order to determine the frequency and severity of musculoskeletal disorders in 18 parts of the body and whether these disorders affected working capacity. The data collected were then analyzed using SPSS 22.0 software with 95% confidence intervals and a significance level of $P = 0.105$. The Kolomogrov-Smirnov test was used to exhibit normal distribution and then an independent sample t-test to test the difference between the 2 sample groups based on averages. Age, height, weight, and body mass index were also incorporated into the data collection.

Selcuk et al (7) collected data from 156 males and 37 females who were participating in the entrance examination for schools of physical education and sports in Yuzuncu Yil University in 2015. The research entailed participants sprinting from a standing position with one foot placed on the start line. Two runs were conducted at the person’s maximum speed, over a 30-meter distance. The person’s foot dominance was then determined by asking them to kick a soccer ball and they were later asked if they had the...
ability to kick the ball with just their right foot, left foot, or both placing them in different categories (unilateral footed or bilateral footed). The Kolomogrov-Smirnov Test was also used to exhibit normal distribution and the Mann Whitney-U test was used to test the difference between the 2 groups.

**RESULTS**

In the study by Tanir et al, the average age of the football players was 16.20 ± 0.96 years, the average length was 1.68 ± 0.08 cm, and body weight was 59.40 ± 8.56 kg. The average body mass index was 20.75 ± 1.91 kg/cm². There was no statistical significance found in terms of difference between the left and right-footed players based on the types of injuries seen in the upper extremity (P > 0.05). This suggested that a player’s dominant foot does not affect injuries that occur in the upper extremity. In regard to injuries located in the lower extremity, there was statistical significance found in terms of injuries exhibited in the left upper leg, left knee, and left lower leg (P < 0.05). They discovered that right-footed players experienced an increase in injuries on their left upper leg, left knee, and left-lower leg when compared to the left footed-players. There were no significant differences recognized between right- and left-footed players when analyzing injuries located in the hip, right upper leg, right knee, and right lower leg (P > 0.05).

In the study by Selcuk et al there was no significant difference between unilateral and bilateral footers in terms of sex. There were 156 males in this study (127 unilateral footed and 29 bilateral footed), 102 were right footed, 25 were left footed, and 29 were bilateral. There were 37 females in this study (29 unilateral footed and 8 bilaterally footed), 28 were right footed, 6 were left footed, and 3 were bilateral. There were significant differences noted in the second 30 meter run between 2 groups of males who were physically similar. In the first sprint, the male average sprint speed was 6.88 meters/second (unilateral footed) and 6.95 meters/second (bilateral footed). In the second sprint, the male average sprint speed was 6.93 meters/second (unilateral footed) and 7.93 (bilateral footed). The average sprint speed for unilateral footed females was 5.59 meters/second and for bilateral footed females, 6.35 meters/second in the first sprint. In the second sprint the average was 5.67 meters/second for unilateral footed and 6.33 meters/second for bilateral footed.

**DISCUSSION**

Based on the studies reviewed, it is evident that the concept of foot dominance holds truth. Being right- or left-footed determines human capability as well as muscular destruction that we are prone to. The concept of mobilization and stabilization plays a crucial role in determining the dominant foot. Investigation in adults has revealed that mobilization tasks are featured by a strong and well-defined preference for a single foot, predominantly the right one (8). Bilateral-footed athletes are superior in terms of neurologic and mechanical advantage when playing sports in comparison to unilateral-footed athletes. Bilateral muscle groups are utilized frequently and maintain a sense of equal strength, protecting them from musculoskeletal injuries.

With dominance comes favoritism and the increased use of one extremity leading to an increase in muscle strength and ability while simultaneously a decrease in muscle strength and ability of the other extremity. It has been foreseen that athletes are more prone to injuries in the non-dominant foot. For example, athletes, such as soccer players, are more likely to injure their non-dominant foot because of insufficient strength (6). This comes as no surprise because with a decrease in utilization of an extremity, comes muscle weakness, leading to an increase in injury. A correlation can be made between the knowledge that the dominant foot is utilized more for actions that require power and strength, which results in asymmetric development of the right and left foot/legs. Having minimal sample size, data, and exploration of topics pose some limitation to our review and this study may be enhanced by including these factors.

In conclusion, the concept of laterality is important because it can lead towards understanding of patient’s injuries based on their activities. This knowledge will enhance the doctor’s treatment plan and will bring the best results for the patient’s healing potential. For example, if a patient is postoperative and must be non-weightbearing, it may be harder for them to be compliant based on whether it is their dominant or non-dominant foot that has been injured. There may be an increase in the patient’s healing potential based on extremity dominance. Understanding dominance with regard to the foot is an amazing tool for podiatrists who can utilize this information within their biomechanic evaluations, musculoskeletal examinations, and neurologic examinations. We suggest that determining of foot dominance should be incorporated into all biomechanic and musculoskeletal foot examinations.
There is a need for research exploring the benefits of foot dominance when treating patients. A podiatry-focused study of the dominant foot could explore aspects of differences in weight-bearing load, deviation of joint axes, and limb-length discrepancies. These topics could help all podiatrists have a heightened understanding of common conditions such as hallux abducto valgus, hammertoes, pes planus, metatarsus adductus, posterior tibial tendon dysfunction, and other foot pathologies that may be associated with abnormal foot mechanics based on foot dominance.

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CHAPTER 23

Formation of Heterotopic Ossification With Use of Standard Saw Versus Ultrasonic Saw Following Transmetatarsal Amputation: A Case Comparison Study

Jared L. Moon, DPM

INTRODUCTION

The current standard of care for amputation surgery in the foot generally involves cutting bone with the use of an oscillating or sagittal saw for procedures such as isolated ray resections or transmetatarsal amputations. Heterotopic ossification (HO), excess bone formation at the amputation stump, is very common following these amputation procedures and has been reported to be as high as 75% (1). When a patient develops HO following amputation surgery, there is a 25% chance of developing recurrent ulceration (1). With advances in technology, surgeons now have access to ultrasonic saw equipment. While this technology is at the moment more commonly used by neurosurgeons it is also available to foot and ankle surgeons and may have benefit for reducing the postoperative incidence of HO. Below we present 2 cases, both of which had an initial transmetatarsal amputation performed with a standard saw and both went on to develop HO. Further we discuss how these 2 patients were managed differently following their revision surgery and how this relates to limiting the reoccurrence of HO.

CASE 1

A 59-year-old male, type 2 diabetic presented for consultation several years after transmetatarsal amputation performed by another surgeon. Initially, amputation was performed secondary to a gunshot wound. Subsequently, the patient developed open ulceration to the plantar amputation stump area that had become chronic. The patient had been treated with conservative care for several years through various wound clinics and by several physicians without success. His diabetes was well controlled without medication and managed through diet. He had adequate blood flow to the lower extremity. Clinical examination showed ankle equinus and the radiographs showed HO (Figure 1).

After additional attempts at conservative treatment under our care the patient again failed to improve and exhibited continued plantar ulceration. The surgical approach initially consisted of an Achilles tendon lengthening, and surgical resection of the HO was not performed. This was unsuccessful as the patient continued to have chronic ulceration at the plantar amputation stump area. Additional surgery was then performed with revision of the transmetatarsal amputation by cutting back each metatarsal more proximally to remove the area of prominent HO. This was done with the use of standard saw instrumentation. This attempt was also unsuccessful as there was reoccurrence of the plantar ulceration. Figures 2 and 3 are radiographs demonstrating the reoccurrence of HO at each metatarsal amputation stump, and the HO is now worse than it was prior to the revision surgery. Unfortunately for the patient his plantar ulcer persisted secondary to our inability to control formation of HO.
CASE 2
A 37-year-old male, type 1 diabetic was initially seen through inpatient consultation with sub-first metatarsal ulceration and osteomyelitis at the first metatarsophalangeal joint. The patient had a previous history of diabetic foot ulcerations to the lesser metatarsal area and was managed by another surgeon with partial third and fourth metatarsal head resections in addition to total right fifth ray amputation. Figure 4 shows the initial radiograph with significant osteomyelitis at the first ray and significant overall distortion to the structure of the right forefoot secondary to multiple previous surgical interventions. In addition to consultation with infectious disease and intravenous antibiotic management, we made the decision to proceed with transmetatarsal amputation. Amputation was performed with a standard bone saw.

Over the next year, the patient continued to have issues through developing pressure ulceration to the transmetatarsal amputation stump. At this point it seemed that this recurrent ulceration was secondary to the varus attitude of the forefoot because the patient had previous total fifth ray resection, which likely disrupted insertion of the peroneus brevis tendon. Additionally, the patient had ankle equinus. These issues were then addressed surgically with a tibialis anterior tendon transfer and gastrocnemius tendon recession. Unfortunately, the foot ulcer still persisted at 7 months postoperative and eventually the diagnosis of HO was made. Figure 5 is a radiograph demonstrating significant HO at the amputation stump. Further surgery was then performed with revision of the transmetatarsal amputation stump by cutting each metatarsal bone back further, although an ultrasonic saw was used. Figure 6 is a radiograph at 6 months postoperative where only minimal HO formation seen. The patient has since remained ambulatory with no open wounds. This case demonstrates successful management of HO with use of ultrasonic bone saw as compared to unsuccessful management with standard bone saw described in Case 1.
DISCUSSION

HO is not a commonly discussed pathology. Foot and ankle literature is relatively limited on this topic other than the articles discussed here. Additionally, HO is rarely, if ever discussed at foot and ankle conferences. This is somewhat surprising to the author considering how common HO is and how negatively it affects the surgical outcome of foot amputation surgery.

HO likely results secondary to bleeding through medullary bone after the amputation saw cut is made, followed by further differentiation of the cells resulting in bone formation. This would mimic the same process we would see with callus formation after a metatarsal shaft fracture. Utilization of an ultrasonic bone saw gives surgeons the ability to increase the power setting, which allows for excess heat production during the cut. This causes a cautery effect on the amputation stump and limits the amount of blood that oozes from the bone and should decrease the chance of developing HO. Additionally, the ultrasonic bone saw can be used in reconstruction surgery when making osteotomies. Through use of the irrigation system that the ultrasonic saw supplies and a lower power setting, the surgeon can limit the amount of heat generated from the saw and have the inverse effect of that which we just described above. This approach would in theory limit the amount of cell death from the bone cut.

Table 1. Surgical techniques that decrease the chance of developing heterotopic ossification

- Make the bone cut with an ultrasonic saw on the high power setting with low irrigation.
- Use local anesthetic with epinephrine to cause vasoconstriction of surrounding blood vessels.
- Irrigate with cold saline to induce vasoconstriction of the surrounding blood vessels using pulse lavage.
- Use a pneumatic ankle tourniquet in cases where peripheral vascular disease is not of concern.
- Leave the surgical site open for 2-3 days and then return to the operating room for final wound closure.

Table 1 presents a list of surgical techniques the author commonly uses to help prevent HO. All are focused on preventing bleeding from the amputation stump. These techniques may not be necessary when the patient has peripheral vascular disease. Research has shown that HO is much less prevalent in patients with PVD (1). Although the above techniques may be very useful in revision cases where a patient has already developed HO from a previous surgery.

Perioperative radiation therapy is another option to consider for prevention of HO. Success with this technique in other locations in the body has been documented (2,3). Boffeli has also published success when using radiation therapy during foot surgery with partial metatarsal amputations (4). The author has no experience with this technique, although this topic of discussion was not complete without its mention.

HO is a common complication almost never discussed. Surgeons need to be more aware of this pathology and the complexities of managing it. Modifying surgical technique can help impact more successful outcomes during limb salvage surgery. New technology such as the ultrasonic saw should be considered and simple surgical techniques to limit bone bleeding can be utilized.

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CHAPTER 24

Current Guidelines for Narcotic Prescribing for DPMs in 2020

Michael C. McGlamry DPM

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.
“I don’t care....It doesn’t effect me”

YOU WILL BE MADE TO CARE

THAT was a FAINT IDEA AND YOUR FREEDOM TO RELIGION

ERICK RICKSON and BILL FLAKSCHSK

Figure 7.

Prescribing Time Limits

• 7 day limit
  - AK, HI, CO, UT, OK, LA, MO, IN, WV, SC, PA, NY, ME, CT, MA
• 5 day limit
  - AZ, NC, NJ
• 4 day limit
  - TN, KY, FL

Figure 8.

New Regulations

ECPS

• Electronic Prescribing of Controlled Substances
• Requires all Medicare part D Rx’s for controlled substances be delivered by e-scribe by Jan 1, 2021

Figure 9.

Figure 10.

Individual state requirements

• NC STOP Act
• Requires e-scribe of controlled substances by Jan 1, 2020
• NY mandate EPS as required 2016
• PA Requires effective October 24, 2019
• AZ, IA, MA, NC, OK, RI Jan 1, 2020
• CA Requires ALL e-scribing Jan 2022
• Walmart initially planned to stop accepting paper Rx’s Jan 1, 2020, postponed as of 12/11/2019

DEA Proposals 2020

• Decrease fentanyl production by 31%
• Decrease hydrocodone production 19%
• Oxycodone 9%
• Hydromorphone 25%
• Oxymorphone 55%

Overall goal to decrease 53% compared to 2016

Figure 11.

Figure 12.
Figure 19.

Figure 20.

Figure 21.

Figure 22.

Figure 23.

Figure 24.
Jury finds podiatrist guilty of operating pill mill

ATLANTA – Dr. Aminia Avery-Kelly, a licensed podiatrist, has been found guilty on federal charges of illegally prescribing opioid painkillers and other drugs at clinic locations purporting to provide podiatric care in Sandy Springs and Lithonia, Ga.

"Dr. Avery-Kelly, DPM, abused her position as a podiatrist and recklessly prescribed very powerful and addictive opioids without any regard for the devastating effects they would have," said Special Agent-in-Charge Derrick L. Jackson, U.S. Department of Health and Human Services, Office of Inspector General, in Atlanta. "HHS-OIG is committed to bringing to justice, those medical practitioners who would endanger our communities, taint their profession and abuse their ability to prescribe these drugs for profit."

Federal investigation began when Georgia Drug and Narcotics Agency agents contacted Dr. Avery-Kelly in November 2013, and again in February 2014, to discuss the high-volume, high-dosage prescriptions she had written for opioids. Despite ODN’s warnings, as well as a subsequent inquiry by the Georgia Podiatry Board, Dr. Avery-Kelly, with the assistance of office manager Brenda Lewis, continued to prescribe large volumes of controlled substances without a legitimate medical need and outside the scope of pediatric practice.
CHAPTER 24

Figure 37.

Figure 38.

Figure 39.

Figure 40.

Figure 41.

Figure 42.

Record Keeping

- Med reconciliation via EHR
- Maintain copies of all narcotic Rx’s

Resources


Thank You!!!
Chapter 25

Staple Fixation for First Metatarsal Transverse Closing Base Wedge Osteotomy: A Cadaver Study

Tyler Slattery, DPM
Gregory Clark, DPM
Donald Green, DPM

Purpose
As a follow up to the comparative analysis of fixation for proximal closing base wedge osteotomy for the first metatarsal, I propose using the staple fixation method in patients for fixation of the osteotomy. We hypothesize fixation of the osteotomy with a dorsal and plantar compression staple is a viable fixation method when compared to a more oblique osteotomy and screw fixation.

Background
Hallux abducto valgus is a common deformity found in the lower extremity and in many cases leads to severe and debilitating discomfort. Many conservative modalities have been developed to accommodate for this deformity, however, once they have all been exhausted with little to no relief surgical intervention is a viable next step.

With a long list of procedures for treatment of hallux abducto valgus, often times surgeons do what works best in their hands. There are considerations, however, that must be evaluated before deciding on one particular osteotomy and form of fixation. The closing base wedge osteotomy was first introduced in 1901 by Loison and initially was not fixated, relying on the intact medial hinge for stability (1). The problem with proximal first metatarsal osteotomies is they are difficult to fixate, and thus Juvara modified the procedure to include a more oblique osteotomy allowing for a screw to be placed (2). In 1977, the Podiatry Institute introduced a long-arm oblique osteotomy to allow for 2 screws to be placed across the osteotomy site (3,4).

The benefit of performing an osteotomy in the metaphyseal portion of the bone is that it consists of mesenchymal stem cells allowing new bone formation, which is stronger than what occurs in the diaphysis (5,6). Also, the blood supply to the metaphyseal portion of the bone is more extensive compared to diaphyseal bone (7). Due to these factors, one could assume that a transverse osteotomy in the metaphyseal portion of the first metatarsal would encourage faster healing and greater likelihood of union if a stable fixation technique was developed for this osteotomy location. The difficulty in performing a transverse osteotomy in the proximal end of the first metatarsal is the inability to utilize screw fixation due to its transverse nature and proximity to the first tarsometatarsal joint.

Staples provide a dynamic fixation method optimal for a transverse osteotomy at the proximal portion of the first metatarsal. (8) By placing a staple dorsal and lateral, the osteotomy is able to be closed down laterally and provide compression (9,10,11). Next, a plantar medial staple can be placed to stabilize the osteotomy in a tension band fashion. Since weight bearing is a dorsal force from the reactive force of gravity, this force will tend to cause gapping of the osteotomy on the plantar aspect. If the transverse staple is placed in the lower half of the metatarsal, this will resist distraction. Therefore, using the tension band principle the ground reactive force of gravity will be converted into a compressive force across the osteotomy site, thus adding an additional factor to the healing condition.

In this cadaver study we perform a transverse closing base wedge osteotomy in the metaphyseal portion of the bone fixated with nitinol staples. We believe a transverse closing base wedge osteotomy with plantar and dorsal fixation facilitates correction of moderate to severe hallux valgus and is a viable surgical method in respect to bony union and patient satisfaction. Performing this in vivo study will demonstrate the elastic recovery and dynamic compression capability.

Methodology
This study was made possible by a grant provided by the Scripps Coastal Medical Group. A total of 15 unpaired specimens were used from 11 male and 4 female with ages ranging from 47 to 75 (mean 59.6 years). Specimens were divided into 3 groups to undergo transverse closing base wedge osteotomy in the metaphyseal portion of the bone and receive either single or dual staple fixation and oblique closing base wedge osteotomy with screw fixation.

The specimens undergoing transverse closing base wedge osteotomy underwent osteotomy 1.2cm from the first tarsometatarsal joint and perpendicular to the weight-bearing surface. A 1-2mm wedge was removed with care to keep the medial cortical hinge intact utilizing a sagittal bone saw. The osteotomy was then fixated with either a
A single staple dorsal and lateral utilizing a nitinol staple oriented dorsal to plantar. The group fixated with two staples also received an additional staple oriented plantar and medial to plantar lateral on the tension side of the bone (Figure 1).

A third group underwent an osteotomy oriented more oblique in the metaphyseal and diaphyseal portion of the bone with the medial hinge left intact approximately 1.2 cm distal to the first tarsometatarsal joint. This osteotomy was then fixated utilizing standard AO technique utilizing 2.7 mm fully threaded solid stainless steel screws.

During dissection and while performing the osteotomy and fixation, all surrounding tissue was left intact for testing. The specimens then underwent amputation at choparts joint to allow for fixation to the biomechanical testing machine. First ray range of motion was measured before and after the procedure was performed as well as after amputation at choparts joint.

After amputation, screws were installed in the cuneiform and navicular to aid in cement fixation. The specimen was mounted in cement at the proximal end with the distal end pointed upward. A threaded pin was inserted to the distal plantar shaft of the first metatarsal.

The specimen was mounted in the VIVO test machine (AMTI), as follows (Figure 2). The cemented proximal mount was fixed to the lower plate. The metatarsal pin was fixed to the upper rotation arm. Rotation of the lower plate was used to align the specimen to the transverse plane. Rotation of the upper rotation arm was used to align the metatarsal pin perpendicular to the plane. This alignment allowed loading to simulate a normal force during standing. The origin of the test environment was placed at the insertion point of the metatarsal pin.

Test load was applied to the plantar surface at the metatarsal pin. Load was cycled from 0 N to 100 N for 2000 cycles. The proximal-distal axis was allowed to move to relieve load, preventing off-axis loading from restricting motion along the axis of interest. Loads and displacements were recorded in the X, Y, and Z directions. Moments and angles or rotation were recorded around the X, Y, and Z axes.

Stiffness was evaluated as the displacement at 100 N from the neutral starting position. Stiffness was compared between the three restoration conditions. Cycle count at failure was noted when available.

After mechanical testing, specimens were evaluated for fracture or loosening at the restoration site. Dissection was performed to note any fracture or loosening that was not apparent with the soft tissue in place (Figure 3).

Data were processed to evaluate stiffness along the loading axis as a function of total displacement of the mount on the metatarsal and the load applied along the plantar-dorsal direction. The first 3 cycles of data were not included in data processing to account for settling of the specimen and mount in the machine.
RESULTS

The average stiffness was greater in the transverse osteotomy with dual staple fixation compared to the single staple fixation and screw fixation groups with a stiffness of 5.53 N/mm compared to 2.21 N/mm for the single staple fixation and 3.48 N/mm for the screw fixation (Figure 4). Additionally, there was an increase in fracture at the osteotomy site for the screw fixation group with catastrophic failure noted in four out of five specimens, while only one fracture was noted in both the single and dual staple fixation groups with fracture of the medial hinge. However, through dissection of the specimens post biomechanical testing, fixations remained intact without catastrophic failure (Table 1). During the surgical procedure in the dual staple fixation group, fracture of the medial hinge was encountered. As a result, stiffness was significantly decreased for this specimen in the dual staple fixation group. When this outlier was removed, the stiffness of the dual fixation group was significantly greater compared to the single staple group (P< 0.05). The average width and depth at 0.5 cm from the joint was 20.8mm and 22.06mm respectively. The average width and depth at 0.7 cm from the joint was 22mm and 26.2mm respectively. The average width and depth at 1.5 cm from the first tarsometatarsal joint was 17.7mm and 22.6mm respectively. The average width and depth at 2.5 cm from the first tarsometatarsal joint was 16.2mm and 15.3mm respectively (Table 2).

The treatment of hallux abductovalgus has a myriad of surgical procedures for treatment and correction. The type of fixation employed is also an important factor as the strongest construct that allows for the most correction with least risk of complication is pivotal when selecting the best treatment option. There is no single correct procedure for treatment of hallux valgus, however patients with increased deformity require a proximal metatarsal osteotomy or first tarsometatarsal joint fusion. In our study, we show that a closing base wedge of the first metatarsal is a viable treatment option for treatment of moderate to severe hallux abductovalgus. Furthermore, we demonstrated that a more transverse osteotomy can be performed in the metaphyseal portion of the bone and stably fixated with the use of nitinol staples.

Our study shows dual staple fixation for a closing base wedge osteotomy is comparable in stiffness to dual screw fixation and a single dorsal lateral staple fixation. Furthermore, dual screw fixation resulted in significantly greater catastrophic fractures after cyclical loading of 1500 cycles at 100N of force. This showed that the fatigue limit for the screw fixation group was much lower than the staple fixation groups. Furthermore, no catastrophic failures occurred in the staple fixation groups. There were fractures of the medial hinge in two of the specimens, however, the fixation remained intact. We can infer from the results of our study that staple fixation provides dynamic compression across the osteotomy compared to static compression from the screw fixation group. Furthermore, by placing a staple plantar and medial to the osteotomy on the tension side of the bone the staple

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fixation Type</th>
<th>Age</th>
<th>Sex</th>
<th>Method of Failure</th>
<th>Failure Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Screw</td>
<td>55</td>
<td>M</td>
<td>Failed at the at the joint proximally</td>
<td>1586</td>
</tr>
<tr>
<td>A2</td>
<td>Screw</td>
<td>48</td>
<td>F</td>
<td>Fracture through the osteotomy and plantar screw</td>
<td>1454</td>
</tr>
<tr>
<td>A3</td>
<td>Screw</td>
<td>64</td>
<td>F</td>
<td>Fracture through plantar osteotomy and plantar screw</td>
<td>1054</td>
</tr>
<tr>
<td>A5</td>
<td>Screw</td>
<td>60</td>
<td>M</td>
<td>Fracture through plantar osteotomy and plantar screw</td>
<td>90</td>
</tr>
<tr>
<td>B5</td>
<td>Dual Staple</td>
<td>69</td>
<td>M</td>
<td>Fracture at hinge displaced dorsally with load. Overall osteotomy intact</td>
<td>2000</td>
</tr>
<tr>
<td>C3</td>
<td>Single Staple</td>
<td>48</td>
<td>M</td>
<td>Fracture of medial hinge.</td>
<td>2000</td>
</tr>
</tbody>
</table>

Table 1. Type of fixation, age of specimen, and method of failure at specific cycle.

<table>
<thead>
<tr>
<th>0.5 cm</th>
<th>0.75 cm</th>
<th>1.2 cm</th>
<th>1.5 cm</th>
<th>2.0 cm</th>
<th>2.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (mm)</td>
<td>20.8</td>
<td>26.2</td>
<td>22.9</td>
<td>22.6</td>
<td>15.3</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>22.1</td>
<td>22.0</td>
<td>17.7</td>
<td>22.6</td>
<td>16.2</td>
</tr>
</tbody>
</table>

Table 2. Measurement of average width and depth at varying portions of the first metatarsal.
prevents distraction forces on the plantar aspect of the bone and converts those forces into compression forces.

During surgical procedure of one of the dual staple fixation specimens (MD19080520) the medial hinge was fractured which significantly compromises the stability of the osteotomy (12). When this specimen was removed from the dual fixation group, the dual fixation group was significantly greater when compared to the single staple fixation group. (P < 0.05)

Our study was not without weakness. Firstly, the study was performed on cadaveric specimens and the foot was amputated at Choparts joint to allow for fixation and biomechanical testing. All remaining soft tissue, however, was left intact with the hopes that this would provide us with a more accurate physiological scenario. Secondly, the small sample of specimens led to a lower power study, which made it more difficult to achieve statistical significance. Furthermore, we only measured displacement in the sagittal plane of each specimen. The proximal segment was the portion that was placed through range of motion because in gait the distal segment is fixed to the ground during this portion of gait. But, this is a one-dimensional model, while the first ray range of motion is tri-planar. By amputating at Choparts joint and keeping all of the remaining soft tissue intact, we attempted to allow for some of the tri-plane motion of the first ray during testing. None of the specimens demonstrated a hallux abductovalgus deformity.

To our knowledge, this is the first study comparing dual staple and single staple fixation for a transverse closing base wedge osteotomy and screw fixation for an oblique closing base wedge osteotomy of the first metatarsal. Our study is novel because surrounding soft tissue was left intact as we believe this contributes to the overall stability of the osteotomy. With the results of this study we can conclude that a transverse closing base wedge osteotomy of the first metatarsal is a viable and stable fixation option for treatment of hallux abductovalgus compared to the standard closing base wedge osteotomy with dual screw fixation. Screw fixation of the closing base wedge osteotomy showed a lower fatigue limit compared to the staple fixation groups. With a more transverse osteotomy in the base of the first metatarsal, greater healing potential is allowed and with the addition of a plantar medial staple, distraction forces on the plantar aspect of the bone are resisted and thus converted to compression forces across the osteotomy.

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