GAIT ANALYSIS BASED ON FIRST MTPJ FUNCTION: The Functional Hallux Limitus Concept

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INTRODUCTION

Gait analysis is an objective tool that the podiatric physician has at his disposal in the assessment and treatment of a wide range of disorders that affect not only the foot, but the entire musculoskeletal system. The prevailing and traditional theory of gait analysis, based on excessive subtalar joint pronation, fails in its ability to be easily applied and documented by simple conventual means. Thus, the demonstration of postural disorders through gait analysis has been limited.

A relatively new concept of gait analysis, functional hallux limitus, has proven to be evident in theory and application. The overall concept is simple and easy to apply, document, and correlate to other musculoskeletal conditions. This represents a new understanding of pathologic foot function.

FUNCTIONAL HALLUX LIMITUS (FHL)

Functional hallux limitus is defined as a momentary failure of the first metatarsophalangeal joint to undergo dorsiflexion at the time of heel-lift (calcaneal unweighting), resulting in the inefficient transfer of weight in the load-bearing foot. In addition, it results in the failure of the weight-bearing foot to initiate the mechanisms of auto-support, and reverse rotation at the end of single limb support.

Clinical Application

Functional hallux limitus (FHL) is an entity that until recently has been largely unrecognized by the human eye. Dananberg, in 1986, first described FHL and its relationship to gait efficiency through the use of high-resolution video tape and vertical load analysis systems (Electrodynogram). Identification of this phenomena as a pathologic entity was thus discovered.

FHL is a dynamic condition that can only be appreciated through the use of these specialized studies. In the usual clinical setting, a patient will commonly have full range of motion of their great toe joint. Evaluation of the patient's first metatarsophalangeal joint motion is performed with the patient's foot in a plantarflexed attitude, or with the foot oriented 90° to the leg. The examiner then places the hallux through its range of motion while holding the first ray stable. (Figure 1) In reality, during gait, it is the metatarsal that moves over a stable and fixed hallux and sesamoid complex.

The determination of the presence of FHL in a static situation is performed by placing the foot at a 90° angle to the leg, loading the first metatarsal at the level of the sesamoids or at the metatarsal head, and then attempting to dorsiflex the hallux. (Figure 2) The lack of motion at the first MPJ is thus indicative of FHL. This condition is present more frequently than once thought to be.

Figure 1. Clinical examination of normal first metatarsophalangeal joint motion. The patient has full excursion of the hallux, both dorsally and plantarly.

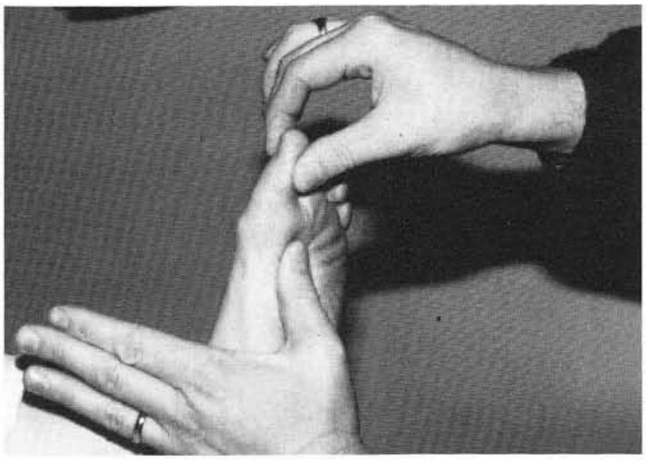

Figure 2. Demonstration of Functional Hallux Limitus in the patient shown in Figure 1. The first ray is loaded beneath the sesamoids, while an attempt is made to dorsiflex the hallux. If FHL is present, the hallux will not exhibit dorsal excursion.

A simple dynamic test for the presence of FHL is to observe the patient's gait in the frontal plane. A typical sign of FHL is the abductory twist that is commonly observed in many patients. Another common clinical finding of FHL is midstance pronation. In simpler terms, if the heel is undergoing lift (the propulsive phase), and the midtarsal and subtalar joint continue to pronate, then the patient is no longer in midstance because by definition the midstance phase ends with calcaneal lift. This phenomena is due to the fact that the subtalar and midtarsal joints are actually plantarflexing while the calcaneus is lifting off of the ground. This is attributed to the lack of first MPJ dorsiflexion, as well as the failure of the windlass mechanism to activate at that moment in time.

Computer Assisted Visualization

The advent and availability of personal computers has significantly altered our view of simple tasks, such as document preparation, but also more complex tasks such as vertical load analysis. Computers are used to collect and processes the data, which can then be reorganized and converted into useable information.

Of the three coronal planes, angular rotation in the sagittal plane of joints of the lower extremity is the first in children to take on the normal adult characteristics. This is usually achieved by two years of age. Since the body moves forward and has its greatest angular displacement in the sagittal plane, then a system that analyzes vertical forces would provide insight to normal and abnormal gait.

The Electrodynogram is a system by which sagittal plane angular displacement is assessed. It is beyond the scope of this text to discuss all of the features and functions of computerized gait analysis, however, if there is motion taking place across a joint, then vertical load sensors placed about that joint should reflect vertical displacement changes. If the motion is actually blocked for a period of time, then a wave form would indicate a flat line as opposed to a sinusoidal type curve. (Figure 3)

PRINCIPLES OF FUNCTIONAL HALLUX LIMITUS

The principles of FHL provide a new perspective or perception of how we actually walk. Due to this fundamental change in the view of human walking, there is a new foundation for communication which utilizes commonly used terms that are at best vaguely defined. The principles involve the process of energy generation and storage as well as the concept of auto-support.

Perspective

Historically, gait analysis has been confined to major research institutions and applied to the most severe cases of abnormalities. Research then moved into the busy clinical setting where it is often performed as an afterthought. The usual approach from a podiatric perspective is to view

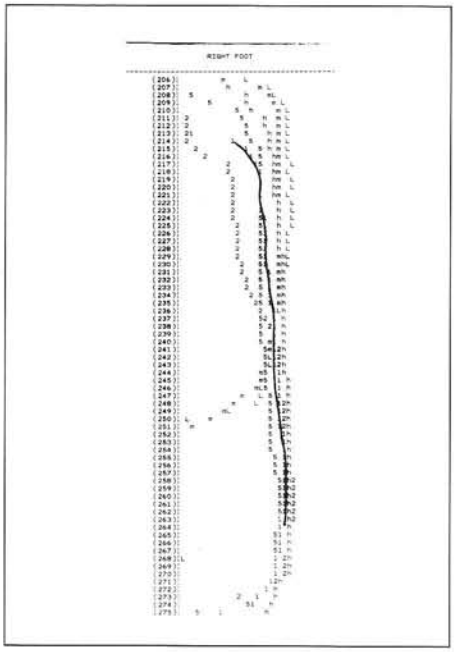

Figure 3. EDG waveform demonstrating functional hallux limitus. The X and 1 sensor are flat during this period of gait. Normal first MPJ function is identified as a smooth curve with an increasing slope.

Figure 5. A similar position in step, but from a posterior attitude. The first MTPJ becomes the pivot point in gait.

the patient from a frontal or posterior view. The patient most often ambulates with their pants rolled up to their knees. This process results in only one degree of information. If the patient's gait is viewed from the sagittal plane perspective, then a whole new appreciation for the angular relationship changes. (Figures 4, 5)

Sagittal Plane Blockade

If each joint of the lower extremity is examined, and its ranges of motion reviewed, it will be found that the ratio of sagittal plane motion to

Figure 4. Different perspectives of foot function yield different results. Medial view of FHL: notice that the first MPJ is locked as the heel has risen off the ground. The arch has flattened as the toe joint has locked.

either of the other planes is approximately four to one. This is significant in terms of overall analysis because the prevailing theory of gait analysis focuses on the frontal plane abnormalities of the rearfoot only. Functional hallux limitus has been described as a locking of the great toe joint. This is essentially a block in normal sagittal plane motion. As a result of the block of sagittal plane motion at the great toe joint, there will be compensation at some level more proximal to the metatarsophalangeal joint. The level of compensation in the foot is usually a combination of medial column plantarflexion, generally exhibited at the metatarsal-cuneiform joint, as well as talonavicular and talocalcaneal joint subluxation. In addition, there is often a marked delay in ankle joint plantarflexion at the point of heel-off.

Terminology Foundation and Physical Principles

New concepts are much like foreign languages. Many of the same words are utilized, but their definitions will vary based on the context. It is important to establish a new foundation as a starting point to facilitate communication. This requires a redefining of the terms. *Force* is any action that tends to maintain or alter the position of a body, or to distort the body. *Vector* describes a force, and requires a magnitude and direction. *Moment* is the tendency of a force acting on a body, causing it to rotate about an axis or point. *Motion* is a change of position. *Pressure* is the action of a force against an opposing force.

Weight Transfer

The principles of weight transfer are described in one of two ways. The most common type of weight transfer is that which occurs between two limbs. The critical aspect of weight transfer is that it occurs within the weight bearing foot itself, as the center of mass moves over the foot. It is this phenomena of weight transfer that permits the use of vertical load analysis. The critical factor to understand is that the waveform reflects the forces acting about a point as body weight is transferred across that axis. If there is motion about a joint, the waveform will change to reflect not only the motion, but also the change in pressure.

Pivot Point

If the foot is viewed as a simple lever system, then in the process of weight transfer and motion during walking, the great toe joint becomes the limiting factor about which the entire body moves as it progresses forward. In essence, the first metatarsophalangeal joint becomes the pivot point in gait. If motion is inhibited at this point during the peak moment of weight transfer (the time when potential energy is converted to kinetic energy), then not only is the step altered but so is the process of energy expenditure.

Power of Movement and Mechanisms of Auto-support

The power of movement and the mechanisms of auto support are complex issues, which will be discussed in brief terms. The power of movement represents the overall mechanics of gait initiation. It involves four major areas from which power is generated, as well as maintained. The primary source of motion is generated from the swing limb and axial skeletal muscles. The remaining aspects include momentum, gravity, and the elastic energy or tissue response. In the simplest terms, it is not the weight bearing limb that propels us forward, rather, it acts as a lever and pivot point. One must think in terms of a man walking on stilts, or an amputee, and how they generate the energy to walk.

The mechanisms of auto support represent a series of actions that take place in the foot during single limb support, which permit the foot to support itself. These actions, which occur almost simultaneously, are: the closed pack effect and the high and low gear push-off originally described by Bosen-Moller, the windlass mechanism as described by Hicks, and the osseous and ligamentous support as described by Basmajian.

NEW MODEL CLOSED CHAIN KINETICS

A new concept of viewing gait, based on the principles of Functional Hallux Limitus, have been described. In addition, some simple definitions have been reviewed. In the past, the phases of gait have been broken down into two major categories, stance and swing. Each of these two categories are further subdivided. Swing phase is divided into an early and late stage, and this will not change or be affected in the FHL concept. However, the phases of stance phase will be described in new terms. These descriptions reflect the input of computer analysis on foot function during gait.

Stance phase can be divided into three major periods: the first is heel contact and forefoot loading, the second is midstance, and the third is the propulsive period. (Figure 6) Heel contact is defined as the period from the strike of the heel

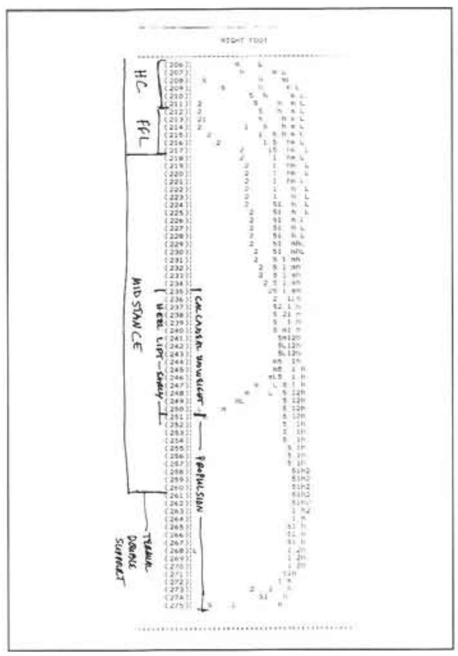

Figure 6. EDG wave form depicting the various phases of gait: heel contact, forefoot loading and foot flat, midstance including calcaneal unweighting and heel-lift, and propulsion with terminal double support.

to the contact of the forefoot on the weight bearing surface. This is followed by forefoot loading, as the remainder of the foot bears weight. The most critical phase of gait is the period of single limb support, or midstance. This is the period when all of the body weight is on the contact limb. It is during this portion of the step when all of the joint rotations must take place. It is during this period of single limb support that the body moves over the foot, and weight is transferred from the heel to the forefoot.

Critical to understanding the FHL concept is that as the weight is transferred forward on the foot, the calcaneus unweights, as the heel prepares for lift. It is during this phase that the load on the forefoot increases. Heel-lift follows calcaneal unweighting, and is easily detected as the sensors stop firing. It is this period of heel-lift that corresponds to early propulsion. If the mechanisms of auto-support are not initiated as the heel lifts, then locking of the first MPJ occurs . This is exhibited as a flat line on an EDG printout. This represents the sagittal blockade and the "New Pathologic Foot Function."

The propulsive phase is divided into early and late stages, and we have identified the early propulsive phase as heel-lift. This phase ends with heel contact of the opposite limb, initiating a new double limb support again. This period has been termed "passive propulsion," but is more appropriately termed terminal double limb support.

Normal Mechanics

In terms of mechanics and timing, the sequence of events can be described as follows: Heel contact with forefoot loading, in which there is subtalar joint pronation. This is followed by midstance, with calcaneal unweighting. The mechanisms of autosupport initiate great toe joint dorsiflexion, creating arch raising (midtarsal and subtalar joints return to the normal and locked position), external leg rotation and ankle joint plantarflexion, and knee and hip extension with lumbar lordosis. Simply stated: heel-lift, first MPJ dorsiflexion, arch raising, external leg rotation, and ankle joint dorsiflexion, are the normal stages of gait.

Abnormal Mechanics

The pathomechanics of FHL are centered around the failure of the great toe joint to dorsiflex at the time of heel-lift. With the failure of great toe dorsiflexion, the arch actually drops (midtarsal joint, subtalar joint plantarflexion), and the ankle joint fails to plantarflex and actually dorsiflexes, all while the heel continues to rise. There is a failure of the leg to externally rotate, followed by hip and spine flexion. This is the basic pathomechanic process of FHL. The result of this pathologic foot function is symptomatology from toe to head.

CLINICAL IMPLICATIONS OF FHL

Foot and Leg Manifestations

Functional Hallux Limitus is manifested in the foot and leg as a wide variety of symptoms. It may be as simple as callous formation at the medial aspect of the hallux, chronic heloma dura formation on the fifth toe, plantar fascitis, hammertoes, bursitis, tendonitis, or neuroma pain.

Postural Manifestations

As stated previously, FHL results in a sagittal blockade of motion. Compensation also occurs primarily in the sagittal plane as well. The usual postural symptoms include: shin splints, patella tendonitis, sciatica, hamstring tendonitis, musculogenic low back pain, increased bulging of vertebral disks, temporomandibular joint dysfunction, and chronic headaches.

TREATMENT: AN OVERVIEW OF MOTION ENHANCEMENT

The treatment of Functional Hallux Limitus depends on restoration of the normal timing and sagittal plane function of the first metatarsophalangeal joint. It is well known that if a body part is braced or casted, the musculature atrophies, weakens, and the function is reduced. This is contrasted by stimulating a part through exercise, increasing its strength and performance. The concept of motion enhancement employs the use of an orthotic that will function during the critical moment of gait. This critical moment is the period of increased forefoot loading during the heel-lift phase. The orthotic must permit the first metatarsal to plantarflex as the heel lifts. The first metatarsophalangeal joint undergoes dorsiflexion as the foot raises, and the metatarsals move into a vertical position in relationship to the ground.

This is accomplished through a series of first ray cutouts on the orthotics device itself. In addition, the first ray cutouts are combined with an aperture pad know as a "kinetic wedge," which further facilitates first MPJ function.

SUMMARY

A new concept of gait pathomechanics, Functional Hallux Limitus, has been introduced. In addition, many symptomatic conditions appear secondary to this new biomechanical phenomena. FHL is an easily recognized and treatable condition. Recognition of this disorder as the underlying pathology in many gait-related problems places the podiatrist in a position as the primary care specialist for walking and postural disorders related to gait.

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SAGITTAL PLANE CONSIDERATIONS IN THE KALISH-AUSTIN BUNIONECTOMY: Quantitative and Qualitative Analysis of the Kalish-Austin Bunionectomy

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ABSTRACT

Sagittal plane shift of the first metatarsophalangeal joint by axis guide manipulation of the Austin bunionectomy has been popularized recently in Podiatry Institute literature. The purpose of this paper is to exam sagittal plane changes in those patients who have undergone hallux valgus correction via the Kalish-Austin bunionectomy. It is the authors' opinion that sagittal plane correction of the first ray will be reflected not only in the angular alignment of the first ray, but also in the entire forefoot and rearfoot complex.

Each patient was objectively assessed preoperatively with a test orthotic system utilizing the Electrodynogram for dynamic evaluation and greater understanding of the first ray function. In addition, each patient was assessed postoperatively to determine outcome analysis. Static evaluation was performed by examining the preoperative and postoperative radiographs and documenting the sagittal plane changes.

INTRODUCTION

Preoperative analysis of transverse plane deformity and anticipated correction of hallux abducto valgus is routinely performed by examining preoperative weight-bearing radiographs. In addition, there is usually significant input from the clinical exam. Radiographs are purely two dimensional. Procedure selection and surgical goals are based upon combined clinical and radiographic examination and findings.

At the present, the consideration for concurrent sagittal plane correction is based upon a number of factors that include the presence of hyperkeratotic lesions beneath the second metatarsal head, along the medial aspect of the hallux interphalangeal joint, or the MPJ itself. Biomechanical exam and intra-operative evaluation may also reveal a significant degree of hypermobility of the first ray. In those obvious cases of first metatarsal elevatus, the surgeon may determine that plantarflexion of the capital fragment will be necessary, in addition to reduction of the intermetatarsal angle. This additional plane of correction has often been discussed, but no concrete parameters have yet been described. It is the attempt of the authors to preoperatively determine the specific amount of plantarflexion that will be needed in conjunction with the transverse plane correction.

METHODS AND MATERIALS

The authors selected 17 cases (25 feet) of patients that had undergone hallux valgus correction via the Kalish-Austin bunionectomy between July, 1989 and December, 1992. All procedures were performed by one surgeon. The patients selected underwent the same surgical procedure and preoperative testing via the test orthotic system, and had a minimum of six months of postoperative follow-up at the time of this writing. In addition, the patients were free of postoperative complications such as fixation failure, second surgeries, and infections requiring incision and drainage. The patients also had preoperative and postoperative weightbearing radiographs available for angular assessment and measurements of the first intermetatarsal angle, first metatarsal declination angle, talar declination angle, and the calcaneal inclination angle. These were only angles considered in the initial study, but the includement of other angles and methods of static assessment will be considered in future studies. Angular measurements were performed using standard techniques, by one of the authors. A summary of the results can be found in Table 1.

Table 1

SUMMARY OF RADIOGRAPHIC ANALYSIS (25 FEET)

	PREOPERATIVE				POSTOPERATIVE			
	IM	FMD	TDA	CIA	IM	FDM	TDA	CIA
Mean	14.2	22.6	30.1	22.4	5.6	22.8	30.2	23.8
Standard Deviation	4.6	3.9	4.2	5.6	1.7	4.1	3.5	5.9
Range	7-25	13-30	23-40	13-34	1-8	20-35	24-40	16-40

IM: First Intermetatarsal Angle, FMD: First Metatarsal Declination Angle, TDA: Talar Declination Angle, CIA: Calcaneal Inclination Angle

Preoperative Test Orthotic System

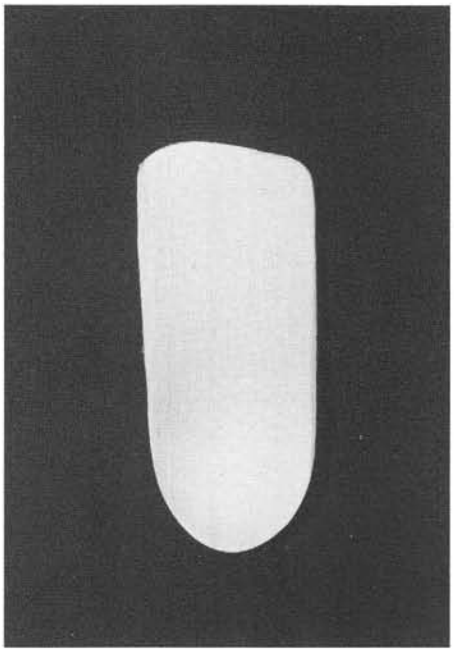
The test orthotic system was designed for this study by one of the authors. Patients were examined preoperatively with a high resolution, bidirectional video tape system. In addition, they would undergo computerized gait evaluation utilizing the Electrodynogram System. In this test system, the sensors were distributed as recommended by the manufacturer: M & L were placed under the tuberosity of the heel, 1 and X were placed over the tibial and fibular sesamoids respectively, the 2, 5 and H sensors were placed proximal to the metatarsal heads and over the interphalangeal joint of the hallux. (Figure 1) The authors' variation from the manufacturers recommendation placed the X and 1 sensors at the level of the first MTPJ. This simple change revealed a number of unusual findings.

Figure 1. Electrodyne sensor distribution.

The second part of the test system was a test orthotic that was fabricated at the time of preoperative testing. It consisted of a neutral position impression taken semi-weight bearing. The materials used were aliplast and plastizote. The device was shaped into a neutral position orthotic with a forefoot post that was neutral positioned in relation to the rearfoot. It was modified to not influence the forefoot in function with the exception of its thickness.

A series of tests were then performed with variations in a first ray cutout. The cutouts were as follows: standard cutout, bidirectional cutout, metatarsal cuneiform cutout. (Figure 2A-D) Each of these cutouts allowed a certain degree of plantar displacement of the first metatarsal during forefoot loading and subsequent lift phase of gait.

Each patient was tested by the same technician, using the previously described techniques. The overall testing process included a series of tests beginning with a barefoot test followed by a shoe test. This sequence was followed by at least three tests utilizing the test orthotics with variations in the first ray cutout.



Figures 2A-D. Test orthotic system with a series of first ray cutouts (medial margin of device). **A.** Neutral shell without first ray cutout.

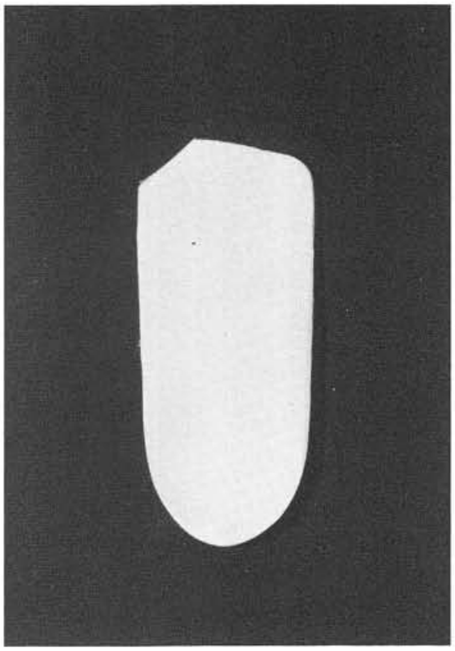


Figure 2B. Standard Cutout.

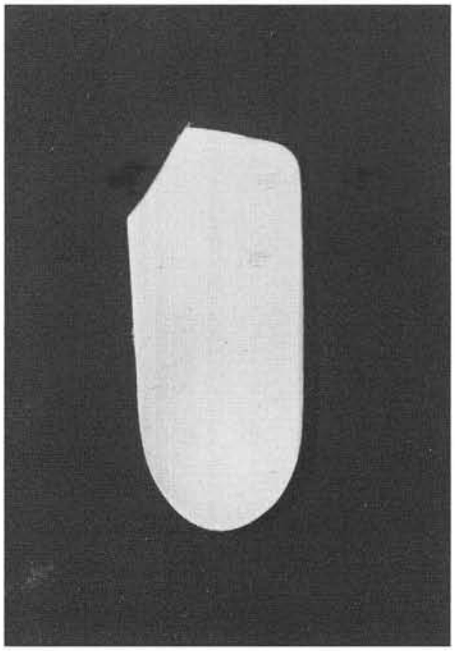


Figure 2C. Bidirectional Cutout.

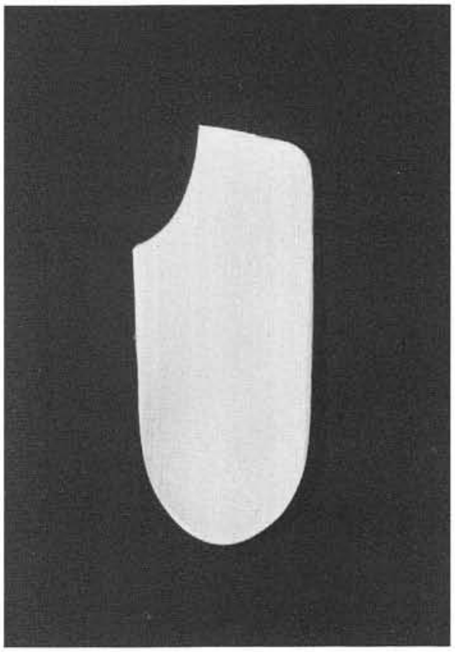


Figure 2D. Metatarsal Cuneiform Cutout.

The important data that was examined from the Electrodynogram printout consisted of the ratio of the total pressure of the X and 1 sensors. (Figure 3) It is postulated that as the ratio of the total pressure reflected by the X and 1 sensors approached one (1) during the gait cycle and that it represented uniform loading of the metatarsophalangeal joint. (Figures 4A-4D)

LEFT
PRESSURE DATA

For a Stance Duration of 600 Msec.

Senor Site	Pressure Duration as a % of Stance	Time of Max Press Peaking as a % of Stance	Peak Press of Kg/Cm2 --- Total Press --- Total Press Normalized To 1 second
L	* 68 (50- 62	21 Range 12- 23)	10.2 394.0 951.4
m	* 70 (50- 62	21 Range 17- 23)	10.2 416.7 967.9
x	64 (0- 0	73 Range 0- 0)	10.2 284.4 720.7
5	80 (75- 90	76 Range 70- 85)	10.2 480.0 978.7
2	85 (70- 85	82 Range 77- 88)	10.2 501.4 970.9
1	70 (70- 85	74 Range 70- 80)	10.2 410.4 961.3
h	* 47 (70- 85	86 Range 85- 95)	10.2 260.8 913.6

RIGHT
PRESSURE DATA

For a Stance Duration of 620 Msec.

Senor Site	Pressure Duration as a % of Stance	Time of Max Press Peaking as a % of Stance	Peak Press of Kg/Cm2 --- Total Press --- Total Press Normalized To 1 second
L	* 69 (50- 62	23 Range 12- 23)	10.2 399.1 920.0
m	* 66 (50- 62	22 Range 17- 23)	10.2 381.4 921.8
x	80 (0- 0	76 Range 0- 0)	10.2 387.9 770.7
5	80 (75- 90	72 Range 70- 85)	10.2 489.0 971.4
2	* 86 (70- 85	* 74 Range 77- 88)	10.2 528.9 985.5
1	82 (70- 85	72 Range 70- 80)	10.2 497.1 962.2
h	75 (70- 85	87 Range 85- 95)	10.2 424.8 908.5

Figure 3. Typical EDG printout of pressures.

Figure 4A-D. Preoperative dorsal plantar, and lateral views of one patient in the study. Her preoperative angular relationships were as follows: IM 10, FMD 24, TDA 33, CIA 33. Postoperative angular relationships: IM 1, FMD 27, TDA 25, CIA 40. The EDG X:1 ratios were as follows: preoperative 0.64, postoperative 0.45.

RESULTS

A summary of the results are found in Tables 1 and 2. A full report of each angular measurement of the patients used is beyond the scope of this current paper and will be reserved for future publication. The radiographic results report on all cases initially examined. However, in reviewing the data, there were 9 feet involving 6 cases that had incomplete EDG data. They were subsequently discarded from the second half of the analysis.

There were a number of variables that were encountered. The first has already been noted and includes a number of the cases reviewed for this initial retrospective study that had incomplete Electrodynogram data, either preoperatively as a result of technical error (one case) or as a result of not undergoing testing (two cases) or data not obtained postoperatively at the time of this writing (6 cases). As a result, the overall sampling size may not be large enough for adequate statistical analysis. The authors will attempt to eliminate all of these variables in the future for a more definitive report.

Figure 4B.

Figure 4C.

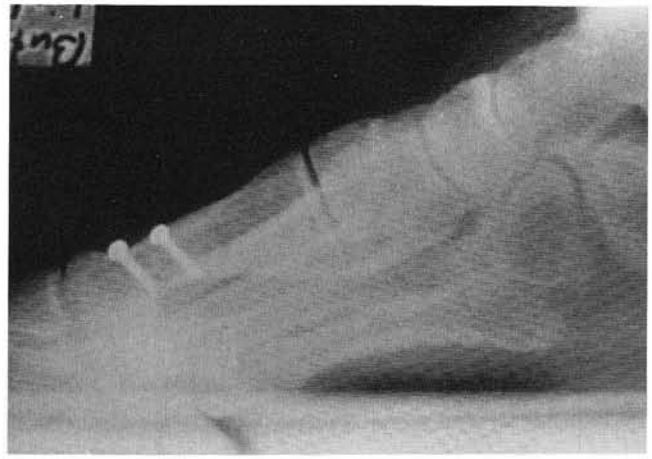


Figure 4D.

Table 2

SUMMARY OF EDG X SENSOR TO 1 SENSOR RATIO (16 FEET, 11 CASES)

	PREOPERATIVE	POSTOPERATIVE
Mean	0.65	0.71
Standard Deviation	0.29	0.27
Range	0.24-1.2	0.20-1.23

DISCUSSION

The purpose of this paper was to examine the sagittal plane changes that occur with the use of the Kalish-Austin bunionectomy by utilizing a preoperative dynamic testing model. It was the authors' assumption that sagittal plane correction needs to be obtained in conjunction with transverse plane correction and that it can be predicted based upon dynamic function utilizing a test model. The best ratio of total pressure between the X and 1 sensor utilizing the preoperative test orthotic system was selected. The cutouts correspond to certain degrees of plantar flexion of the apical axis guide during the surgical procedure: standard/(0-5°), bidirectional/(5-10°), and metatarsal cuneiform/(15-20°). These values were initially obtained through trial and error and then became rather predictable as the number of cases increased over a three-year period. However, the statement that a bidirectional cutout can produce a similar overall angular change in the sagittal plane can not be made at this time. In reviewing the summary data, it can be noted that there was an overall increase in the total pressure ratio of the X:1 in the postoperative test, 0.65 to 0.71. A thorough statistical analysis has not been performed, yet the authors believe that this does show a trend.

The overall angular changes reveal that the Kalish-Austin bunionectomy can achieve a wide range of correction in both the transverse plane as well as the sagittal plane. The average change in the transverse plane (first intermetatarsal angle) was 8.6° degrees. If the authors' overall concept holds true, there should be corresponding sagittal plane changes as well. These changes should be reflected as an increased first metatarsal declination angle, a decrease in the talar declination angle and an increase in the calcaneal inclination angle. In examining the data summary, it does reflect a significant change in the first metatarsal declination angle, 5.6°, however the changes in the talar declination angle (0.1°) and the calcaneal inclination angle (1.4°) were not nearly as significant.

It has been the authors' attempt to quantify and qualify the sagittal plane changes in the Kalish-Austin bunionectomy through a retrospective study. It cannot be stated at this time that the current model in use can predict and determine both the needed amount of sagittal plane correction via the apical axis guide as well as the resultant sagittal plane change seen postoperatively. Testing will continue and a more in depth paper will be published.

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