CHAPTER 7

LONG-TERM FOLLOW-UP OF THE GREEN-WATERMANN OSTEOTOMY FOR HALLUX LIMITUS

Jason Dickerson, D.P.M.
Richard Green, D.P.M.
Donald Green, D.P.M.

INTRODUCTION

Hallux limitus rigidus is a well-known entity to physicians treating the foot and ankle. There are numerous approaches to the surgical treatment of hallux limitus ranging from the simple soft tissue release, and cheilectomy[1-7] to the joint destructive procedures.[8-11] Between these extremes are various phalangeal and metatarsal osteotomies utilized for hallux limitus.[8,9,12-22] (Table 1) Choosing the most appropriate surgical approach, with such a wide array of procedures having various indications, contraindications, advantages and disadvantages, can be a challenging task.

In 1987, Bernbach and McGlamry[15] suggested a step-wise surgical approach to hallux limitus. This began with a cheilectomy, progressed to a Watermann-type or Austin-type procedure, then to a plantar-declinatory wedge osteotomy, and finally an implant. The following year, Bernbach[16] added an additional procedure to this step-wise approach: the Green-Watermann procedure. Laakman presented a preliminary report on this procedure with very positive results in 1996.[23] The purpose of this paper is to present a retrospective analysis of the long-term efficacy of the Green-Watermann procedure for hallux limitus.

MATERIALS AND METHODS

Letters were sent to all eighty patients who had the Green-Watermann procedures for painful hallux limitus/rigidus performed by authors DG and RG between 1990 and 1999. Thirty-two patients responded to the subjective questionnaire regarding preoperative and postoperative pain and level of function, complications, need for further surgery, and overall patient satisfaction.(Table 2) The medical records and radiographs of the 32 patients representing 40 Green-Watermann procedures were reviewed.

Table 1

HALLUX LIMITUS RIGIDUS SUMMARY OF PROCEDURES

I. Joint Destructive
   A. Resectional arthroplasty
      1. Resect proximal phalanx base (Keller)
      2. Resect metatarsal head (Mayo, Heuter, Stone)
   B. Implant arthroplasty
      1. Silastic (hemi or total)
      2. Metallic (hemi or total)
   C. Arthrodesis 1 First MTPJ (McKeever)
II. Joint Preserving
   A. Proximal phalangeal
      1. Basilar dorsal wedge osteotomy (Kessel & Bonney)
      2. Regnauld enclavement
      3. Sagittal-Z osteotomy
   B. First metatarsal
      1. Long diaphyseal osteotomy
      2. Green-Watermann osteotorny
      3. Shortening, Offset, long-arm chevron osteotomy (Youngswick/ Selnar)
      4. Plantarflexory wedge osteotomy
      5. Sagittal-Z osteotomy
      6. Double osteotomy
   C. Cheilectomy
      1. Valenti modification
   D. First metatarsal -cuneiform arthrodesis (Lapidus)

Using the preoperative radiographs, the first metatarsophalangeal joints were graded according to the modified Drago, Oloff, and Jacobs and Regnauld scale[1,24] as grade I, grade II, grade III, or grade IV (Table 3). One patient (3%) had hallux limitus/rigidus grade I that showed no radiographic

Table 2

SUBJECTIVE PATIENT SURVEY
PATIENT SURVEY

PRIOR TO SURGERY:

Which big toe joint was operated on? Right_____ Left_____ Both_____
On a scale of 1 to 10 (10 being worst), what was your level of pain before surgery? _____
Did the pain in your big toe joint limit you from daily activities? Yes_____ No_____
Did the pain limit you from sports activities? Yes_____ No_____
Did the pain limit you from wearing certain shoes? Yes____ No____
Describe the stiffness you experienced before surgery: Very Stiff ____ Not very stiff_____
No Stiffness at all _____.

FOLLOWING SURGERY:

Pain

Did your surgery relieve the pain in your big toe joint? Yes____ No_____
Do you experience any pain now in your big toe joint with normal daily activities?
No Pain _____ Mild, occasional pain_____ Moderate, daily pain _____ Severe pain_____
3. Do you experience any stiffness now in your big toe joint? Yes_____ No_____
4. Are you able to participate in sports activities without pain? Yes_____ No_____
5. Do you have any painful calluses on the ball of your foot? Yes_____ No _____

Function

1. Are you satisfied with the amount of motion in your big toe joint? Yes_____ No____
The amount of motion in my big toe joint following surgery has:
Increased greatly_____ Increased somewhat_____ No change_____ Decreased_____
Does your big toe joint limit your normal daily activities?
No limitations_____ Some limitations_____ Severe limitations_____
Does your big toe joint restrict the type of shoes you can wear?
No restrictions_____ Restricted to wide shoes/sneakers_____ Restricted to many types_____
What sports activities/hobbies are you involved in that require increased physical d mands?
(Walking, running, golf, bowling, etc. _____)

Complications

Were there any complications following your surgery? Yes_____ No____ If Yes, what were they?
How long were you wearing a surgical shoe? 2weeks___ 3weeks___ 4weeks___ Over 4 wks_____
Have you required additional surgery on your big toe joint? Yes____ No____
Are you pleased with the appearance of your big toe joint? Yes____ No____
Do you have any swelling of the big toe joint? None____ Slight____ Constant_____
Did you have any type of physical therapy after surgery Yes____ No _____

Overall impression

Chief complaints satisfactorily resolved: (Please check one)
Very strongly agree (90% or more improved) _____
Strongly agree (70% improved) _____
Agree (50% improved)_____
Disagree (less than 50% improved)_____
Strongly disagree (minimal improvement, worse)_____

Overall Satisfaction:

Very Pleased (would highly recommend) _____
Pleased (would recommend) _____
Displeased (would not recommend) _____

Table 3

PREOPERATIVE GRADING SCALE FOR HALLUX LIMITUS/RIGIDUS

Grade of Hallux Limitus	Characteristics	Number of Feet
Grade I	Functional Limitus No radiographic changes	1
Grade II	Joint adaptation Proliferative and destructive joint changes	32
Grade III	Joint deterioration and arthritis	7
Grade IV	Ankylosis	0

Based on the modified Drago, OIoff, Jacobs, and Regnauld system.

changes, but had a functional limitus. Thirty-two joints (80%) had joint adaptation and proliferative and destructive joint changes noted as grade II. Seven (18%), as a grade III, demonstrated joint deterioration and arthritis. No joints were graded IV with ankylosis. Twenty-four of the thirty-two patients representing twenty-eight Green-Watermann procedures were returned for clinical evaluation.

Of the thirty-two patients who responded to the subjective questionnaires, 17 were males and 15 were females. The average age at the time of surgery was 55 years (range 41 to 69 years). The average length of follow-up was 4 years (range 1 to 10 years). Eight patients had bilateral surgery for a total of 40 Green-Watermann procedures performed. There were twenty-five procedures on the right foot and fifteen on the left foot.

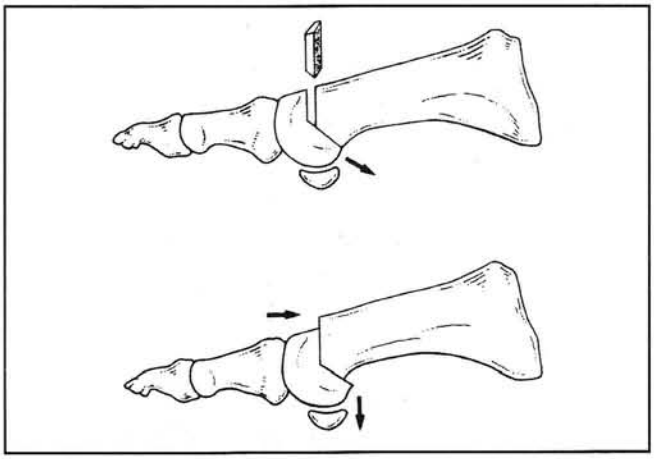

Figure 1. The modified Watermann procedure shortens and plantar declinates the metatarsal head. An appropriate portion of bone is removed dorsally to allow the desired shortening. The angle of the plantar cut determines the ratio of shortening to plantar declination.

SURGICAL TECHNIQUE

The surgical technique used in the Green-Watermann procedure has been previously published by Bernbach[16] in 1988 and by Feldman[17] in 1992. (Fig. 1) The procedure begins with a standard bunion approach with anatomic dissection in layers down to the first metatarsophalangeal joint capsule. A capsulotomy of choice is then performed (usually a dorsomedial linear capsulotomy), and the capsule is reflected to allow exposure of the first metatarsal head. An attempt is made to preserve the dorsal metatarsophalangeal joint plica if possible. A dorsal cheilectomy or generous resection of the first metatarsal prominence is performed, which often requires sacrifice of the dorsal plica to resect the whole dorsal shelf of bone. (Fig. 2) Resection of an

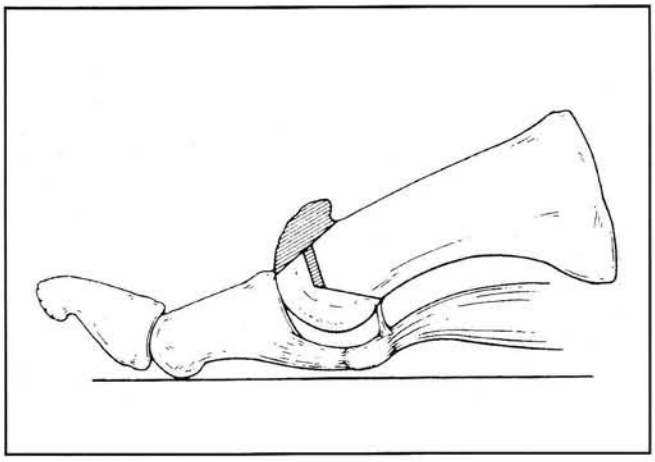

Figure 2. Resection of the dorsal exostosis (cheilectomy) is usually required

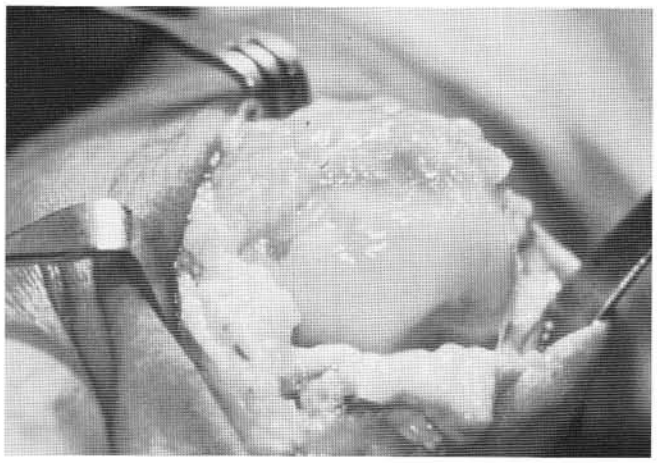

Figure 3A. Appearance of the first metatarsal head prior to remodeling of the dorsal exostosis. Exuberant bone proliferation is noted.

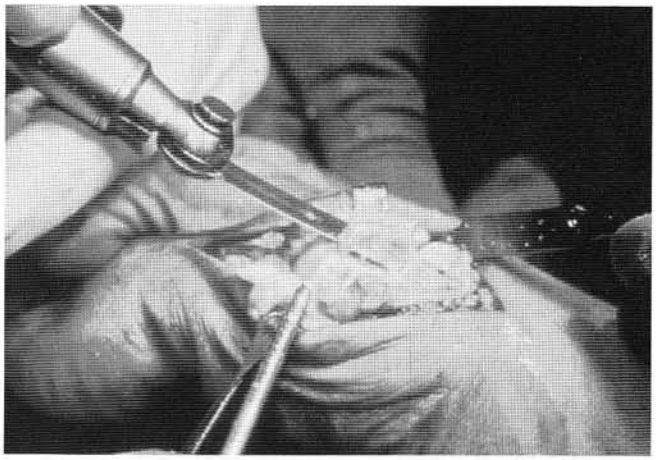

Figure 3B. Remodelling and resection of the dorsal exostosis with a power saw.

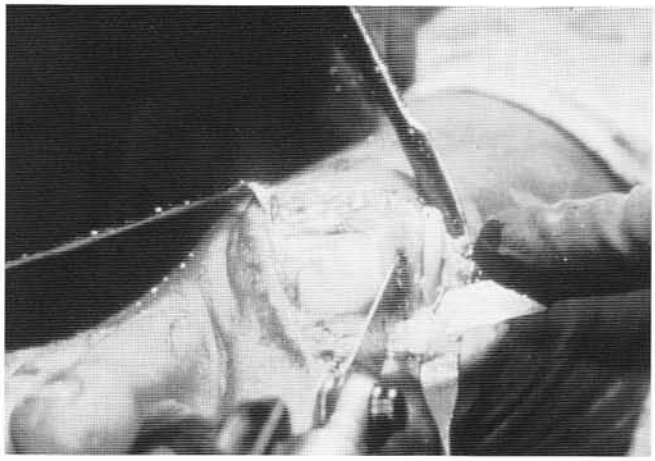

Figure 3C. Remodelling of the medial eminence with a power saw.

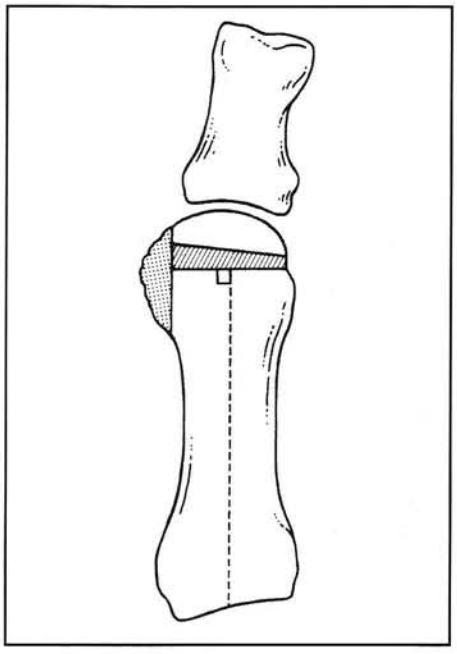

Figure 4. The medial eminence is resected if needed. The PASA correction can be achieved via a trapezoidal dorsal wedge. The capital fragment can be transposed laterally if necessary.

appropriate amount of medial eminence is then performed. (Fig. 3A)

Next, a through-and-through osteotomy is made from medial to lateral in the lower two-thirds of the metatarsal head and neck. The osteotomy is made from the plantar cortex just proximal to the attachment of the plantar plica and extends dorsally and distally into the metatarsal head. (Fig. 3B) The amount that the osteotomy is angled from the weight-bearing surface will determine the ratio of metatarsal shortening to plantar-declination. A standard 45-degree angle will give a 1:1 ratio. A more parallel angle will give greater shortening relative to plantar transposition, while a more vertical angle will give greater plantar transposition relative to metatarsal shortening.[17] The saw blade can then be detached from the power equipment and left in the plantar osteotomy to assist in accurate placement of the dorsal osteotomies. (Fig. 3C)

A rectangular or trapazoidal section of bone in the dorsal one-third of the metatarsal head is resected, maintaining a perpendicular relationship to the weight-bearing surface. The width of the rectangular section of bone will determine the amount of shortening. The distal osteotomy is performed first, and is usually made parallel to the proximal articular set angle (PASA) of the first metatarsal head in order to correct the angle to zero to eight degrees. The inferior aspect of the osteotomy should intersect the distal aspect of the plantar osteotomy utilizing

the plantar saw blade as a guide. The proximal osteotomy is performed next, and can be made perpendicular to the long axis of the first metatarsal. This creates a dorsal trapezoidal-shaped wedge of bone with a wider base medial. (Fig. 4) If no PASA correction is desired, one can also perform the distal osteotomy perpendicular to the longitudinal axis of the first metatarsal creating a dorsal rectangular-shaped wedge of bone. (Fig. 5)

The section of bone is removed to allow shortening, and the capital fragment is slid proximally and declinated along the plantar slope of bone. (Fig. 6) Lateral transposition of the capital fragment can also be performed at this time if a relative reduction of the intermetatarsal angle is desired. Reciprical planing may be necessary to insure a flush fit of the bone edges.

Fixation of the osteotomy site is then accomplished with either a 0.062" threaded K-wire or a 4.0 mm AO cancellous screw. (Fig. 7) The fixation is usually proximal-dorsal to distal-plantar insuring the fixation is not exposed at the plantar articulating surface. The capital fragment is then inspected for stability, and if necessary, a second threaded K-wire is placed. The K-wire is cut flush with the metatarsal cortex dorsally and adequately countersunk as necessary to prevent dorsal impingement. (Fig. 8) Standard layered closure of the soft tissues is then achieved with adjunctive capsulorrhaphy done as determined intra-operatively by the surgeon. PASA correction, lateral transposition of the capital fragment, and/or lateral release of the metatarsophalageal joint are not usually required, but may be necessary if a dorsal medial bunion is associated with the hallux limitus.

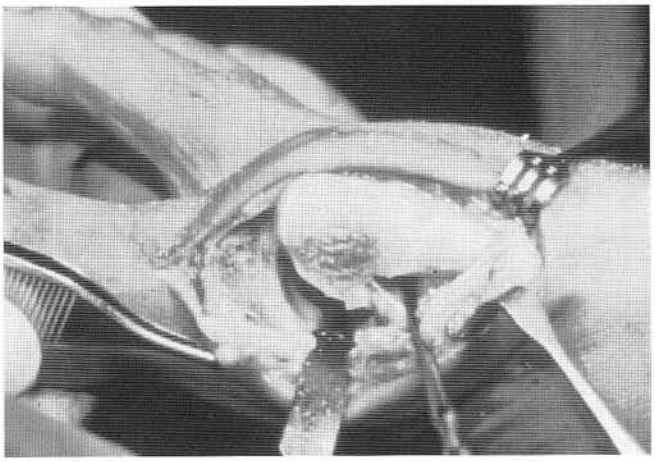

Fig 5A. Disection of the plantar tissues in preparation for the plantar arm of the osteotomy. Note the preservation of the plantar attachment of the capsular tissue.

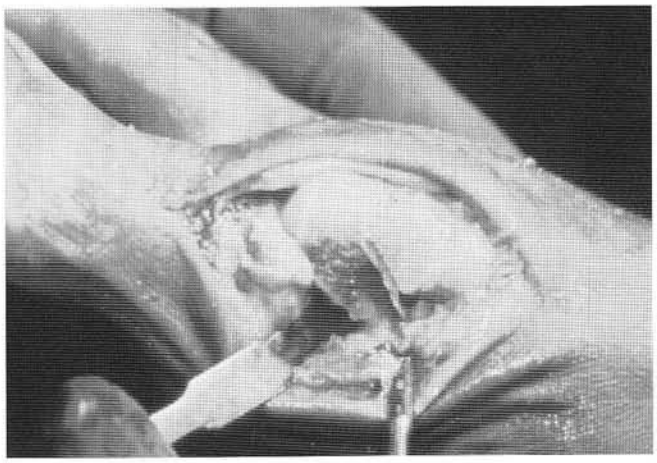

Fig 5B. Execution of the plantar arm of the osteotomy. The saw blade is left in place to help guide execution of the dorsal osteotomy.

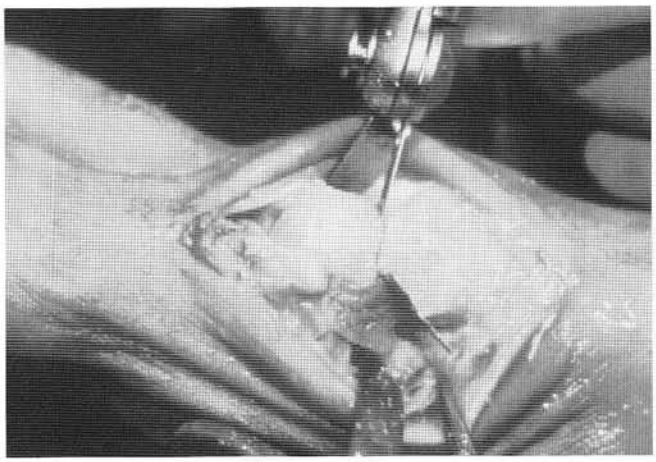

Fig 6A. Execution of the dorsal osteotomy resulting in removal of a segment of bone to shorten the first metatarsal. Removal of a trapezoidal section of bone will allow simultaneous correction of the PASA.

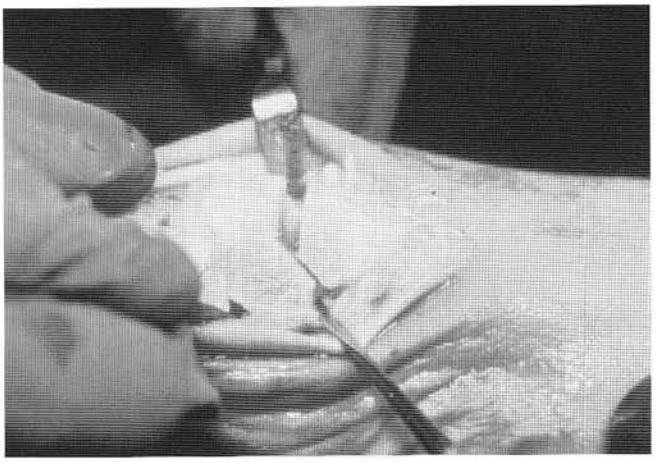

Fig 6B. First metatarsal osteotomy completed. The distal capital fragment will shorten and plantarflex based upon this osteotomy.

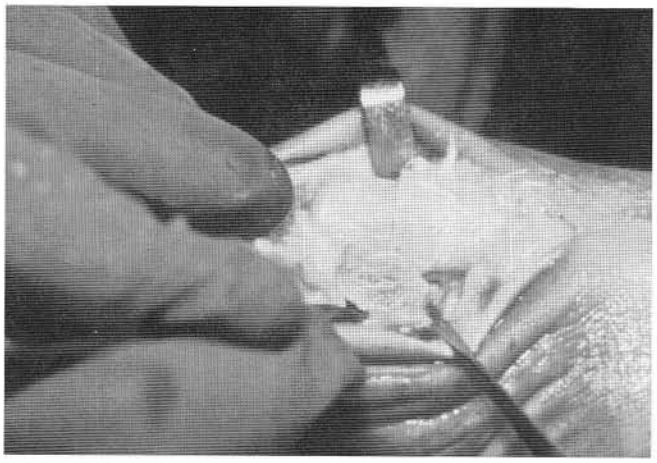

Fig 7A. Appearance following translocation of the first metatarsal head. Note good apposition of the osteotomy surfaces.

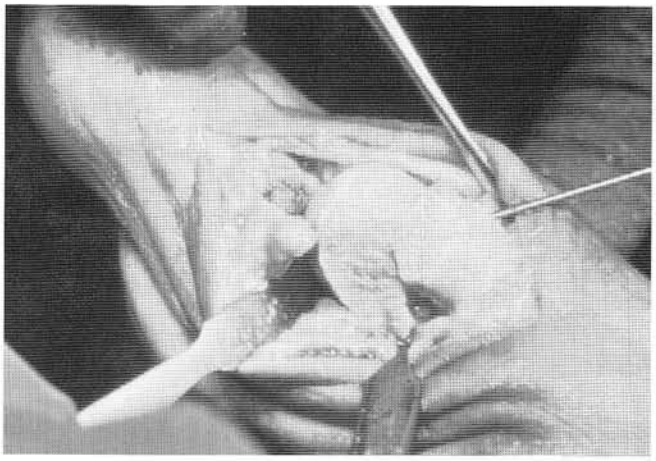

Fig 7B. Fixation of the osteotomy with Kirschner wire.

Fig 8A. Postoperative lateral radiograph showing plantar flexion of the capital fragment and fixation with a single Kirschner wire from dorsal proximal to plantar distal.

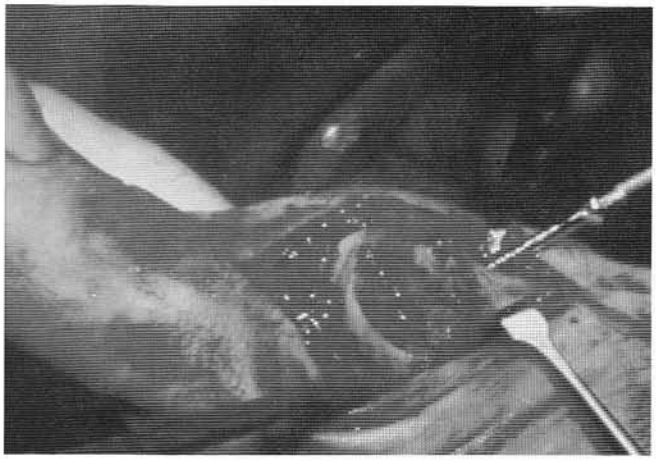

Fig 8B. Direction and placement of a cancellous screw for fixation of the osteotomy. Note the direction and location are the same as for Kirschner-wire fixation.

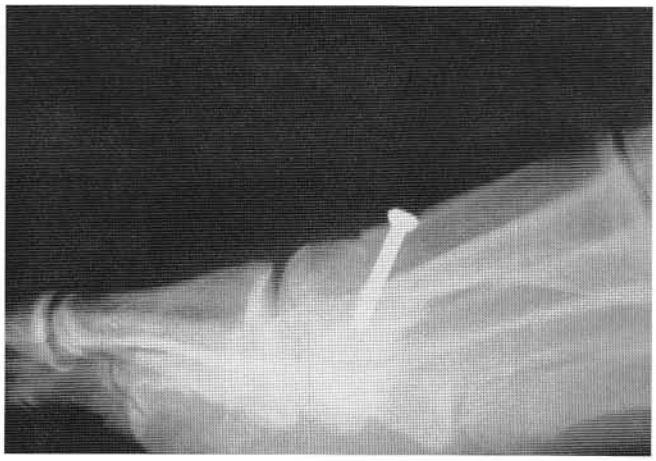

Fig 8C. Postoperative lateral radiograph showing fixation of a Green-Waterman Osteotomy with a cancellous screw providing enhanced fixation of the osteotomy.

POSTOPERATIVE MANAGEMENT

The patient is discharged in a rigid surgical shoe, and allowed to bear weight as tolerated. Often a betadine soaked gauze bandage is applied postoperatively as a betadine cast. Passive range of motion exercises are begun no later than postoperative day three, and then gradually and progressively increased until full motion is achieved. Physical therapy is often prescribed beginning 2 to 3 weeks postoperatively consisting of active and passive range of motion exercises. The rigid surgical shoe is usually worn for 3 weeks while the metaphyseal osteotomy is healing.

SUBJECTIVE RESULTS

On a scale of 1-10 (10 being the worst) patients reported an average pain rating of 8 preoperatively (range 4 to10). All patients reported pain and stiffness in the first metatarsophalangeal joint before surgery. Sixty-two percent of the patients reported limitations with daily activities. Twenty-eight patients (88%) had limitations with sports, and 24 patients (75%) had limitations in shoe gear.

Thirty patients (94%) reported that surgery had significantly relieved the pain in the great toe joint. No patients admitted to worsening pain. Eleven patients (34%) had no pain, eighteen (56%) had mild, occasional pain; three (9%) had moderate pain: and no patients had severe pain. Twenty-five patients (78%) were able to participate in sporting activities which included walking, running, tennis, bowling, squash, basketball, golf, hockey, weight-lifting, aerobics, biking, and skiing. None of the patients reported the development of painful calluses following surgery. Although six patients (18%) developed pain sub 2nd metatarsal head, all were relieved with orthotics and padding. One patient complained of pain sub 1st metatarsal directly in the sesamoid area bilateraly.

All patients reported satisfaction with the appearance of their great toe joint following surgery, and 24 patients (75%) reported a marked increase in their first metatarsophalangeal joint range of motion. Five patients (16%) reported a decrease in first metatarsophalangeal range of motion following surgery and three patients (9%) related no change in first metatarsophalangeal joint range of motion. Only eight patients(25%) reported that their great toe joint still limited them from some daily activities, and sixteen patients (50%) related limitations to the type of shoes they can wear. This was reported mostly by the female patients, who were not able to wear high heals. None of the patients related any complications following surgery, such as infection, wound dehiscence, or dislocation. Surgical shoes were worn for 2 to 4 weeks, and passive range-of-motion exercises were performed by all of the patients, ranging from immediately following surgery to 2 weeks. All patients had postoperative orthotics. Nine patients related slight occasional swelling. None related continual swelling.

The results were then calculated using the modified American Orthopedic Foot and Ankle Society Rating System for Hallux Metatarsophalangeal-Interphalangeal Scale.[25] An average score of 83 (range, 38-100) was obtained. (Table 4) Twenty procedures were rated as having excellent results, fifteen as good, none as fair, and five as poor.(Table 5)

Table 4

MODIFIED AMERICAN ORTHOPEDIC FOOT AND ANKLE SOCIETY RATING SYSTEM FOR HALLUX METATARSOPHALANGEAL SCALE

Pain (40 points)	
None	40
Mild, occasional	30
Moderate, daily	20
Severe	0
Function (40 points)	
Activity limitations	
No limitations	10
Some limitations of daily activities including recreational and leisure activities (shopping, employment requirements)	5
Severe limitation of daily and recreational activities	0
Footwear requirements	
No restrictions	10
Restricted to sneakers, wide shoes	5
Restricted to many types	0
Range of motion	
Completely satisfied	10
Nonpainful, limited motion	5
Painful, restricted motion	0
Calluses	
None or present and nonpainful	5
Painful	0
Swelling	
None	5
Slight	3
Constant	0
Alignment/cosmesis (10 points)	
Good, pleased	10
Fair	5
Poor, unhappy	0
Success of surgery (10 points)	Percent/100

Total number of patients surveyed = 32; total number of procedures = 40; average score 83 /100 (range 38 to 100).

Table 5

RESULTS OF SUBJECTIVE SURVEY

Result	Score	Number of Procedures
Excellent	90-100%	20
Good	70-89%	15
Fair	60-69%	0
Poor	<60%	5

Based on the modified American Orthopedic Foot and Ankle Society Rating System for HalIux MetatarsophaIangeal Scale

Twenty-two patients (68%) felt that their chief complaints were >90 percent resolved. Six (18%) felt that they were >70% improved. One (3%) felt >50% improved. Three (9%) indicated no improvement. No patient felt they were made worse from the procedure. Thus 88% of the patients were more than 70% improved, and 90% of the patients were improved by at least 50%. Twenty-nine patients (90%) said they would undergo the same procedure again. Three patients (9%) had reservations about their surgery.

OBJECTIVE RESULTS

Twenty-four out of 32 patients (28 procedures) agreed to a follow-up examination and a long term updated radiographic evaluation. The patients were also evaluated regarding appearance, edema, scar, neurological status, deformity, dorsiflexion and plantarflexion range of motion measurements, and pain on range of motion and palpation. The mean follow-up time was 4 years (range 1 to 10 years). Average age at the time of follow-up was 55 years old (range 45 to 62 years). There were 19 procedures on the right foot and 9 procedures on the left foot.

Two patients had some pain upon palpation and range of motion. No patients had persistent periarticular edema. None of the patients had hypertrophic scars. One patient had an asymptomatic recurrence as noted by palpable prominent dorsal exostosis. One patient had a palpable K-wire fixation dorsally, but it was not painful. Six patients responded positively with tenderness to palpation plantar to the second metatarsal head. Two of the patients had non-tender tyloma formation beneath the second metatarsal. One patient reported sesamoid pain following surgery on both feet.

The attending physicians generally recorded a limitation of motion of the first metatarsolphalangeal joint preoperatively, but did not consistently record the range of motion in degrees. Only postoperative degrees of range of motion were recorded. The average degree of dorsiflexion at follow-up was 58 degrees (range 44 to 85 degrees). The average degree of plantarflexion motion was 9 degrees (range 5 to 20 degrees).

Radiographic studies at the time of follow-up included dorsoplantar and lateral views. The metatarsal protrusion distance (MPD) preoperatively, ranged from 5mm to -5mm with an average of -.27mm. Negative numbers are recorded when the first metatarsal is shorter than the second. Postoperatively the MPD averaged -4.27mm (range 0 to (-11) mm) with an average shortening of the first metatarsal of -4mm (range 0 to (-7) mm).

Although the first metatarsal is often elevated above the second metatarsal on the lateral radiograph, it is the change in the elevation from the base to the metatarsal head that is of greater significance. Camasta described the variability in superimposition of the first and the second metatarsals on the lateral radiograph with positional changes in the x-ray machine tubehead.[26] Seiberg described a reproducible method of evaluating radiographic elevatus by using standard reference points.[27] The Seiberg index (S.I.), compares the difference between the cortices of the 1st and 2nd metatarsals at 1.5cm distal to the metatarsocuneiform joint and at the surgical neck of the 1st metatarsal.(Fig. 9) The distance in mms of the proximal measurement is subtracted from the distance in mms of the distal measurement to give the index. The S.I. is positive, with a metatarsus primus elevatus. Preoperatively the S.I. was positive for all patients except two patients whose index was zero (neither elevated/declinated). The average preoperative S.I. was 2.1 (range 0 to 4).

Postoperatively the capital fragment plantar transposition was measured by using a modified S.I. (the difference between the dorsal cortex of the 1st metatarsal proximal and distal to the osteotomy site). All osteotomies obtained plantarflexion of the capital fragment of 1mm to 2mm with an average of 1.25mm. Negligible changes

were noted in the intermetatarsal angle, sesamoid position, and the base of the proximal phalanx in relationship to the head of the metatarsal. There was a small amount of reduction in the hallux abductus angle.

COMPLICATIONS

Three patients felt their symptoms had not improved postoperatively. Two patients were available for follow-up examination. The first patient was a 54-year-old nurse who had surgery five years prior for grade II hallux limitus bilaterally. Postoperatively, her symptoms seemed to be resolved for 1 or 2 years. She then began to have sub 1st metatarsal pain and pain with range of motion worse with plantarflexion. Orthotic devices helped, but did not eliminate the pain. She was unable to ambulate without shoes/orthotic devices. She had a very thin plantar pad beneath the first metatarsal and a prominent tibial sesamoid bilaterally. She was able to speed walk with her shoes and orthotic devices and feels she is not worse than she was pre-operatively. Tibial sesamoiditis and progression of her degenerative joint pain may require further surgery, which will probably include a Keller procedure and/or removal of the tibial sesamoid.

The second patient is a 47-year-old female who works for the FBI. She underwent a Green-Watermann procedure three years prior for grade II hallux limitus. Postoperatively she continued to have joint pain and stiffness that seemed to be improving with physical therapy. Five months post-operatively she had a comminuted fracture of her 5th metatarsal base requiring 3 months in a short leg cast. Currently she has 35 degrees of dorsiflexion but no plantarflexion. She has pain with end range of motion. She denies sub 1st or 2nd metatarsal pain. She continues to work as a field officer, but notices increased pain after long days on her feet. The inability to continue with physical therapy and cast immobilization for 3 months may have considerably added to her joint stiffness. Currently she states the pain has not stopped her from working. Eventually she may require a joint destructive procedure.

The third patient is a 42-year-old female who underwent bilateral Green-Watermann osteotomies for grade I and grade II hallux limitus 4 years prior. This patient was not available for follow-up examination. Her questionnaire indicates her pain is in her entire forefoot. She also answered yes when asked if the pain in her first metatarsal joint had decreased. She does feel that she has joint stiffness and is limited in her shoe gear. Her 6-week postoperative x-rays show well-healed, well-aligned osteotomies with no degenerative changes of significance.

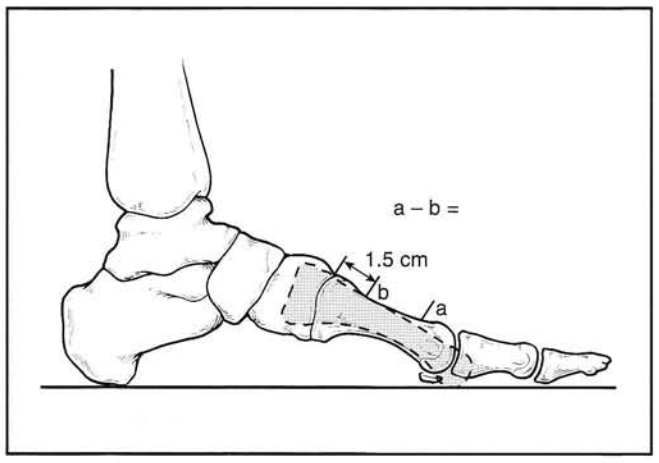

Figure 9. Seiberg Index is a sagittal measurement of the relationship of the first metatarsal to the second metatarsal. The perpendicular distance from the dorsum of the second metatarsal to the dorsum of the first metatarsal shaft is measured at the first metatarsal neck and 1.5 cm from the first metatarsal base. The proximal measurement is subtracted from the distal measurement to give the Seiberg Index.

DISCUSSION

Root et. al indicate that 65 to 75 degrees of dorsiflexory motion is necessary at the first MPJ for normal ambulation.[28] Hallux limitus is the restriction of motion at the first metatarsophalangeal joint (MTPJ). Functional hallux limitus is the condition in which the limitation of hallux dorsiflexion is only present upon weightbearing. In a structural hallux limitus, the restriction of motion is present on both weightbearing and non-weightbearing. The condition in which there is no range of motion at the first metatarsophalangeal joint is referred to as hallux rigidus.

Numerous authors[3,12,18,20,28-34] have proposed anatomic abnormalities of the foot as the primary cause of this condition, suggesting pes planus, forefoot pronation, metatarsal elevation, and an abnormally long 1st ray, hallux and/or metatarsal. (Table 6) Davies-Colley[33] originally described it as hallux flexus in 1887 suggesting an abnormally long hallux as an etiology. Cotterill, several months later designated the term of hallux rigidus.[35]

Cochrane in 1927, felt that hallux rigidus, was secondary to shortened and contracted plantar first metatarsophalangeal joint structures.[36] In 1954,

Table 6

ETIOLOGIC FACTORS OF HALLUX LIMITUS

Configuration of the head of the first metatarsal
(round, square)
Hypermobility of the first ray
Abnormal prontation of the subtalar joint
Immobility of the first ray
DJD at the Lisfranc=s articulation
Congenital coalition between the first metatarsal and first cuneiform or between the navicular and calcaneus
Long first metatarsal
Overloading of the first metatarsal
Metatarsus primus elevatus
Congenital
Acquired
Iatrogenic
DJD of the first metatarsophalangeal joint
Trauma
Acute gross injury
Chronic microtrauma
Occupation/activities
Degenerative joint disease,

Hicks[32] discussed the inter-relationship of the plantar aponeurosis and its effect on extension of the toes at the metatarsophalangeal joint, including the hallux. Durrant and Siepert[34] believed, that soft tissue structures: flexor hallucis brevis and sesamoid apparatus, medial plantar fascial slip; and scarring of the joint capsule, were all capable of limiting motion of the 1st MTPJ.

Lambrinudi[31] reported on dorsal elevation of the first metatarsal head as an anatomic abnormality. He used the term "metatarsus primus elevatus" to describe an abnormal elevation of the first ray as a cause of hallux rigidus. Meyer et al.[37] reported on the elevation of the first metatarsal in a group of 120 randomly selected foot radiographs. The diagnosis of hallux limitus was made in 22 of the 120 patients. The mean elevation of the first metatarsal above the 2nd at the metatarsal neck was 6.9 mm for the group as a whole. They concluded that approximately 7.0 mm of first ray elevation is a consistent radiographic finding in-patients with and without hallux rigidus. Horton et al.[29] found similar results with an average of nearly 8mm of metatarsus elevatus as a normal finding in patients with hallux rigidus as well as in normal subjects. Meyer felt that metatarsus elevatus was paramount in the pathogenesis of hallux rigidus, while Horton considered it a secondary phenomenon rather than a primary cause.[29,37] Root, Orien, and Weed[28] felt that acquired hallux limitus can develop from abnormal subtalar joint pronation which allows for hypermobility of the first ray and metatarsus elevatus.

Kinematic analysis of the first metatarsohpalangeal join in patients who have hallux rigidus reveals a decrease in the total arc of motion, with relatively normal plantar flexion but markedly restricted dorsiflexion. Motion analysis reveals instant centers of rotation that are displaced and located eccentrically about the metatarsal head.[38,39]

Roukis et al.[30] quantitatively demonstrated that motion of the first metatarsophalangeal joint is influenced by the position of the first ray. First metatarsophalangeal joint dorsiflexion decreased 19% as the first ray was moved from the weightbearing resting position to 4 mm dorsiflexed, and decreased 34.7% as the first ray was moved from the weightbearing resting position to 8 mm dorsiflexed.

The increased motion of the first metatarsophalangeal joint when subjects are non-weight-bearing has been attributed to unrestricted plantar flexion of the first metatarsal, which allows the transverse axis to remain within the center of the head of the first metatarsal. This mechanism allows the hallux to glide and rotate without impaction on the first metatarsal head.[38,40]

Plantar declination of the capital fragment in conjunction with shortening produces a better mechanical environment for hallux range of motion and weightbearing. The author believes that the most important structural change is the shortening of the metatarsal to allow a "slack in the line." This will effectively relax the plantar structures for increase range of motion.[9,14-16,18,22,23,28,30]

The Green-Watermann procedure obtains surgical correction by three mechanisms: shortening the first metatarsal, plantar transposition of the first metatarsal head, and a dorsal cheilectomy. In those cases that may require it, correction of PASA and lateral transposition of the capital fragment is available. The procedure requires five osteotomies and allows the first metatarsal capital fragment to be moved in four different directions.[17]

The subjective results showed a decrease in the patient's mean level of pain. The largest difference was an increase in the patient's mean overall satisfaction when comparing preoperative and postoperative assessments. Twenty-nine patients (90%) said they would highly recommend the surgery to patients with similar symptoms. Patients also experienced a mean increase in their level of activity, an improved appearance of the foot, less limitation in the style of shoes that could be tolerated, and an increase in the amount of motion at the big toe joint. It is interesting to note that patients achieved a more substantial decrease in the level of pain rather than in the amount of first metatarsophalangeal joint range of motion.

Objective biomechanical results showed adequate range of motion of the first metatarsophalangeal joint. Although no preoperative comparisons could be made, patients felt a significant increase in range of motion. There was a significant decrease in the level of pain with range of motion, which may have contributed to the sensation of an increased range of motion.

The mean metatarsal protrusion distance was decreased postoperatively as was expected indicating that the metatarsal was indeed shortened. The mean Seiberg sagittal plane displacement was recorded to be 1.25 millimeters of declination. One needs to appreciate that, due to the declination of the metatarsal, ordinarily any capital fragment shortening will concomitantly elevate it as well. The angulation of the plantar osteotony will mitigate this elevation to some extent or may even plantardeclinate the capital fragment. However, six of our thirty-two patients complained of sub 2nd metatarsal pain (relieved with orthotic devices). Of note, four of the six patients had a Seiberg index of 3 or greater. Placing the plantar arm closer to the vertical plane (allowing for more plantar transposition), may alleviate this problem. One patient (two feet) had increased sesamoid pain. The Seiberg Index was -5 and -3 respectively. Placing the plantar arm closer to the horizontal plane (allowing less plantar transposition) may have prevented this problem.

The disadvantages of the Green-Watermann osteotomy include the precision necessary in performing the procedure, the requirement of fine instrumentation, and the inherent instability of the design. All patients in the study had uneventful healing with no delayed healing or nonunions.

CONCLUSION

The Green-Watermann procedure has shown to be an effective treatment of hallux limitus as a joint preservation procedure. It addresses the elevated first metatarsal and shortens to allow for decreased tension in the soft tissue structures. With preservation of the first metatarsophalangeal joint, this procedure also allows for maintenance of a propulsive gait postoperatively. Even in many grade III hallux limitus cases, good results have been gained. Of course good funtional control postoperatively in an orthotic device have helped to neutralize the pathologic forces causing the elevated 1st ray. The procedure is not intended to reverse the arthritis that has already occurred. The patients are made aware that, in the future, joint destructive procedures may be required as the aging process continues. The good functional results are giving patients a stable joint with significant reduction in symptoms and years of a more active lifestyle.

REFERENCES

1. Drago JL, Oloff L, Jacobs AM: A comprehensive review of hallux limitus. *J Foot Surg* 23(3):213-220, 1984.
2. Gould N: Hallux rigidus: Cheilectomy or implant? *Foot Ankle* 1(6):315-320, 1981.
3. Mann RA, Clanton TO: Hallux rigidus: Treatment by cheilectomy. *J Bone Joint Surg* 70A(3):400-406, 1988.
4. Geldwert JJ, Rock GD, Mcgrath MP, Mancuso JE: Cheilectomy: Still a useful technique for Grade I and Grade II Hallux limitus/rigidus. *J Foot Surg* 31 (2):154-159, 1992.
5. Hattrup SJ, Johnson KA: Subjective results of hallux rigidus following treatment with cheilectomy. *Clin Ortho Res* 226: 182-191, 1988.
6. Grady J, Axe T, The modified Valenti prodedure for the treatment of hallux limitus. *J Foot Ankle Surg* 33:365-367, 1994.
7. Saxena A. The Valenti procedure for hallux limitus/rigidus. *J Foot Ankle Surg* 34:485-488, 1995.
8. McKeever DC: Arthrodesis of the first metatarsophalangeal joint for hallux valgus, hallux rigidus and metatarsus primus varus. *J Bone Joint Surg* 34A:129-134, 1952.
9. Chang TJ: Stepwise approach to hallux limitus. A surgical perspective. *Review Clin Podiatr Med Surg* 13(3):449-59, 1996.
10. Gerbert J: *Textbook of Bunion Surgery* Mt. Kisco, NY: Futura 453-492, 1991.
11. Quinn M, Wolf k, Hensley J, Kruljac S: Keller arthroplasty with autogenous bone graft in the treatment of hallux limitus. *J Foot Surg* 29(3):284-291, 1990.
12. Kessel I, Bonney G: Hallux rigidus in the adolescent. *J Bone Joint Surg* 40B:668, 1958.
13. Cavolo Du, Cavallaro Dc, Arrington Le: The Watermann osteotomy for hallux limitus. *J Am Podiatry Assoc* 69(1):52-57, 1979.
14. Youngswick F: Modification of the Austin Bunionectomy for treatment of metatarsus primus elevatus associated with hallux limitus. *J Foot Surg* 21:114, 1982.
15. Bernbach M, McGlamry ED: Hallux limitus. In McGlamry ED, ed., *Reconstructive Surgery of the Foot and Leg, Update '87* Tucker, GA: Doctors Hosptial Podiatric Education and Research Institute 81-85, 1987.
16. Bernbach M: Hallux limitus: Follow-up study. In McGlamry ED , ed., *Reconstructive Surgery of the Foot and Leg, Update '88* Tucker, GA: Doctors Hospital Podiatric Education and Research Institute 109-111, 1988.
17. Gusman DN, et al. Newell decompression prodedure for hallux limitus. A preliminary report. *J Am Podiatry Med Assoc* 85(12):749-52, 1995.
18. Kissel CG, et al. Cheilectomy, chondroplasty, and sagittall "Z" osteotomy: a preliminary report on an alternative joint preservation approach to hallux limitus. *J Foot Ankle Surg* 34(3):312-8, 1995
19. Cohen M, et al. A modification of the Regnauld procedure for hallux limitus. *J Foot Surg* 31(5):498-503, 1992.
20. Viegas GV, Resconstruction of hallux limitus deformity using a first metatarsal sagittal- Z osteotomy. *J Foot Ankle Surg* 37(3):204-11, 1998
21. Selner AJ et al. Tricorrectional osteotomy for the correction of late-stage hallux limitus/rigidus. *J Am Podiatry Med Assoc* 87(9): 414-24, 1997.
22. Laakmann G, Green R, Green D: The Modified Watermann Prodedure. A Preliminary Retrospective Study. In *Reconstructive Surgery of the Foot and Ankle, Update '96.* Tucker Georgia, The Podiatry Institute, pp.128-135, 1996.
23. Feldman KA: The Green-Watermann procedure: Geometric analysis and preoperative radiographic template technique. *J Foot Surg* 31(2):182-185, 1992.
24. Regnauld B: The Foot: Pathology, Etiology, Seminology, Clinical Investigation & Therapy, pp.268-277, 287-290, 335-350, 507-529, Springer-Verlag, New York, 1986.
25. Kitaoka HB., Alexander IJ., Adelaar RS, et al. Clinical rating systems for the ankle-hindfoot, hallux, and lesser toes. *Foot Ankle* 15:349-352, 1994.
26. Camasta CA: Radiographic Evaluation and Classification of Metatarsus Primus Elevatus. In *Reconstructive Surgery of the Foot and Ankle, Update '94.* Tucker Georgia, The Podiatry Institute, pp.122-127, 1994.
27. Seiberg M, Felson S, Colson JP, et al: Closing base wedge versus Austin bunionectomies for metatarsus primus adductus. *J Am Podiatry Med Assoc* 84:548-563, 1994.
28. Root M, Orien W, Weed J: Normal and Abnormal Function of the Foot. Los Angeles, Clinical Biomechanics Cor., 1977.
29. Horton GA, Hong-Wook P, Myerson M: Role of Metatarsus Primus Elevatus in the Pathogenesis of Hallux Rigidus. *Foot Ankle Int* 20(12): 777-780, 1999.
30. Roukis TS, et al. Position of First Ray and Motion of the First Metatarsophalangeal joint. *J Am Podiatry Med Assoc* 86(11):538-46, 1996.
31. Lambrinudi C: Metatarsus primus elevatus. *Proc R Soc Med* 31:1273, 1938.
32. Hicks JH: The mechanics of the foot II. The plantar aponeurosis and the arch. *J Anat* 88:25,1954.
33. Davis-Colley N: Contraction of the MTPJ of the Great Toe (Hallux Flexus). *Br Med J* 1:728, 1887.
34. Durrant MN, Siepert KK: Role of soft tissue structures as an etiology of hallux limitus. *J Am Podiatry Med Assoc* 83(4):173-180.
35. Cotterill JM: Condition of Stiff Great Toe in adolescents. *Edinbeurger Med. J.*33: 459-462, 1887.
36. Cochrane LA: An operation for hallux rigidus. *Br Med J* 1:1095-1096, 1927.
37. Meyer JO, Nishon LR, Weiss L, Docks G: Metatarsus Primus Elevatus and the Etiology of Hallux Rigidus. *J Foot Surg* 26: 237-241, 1987.
38. Sherell MJ, Benjamin FJ, Kummer FJ: Kinematics of the First Metatarsophalageal Joint. *J Bone Joint Surg* 68-A:392-398, 1986.
39. Shereff MJ, Baumhauer JF: Current Concepts Review, Hallux Rigidus and Osteoarthrosis of the First Metatarsophalageal Joint. *J Bone Joint Surg* 80(A):898-908, 1998.
40. Nawoczenki DA, Baumhauer JF, Unberger BR: Relationship Between Clinical Measurements and Motion of the First Metatarsophalangeal Joint During Gait. *J Bone Joint Surg* 81(A):370-376, 1999
41. Kurtz DH, Harrill JC, Kaczander BI, Solomon MG. The Valenti Procedure for Hallux Limitus: A Long-Term Follow-up and Analysis. *J Foot Ankle Surg* 38(2): 123-130, 1999.