

# Interpositional Arthroplasty of the First MTP Joint Using a Regenerative Tissue Matrix for the Treatment of Advanced Hallux Rigidus

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## ABSTRACT

**Background:** Treatment options are limited for young and active patients with hallux rigidus of the first metatarsophalangeal (MTP) joint. Soft-tissue interpositional arthroplasty is a promising alternative. **Methods:** The surgical technique for interpositional arthroplasty utilizing a human acellular dermal regenerative tissue matrix as a spacer is described. A retrospective review of a consecutive series of the first nine patients with Coughlin grade 3 hallux rigidus who underwent this procedure is presented. Five patients were female and four were male, with a mean age of 53.3 years, a mean body mass index of 28.6, and a mean duration of symptoms of 3.1 years. **Results:** The mean length of followup was 12.7 months, with no reported complications or failures. The mean total AOFAS score and pain sub-score were significantly higher at the most recent followup (87.9 and 34.4, respectively) versus preoperatively (63.9 and 17.8, respectively). **Conclusions:** These excellent early results and lack of complications may be due to the minimal bone resection associated with the procedure. This technique does not require autograft harvesting, is bone-sparing by preserving the plantar plate, and maintains the natural intrinsic of the joint by preserving its associated tendons and the FHB insertion. The sesamoid articulation also is resurfaced. Although further followup is needed, this technique may offer the young and active patient with advanced hallux rigidus an opportunity to maintain an active lifestyle, while retaining the possibility for more surgical options should the condition progress.

**Key Words:** Hallux rigidus; Interpositional arthroplasty; Acellular dermal regenerative tissue matrix; Allograft

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## INTRODUCTION

Hallux rigidus, or osteoarthritis of the first metatarsophalangeal (MTP) joint, is the most common form of osteoarthritis of the foot, affecting an estimated one in 40 adults over the age of 50 years,<sup>26,25</sup> and is one of the most common disorders of the first MTP joint, second only to hallux valgus.<sup>4,35,50</sup> Various functional and structural deformities limit the normal sliding and gliding motions of the first MTP joint by producing plantar subluxation of the base of the proximal phalanx in relation to the first metatarsal head.<sup>7,50</sup> Impaction of the dorsal joint surfaces occurs with continued ambulation, which is associated with degenerative changes to the joint.<sup>7,50</sup> This progressive joint destruction causes stiffness resulting in hallux rigidus.<sup>4,7</sup>

This condition is characterized by the following clinical findings: pain, which is most severe during terminal heel-rise just before toe-off; restriction in range of motion, especially in dorsiflexion; and bulk of the first MTP joint.<sup>3,4,21,26</sup> Range of motion is limited due to the presence of generalized joint inflammation, periarticular osteophytes, and soft tissue contracture.<sup>3</sup> The osteophytes primarily are localized to the dorsal aspect of the first metatarsal head and the base of the proximal phalanx of the hallux.<sup>3,4</sup> During the propulsive phase of gait, the restricted motion and pain cause internal rotation of the forefoot, which reduces push-off and creates transfer metatarsalgia.<sup>21</sup>

Initially, conservative measures, such as nonsteroidal anti-inflammatory medications, reduction in high-impact weight-bearing activities, and modifications in footwear, should be attempted.<sup>3,50</sup> Such nonoperative treatments may not be feasible for some patients, however, due to occupational or lifestyle demands or given a high degree of discomfort.<sup>50</sup> Unfortunately, no conservative treatment will reverse the progressive disease process; therefore, surgical intervention is warranted when these measures either fail to provide pain relief or are inappropriate.<sup>3,26,35,50</sup>

The surgical indication for hallux rigidus is pain accompanied by degenerative changes of the first MTP.<sup>7,10,21,35,50</sup> Surgical options include cheilectomy,<sup>11,13,16,20,29,35,38,42,46,49</sup> interpositional arthroplasty,<sup>2,7,10,19,26,35,45,50</sup> resection or excisional arthroplasty,<sup>6,32,58</sup> implant arthroplasty,<sup>12,24,27,31,33,44,49,54,56</sup> and arthrodesis.<sup>8,11,17,30,37,43</sup> Cheilectomy may be a sufficient first line of treatment for patients with less severe arthritic changes,<sup>2,3,16,20,26,29,50</sup> whereas more aggressive procedures, such as interpositional arthroplasty, resection arthroplasty, implant arthroplasty, or arthrodesis, may be required for more advanced cases of hallux rigidus.<sup>3,26,50</sup>

Although resection arthroplasty, implant arthroplasty, and arthrodesis may be suitable for less active patients, their associated complications may make them less than ideal procedures for younger patients with higher functional demands who are suffering from advanced hallux rigidus.<sup>3,7,10,26</sup> Interpositional arthroplasty, in which a biologic substance is utilized as an interpositional spacer in the first MTP joint, has been developed in an effort to address the shortcomings of these other procedures.<sup>3</sup> In theory, because interpositional arthroplasty preserves more bone, joint motion, stability, and length, the overall function of the MTP joint and, possibly, the long-term success rate of the procedure, is improved.<sup>3</sup> In addition, since overall bone loss with interpositional arthroplasty is minimal, more surgical treatment options remain available should the disease process progress.

The purpose of this retrospective study is two-fold. First, the surgical technique for interpositional arthroplasty utilizing a human acellular dermal regenerative tissue matrix (RTM) as a spacer is described. In addition, the early results of this technique in nine consecutive patients with advanced hallux rigidus are reported and compared to those from other soft-tissue interpositional arthroplasty studies.

## SURGICAL TECHNIQUE

Four fellowship-trained foot and ankle surgeons performed all surgical procedures at one of two institutions using the following standard operative protocol:

### Patient Preparation

The patient is placed in a supine position on the operating table. If necessary, a bump is placed under the ipsilateral hip to allow the foot to rest straight up. Monitored anesthesia care with a regional popliteal block works well for this procedure. A carefully padded pneumatic thigh tourniquet is applied, and the extremity is prepped and draped in the standard sterile fashion. The limb is exsanguinated and the tourniquet is inflated.

### Surgical Approach and Exposure

A standard dorsal first MTP arthrotomy approach is used. A dorsal linear incision is created just medial to the extensor hallucis longus (EHL) tendon. Sharp and blunt dissection

techniques are used, taking care to protect the neurovascular structures. A full thickness capsulotomy is performed to gain exposure to the joint. The EHL and capsule are reflected and protected laterally. The medial and lateral collateral ligaments are released to allow full exposure of the joint. Any inflamed synovium is sharply debrided and removed, as are any loose bodies.

### Cheilectomy

Typically, a large dorsal osteophyte is present on the metatarsal head. Often, the dorsal portion of the metatarsal head shows evidence of cartilage erosion and loss. An aggressive cheilectomy of the dorsal chondromalacia and osteophyte is performed using a power sagittal saw. Any additional osteophytes on the medial and lateral aspects of the metatarsal head or on the dorsal aspect of the proximal phalangeal base also are removed.

### Metatarsal-Sesamoid Joint Mobilization

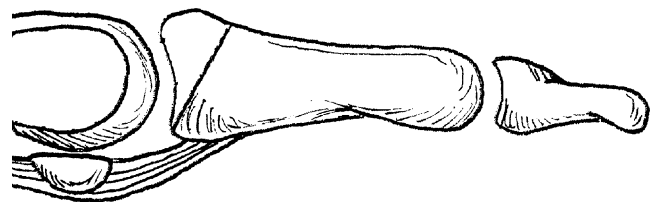
Attention is now directed to the plantar aspect of the first MTP joint. The metatarsal-sesamoid articulation also is affected in Coughlin grade 3 cases of hallux rigidus. In these cases, the sesamoids will have fibrotic adhesions to the plantar metatarsal head, which prevent normal excursion during motion of the joint. A McGlamry elevator is used to release these adhesions, as well as the sesamoid suspension ligaments. Care is taken to protect both the flexor hallucis longus (FHL) and brevis (FHB) during this maneuver.

### Modified Keller Osteotomy

If additional decompression is needed, a modified Keller osteotomy of the proximal phalanx is performed (Figure 1).<sup>6,32,58</sup> This intraoperative decision is made if bone impingement from arthritic changes in the proximal phalanx remains after the cheilectomy has been performed. In this series, it was necessary in 7 of 9 (77.8%) cases. The goal of this type of osteotomy is to create additional joint decompression from the phalanx side with minimal bone resection and maintenance of the plantar intrinsics, such as the attachment of the FHB. This modified osteotomy retains the base of the proximal phalanx, as well as the plantar intrinsics, for stability.

### Contouring of Metatarsal Head

Following exophytic bone removal, the metatarsal head is re-shaped both medially and laterally to a more normal



**Fig. 1:** Illustration of a modified Keller osteotomy of the proximal phalanx, which creates additional decompression from the phalanx side with minimal bone resection and preservation of the plantar intrinsic.<sup>6,32,58</sup>

anatomical contour. In addition, the plantar-leading edge of the metatarsal head is contoured to remove any sharp edges. This process effectively prepares the metatarsal head for later implantation of the periosteum replacement scaffold.

#### Regenerative Tissue Matrix (RTM) Preparation

A 5 × 5-cm GRAFTJACKET Matrix (Wright Medical Technology, Inc., Arlington, Tennessee), an immunologically-inert RTM consisting of collagen and extracellular protein matrices and created from human cadaver tissue, is used as the interpositional spacer. Rehydration of the freeze-dried RTM is achieved by placing it in a sterile saline bath for a minimum of five minutes, until it becomes pliable.

#### Interpositional Arthroplasty

A 3/32-mm Steinman pin is used to create two bone tunnels from dorsal to plantar in the metatarsal neck. The tunnels should exit just proximal to the most proximal extension of the sesamoid motion arc. Two Hewson suture passers (Smith & Nephew Endoscopy, Andover, Massachusetts) are passed through the tunnels until the passer loops are seen plantarly. The RTM is removed from the saline and cut to fit the head using scissors. The paper backing then is removed from the RTM. 0-Vicryl (Ethicon, Inc., Somerville, New Jersey) suture is used to create two grasping stitches at one end of the RTM.

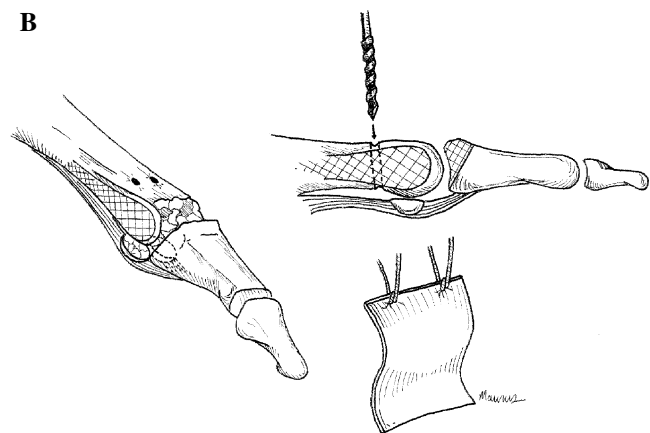
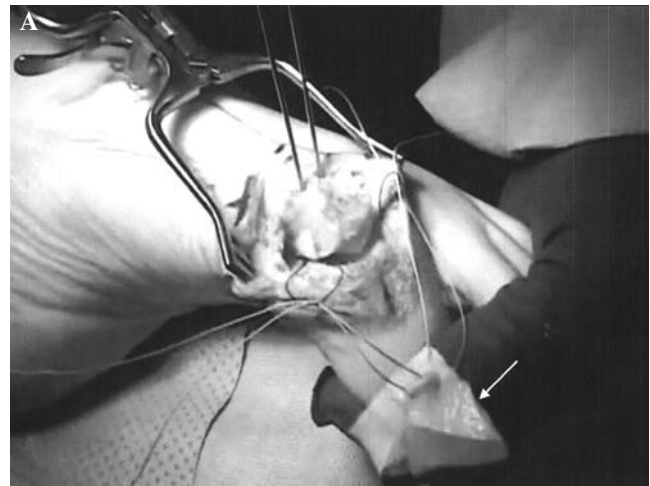
The RTM then is brought into the sterile field and is advanced into the plantar metatarsal sesamoid joint. The two grasping stitches are passed into the Hewson passer loops. For incorporation, it is important to place the reticular layer, or “shiny side,” of the RTM against the metatarsal head, which orients the reticular surface to the vascular supply of adjacent tissue (Figure 2). The Hewson passers are withdrawn from the dorsal drill holes, as are the 0-Vicryl stitches. Both sutures are tied at the dorsal metatarsal head to secure the plantar extent of the RTM. The remainder of the RTM now is draped over the metatarsal head (Figure 3).

A free needle is used to secure the dorsal aspect of the RTM to the anchored 0-Vicryl stitch. Medial and lateral sutures are used to complete the snug fit of the RTM over the metatarsal head.

A copious amount of normal sterile saline is used to irrigate the joint. Adequate decompression of the joint and an improvement in the joint space is confirmed. In addition, range of motion is re-assessed through maximum dorsiflexion and plantarflexion to confirm that appropriate dorsiflexion is possible with the RTM in place.

#### Closure

Redundant RTM is trimmed as needed using scissors. A 0-Vicryl suture is used to close the capsule and 2-0 Vicryl is used in the subcutaneous tissues. The skin is closed with a running nylon stitch. Range of motion is evaluated a final time to ensure proper dorsiflexion and stability of the toe is confirmed. A light,

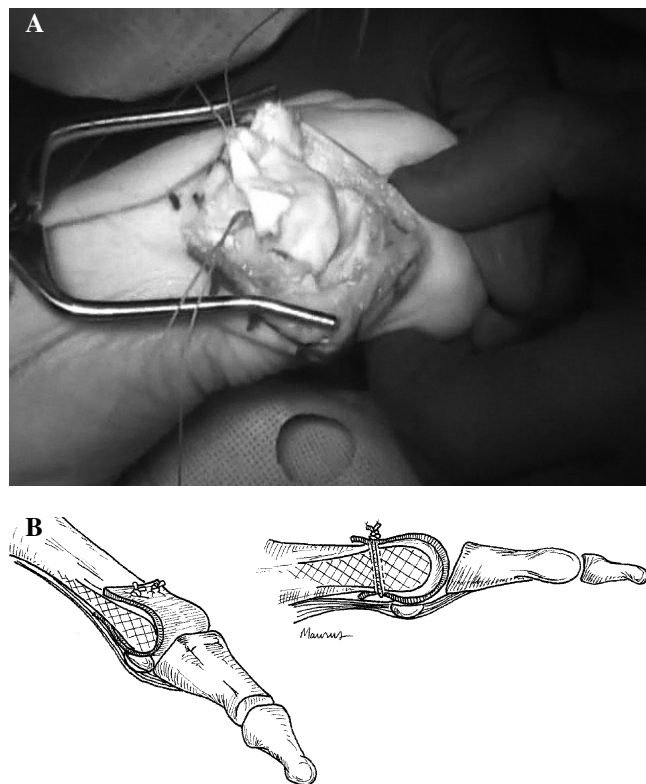


**Fig. 2:** Intraoperative photograph (A) and corresponding illustration (B) depicting interpositional arthroplasty technique using the RTM as the interpositional spacer. The proper placement of the reticular layer (arrow), or “shiny side,” of the RTM against the metatarsal head, which orients the reticular surface to the vascular supply of adjacent tissue, is critical for incorporation.

sterile compressive dressing with toe spica is applied. Care is taken to maintain the toe in the desired alignment.

#### Postoperative Rehabilitation

Patients are discharged at a partial weightbearing status. The postoperative physiotherapy and rehabilitation routine is identical for all patients and involves weekly compression dressing changes. All patients are placed in postoperative fracture shoes on the day of surgery and are allowed to heel weight-bear as tolerated. Range-of-motion exercises begin 10 days postoperatively. Patients are weaned from postoperative shoes to laced athletic shoes at four weeks postoperatively. Formal physical therapy begins at this time, with three sessions per week for three weeks.



**Fig. 3:** Intraoperative photograph (A) and corresponding illustration (B) demonstrating placement of the RTM against the metatarsal head.

## MATERIALS AND METHODS

### Demographics

This retrospective study is comprised of a consecutive series of the first nine patients with a Coughlin grade 3

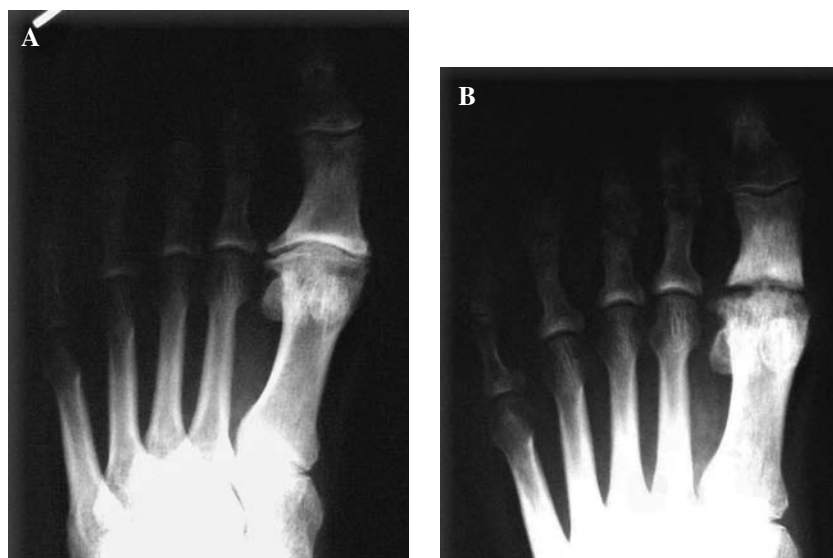
classification who underwent interpositional arthroplasty for the treatment of advanced hallux rigidus of the first MTP joint. All procedures were performed between November 2003 and September 2004 using the technique described above. All nine patients returned for a followup examination.

Five patients were female and four were male. Five cases involved the left first MTP joint, whereas four cases involved the right joint. The diagnosis for all patients was advanced hallux rigidus of the first MTP joint in which conservative management failed and which was significant enough to warrant surgical intervention. The mean age at the time of surgery was 53.3 (35.5 to 71.0) years. The mean body mass index was 28.6 (20.3 to 39.3).

### Clinical Assessment

The AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale Assessment was used for all pre- and postoperative clinical evaluations.<sup>34</sup> This 100-point scoring system is comprised of three subcomponents: pain (40 points), alignment (15 point), and function (45 points).<sup>34</sup> A medical chart review also was performed for all patients, in which any complications, subsequent surgeries, and failures were documented.

The mean duration of symptoms was 3.1 (0.5 to 10) years. A specific traumatic episode involving the affected MTP joint and/or ankle was reported by two patients. One injury involved a blunt trauma to the first MTP joint, whereas the other resulted from a biking accident in which the spoke of a wheel penetrated the posteromedial aspect of the ankle. One patient had a prior failed cheilectomy, which was performed at another institution approximately one year prior to the index operation. The preoperative AOFAS clinical assessment values are presented in Table 1.



**Fig. 4:** A, Preoperative radiograph of the left foot of a 62-year-old male with Coughlin grade 3 advanced hallux rigidus of the first MTP. Because the patient was not satisfied with the functional outcome of a previous arthrodesis on the contralateral side, he opted to undergo interpositional arthroplasty. B, Postoperative radiograph of the left foot obtained 10.7 months after the interpositional arthroplasty demonstrates successful joint decompression.

**Table 1:** Direct comparison of preoperative versus most recent followup AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale Assessment results

	<b>Total AOFAS Score (Max Score = 100 pts)</b>	<b>Pain (No Pain Score = 40 pts)</b>	<b>Alignment (Max Score = 15 pts)</b>	<b>Function* (Max Score = 45 pts)</b>
<b>Mean Preoperative Score <math>\pm</math> SD<sup>ψ</sup></b>	63.9 $\pm$ 10.2  (median, 67.0; range, 44–72)	17.8 $\pm$ 6.7  (median, 20; range, 0–20) (Severe—Moderate Pain)	15 $\pm$ 0.0  (median, 15; range, 15–15) (Good Alignment)	31.1 $\pm$ 6.0  (median, 29; range, 19–40)
<b>Mean Most Recent Followup Score <math>\pm</math> SD<sup>ψ</sup></b>	87.9 $\pm$ 9.3  (median, 87.0; range, 72–100)	34.4 $\pm$ 5.3  (median, 30; range, 30–40) (Mild/Occasional—No Pain)	15 $\pm$ 0.0  (median, 15; range, 15–15) (Good Alignment)	38.4 $\pm$ 5.5  (median, 40; range, 27–45)

\* Function = Activity Limitations + Footwear Requirements + MTP Joint Motion + IP Joint Motion + MTP-IP Stability + Callus.

<sup>ψ</sup> SD = Standard Deviation.

### Radiographic Evaluation

Two authors performed a blinded review of both the preoperative followup radiographs using the Coughlin Clinical-Radiographic System for grading hallux rigidus preoperatively.<sup>11</sup> All nine patients presented with a preoperative Coughlin grade 3 classification.

### Statistical Analysis

An independent statistician performed the statistical analysis using SigmaStat software, version 2.0 (SPSS, Inc.; Chicago, IL). Means and standard deviations were used to describe continuous data. Clinical assessment and radiographic evaluation variables were compared between the pre- and postoperative time intervals. For continuous variables that were normally distributed, a paired t-test was used to determine statistical significance. The Wilcoxon Signed-Ranked Test was used to compare ordinal variables. Statistical differences were considered significant when the p value was less than or equal to 0.05 with a power of at least 0.8. Ninety-five percent confidence intervals were used throughout the statistical analysis.

### RESULTS

The mean length of followup was 12.7 (8.1 to 18.4) months, with no reported failures (Figure 4). Based upon clinical examination and subjective interview, no complications, such as infection, inflammatory reactions, prolonged edema, wound healing problems, loss of push-off strength, malalignment, or instability occurred in any of the patients.

The most recent AOFAS clinical assessment values are compared with those obtained at the preoperative evaluation in Table 1. The mean total AOFAS score and pain sub-score were significantly higher at the most recent followup evaluation versus the preoperative scores (Table 2). The mean total AOFAS score improvement was 25.4 (2 to 46) points, with a mean pain sub-score improvement of 16.7 (10 to 30) points. Although a higher function sub-score was observed at the most recent followup examination, the difference from the preoperative sub-score was not statistically significant. The alignment sub-score did not vary from the preoperative to the most recent followup examination, as all patients exhibited good alignment at both time intervals.

### DISCUSSION

Hallux rigidus is a common condition often necessitating surgical treatment.<sup>3,26,35,50</sup> The ideal surgical option, however, is debatable, as each has accepted limitations.<sup>10,16,35</sup> Cheilectomy is considered a first step in the surgical management of hallux rigidus and frequently is successful in cases where a dorsal osteophyte is present, but some degree of joint space is maintained.<sup>3,16,20,26,29,50</sup> Unfortunately, this technique is less successful in patients with more advanced grades of hallux rigidus,<sup>10,13,26,49,50</sup> who ultimately will require a more aggressive surgical intervention,<sup>26</sup> such as interpositional arthroplasty, resection arthroplasty, implant arthroplasty, or arthrodesis.<sup>3,26,50</sup>

**Table 2:** Summary of statistically significant variables between preoperative and most recent followup evaluations

Study Variable	Trend	P-value	Power	Statistical Test
Total AOFAS Score	Significantly Higher Followup Scores	<b>0.002</b>	0.988	Paired t-Test
AOFAS Pain Sub-Score	Significantly Higher Followup Scores	<b>&lt;0.001</b>	1.000	Paired t-Test

The treatment options for young and active patients with advanced hallux rigidus are limited due to the disadvantages associated with the aforementioned procedures.<sup>3,7,10,26</sup> Cheilectomy typically is not as successful in more advanced cases of hallux rigidus,<sup>10,13,49,50</sup> and the more aggressive procedures, such as resection and implant arthroplasties, often are associated with complications that render them less than ideal for young and active patients for whom postoperative participation in weightbearing activities is not only a priority, but also essential to maintaining their quality of life.<sup>3,7,10,26</sup> Of the available options, foot and ankle surgeons currently consider arthrodesis as the gold standard for the treatment of advanced hallux rigidus in young patients due to its reliability and durability over time and with activity.<sup>3</sup> However, many young and active patients may not consider it to be a viable option due to the associated restricted motion, limitations in activity, and decreased footwear options.<sup>10,26</sup> Therefore, additional treatment options that meet the goals of relieving pain and preserving strength and motion, thus permitting continued participation in more vigorous activities, are needed for the young and active patient with advanced hallux rigidus.

Interpositional arthroplasty, in which a biologic substance is utilized as an interpositional spacer in the first MTP joint, was developed as an alternative for the treatment of advanced hallux rigidus.<sup>3</sup> First described in the United States by Keller and later modified in Europe by Brandes, the technique involved resection of the base of the proximal phalanx base with the interpositioning of medial capsular tissue.<sup>50</sup> In theory, because interpositional arthroplasty preserves more bone, joint motion, stability, and length, the overall function of the MTP joint and, ultimately, the long-term survivorship of the procedure, is improved.<sup>3</sup> In addition, because the technique is less invasive than many of the other procedures, more surgical treatment options remain available if the condition progresses.<sup>3,7</sup>

Several soft-tissue interpositional arthroplasty techniques have been described<sup>2,7,10,19,26,35,45,50</sup> and may be classified into capsular<sup>7,26,35,45,50</sup> and bundle techniques.<sup>2,10</sup> Most techniques combine a cheilectomy with some type of resection arthroplasty, which is followed by the interpositional arthroplasty. The majority of capsular soft-tissue interpositional techniques are based on a Keller-type proximal resection, with a layer of soft tissue interposed at the arthroplasty site.<sup>7,26,35,45</sup> Along with portions of the joint capsule, various types of soft-tissue autografts are used as the interpositional

spacer, including the extensor digitorum longus (EDL),<sup>26,50</sup> the extensor hallucis brevis (EHB),<sup>35,45</sup> the EHL,<sup>7</sup> and the gastrocnemius-soleus (GS) tendon.<sup>7</sup>

Instead of interpositioning soft tissue around the metatarsal head, the bundle soft-tissue interpositional arthroplasties involve reaming the base of the proximal phalanx to create a concave space for the insertion of a soft-tissue bundle into the MTP joint, which acts as an interpositional spacer.<sup>2,10</sup> Autografts that have been used to create the bundle spacers include the plantaris<sup>2</sup> and gracilis<sup>10</sup> tendons.

The use of soft-tissue interpositional arthroplasty for the treatment of advanced hallux rigidus offers numerous advantages versus implant arthroplasty, resection arthroplasty, and arthrodesis. By utilizing soft tissue as an interpositional spacer, all complications associated with the use of a prosthetic implant, including implant wear and failure, foreign body immune reactions and synovitis, and the greater amount of bone resection required for implantation, are eliminated.<sup>2,7,10,18,22,23,26,27,48,50,53,55,56</sup> Furthermore, if implant arthroplasty fails, the resulting bone loss limits future treatment options.<sup>7</sup> Since interpositional arthroplasty does not involve invading the bone to seat an implant, a reduction in the risk of infection also has been suggested as a potential advantage.<sup>7</sup> Compared to resection arthroplasty, the amount of bone removal and, hence, the associated complications,<sup>2,3,9,10,26</sup> generally are less with interpositional arthroplasty. Interpositional arthroplasty also does not have the risk of nonunion, restricted motion, limitations in activity, and decreased footwear options associated with arthrodesis,<sup>3,10,26</sup> as it does not involve fusion. Because soft-tissue interpositional arthroplasty involves the insertion of viable tissue into the MTP joint, it has the distinctive benefit of providing a matrix for bioingrowth, thus offering the potential for revascularization and cellular repopulation postoperatively. Regardless of the specific soft-tissue interpositional technique employed, weightbearing may be initiated immediately, which minimizes the development of scar tissue, adhesions, and tissue necrosis.<sup>50</sup> In our opinion, the procedure also may be performed bilaterally, if necessary, and because specialized equipment is not required, the procedure is inexpensive and easily reproducible.<sup>50</sup>

This is the first known report describing the use of a biologically-engineered allograft, as opposed to an autograft, as an interpositional spacer for the treatment of hallux rigidus. This immunologically-inert RTM is derived from

human cadaver tissue and consists of collagen and extracellular protein matrices. The RTM is biologically inert because all cellular components are extracted during the manufacturing process, which renders the matrix free of immune response targets. Since it is derived from human tissue and its structure and biochemical integrity is retained during processing, the RTM is easily recognized by the body's immune system and, therefore, does not provoke a foreign body or inflammatory tissue response.<sup>5,25,57</sup> The pluripotent membrane provides a favorable microenvironment for bioingrowth by promoting nutritional diffusion, cellular proliferation, and osteogenesis at the graft site, while preventing fibrous and other non-osseous tissue ingrowth and selectively excluding the migration of competing muscle and soft tissue cells.<sup>15,25,39,41</sup> The theoretical net effects of these properties are the rapid revascularization and cellular repopulation of the matrix scaffold, which are followed by gradual remodeling and incorporation by the surrounding host tissue.<sup>5,14,28,36</sup> In addition, the RTM scaffold has stronger suture retention strength than its commercially available counterparts.<sup>1</sup> Finally, the other biologically-engineered graft products commercially available are xenografts, produced from either bovine or porcine sources, and have been shown to induce an inflammatory reaction in both animal models and humans.<sup>40,59</sup>

Besides the general benefits of interpositional arthroplasties outlined above, the use of the RTM offers additional advantages because it achieves the goals of interpositional arthroplasty without the complications associated with autograft spacers. The technique is simple and efficient compared to the other soft-tissue interpositional techniques, which involve autograft harvesting and the associated dissection and repair. In addition, several of the techniques require a second incision for graft harvest.<sup>2,7,10</sup> Because harvesting of native tissue is not necessary with the RTM technique, there are no donor site morbidity issues, such as infection, disruption in strength or function, and wound-healing issues at the harvest site. Furthermore, wound healing of the interpositional arthroplasty incision may be compromised if complications arise from harvesting the EHB, which lies directly under the interpositional arthroplasty wound site.<sup>35,45</sup> If the graft harvesting dissection and repair techniques are not meticulous, rupture of the remaining portion of tendon, as well as painful adhesions and possible restricted range of motion, also is possible.<sup>7,50</sup>

In addition to eliminating autograft harvesting, the RTM technique involves minimal bone resection, as both the plantar plate and the FHB insertion are preserved. More bone stock is retained compared to those techniques that require a greater Keller-type osteotomy, thus reserving more surgical options should further deterioration of the joint occur. Because the current technique preserves FHB insertion and the integrity of the first metatarsal-sesamoid articulation, the first metatarsal will continue to bear weight during gait and maintain plantarflexion power of the hallux,

thereby reducing the risk of transfer metatarsalgia and hallux hammer toe deformity, respectively, common complications that have been associated with some soft-tissue interpositional techniques in which the FHB insertion is not maintained (Table 5).<sup>26,35</sup> Another concern of the modified Keller-type interpositional arthroplasty techniques is the thin layer of interpositional material used,<sup>26,35</sup> which may provide inadequate first metatarsal head coverage.<sup>50</sup> Roukis et al. asserts that because these procedures are modified Keller-type interpositional arthroplasties, the same potential complications as the original Keller procedure are possible, including a shortened or "floppy" hallux with loss of plantar purchase, hallux hammer toe or extension deformity, and transfer keratosis and metatarsalgia.<sup>50</sup>

The RTM technique is unique in that the sesamoid articulation is resurfaced, which is of particular significance in Coughlin grade 3 cases in which the articulation is affected by degenerative changes. Resurfacing may prolong the survivorship of the procedure. Like the distally-based capsular technique by Roukis et al., the current technique involves interpositioning the graft between the plantar surface of the first metatarsal head and the sesamoid apparatus, thereby preventing osseous contact-induced irritation.<sup>50</sup> In addition, both the current technique and that described by Roukis et al. involve the firm attachment of the graft to the undersurface of the metatarsal head through the use of drill holes and suturing, which prevents the migration of the graft during the postoperative recovery period that is a potential risk with the other capsular techniques.<sup>50</sup> To reduce this risk and to assist in stabilizing the phalangeal osteotomy, some techniques employ the use of a K-wire in the immediate postoperative recovery period to immobilize the hallux (Table 3), but because of the associated increased stiffness, Mroczek and Miller discontinued its use after their first eight cases.<sup>45</sup> The use of a K-wire also adds complexity to the postoperative recovery process.<sup>10</sup>

With the current technique, there are no limitations regarding relatively equal lengths of the first and second metatarsals, as is recommended with other soft-tissue interpositional arthroplasty capsular techniques.<sup>26</sup> According to Hamilton et al., performing a resection arthroplasty in patients with short first metatarsals would further shorten the medial column, thereby increasing the likelihood of developing a transfer lesion.<sup>26</sup> The current authors suggest that the risk of developing transfer metatarsalgia is related more to technique and, therefore, is not an issue when the plantar intrinsic, such as the FHB insertion, are maintained. Maintaining the overall metatarsal cascade is of prime importance in reducing the likelihood of complications following interpositional arthroplasty. The minimal bone resection that

**Table 3:** Summary of methodologies for reporting results in recently published interpositional arthroplasty studies

Interposition Material	Study Type	Number of Cases	Average Age at Surgery (years)	Average Followup (months)	Hallux Rigidus Grading/ System	Clinical Assessment	Use of K-Wire for External Fixation	Preservation of FHB Insertion
<b>RTM/ Capsular Technique</b> Berlet GC et al. (2005)	Retrospective/ Prospective	9	53.3	12.7	Grade III Coughlin & Shurnas <sup>11</sup>	AOFAS Hallux Metatarsophalangeal- Interphalangeal Scale <sup>34</sup>	No	Yes
<b>EHB/ Capsular Technique</b> Lau JT & Daniels TR (2001) <sup>35</sup>	Retrospective	11	N/A (59.0 at followup)	24	Grade III (10/11 cases) Hattrup & Johnson <sup>29</sup>	AOFAS Hallux Metatarsophalangeal- Interphalangeal Scale <sup>34</sup>	Yes	No
<b>Gracilis Tendon/ Bundle Technique</b> Coughlin MJ & Shurnas PJ (2003) <sup>10</sup>	Retrospective	7	56	42	Grade III Coughlin & Shurnas <sup>11</sup>	AOFAS Hallux Metatarsophalangeal- Interphalangeal Scale <sup>34</sup>	No	Yes

RTM, regenerative tissue matrix; FHB, flexor hallucis brevis; EHB, extensor hallucis brevis.

**Table 4:** Direct comparison of preoperative versus most recent followup AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale Assessment results among published interpositional arthroplasty techniques

AOFAS Score Component	RTM/Capsular Technique Berlet GC et al. (2005)		EHB/Capsular Technique Lau JT & Daniels TR (2001) [35]		Gracilis Tendon/ Bundle Technique Coughlin MJ & Shurnas PJ (2003) [10]	
	Mean Preoperative Score $\pm$ SD $^{\psi}$	Mean Most Recent Followup Score $\pm$ SD $^{\psi}$	Mean Preoperative Score $\pm$ SD $^{\psi}$	Mean Most Recent Followup Score $\pm$ SD $^{\psi}$	Mean Preoperative Score $\pm$ SD $^{\psi}$	Mean Most Recent Followup Score $\pm$ SD $^{\psi}$
<b>Total Score</b> (Max Score = 100 pts)	63.9 $\pm$ 10.2 (range, 44–72)	87.9 $\pm$ 9.3 (range, 72–100)	N/A	71.6 $\pm$ 16.1	46 (range, 32–60)	86 (range, 80–95)
<b>Pain</b> (No Pain Score = 40 pts)	17.8 $\pm$ 6.7 (range, 0–20) (Moderate Pain)	34.4 $\pm$ 5.3 (range, 30–40) (Mild/Occasional—No Pain)	N/A	22.7 $\pm$ 12.7 (Moderate—Mild/ Occasional Pain)	N/A	N/A
<b>Alignment</b> (Max Score = 15 pts)	15 $\pm$ 0.0 (range, 15–15) (Good Alignment)	15 $\pm$ 0.0 (range, 15–15) (Good Alignment)	N/A	15	N/A	N/A
<b>Function*</b> (Max Score = 45 pts)	31.1 $\pm$ 6.0 (range, 19–40)	38.4 $\pm$ 5.5 (range, 27–45)	N/A	33.9 $\pm$ 5.9 (Good Alignment)	N/A	N/A

\* Function = Activity Limitations + Footwear Requirements + MTP Joint Motion + IP Joint Motion + MTP-IP Stability + Callus.  
 $\psi$  SD = Standard Deviation.

occurs with the current technique offers a two-fold benefit by preserving the plantar intrinsics, while not impacting the overall metatarsal length. A recent prospective study by Roukis et al. revealed differences in first metatarsal length between mild and advanced cases of hallux rigidus.<sup>51</sup> According to the study, patients with grades I and II hallux rigidus had first metatarsals that were equal or greater in length than the second metatarsals, whereas patients with grade III hallux rigidus had shorter first metatarsals compared to the second metatarsals.<sup>51</sup> This finding is supported by two additional studies.<sup>46,47</sup> These results raise concern about the applicability of techniques requiring relatively equal lengths of the first and second metatarsals in young and active patients with more advanced cases of hallux rigidus.<sup>50</sup>

In addition to requiring a second incision to harvest the gracilis tendon, the interpositional bundle technique described in the literature differs from the current technique in that it requires more bone resection to create a concave space for bundle insertion and does not resurface the sesamoid articulation.<sup>2,10</sup> Because the bundle merely functions as a spacer, there is no interpositioning of the graft around the metatarsal head and sesamoid articulation; consequently, osseous contact-induced irritation is possible at this location<sup>50</sup> and little protection is afforded from the future progression of the disease at the metatarsal-sesamoid articulation.

According to Mann and Clanton, the goal of hallux rigidus treatment is to relieve pain, maintain first ray strength, and maintain or restore motion, if possible.<sup>42</sup> The results of this study demonstrate that interpositional arthroplasty utilizing a acellular periosteum replacement scaffold graft meets the goals of hallux rigidus treatment, while maintaining safety and reliability. Relief of pain was achieved, as evidenced by the significant difference between the AOFAS pain subscore from the preoperative clinical assessment to the most recent followup postoperative evaluation (Tables 1 and 2). The technique was effective in maintaining or restoring strength and motion, yielding a mean postoperative total AOFAS score of 87.9 points at the most recent followup, which is significantly higher than the preoperative total score of 63.9 points (Tables 1 and 3). No complications, such as infection, inflammatory reactions, prolonged edema, wound-healing problems, loss of push-off strength, malalignment, or instability occurred. In addition, there were no incidences of first metatarsal shortening, hallux hammer toe deformities, or transfer metatarsalgia, which have been associated with other interpositional arthroplasty techniques.<sup>26,35</sup> Finally, at a mean length of followup of 10.1 months, there were no reported failures, suggesting early durability of the procedure.

As summarized by Coughlin and Shurnas,<sup>10</sup> the previously published interpositional technique studies have significant limitations, including unknown or short-term followup intervals,<sup>7,26</sup> a substantial loss of cases available for followup

evaluation,<sup>26,35</sup> a lack of radiographic evaluation at follow-up,<sup>7</sup> and the reporting of a combination of surgical techniques within a single study.<sup>7</sup> Aside from the current study, only two others<sup>10,35</sup> incorporated the AOFAS-derived Hallux Metatarsophalangeal-Interphalangeal Scale as a clinical assessment (Table 3).<sup>34</sup> In general, the various interpositional arthroplasty techniques appear to be utilized in patients with advanced hallux rigidus, but only two studies, the current study and that by Coughlin and Shurnas, incorporated the same standardized system for grading hallux rigidus (Table 3).<sup>11</sup> Both studies were comprised of Coughlin grade 3 hallux rigidus cases.<sup>10</sup>

The study by Lau and Daniels was a retrospective comparison of cheilectomy with a capsular interpositional arthroplasty technique involving the use of an EHB tendon graft, of which 11 cases (five females and six males) were treated with the latter procedure.<sup>35</sup> All but one case exhibited a Hattrup and Johnson radiographic classification of grade III, which corresponds to marked osteophyte formation and loss of visible joint space (with or without subchondral cyst formation) [29,35]. Reported complications included asymptomatic calluses (3/11, 27.3%), postoperative weakness of the great toe (8/11, 72.7%), and metatarsalgia (3/11, 27.3%).<sup>35</sup> In addition, one patient suffered a stress fracture of the second metatarsal, which was treated nonoperatively, and one patient was awaiting arthrodesis.<sup>35</sup>

The Coughlin and Shurnas study was a retrospective review of seven cases involving an interpositional arthroplasty technique that incorporated a gracilis tendon bundle. All seven cases were females and presented with Coughlin grade 3 hallux rigidus. Reported complications included lateral metatarsalgia (4/7, 57.1%) and the presence of a mild callus beneath the second metatarsal head (3/7, 42.8%). One case of second MTP joint instability with a mild callus beneath the third metatarsal also was reported in a patient who underwent reconstruction of that joint at the time of the interpositional arthroplasty. Finally, a sensory neuroma corresponding to the tissue harvest site and associated with a loss of sensation in the lateral superior calf occurred in one patient.<sup>10</sup>

Similarities between the three studies include the implementation of interpositional arthroplasties in patients with advanced hallux rigidus, as well as approximately equal patient population sizes, all of which are relatively small (Table 3). Although the mean ages are comparable in the studies by Lau and Daniels and Coughlin and Shurnas, the mean age in the current study is younger (Table 3). The gender distribution varied among the studies, with the Coughlin and Daniels study solely involving females, whereas the female distribution was 55.6% for the current study and 45.5% for the Lau and Daniels study.<sup>10,35</sup> The followup intervals varied considerably between the studies, with the Coughlin and Shurnas study encompassing the longest average followup of 42 months (Table 3). The Lau

and Daniels study was the only study of the three incorporating the use of a K-wire in the immediate postoperative recovery period (Table 3). Additional time is needed for the patients in the current study to ascertain the long-term effectiveness of the RTM technique, but the early clinical results are quite promising compared to previously published results (Tables 3 and 4).

The relatively high incidence of complications and the lower postoperative AOFAS score observed in the Lau and Daniel study<sup>35</sup> may lend support to the Roukis et al. theory asserting that many of the capsular interpositional arthroplasty techniques are merely modifications of the original Keller procedure and, hence, are associated with the same complications.<sup>50</sup> These results raise questions regarding the EHB/capsular interpositional technique's use in young and active patients and may have led Lau and Daniels to conclude that it should be considered a salvage procedure with less reliable results compared to cheilectomy,<sup>35</sup> which is the same indication as the resection (Keller) arthroplasty.<sup>3,9,10,26</sup> The presence of the persistent metatarsalgia and transfer lesions in the Coughlin and Shurnas study led the authors to conclude that the function of the MTP joint is inalterably changed by both the disease process and the interpositional arthroplasty.<sup>10</sup> Despite the authors' preference of arthrodesis over interpositional arthroplasty in severe cases of hallux rigidus, arthrodesis was not an acceptable alternative to any of the study patients.<sup>10</sup> The complications reported in these two studies<sup>10,35</sup> were not observed in the current study and, despite its relatively short followup interval, most likely would have already presented in the early postoperative period. This absence of complications compared to the incidences reported in the other published studies perhaps best demonstrates the potential promise of the RTM technique in the young and active patient and is indicative of the differences in techniques between the studies.<sup>10,35</sup>

A strength of the current study is the use of standardized radiographic and clinical assessments, which allow for direct comparison of results with other studies that also utilize standard assessments. Weaknesses of the current study include the retrospective study design for most of the patients, the small patient population, and the early followup interval. It must be noted, however, that despite the small number of patients, significance was achieved in the AOFAS total score and pain sub-score comparisons between the preoperative and most recent followup examinations (Table 3).

In the future, larger, prospective randomized studies directly comparing the various soft-tissue interpositional spacer materials may assist in determining the optimal spacer for performing interpositional arthroplasty. Studies with longer duration followup intervals also are needed to assess the long-term efficacy of such procedures. Finally, additional studies are needed to further delineate the most appropriate indications for performing interpositional arthroplasty compared to the other procedures used to treat advanced hallux rigidus.

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