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Current Concepts Review: Hallux Rigidus

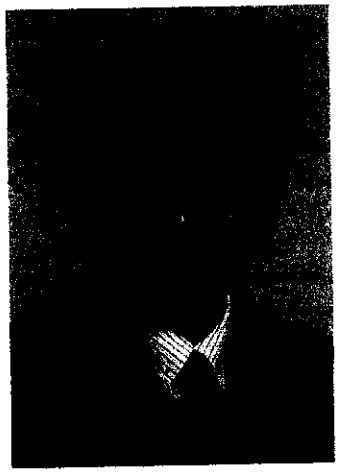
Gilbert Yee MD, MEd, MBA, FRCSC; Johnny Lau MD, MSc, FRCSC
Toronto, Canada

INTRODUCTION

Hallux rigidus refers to degenerative arthritis of the first metatarsophalangeal (MTP) joint. Although Davies-Colley provided the first description of the condition in 1887, Cotterill coined the term hallux rigidus to characterize the painful limitation of motion at the first MTP joint.[15,18] After hallux valgus, it is the most common affliction of the great toe and the most common form of degenerative joint disease in the foot.[34]

A wide spectrum of options is available for the treatment of hallux rigidus, although current literature emphasizes surgical intervention, ranging from simple cheilectomy to more complex osteotomies and joint arthroplasty. Considerable controversy surrounds several of these procedures regarding their indications and outcomes. Moreover, one must be mindful of the variability in natural history of hallux rigidus. In some cases, the condition takes a relatively benign course without a progression of symptoms. Smith and colleagues reported on a small series of symptomatic patients treated nonoperatively for duration of 12 to 19 years[80] (Level IV evidence). Although 67% of patients showed measurable loss of cartilage space radiographically over time, only 1 of 22 patients reported worsening of their pain. Nearly 75% of the cohort stated that they would still choose nonoperative treatment at latest followup. The abundance of options combined with the uncertainty of their outcomes renders clinical decision-making challenging. This review will evaluate the broad array of nonoperative and operative alternatives currently available for the management of hallux rigidus.

Although various etiologies have been proposed for hallux rigidus, its exact cause has yet to be elucidated. Trauma or osteochondritis dissecans may damage the articular surfaces of the MTP joint.[56] Several biomechanical and structural factors may play a role in the development of hallux rigidus. Nilsonne proposed that a long first metatarsal may increase the stress concentrated at the MTP joint during toe-off.[61] Lambrinudi theorized that an elevated first metatarsal leads to excessive plantarflexion of the phalanges and results in a flexion contracture of the joint.[47] Hypermobility of the first ray, pronation, hallux valgus interphalangeus, hallux valgus, and metatarsus adductus have been implicated.[5,13,15,61] Inflammatory or metabolic conditions such as gout, rheumatoid arthritis, and seronegative arthropathies have also been suggested as possible etiologies of hallux rigidus.[39] However, most of these explanations are theoretical and unsupported. In fact, a lack of correlation between hallux rigidus and metatarsus primus elevatus, a long metatarsal, and hypermobility of the first ray has been demonstrated in separate studies.[13,19,38,57] Only Coughlin identified a correlation between hallux rigidus and hallux valgus interphalangeus.[13]



Johnny Lau MD, MSc, FRCSC

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Corresponding Author:
Johnny Lau, MD, MSc, FRCSC
Assistant Professor
Department of Surgery, Division of Orthopaedic Surgery
University of Toronto
399 Bathurst Street
1 East Wing—438
Toronto, Ontario
CANADA M5T 2S8
E-mail: drjohnnylau@sympatico.ca
For information on prices and availability of reprints, call 410-494-4994 x226

Table 1: Level of evidence and grades of recommendation

Level of Evidence
- Level I: high quality prospective randomized clinical trial
- Level II: prospective comparative study
- Level III: retrospective case control study
- Level IV: case series
- Level V: expert opinion

Grades of Recommendation (given to various treatment options based on Level of Evidence supporting that treatment)
- **Grade A** treatment options are supported by strong evidence (consistent with Level I or II studies)
- **Grade B** treatment options are supported by fair evidence (consistent with Level III or IV studies)
- **Grade C** treatment options are supported by either conflicting or poor quality evidence (Level IV studies)
- **Grade I** when insufficient evidence exists to make a recommendation

Table 2: Radiographic Classification

Grade I:	Mild to moderate osteophyte formation preservation of the joint space.
Grade II:	Moderate osteophyte formation joint space narrowing subchondral sclerosis.
Grade III:	Marked osteophyte formation severe loss of joint space subchondral cyst formation

CLINICAL PRESENTATION AND EVALUATION

Patients commonly present with pain and stiffness at the first MTP joint. In the early stages, the discomfort predominates at the dorsal aspect of the joint and becomes more diffuse with the progression of the disease. Walking worsens the pain, particularly during heel-rise and toe-off. Prolonged activity while barefoot or in soft-sole shoes is often difficult. Patients may experience pain along the lateral border of the foot due to a compensatory increase in weightbearing to unload the first ray during gait. Patients frequently complain of a dorsal prominence that becomes inflamed and painful from constant rubbing against the shoe. This direct pressure may irritate the dorsomedial cutaneous nerve resulting in dysesthesia or numbness along the medial border of the hallux. In some cases, significant synovitis may accompany these complaints.

On physical examination, motion of the joint is restricted, especially dorsiflexion. Early in the course of the disease, pain may be elicited at terminal dorsiflexion and plantarflexion. In the later stages, crepitance and pain in the mid-arc of passive motion may develop. Also, the patient's gait may become increasingly antalgic as the MTP joint stiffens and progressive transfer of weight to the lateral border of the foot continues. Evidence of transfer metatarsalgia, lesser toe deformities, or malalignment of the foot should also be noted. A positive Tinel's sign may be elicited over the dorsal prominence if chronic compression of the dorsomedial cutaneous nerve exists.

Standing anteroposterior, lateral, and oblique views of the foot should be obtained. The lateral view often reveals a dorsal osteophyte at the head of the metatarsal. Other findings indicative of hallux rigidus include joint space narrowing, subchondral cyst formation, and sclerosis. In the early stages, these findings are confined to the dorsal aspect of the joint. They extend the remainder of the joint as the disease progresses. Hattrup and Johnson developed an unvalidated radiographic classification scheme to assess the extent of degeneration (Table 1).[37]

NONOPERATIVE MANAGEMENT

The use of foot orthoses, modifications in shoewear, limitations in activity, and injections with corticosteroid or sodium hyaluronate are the measures commonly employed in the nonoperative management of hallux rigidus. However, a paucity of high-quality evidence exists to judge their effectiveness.

Foot orthoses and modified shoewear are used to limit irritation of the dorsal osteophyte and to reduce motion, impingement and mechanical stress on the joint.[72] A high toe box prevents direct contact of the dorsal osteophyte with the shoe. A shoe with a low heel and a rocker bottom sole or rigid medial shank will limit dorsiflexion during gait. A custom orthoses with a navicular pad and Morton's extension will restrict motion also. While biomechanical studies have shown that functional orthoses can either restrict dorsiflexion in a painful joint or conversely increase dorsiflexion for earlier stages of hallux rigidus, no clinical correlation has been demonstrated[44,73] (Level V evidence). One clinical study found that 47% of patients responded to custom orthoses alone, while another 10% responded to simple shoe modifications[34] (Level IV evidence).

Injections with corticosteroid or sodium hyaluronate may provide temporary relief of symptoms. Solan and colleagues (Level IV evidence) reported on effects of manipulation and corticosteroid injection of the MTP joint.[82] They found that patients with Grade I findings reported relief for a mean of 6 months. Relief from pain decreased to 3 months for patients with Grade II findings, and patients with Grade III findings had no relief from their pain. The effect of

injections with sodium hyaluronate has also been investigated in patients with early-stage hallux rigidus. Pons and colleagues (Level II evidence) prospectively compared the effects of injections with either corticosteroid or sodium hyaluronate.[64] They found that pain and function measured by visual analog scales were improved for both groups at 3 months. However, the difference in pain relief in the patients injected with sodium hyaluronate was significant compared to those injected with corticosteroid only at 28 and 56 days after the injection. Analyzing the American Orthopaedic Foot and Ankle Society (AOFAS) scores, the authors reported that both groups demonstrated significantly improved scores compared to baseline, but the sodium hyaluronate group scores were significantly better than those of the corticosteroid group. The only reported adverse events were limited to pain or swelling at the injection site in 8% of patients.

Grady and colleagues (Level IV) reviewed 772 patients with symptomatic hallux rigidus treated both nonoperatively and operatively.[34] They found that 55% of all patients were treated successfully with conservative care only, while another 6% either refused surgery or were not surgical candidates. Based on their results, they concluded that the majority of patients can be treated successfully with conservative measures.

The results of these studies indicate that the use of foot orthoses, modified shoewear or injections either with corticosteroid or sodium hyaluronate relieves the pain associated with daily activities and constitute fair evidence (Grade B recommendation) to support a trial nonoperative management prior to considering surgical intervention in patients with symptomatic hallux rigidus.

OPERATIVE MANAGEMENT

Numerous surgical procedures have been described for the management of hallux rigidus. These operations can be divided into two broad categories: joint salvage and joint destructive procedures. Joint salvage procedures include cheilectomy and metatarsal or phalangeal osteotomies. Joint destructive procedures include arthrodesis, resection arthroplasty, interpositional arthroplasty, and implant arthroplasty.

Choosing the most appropriate operation for a patient is not always straightforward. The decision-making process considers many factors, which include the age, activity level, the severity of disease based on clinical and radiographic evaluation and the comorbidities of the patient. Also, interpreting the results of surgical intervention for hallux rigidus is difficult. Most published reports with joint salvage or joint destructive procedures include patients with diagnoses other than hallux rigidus and are retrospective case series that lack consistent, validated measures of outcome.

CHEILECTOMY

Cheilectomy, as first described by DuVries in 1959, involves the resection of the dorsal osteophyte and the degenerative portion of the articular surface on the head of the metatarsal.[20] Generally, the dorsal one-third of the articular surface is removed. The procedure commonly includes the resection of dorsal osteophytes from the base of the proximal phalanx, the removal of loose bodies, a synovectomy and a release of the medial and lateral capsule and ligaments.[25,55] The advantages of a cheilectomy are that it preserves or improves motion, maintains joint stability, has low morbidity, and allows for secondary procedures in the future.[25,37,55]

Numerous retrospective case series (Level IV evidence) have reported good results with cheilectomy for early-stage (Grade I and II) hallux rigidus with success rates ranging from 72% to 100% and poorer results for advanced disease (Grade III).[14,31,37,51,60] Some authors advocate the use of cheilectomy regardless of grade[25,43,54] while others recommend this procedure for early to moderate stage involvement.[31,37,51,60] Feltham and colleagues reported on the results of 67 patients treated with cheilectomy for all three grades of hallux rigidus followed for an average of 65 months and found a 91% patient satisfaction rate[25] (Level IV evidence). The authors concluded that the preoperative grade did not correlate with clinical outcome; however they excluded patients with continuous intra-articular pain from their study. Easley and colleagues reported on their results with cheilectomy in 68 cases of hallux rigidus encompassing all grades of disease at 5-years followup[21] (Level IV evidence). They noted a 90% satisfaction rate and average increase in dorsiflexion of the MTP joint from 19 to 39 degrees. Nine feet remained symptomatic, eight of which had Grade III involvement preoperatively. In all nine, the authors found pain at the midrange of the arc of motion before surgery. They concluded that this finding indicated advanced degenerative change of the joint and was a negative prognostic sign. Coughlin et al. published the largest series of patients treated with cheilectomy. In this series, 93 cases were reviewed retrospectively at an average followup of 9.6 years[14] (Level IV evidence). The authors found that 97% of patients had an excellent or good self-assessment score and a mean increase in dorsiflexion from 14.5 to 38.4 degrees. Nine feet had Grade III changes preoperatively. In five of these feet, the cheilectomy failed and was salvaged with an arthrodesis at a mean of 6.9 years. These authors echoed the conclusions of Easley et al. that poor results may ensue after cheilectomy in the patients with advanced degeneration of the joint.

The dorsal osteophyte may recur after cheilectomy in up to 31% of cases.[21] However, recurrence does not appear to correlate with clinical failure or the return of symptoms.[1,55] Other complications reported following cheilectomy include infection, neuroma formation, transient paraesthesia of the

hallux, and reflex sympathetic dystrophy. Incidence rates are low and range from 0% to 3%.[14,21,60]

The consistently favorable results reported in several level IV studies constitute fair evidence (Grade B recommendation) to support the use of cheilectomy in patients with Grade I and II hallux rigidus. Two separate studies observed poor results with cheilectomy in a small subset of patients with advanced degeneration of the MTP joint. Based on this evidence, cheilectomy cannot be recommended for Grade III hallux rigidus.

OSTEOTOMIES

Proximal Phalangeal Osteotomies

Bonney and Macnab first described a dorsal closing-wedge osteotomy of the proximal phalanx in 1952 for the treatment of early hallux rigidus in adolescents.[6] Their procedure shifted the limited arc of MTP joint motion dorsally and placed the hallux into a more dorsiflexed position, thus allowing for improved function.[10] Moberg et al. subsequently reported good short-term results with this operation in adults and recommended further investigation of its efficacy.[53] Citron and Neil reviewed 8 patients, ranging in age from 10 to 52 years at an average of 22 years after the procedure[10] (Level IV evidence). While all 8 patients had complete pain relief initially, only five were pain-free at latest followup. The complications included one painful malunion, one nonunion requiring arthrodesis of the MTP joint, and one case of interphalangeal joint arthritis requiring arthrodesis. Radiographic progression of degenerative change was revealed in 9 of the 10 feet; however, this did not correlate with the recurrence of symptoms.

Other authors have investigated the combination of a dorsal closing wedge osteotomy and a cheilectomy.[7,88] Blyth et al. reviewed 18 patients with Grade I to III hallux rigidus treated with these combined procedures[7] (Level IV evidence). Fourteen patients demonstrated good or excellent results and a substantial improvement in motion of the MTP joint at mean followup of 4 years. One patient with a poor result went on to arthrodesis. Additional complications included transfer metatarsalgia and one injury of dorsomedial cutaneous nerve. Thomas and Smith reviewed 17 patients (24 feet) with radiographic Grade I or II changes at a median followup of 30 months[88] (Level IV evidence). A 96% satisfaction rate was obtained without any reported complications. The authors concluded that the addition of a proximal phalanx osteotomy provided better results than cheilectomy alone.

Based on the limited number of patients from the few published studies, there is insufficient evidence (Grade I recommendation) to support the use of a dorsal closing wedge proximal phalanx osteotomy with or without a cheilectomy in the management of hallux rigidus.

Metatarsal Osteotomies

Several osteotomies of the first metatarsal have been described for the treatment of hallux rigidus. These procedures are designed to decompress the joint by shortening the metatarsal, realign the articular surface to bring the residual arc of motion into a more functional range, and to correct metatarsus primus elevatus by plantarflexing the first ray.

The Green-Watermann osteotomy redirects healthy plantar articular cartilage dorsally to serve as the bearing surface of the joint. Dickerson and colleagues retrospectively reviewed 32 patients who underwent a Green-Watermann osteotomy using a subjective questionnaire over an average followup of 4 years and reported 94% of patients had significant improvement in their pain[93] (Level IV evidence). Ronconi et al. reviewed 26 patients who underwent a distal oblique osteotomy of the first metatarsal for Grade I or II hallux rigidus[67] (Level IV evidence). This procedure repositions the capital fragment plantarly and proximally thereby shortening the metatarsal and decompressing the joint. The authors reported that 84% of patients had good to excellent results with improved dorsiflexion postoperatively. Roukis et al. prospectively evaluated 47 patients who underwent various decompressive osteotomies which included Austin-Youngswick, Watermann-Green, Weil, or a telescoping Scarf[69] (Level III evidence). Although 92% of patients stated they would undergo the same procedure again, the investigators found that radiographically there was significant worsening of the lateral talar-first metatarsal angle, progressive medialization of the second digit, and persistent metatarsus primus elevatus. The authors concluded that the iatrogenic shortening of the first metatarsal consequently led to medial column instability.

Kilmartin et al. prospectively compared (Level III evidence) treatment of Grade II hallux rigidus with either phalangeal or first metatarsal decompressive osteotomy.[45] The first 49 patients underwent a phalangeal osteotomy while the subsequent 59 patients underwent a metatarsal osteotomy. The average followup for the phalangeal group was 29 months compared to 15 months for the metatarsal group. In the phalangeal osteotomy group, 65% of patients were completely satisfied compared to 54% in the metatarsal osteotomy group. Numerous complications were encountered with both osteotomies. In the phalangeal group, 2 patients had delayed unions and 2 patients with continued pain went on to a Keller procedure. Three patients developed interphalangeal joint pain with 2 requiring subsequent IP joint arthroplasty. Four patients developed transfer metatarsalgia. In the metatarsal osteotomy group, 2 patients had continued pain and underwent subsequent Keller procedures, 3 patients developed a delayed union, 2 patients developed avascular necrosis of the metatarsal head, and 18 patients developed transfer metatarsalgia. Six of these 18 patients required lesser metatarsal osteotomies to alleviate their pain. The authors concluded that neither osteotomy could be considered definitive treatment for hallux rigidus.

The lack of standardization in the surgical technique and objective measures of outcome precludes straightforward interpretation of the results. The limited and conflicting nature of the evidence noted above qualifies, at best, a Grade C recommendation for the use of any metatarsal osteotomy in the treatment of hallux rigidus.

KELLER RESECTION ARTHROPLASTY

In 1904, Keller described resection of the base of the proximal phalanx for treatment of hallux valgus with associated osteoarthritis of the first metatarsophalangeal joint.[41] This procedure decompressed the joint at the expense of stability. This costly trade-off often manifested as a cock-up deformity of the hallux with complaints of weakness and transfer metatarsalgia.[5, 7] For this reason, the Keller procedure has been recommended only for low-demand and elderly patients.

Wrighton reviewed the results of 14 patients who underwent a Keller arthroplasty for hallux rigidus with a minimum followup of 10 years[61] (Level IV evidence). Although 5 patients had residual pain, all were satisfied with their result. Three patients experienced metatarsalgia although no further intervention was warranted. Love et al. prospectively followed 75 feet in 44 patients with the diagnosis of hallux valgus and hallux rigidus who underwent a resection arthroplasty for a mean followup of 31 months[50] (Level IV evidence). The inclusion criteria were age over 50 years, low-demand lifestyle, and symptomatic first MTP arthritis. There was no differentiation of the grade of hallux rigidus among the cohort. Pain was alleviated in 40 of 44 patients and 77% of the cohort was satisfied with their results. A postoperative cock-up toe deformity was reported in 18 patients although none developed painful callosities.

O'Doherty et al. published a prospective randomized trial including 110 cases comparing a Keller procedure and arthrodesis of the first MTP joint for the diagnosis of hallux valgus and hallux rigidus with a minimum followup of 2 years[62] (Level II evidence). All patients were at least 45 years old, with an average age of 60.5 years. These authors reported a satisfactory or excellent result in 98% of individuals undergoing a Keller arthroplasty compared to 95% in the arthrodesis group. No significant difference was noted in the prevalence of postoperative transfer metatarsalgia or cock-up deformity between the groups. The prevalence of non-union in the arthrodesis group was 44%, although only 4 cases requiring revision for pain. The authors attributed the high rate of nonunion to the use of wire suture and Kirschner wires for fixation.

Given the favorable results from Level II and IV studies, there is fair evidence (Grade B recommendation) to support the use of resection arthroplasty for the treatment of hallux rigidus in older and low demand patients. However, the possibility of a cock-up deformity and transfer metatarsalgia must be considered.

INTERPOSITIONAL ARTHROPLASTY

Interpositional arthroplasty has been investigated for the treatment of advanced-stage hallux rigidus. It combines a traditional resection arthroplasty with the insertion of a biologic spacer into the joint to avoid some of the difficulties associated with an isolated resection arthroplasty. Various tissues, including the extensor hallucis brevis (EHB), plantaris, and gracilis tendons have been utilized as the interpostional graft. Theoretically, this procedure necessitates less bone resection from the proximal phalanx and better maintains joint stability and motion.

Hamilton et al. reviewed the results of 30 patients with advanced-stage hallux rigidus treated with EHB tendon-capsular interpositional arthroplasty over a 10-year period[35] (Level IV evidence). They interposed capsule and resected EHB tendon in the joint and resected 25% or less of the base of the proximal phalanx. The AOFAS scores improved from an average of 23 preoperatively to 37 postoperatively, average dorsiflexion improved from 10 to 50 degrees and 93% of patients reported that they would undergo the procedure again No weakness, transfer metatarsalgia, or metatarsal callosities were reported. Kennedy et al. reported on 18 patients (21 feet) who underwent interpositional arthroplasty with EHB tendon at a mean followup was 38 months[42] (Level IV evidence). Three feet demonstrated Grade II changes while the remainders were classified as Grade III. All patients reported improvement in pain and all but one would undergo the same procedure again. Dorsiflexion increased an average of 37 degrees. The complications included restricted motion (to less than 20 degrees) in 2 patients and transfer metatarsalgia in one patient who subsequently developed a stress fracture of the second metatarsal. The investigators concluded that interpositional arthroplasty with EHB tendon was indicated in the treatment of advanced-stage hallux rigidus. Lau et al., using a similar technique, reported on 11 patients with a mean followup of 2 years[48] (Level IV evidence). Ten patients had Grade III disease and one was classified as Grade II. Eight of eleven patients were satisfied with their result. However, eight patients reported weakness of the hallux and three reported lateral metatarsalgia. The authors concluded that interpositional arthroplasty should be considered a salvage procedure.

Barca et al. evaluated the results of interposed plantaris tendon combined with a 20 to 30 degree dorsal closing wedge osteotomy of the proximal phalanx in 12 patients over a period of 21 months[2] (Level IV evidence). An external fixator was applied to maintain diastasis of the joint. All patients reported good or excellent results and dorsiflexion was improved by an average of 44 degrees. Finally, Coughlin et al. reported on the use of the gracilis tendon as a biologic spacer in 7 patients who were followed for an average of 42 months[12] (Level IV evidence). All seven rated their result as good or excellent. There was a mean increase in AOFAS scores from 42 preoperatively to 86 postoperatively

and the mean dorsiflexion range of motion improved from 9 to 34 degrees. Four patients reported mild metatarsalgia but none demonstrated weakness in plantarflexion. Coughlin concluded that this procedure gave excellent pain relief and reliable function of the hallux.

Considering the limited quantity and quality of the data, there is insufficient evidence (Grade I recommendation) to recommend interpositional arthroplasty for the treatment of hallux rigidus.

ARTHRODESIS

Arthrodesis of the first metatarsophalangeal joint is an accepted surgical option for advanced-stage hallux rigidus, particularly in younger and more active patients. It eliminates painful motion and maintains stability of the first ray. Reported complications include non-union, progressive arthritis of the interphalangeal joint, and lateral metatarsalgia.[27,36,59]

Several studies (Level IV evidence) have observed fusion rates between 90 and 100% with various surgical techniques.[11,26,27,32,36,53,79,92] Goucher et al. prospectively evaluated 50 patients who underwent first MTP arthrodesis using dome-shaped reamers to prepare the joint and a dorsal plate with a single compression screw for fixation[32] (Level IV evidence). Preoperative diagnoses included hallux rigidus, hallux valgus, rheumatoid arthritis, hallux varus, failure of prior procedures, and neuromuscular disorders. A 96% satisfaction rate, 92% percent union rate, and significant increase in AOFAS scores were achieved at an average followup of 16 months. The revision rate was 4%. 13 patients had single-grade radiographic progression of arthritic change at the interphalangeal joint. Flavin et al., prospectively followed 12 patients who underwent first MTP arthrodesis using dorsal plate fixation with an average followup was 18 months (Level IV evidence).[26] Preoperative diagnoses included hallux valgus, hallux rigidus, and non-union of a previous fusion. All patients showed radiographic signs of union at 6 weeks and there was a significant increase in AOFAS hallux and SF-36 scores. No complications were reported in this small series.

Numerous studies (Level II evidence) have compared arthrodesis with a Keller arthroplasty and hemiarthroplasty of the hallux MTP joint.[29,62,95] In all studies, arthrodesis demonstrated equivalent or superior results with fewer complications.

The consistently favorable results reported in many Level II and IV studies constitute fair evidence (Grade B recommendation) to support the use of arthrodesis for the treatment of advanced-stage hallux rigidus.

TOTAL PROSTHETIC REPLACEMENT ARTHROPLASTY

The success of total joint replacement surgery elsewhere in the body has generated interest for the development of total prosthetic replacement arthroplasty (TPRA) for the MTP joint. Theoretically, TPRA would not only provide pain relief, but also restore motion and maintain joint stability.

Silastic Implants

Due to the initial success of silastic joint replacement in the hand, these implants were adapted for use in the MTP joint. A double-stemmed prosthesis designed as a dynamic spacer would maintain joint space and motion. Swanson et al. reported the results of the procedure in 105 patients, predominately with rheumatoid arthritis, with a mean followup of 2.5 years[84] (Level IV evidence). Radiographically, there was no evidence of implant fracture, osteophyte formation, or bone resorption. While other clinical trials (Level IV evidence) also reported initial good clinical results, the question of implant longevity still remained.[16,30,66,75] Cracchiolo and colleagues prospectively followed 86 patients with rheumatoid arthritis or hallux rigidus for a mean duration of 5.8 years[16] (Level IV evidence). 83% of patients reported subjective satisfaction with an average range of motion of 42 degrees. Radiographically, however, osteophyte formation was noted in 23 patients and 12 of these had nearly 50% articular space encroachment. Radiographic cysts were identified in 35% of patients and eight implant fractured. There was no difference in outcomes between the rheumatoid and hallux rigidus groups.

These "first generation" implants failed due to high shear forces concentrated at the prosthetic hinge. To address this, new systems were redesigned for insertion with titanium grommets to reduce the stress applied to the silastic in order to increase survival of the arthroplasty. Sebold et al. reported on 47 patients with rheumatoid arthritis or hallux rigidus who joints were replaced with this new design at an average followup of 51 months[74] (Level IV evidence). Subjectively, 30 patients were completely satisfied. No implant fractured, although arthroplasties developed periprosthetic radiolucencies in 5 patients, and the implants subsided in 15 patients. The authors contrasted their results with a similar group of 41 patients who had received hinged implants. Thirty of these arthroplasties had of radiolucencies and 2 implants fractured. The authors concluded that the use of titanium grommets protected the silicone prosthesis and improved longevity of the arthroplasty.

Despite these improvements, concerns persist regarding the potential effects of silicone debris leading to foreign-body reaction, synovitis, and bone erosion in the hallux. In addition, the systemic effects of silicone microfragments invading the lymphoreticular system are still unknown.[77,78,90] The conflicting evidence weakly supports TPRA with silastic implants in patients with hallux rigidus (Grade C recommendation).

Total Metallic Implants

TPRA with unconstrained metallic implants has also been evaluated. Pulavarti et al. reviewed the results of 36 patients

implanted with a Bio-Action prosthesis, a nonconstrained uncemented implant at a minimum followup of 3 years[65] (Level IV evidence). The diagnoses of the cohort included hallux rigidus, hallux valgus with degenerative changes, failed hallux surgery, gouty and rheumatoid arthritis. The authors noted a significant improvement in dorsiflexion, MTP motion, and AOFAS outcome scores following surgery. Satisfaction was rated as either excellent or good in 77.5% of patients. Two arthroplasties required salvage, one with a resection arthroplasty and other with an arthrodesis. Radiographs revealed periprosthetic radiolucencies and subsidence in one-third of the arthroplasties. Fuhrmann et al. reviewed the results of 43 TPRA using the ReFlexion prosthesis, a modular, nonconstrained, porous-coated prosthesis that may be implanted with or without cement with an average followup of 3 years[28] (Level IV evidence). The indication for replacement was end-stage hallux rigidus in 32 cases and failed MTP joint surgery in the nine cases. The authors cemented 20 phalangeal and 5 metatarsal components due to poor bone quality. All patients reported a significant reduction in pain measured on a visual analogue scale. The Hallux AOFAS functional ratings scores and passive dorsiflexion improved significantly. However, several arthroplasties became unstable; 16% and 28% developed instability in the axial and sagittal plane instability respectively. Also, 30% developed valgus deformities, 9% developed varus deformities, and 21% of the arthroplasties developed plantar subluxation of their phalangeal component. Radiolucent lines were evident around 23% of phalangeal components and 9% of metatarsal components.

Gibson et al. performed a prospective, randomized controlled trial comparing arthrodesis versus total arthroplasty for patients with symptomatic hallux rigidus[29] (Level II evidence). Sixty-three patients (77 feet) were randomized to either arthrodesis or an uncemented arthroplasty. The mean patient age was 55 years (range, 34 to 77 years). The arthrodesis was performed with flat cuts and stabilized with a cerclage wire and single Kirschner wire. All 38 arthrodeses united. Seven developed minor wound infections and 2 required hardware removal. Six of the 39 arthroplasties failed due to loosening of the phalangeal components. The postoperative VAS pain scores were significantly reduced in both groups when compared to the preoperative scores. More patients in the arthrodesis group preferred their functional and cosmetic result. At 2 years after surgery, 40% of patients in the arthroplasty group would not undergo surgery again compared to only 3% of patients in the arthrodesis group. The authors concluded that the outcome with arthrodesis was better than with arthroplasty.

Given these unfavorable results in multiple studies with different implants, TPRA cannot be recommended at this time for the management of hallux rigidus. The results of Gibson's prospective, randomized trial constitute a Grade B recommendation of arthrodesis instead of arthroplasty. However, more level I or II evidence is warranted to confirm this impression.

HEMIARTHROPLASTY

Hemiarthroplasty of the proximal phalanx has been available for over 50 years. Nevertheless, only a few studies investigating its efficacy have been published. Proponents of the procedure using a metallic implant feel that it avoids the high dorsal shear forces associated with metatarsal head replacement as well as the inherent structural flaws of silastic implants.[46,86,89]

Townley et al. performed a large retrospective review of 279 patients treated with a metallic hemiarthroplasty of the proximal phalanx with followup ranging from 8 months to 33 years[89] (Level IV evidence). Preoperative diagnoses included hallux rigidus, rheumatoid arthritis, and hallux valgus associated with osteoarthritis. The authors reported good or excellent results in 95% of patients. Only 2 patients with a diagnosis of hallux rigidus patients were unsatisfied with their result. One patient had a postoperative infection while the other received an oversized implant. The remaining failures occurred in 8 patients with hallux valgus and 3 with rheumatoid arthritis. There was only one case of clinical or radiographic evidence of loosening which occurred in a patient with rheumatoid arthritis and poor bone quality. Taranow et al. retrospectively reviewed 28 patients who underwent hemiarthroplasty for severe hallux rigidus with an average followup of 33 months[86] (Level IV evidence). Twenty-three patients were completely satisfied, 3 were satisfied with reservations, and 2 were dissatisfied. Radiographically, 4 implants were inserted in a dorsiflexed position and 3 of implants showed evidence of subsidence and loosening. Two patients demonstrated a recurrence of their osteophytes, but this did not correlate with patient satisfaction.

Roukis et al. prospectively compared 16 patients who underwent a periarticular metatarsal osteotomy with 9 patients underwent hemiarthroplasty with a followup of 1 year[68] (Level III evidence). Both groups significantly improved their pain scores and motion of the joint. The authors did not report any complications, but were concerned about the effect of iatrogenic metatarsal shortening in the osteotomy group. However, the results of other studies have not been as promising. Konkel et al. retrospectively reviewed 10 patients (13 feet) who underwent a titanium hemi-arthroplasty for grade II or III hallux rigidus[46] (Level IV evidence). The followup ranged from 37 to 105 months. Eleven hemiarthroplasties eliminated pain. All implants developed radiolucencies and subsidence. One implant was salvaged with an interpositional arthroplasty for periprosthetic fracture and a subsequent painful nonunion. Raikin et al. retrospectively compared patients with severe hallux rigidus who were treated with either a metallic hemiarthroplasty or an arthrodesis[95] (Level III evidence). Twenty-one

hemiarthroplasties with a mean followup of 79 months were compared to 27 arthrodeses with a mean followup of 30 months. All arthrodeses united and only 2 patients required hardware removal. Five of the 21 hemiarthroplasties failed. One was revised; four were salvaged with an arthrodesis. An additional eight hemiarthroplasties that were not considered failures had cut out of the stem through the plantar cortex of the phalanx. The authors reported that the patients who underwent arthrodesis had significantly higher satisfaction rates, higher AOFAS scores, and lower VAS pain scores compared to the hemiarthroplasty group. The authors concluded that arthrodesis was more predictable than hemiarthroplasty for alleviating symptoms and restoring function in patients with severe hallux rigidus.

Except for the study by Townley, the use of hemiarthroplasty in the management of hallux rigidus is supported by conflicting or poor quality evidence (Grade C recommendation). The long-term consequences for hemiarthroplasties that have not failed but are malpositioned, subsided or surrounded by radiolucencies remains uncertain. Further studies designed to yield level I or II evidence are warranted to address these concerns.

SUMMARY

1. The evidence supports the use of nonoperative measures which may include foot orthosis, shoe modifications and injections with either corticosteroid or sodium hyaluronate prior to considering surgery in patients with hallux rigidus.
2. The evidence supports the use of cheilectomy in patients with Grade I and II hallux rigidus. These favorable results have not been demonstrated reliably in patients with Grade III hallux rigidus. Patients who experience pain in the midrange arc of motion may not achieve the same result after cheilectomy as those patients who do not exhibit this finding.
3. There is limited and conflicting evidence is to recommend the use of a osteotomy of the proximal phalanx, the first metatarsal or both for hallux rigidus.
4. Keller resection arthroplasty can be considered for advanced stages of hallux rigidus in elderly and low-demand patients; however, complications such as cock-up deformity, weakness, and lateral metatarsalgia may develop with this procedure.
5. Arthrodesis is the mainstay of surgical treatment for patients with advanced stages of the disease.
6. The evidence is insufficient to recommend interpositional arthroplasty with a biologic spacer. The evidence weakly supports hemiarthroplasty and total prosthetic replacement arthroplasty with a silastic prosthesis implanted with grommets. Total prosthetic replacement arthroplasty is not recommended for the management of hallux rigidus.

REFERENCES

1. **Anderl, W; Knahr K; Steinbock, G:** Long term results of the Keller-Brandes method of hallux rigidus surgery. Z Orthop Ihre Grenzgeb. **112**:266–269, 1991.
2. **Barca, F:** Tendon arthroplasty of the first metatarsophalangeal joint in hallux rigidus: preliminary communication. Foot Ankle Int. **18(4)**:222–228, 1997.
3. **Beertema, W; Draijer, WF; van Os, JJ; Pilot, P:** A retrospective analysis of surgical treatment in patients with symptomatic hallux rigidus: long-term followup. J. Foot Ankle Surg. **45(4)**:244–251, 2006. http://dx.doi.org/10.1053/j.jfas.2006.04.006
4. **Bingold, AC; Collins, DH:** Hallux rigidus. J. Bone Joint Surg. Br. **32**:214–222, 1950.
5. **Blyth, MJ; Mackay, DC; Kinninmonth, AW:** Dorsal wedge osteotomy in the treatment of hallux rigidus. J. Foot Ankle Surg. **37(1)**:8–10, 1998.
6. **Bonney, G; Macnab, I:** Hallux rigidus in the adolescent. J Bone Joint Surg. **34-B(3)**:366–385, 1952.
7. **Citron, N; Neil, M:** Dorsal wedge osteotomy of the proximal phalanx for hallux rigidus. Long-term results. J Bone Joint Surg. Br. **69(5)**:835–837, 1987.
8. **Cotteril, JM:** Stiffness of the great toe in adolescents. British Med. J. **1**:158, 1888.
9. **Coughlin, MJ; Abdo, RV:** Arthrodesis of the first metatarsophalangeal joint with Vitallium plate fixation. Foot Ankle Int. **15**:18–28, 1994.
10. **Coughlin, MJ; Shurnas, PS:** Soft-tissue arthroplasty for hallux rigidus. Foot Ankle Int. **24(9)**:661–672, 2003.
11. **Coughlin, MJ; Shurnas, PS:** Hallux Rigidus: Demographics, Etiology, and Radiographic Assessment. Foot Ankle Int. **24(10)**:731–743, 2003.
12. **Coughlin, MJ; Shurnas, PJ:** Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg. **85-A(11)**:2072–2088, 2003.
13. **Cracchiolo, A 3rd; Weltmer, JB Jr; Lian, G; Dalesth, T; Dorey, F:** Arthroplasty of the first metatarsophalangeal joint with a double-stem silicone implant. Results in patients who have degenerative joint disease, failure of previous operations, or rheumatoid arthritis. J. Bone Joint Surg. **74-A(4)**:552–563, 1992.
14. **Davies-Colley, M:** Contraction of the metatarso-phalangeal joint of the great toe. BMJ. **1**:728, 1887.
15. **Dickerson, JB; Green, R; Green, DR:** Long-Term followup of the Green-Watermann osteotomy for hallux limitus. J. Am. Podiatr. Med. Assoc. **92(10)**:543–554, 2002.
16. **Drago, J; Oloff, L; Jacobs, AM:** A comprehensive review of hallux limitus. J. Foot Surg. **23(3)**:213–220, 1984.
17. **DuVries, HV:** Surgery of the foot. St. Louis (MO): Mosby Year book. 392–399, 1959.
18. **Easley, ME; Davis, WH; Anderson, RB:** Intermediate to long-term followup of medial-approach dorsal cheilectomy for hallux rigidus. Foot Ankle Int. **20(3)**:147–152, 1999.
19. **Ettl, V; Radke, S; Gaertner M; Walther, M:** Arthrodesis in the treatment of hallux rigidus. Int. Orthop. **27(6)**:382–385, 2003. http://dx.doi.org/10.1007/s00264-003–0492-3
20. **Feltham, GT; Hanks, SE; Marcus, RE:** Age-based outcomes of cheilectomy for the treatment of hallux rigidus. Foot Ankle Int. **22(3)**:192–197, 2001.
21. **Fitzgerald, JA:** A review of long-term results of arthrodesis of the first metatarsophalangeal joint. J. Bone and Joint Surg. **51-(3)**:488–493, 1969.
22. **Flavin, R; Stephens, MM:** Arthrodesis of the first metatarsophalangeal joint using a dorsal titanium contoured plate. Foot Ankle Int. **25(11)**:783–787, 2004.
23. **Fuhrmann, RA; Wagner, A; Anders, JO:** First metatarsophalangeal joint replacement: the method of choice for end-stage hallux rigidus? Foot Ankle Clin North Am. **8**:711–721, 2003. http://dx.doi.org/10.1016/S1083-7515(03)00146-3

24. **Gibson, A; Thomson, CE:** Arthrodesis or total replacement arthroplasty for hallux rigidus. Foot Ankle Int. **26(9)**:680–690, 2005.
25. **Granberry, WM; Noble, PC; Bishop JO; Tullos, HS:** The use of hinged silicone prosthesis for replacement arthroplasty of the first metatarsophalangeal joint. J. Bone Joint Surg. **73-A**:1453–1459, 1991.
26. **Geldwert, JJ; Rock, GD; McGrath. MP; Mancuso, JE:** Cheilectomy: still a useful technique for grade 1 and 2 hallux limitus/rigidus. J. Foot Surg. **31**:154–159, 1992.
27. **Goucher, NR; Coughlin, MJ:** Hallux metatarsophalangeal joint arthrodesis using dome-shaped reamers and dorsal plate fixation: a prospective study. Foot Ankle Int. **27(11)**:869–876, 2006.
28. **Gould, N; Schneider, W; Ashikaga, T:** Epidemiological survey of foot problems in the continental United States: 1978–1979. Foot Ankle Int. **1(1)**:8–10, 1980.
29. **Grady, JF; Axe, TM; Zager, EJ; Sheldon, LA:** A retrospective analysis of 772 patients with hallux limitus. J. Am. Podiatr. Med. Assoc. **92(2)**:102–108, 2002.
30. **Hamilton, W; O'Malley, MJ, Thompson, FM; Kovatis, PE:** Capsular interpositional arthroplasty for severe hallux rigidus. Foot Ankle Int. **18**:68–70, 1997.
31. **Harrison, MH; Harvey, FJ:** Arthrodesis for the first metatarsophalangeal joint for hallux valgus and rigidus. J. Bone and Joint Surg. **45-A**:471–480, 1963. 45-A:
32. **Hattrup, SJ; Johnson, KA:** Subjective results of hallux rigidus following treatment with cheilectomy. Clin Orthop Related Res. **226**:182–191, 1988.
33. **Henry, AP; Waugh, W; Wood, H:** The use of footprints in assessing the results of operations for hallux valgus: a comparison of Keller's operation and arthrodesis. J. Bone and Joint Surg. **57-B(4)**:478–481, 1975.
34. **Herton, GA; Park, YW; Myerson, MS:** Role of metatarsus primus elevatus in the pathogenesis of hallux rigidus. Foot Ankle Int. **20(12)**:777–780, 1999.
35. **Karasick, D; Wapner, KL:** Hallux rigidus deformity: radiologic assessment. Am. J. Roentgenol. **157**:1029–1033, 1991. 157:
36. **Keller, WL:** The surgical treatment of bunions and hallux valgus. New York Med J. **80**:741–742, 1904.
37. **Kennedy, JG; Brodsky, AR; Gradl, G; Bohne, WH:** Outcomes after interposition arthroplasty for treatment of hallux rigidus. Clin Orthop Related Res. **445**:210–215, 2006.
38. **Keogh, P; Nagaria, J; Stephens, M:** Cheilectomy for hallux rigidus. Ir J Med Sci. **161(12)**:681–683, 1992.
39. **Kilmartin, TE; Wallace WA; Hill, TW:** Orthotic effect on metatarsophalangeal joint extension. A preliminary study. J. Am. Podiatr. Med. Assoc. **81(8)**:414–417, 1991.
40. **Kilmartin, TE:** Phalangeal osteotomy versus first metatarsal decompression osteotomy for the surgical treatment of hallux rigidus: a prospective study of age-matched and condition-matched patients. J. Foot Ankle Surg. **44(1)**:2–12, 2005. http://dx.doi.org/10.1053/j.jfas.2004.11.013
41. **Konkel, KF; Menger, AG:** Mid-term results of titanium hemi-great toe implants. Foot Ankle Int. **27(11)**:922–929, 2006.
42. **Lambrinudi, P:** Metatarsus primus elevatus. Proc. R. Soc. Med. **31**:1273, 1938.
43. **Lau, JT, Daniels, TR:** Outcomes following cheilectomy and interpositional arthroplasty in hallux rigidus. Foot Ankle Int. **22(6)**:462–470, 2001.
44. **Lombardi, CM; Silhanek, AD; Connolly, FG; Dennis, LN; Keslonsky, AJ:** First metatarsophalangeal arthrodesis for treatment of hallux rigidus: a retrospective study. J. Foot Ankle Surg. **40(3)**:137–143, 2001.
45. **Love, TR; Whynot AS, Farine, I; Lavoie, M; Hunt, L; Gross, A:** Keller Arthroplasty: A prospective review. Foot Ankle. **8(1)**:46–54, 1987.
46. **Mackay, DC; Blyth, M; Rymaszewski, LA:** The role of cheilectomy in the treatment of hallux rigidus. J. Foot Ankle Surg. **36(5)**:337–340, 1997.
47. **Mahiquez, MY; Wilder, FV; Stephens, HM:** Positive hindfoot valgus and osteoarthritis of the first metatarsophalangeal joint. Foot Ankle Int. **27(12)**:1055–1059, 2006.
48. **Mann, RA; Coughlin, MJ; DuVries, HL:** Hallux rigidus. A review of the literature and a method of treatment. Clin. Orthop. **142**:57–63, 1979.
49. **Mann, RA; Oates, JC:** Arthrodesis of the first metatarsophalangeal joint. Foot Ankle. **1**:159–166, 1980.
50. **Mann, RA; Clanton, TO:** Hallux Rigidus: Treatment by cheilectomy. J. Bone Joint Surg. **70-A (3)**:400–406, 1988.
51. **McMaster:** The pathogenesis of hallux rigidus. J. Bone Joint Surg. **60-B(1)**:82–87, 1978.
52. **Meyer JO; Nishon, LR; Weiss, L; Docks, G:** Metatarsus primus elevatus and the etiology of hallux rigidus. J. Foot Surg. **26(30**:237–241, 1987.
53. **Moberg, E:** A simple operation for hallux rigidus. Clin. Orthop. **142**:55–56, 1979.
54. **Moynihan, FJ:** Arthrodesis of the metatarso-phalangeal joint of the great toe. J. Bone and Joint Surg. **49-(3)**:544–551, 1967.
55. **Mulier, T; Steenwerckx, A; Thienpont, E; Sioen, W; Hoore, KD; Peeraer, L; Dereymaeker, G:** Results after cheilectomy in athletes with hallux rigidus. Foot Ankle Int. **20(4)**:232–237, 1999.
56. **Nilsonne, H:** Hallux rigidus and its treatment. Acta Orthop Scand. **1**:295–303, 1930.
57. **O'Doherty, DP; Lowrie, IG; Magnussen, PA; Gregg, PJ:** The management of the painful first metatarsophalangeal joint in the older patient. J. Bone Joint Surg. **72-B(5)**:839–842, 1990.
58. **Politi, J; John, H; Njus, G; Bennett, GL; Kay, DB:** First metatarsalphalangeal joint arthrodesis: a biomechanical assessment of stability. Foot Ankle Int. **24(4)**:332–337, 2003.
59. **Pons M; Alvarez F; Solana, J; Viladot, R; Varela, L:** Sodium hyaluronate in the treatment of hallux rigidus. A single-blind, randomized study. Foot Ankle Int. **28(1)**:38–42, 2007. http://dx.doi.org/10.3113/FAI.2007.0007
60. **Pulavarti, RS; McVie, JL; Tulloch, CJ:** First metatarsophalangeal joint replacement using the Bio-Action great toe implant: Intermediate results. Foot Ankle Int. **26(12)**:1033–1037, 2005.
61. **Rahman, H; Fagg, PS:** Silicone granulomatous reactions after first metatarsophalangeal hemiarthroplasty. J. Bone Joint Surg., **75-B(4)**:637–639, 1993.
62. **Raikin, SM; Ahmad, J; Pour, AE; Abidi, N:** Comparison of arthrodesis and metallic hemiarthroplasty of the hallux metatarsophalangeal joint. J. Bone Joint Surg. **89**:1979–1985, 2007. http://dx.doi.org/10.2106/JBJS.F.01385
63. **Ronconi, P; Monachino, P; Baleanu, PM; Favilli, G:** Distal oblique osteotomy of the first metatarsal for the correction of hallux limitus and rigidus deformity. J. Foot Ankle Surg. **39(3)**:154–160, 2000.
64. **Roukis, TS; Jacobs, PM; Dawson, DM; Erdmann, BB; Ringstrom, JB:** A prospective comparison of clinical, radiographic, and intraoperative features of hallux rigidus. J. Foot Ankle Surg. **41(2)**:76–95, 2002.
65. **Sammarco, VJ; Nichols, R:** Orthotic management for disorders of the hallux. Foot Ankle Clin. **10(1)**:191–209, 2005. http://dx.doi.org/10.1016/j.fcl.2004.09.003
66. **Scherer, PR; Sanders, J; Eldredge, DE; Duffy, SJ; Lee, RY:** Effect of Functional Foot Orthoses on First Metatarsophalangeal Joint Dorsiflexion in Stance and Gait. Journal of the American Podiatric Medical Association. **96(6)**:474–481, 2006.
67. **Sebold, EJ; Cracchiolo, A 3rd:** Use of titanium grommets in silicone implant arthroplasty of the hallux metatarsophalangeal joint. Foot Ankle Int. **17(3)**:145–151, 1996.
68. **Shankar, NS; Asaad, SS; Craxford, AD:** Hinged silastic implants of the great toe. Clin. Orthop. Relat Res. **272**:227–234, 1991.

69. **Shereff, MJ; Jahss, MH:** Complications of silastic implant arthoplasty in the hallux. Foot Ankle. **1(2)**:95–101, 1980.
70. **Shiel, WC Jr; Jason, M:** Granulomatous inguinal lymphadenopathy after bilateral metatarsophalangeal joint silicone arthroplasty. Foot Ankle. **6(5)**:216–218, 1986.
71. **Smith, RW; Joanis, TL; Maxell, PD:** Great toe metatarsophalangeal joint arthrodesis: a user friendly technique. Foot Ankle. **13**:367–376, 1992.
72. **Smith, RW; Katchis, SD; Ayson, LC:** Outcomes in hallux rigidus patients treated nonoperatively: a long-term followup study. Foot Ankle Int. **21(11)**:906–913, 2000.
73. **Solan, MC; Calder, JD; Bendall, SP:** Manipulation and injection for hallux rigidus. Is it worthwhile? J. Bone Joint Surg. **83-B(5)**:706–708, 2001
74. **Southgate, JJ; Urry, SR:** Hallux rigidus: the long-term results of dorsal wedge osteotomy and arthrodesis in adults. J Foot Ankle Surg. **36(2)**:136–140, 1997.
75. **Swanson, AB; Lumsden, RM; Swanson, GD:** Silicone implant arthroplasty of the great toe: a review of single stem and flexible hinge implants. Clin. Orthop. **142**:30–43, 1979.
76. **Swanson, AB; de Groot, SG:** Use of grommets for flexible hinge implant arthroplasty of the great toe. Clin. Orthop. Relat. Res. **340**:87–94, 1997. http://dx.doi.org/10.1097/00003086-199707000-00012
77. **Taranow, WS; Moutsatson, MJ; Cooper, JM:** Contemporary Approaches to Stage II and III hallux rigidus: The role of metallic hemiarthroplasty of the proximal phalanx. Foot Ankle Clin N. Am. **10**:713–28, 2005. http://dx.doi.org/10.1016/j.fcl.2005.06.011
78. **Taylor, DT; Sage, RA; Pinzur, MS:** Arthrodesis of the first metatarsophalangeal joint. Am. J. Orthop. **33(6)**:285–288, 2004.
79. **Thomas, PJ; Smith, RW:** Proximal phalanx osteotomy for the surgical treatment of hallux rigidus. Foot Ankle Int. **20(1)**:3–12, 1999.
80. **Townley, CO; Taranow, WS:** A metallic hemiathroplasty resurfacing prosthesis for the hallux metatarsophalangeal joint. Foot Ankle Int. **15(11)**:575–580, 1994.
81. **Verhaar, J; Vermeulen, A; Bulstra, S; Walenkamp, G:** Bone reaction to silicone metatarsophalangeal joint-1 hemiprothesis. Clin. Orthop. **245**:228–232, 1989.
82. **Wrighton, JD:** A ten-year review of Keller's Operation. Review of Keller's operation at the Princess Elizabeth Orthopaedic Hospital Exeter. Clin. Orthop. **89**:207–214, 1972. http://dx.doi.org/10.1097/00003086-197211000-00027
83. **Wu, KK:** Arthrodesis of the metatarsophalangeal joint of the great toe with Herbert screw: a clinical analysis of 27 cases. J. Foot Ankle Surg. **32**:47–52, 1993.