Descriptive analysis of biomechanical and radiographic characteristics of the lower extremity of runners with Mortons foot syndrome
by Gloria Jean Ferrandino

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Physical Education
Montana State University
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Abstract:
A study was conducted to describe, compare and analyze twenty biomechanical, radiographic and weight-bearing characteristics of the lower extremity and the Morton's Foot syndrome found in eighty-eight runners of Bozeman, Montana who were known to exercise on a regular basis. All subjects were selected on the basis of the visible presence of a long second toe and the existence or non-existence of pain. The selected subjects were then classified into five groups: Group I (N=22), no outwardly appearing long second toe, no pain; Group II (N= 23), an outwardly appearing long second toe, no pain; Group IIIA (N= 17), an outwardly appearing long second toe, slight pain; Group IIIB (N=14), an outwardly appearing long second toe, moderate pain; and Group IIIC (N=12), an outwardly appearing long second toe, severe pain.

The data were treated by means of an analysis of variance and a step-wise regression analysis. Hand calculations were made to determine: the mean, mode and median differences in length of metatarsal I to metatarsal II acquired by Morton's, Schuster's and Sheer's methods; the group means for the parabolic weight-bearing curve angle; Ithe relationship incidence of the length difference of metatarsal I Ito metatarsal II acquired by Morton's, Schuster's and Sheer's methods to the metatarsus location of the greatest concentration of dynamic weight distribution; the mean incidence of the first ray ranges of motion; and the metatarsal location of greatest weight-bearing and calluses with and without first ray consideration.

No significant differences among the biomechanical, radiographic and weight-bearing measures were found to exist between the groups examined thereby making it impossible to independently describe any one of the groups.

The findings showed that either method by Morton, Schuster or Sheer could be used to determine the length difference of metatarsal I to metatarsal II as seen in the radiograph.

Pain related to Morton's Foot syndrome was found to be significantly predicted by: the percentage of length difference of metatar- sal I to metatarsal II; the ranges of internal and external rotation of the femur with the hip straight; the metatarsal location of the greatest concentration of dynamic body weight distribution; and eversion of the subtalor joint.

Those runners having an outwardly appearing long second toe with varying degrees of pain were found to have a shorter metatarsal I than did those runners having no outwardly appearing long second toe, and were found to bear the greatest dynamic weight on the heads of metatarsals II and III. Those runners having no outwardly appearing long second toe tended to bear the greatest weight on the heads of metatarsals I, II and III.

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Date 7 March 1978

DESCRIPTIVE ANALYSIS OF BIOMECHANICAL AND RADIOGRAPHIC CHARACTERISTICS OF THE LOWER EXTREMITY OF RUNNERS WITH MORTON'S FOOT SYNDROME

by

GLORIA JEAN FERRANDINO

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Approved:

Ellen Kreighbaum
Chairperson, Graduate Committee

George F. Shrader
Head, Major Department

Henry L Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
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ABSTRACT

A study was conducted to describe, compare and analyze twenty biomechanical, radiographic and weight-bearing characteristics of the lower extremity and the Morton's Foot syndrome found in eighty-eight runners of Bozeman, Montana who were known to exercise on a regular basis. All subjects were selected on the basis of the visible presence of a long second toe and the existence or non-existence of pain. The selected subjects were then classified into five groups: Group I (N=22), no outwardly appearing long second toe, no pain; Group II (N=23), an outwardly appearing long second toe, no pain; Group IIIA (N=17), an outwardly appearing long second toe, slight pain; Group IIIB (N=14), an outwardly appearing long second toe, moderate pain; and Group IIIC (N=12), an outwardly appearing long second toe, severe pain.

The data were treated by means of an analysis of variance and a step-wise regression analysis. Hand calculations were made to determine: the mean, mode and median differences in length of metatarsal I to metatarsal II acquired by Morton's, Schuster's and Sheer's methods; the group means for the parabolic weight-bearing curve angle; the relationship incidence of the length difference of metatarsal I to metatarsal II acquired by Morton's, Schuster's and Sheer's methods to the metatarsus location of the greatest concentration of dynamic weight distribution; the mean incidence of the first ray ranges of motion; and the metatarsal location of greatest weight-bearing and calluses with and without first ray consideration.

No significant differences among the biomechanical, radiographic and weight-bearing measures were found to exist between the groups examined thereby making it impossible to independently describe any one of the groups.

The findings showed that either method by Morton, Schuster or Sheer could be used to determine the length difference of metatarsal I to metatarsal II as seen in the radiograph.

Pain related to Morton's Foot syndrome was found to be significantly predicted by: the percentage of length difference of metatarsal I to metatarsal II; the ranges of internal and external rotation of the femur with the hip straight; the metatarsal location of the greatest concentration of dynamic body weight distribution; and eversion of the subtalor joint.

Those runners having an outwardly appearing long second toe with varying degrees of pain were found to have a shorter metatarsal I than did those runners having no outwardly appearing long second toe, and were found to bear the greatest dynamic weight on the heads of metatarsals II and III. Those runners having no outwardly appearing long second toe tended to bear the greatest weight on the heads of metatarsals I, II and III.

Chapter 1

INTRODUCTION

Research in exercise physiology supports jogging as a means of improving physical fitness. Accompanying this scientific basis was an increased interest of the individual to improve his health and physical fitness by means of jogging. Concomitant to the ever increasing masses of joggers were "runners' injuries", which are "... linked directly or indirectly to foot-plant" (i:vi).

Sheehan writes:

> "The human body is a marvelous instrument. When in perfect alignment and balance, there is almost no feat of endurance the body cannot handle even on a regular basis. However, structure imbalance of even minor degrees can result in incapacitating injuries and persistent disability. Prevention and treatment of muscoskeletal problems in the athlete, therefore rests on the establishment of the structural balance and architectural integrity of the body - and its re-establishment should injury occur." (24:106)

One such structural problem found in runners is diagnosed as Morton's Foot syndrome, also known as "Runner's Foot". The Morton's Foot syndrome is believed by Sheehan to be a prime cause of runner's complaints (30:10).

Sheehan suggests that the structural deformity characterizing this syndrome is the cause of such problems as chondromalacia of the knee, posterior tibial tendonitis and the heel spur syndrome. Such

complaints are not traumatic in nature, but rather, of an "overuse" nature (8:23).

Overuse complaints result from repetitive stress exerted on a mechanically inefficient body part or tissue (8:23). Such mechanical inefficiency often occurs as a result of a structural imbalance which causes the neighboring structures, muscles and ligaments to be altered in order to compensate for the existing abnormality. A structural abnormality in the foot exhibits compensatory faults in the ankle, leg and knee (35:226). Since the foot is chiefly supported by the muscles during action patterns (35:226), it is likely that structural imbalances in the foot and leg would be of greater significance to the runner than they would be to the non-runner (19:67).

The following study was conducted to investigate common alignments of structural deformity of the foot with various symptom levels of severity in order to determine if correlations existed and whether inferences for treatment and/or prevention of such runner's complaints could be made.

Statement of the Problem

The general purpose of this study was to describe, compare and analyze biomechanical, radiographic and weight-bearing characteristics of the lower extremity of runners with an outwardly appearing

long second toe.

Specifically, this study attempted:

1. to examine variances of biomechanical, radiographic and weight-bearing measures among those runners having no outwardly appearing long second toe who experienced no complaints, those runners having an outwardly appearing long second toe who experienced no complaints, those runners having an outwardly appearing long second toe who experienced complaints slight in nature, those runners having an outwardly appearing long second toe who experienced complaints moderate in nature and those runners having an outwardly appearing long second toe who experienced complaints severe in nature.
2. to determine correlations among the methods used by Morton (14), Schuster (21) and Sheer (26) to measure the ratio of difference of the length of metatarsal I with that of metatarsal II.
3. to examine differences among the following: the ratio of the length difference of metatarsals I and II; the existence or non-existence of an outwardly appearing long second toe; the parabolic weight bearing curve created by the heads of all metatarsals; and the metatarsus location of the greatest concentration of dynamic weight

distribution.

4. to determine if significant variances of the selected measures existed among the five groups investigated.

5. to determine which, if any, of the biomechanical, radiographic and weight-bearing measures could best describe the Morton's Foot syndrome.

The basis for such determinations were the selected biomechanical, radiographic and weight-bearing measures of: dorsiflexion and plantarflexion ranges of motion of the first ray; inversion and eversion of the subtalor joint; dorsiflexion of the ankle with the knee both flexed and extended; flexibility of the hamstring muscle groups; internal and external rotation of the femur with the hip flexed and extended; position of the forefoot with the rearfoot; calcaneal position to the floor with the subtalor joint neutral; calcaneal stance position in static angle of gait; frontal plane position of the tibia with the subtalor joint static; length of metatarsal I to metatarsal II; the angle of parabolic weight-bearing curve; and the metatarsus location of dynamic weight distribution.

Hypotheses

Null hypotheses. It was hypothesized that there would be no significant difference in the characteristics of the lower extremity as described by the selected biomechanical, radiographic and

weight-bearing measures among those runners having no outwardly appearing long second toe who experienced no complaints, and those runners having an outwardly appearing long second toe who experienced no complaints, who experienced complaints slight in nature, who experienced complaints of moderate severity and who experienced complaints severe in nature.

Further, it was hypothesized that no significant differences would be found among the ratio of differences in length of metatarsals I and II, the existence or non-existence of an outwardly appearing long second toe, the parabolic weight-bearing curve, nor the evidence of metatarsus location of the greatest concentration of dynamic weight distribution.

Alternate Hypotheses. It was hypothesized that a significant difference would be found among the characteristics of the lower extremity as described by the selected biomechanical, radiographic and weight-bearing measures among those runners having no outwardly appearing long second toe who experienced no complaints, and those runners having an outwardly appearing long second toe who experienced no complaints, who experienced complaints slight in nature, who experienced complaints of moderate severity, and who experienced complaints severe in nature.

Further, it was hypothesized that significant differences would be found among the ratio of difference in length of metatarsals

I and II, the existence and non-existence of an outwardly appearing long second toe, the parabolic weight-bearing curve, and the evidence of metatarsus location of the greatest concentration of dynamic weight-bearing distribution. Thus, it would be possible to determine those biomechanical, radiographic and weight-bearing measures that best describe the Morton's Foot syndrome.

Definition of Terms

Abduction. Abduction is any motion during which the distal aspect of the foot, or any part of the foot, moves away from the mid-line of the body. This motion occurs in a transverse plane about a vertical axis lying in the frontal and sagittal planes (17:20).

Adduction. Adduction is any motion during which the distal aspect of the foot, or any part of the foot, moves in a transverse plane toward the midline of the body. This motion occurs about a vertical axis lying in the frontal and sagittal planes (17:20).

Ankle Equinus. Ankle Equinus is a structural condition which limits the ankle joint to less than 10° dorsiflexion from its neutral position (17:24).

Axis of Balance. The axis of balance is a functional division of the foot, running from the center of the heel forward between metatarsals II and III, which coincides with the center of weight exerted upon the talus, thus bisecting its structural stability into

lateral directions (14:109-110).

Compensation. Compensation occurs when one or more neighboring body parts take over the action and/or support normally maintained by another body part that has ceased to function properly. Improper functioning may be due to structural deformity or biomechanical alterations.

Dorsiflexion. Dorsiflexion is any motion in which the distal aspect of the foot, or any part of the foot, moves in a sagittal plane toward the tibia. The axis of rotation is about the frontal and transverse axis (16:16).

Dorsiflexion of the First Ray. Dorsiflexion of the first ray exists when the dorsiflexion measurement exceeds that of plantarflexion. Inversion accompanies this condition (17:84).

Eversion. Eversion is any motion occuring in the frontal and sagittal planes during which the plantar surface of the foot, or any part of the foot, tilts away from the body's midline (17:14).

First Ray. The first ray consists of the first cuneiform and first metatarsal which move about a common axis (17:76).

Hallux Abductus Valgus. Hallux abductus valgus is a deformity of the great toe in which the hallux rotates in the frontal plane causing its plantar surface to become prominent in the lateral direction. Further, the hallux deviates laterally in the transverse plane (5:17).

Hypermobility. Hypermobility is any motion occuring in a joint, in response to gravity, at a time when that joint should be stable under such force. Hypermobility of the first ray is either dorsiflexed or plantarflexed in nature (17:24).

Inversion. Inversion is any motion about the frontal and sagittal planes during which the plantar surface of the foot, or any part of the foot, tilts toward the body's midline (17:14).

Leverage Axis. The leverage axis is a functional line located directionally from the center of the heel forward between metatarsals I and II, the heads of which balance body-weight stresses as they act as the fulcrum during the propulsive phase of locomotion (14: 137-138).

Metatarsalgia. Metatarsalgia is a "wastebasket" term used to describe forefoot disorders (15).

Metatarsus. Metatarsus consist of the first through fifth metatarsals comprising the forefoot (17:26).

Morton's Foot Syndrome. Morton's Foot syndrome is a structural abnormality characterized by a short first metatarsal and a longer second metatarsal, a hypermobile first ray segment, and evidence of greater weight-bearing at the head of the second metatarsal (14).

Neutral Position of the Subtalor Joint. The neutral position of the subtalor joint is that alignment of the calcaneus and talus that allows the calcaneus to invert twice as many degrees as it

everts (17:54).

Normal First Ray. A normal first ray exists when the range of motions of dorsiflexion equals that of plantarflexion (17:82).

Plantarflexion. Plantarflexion is any motion in which the distal aspect of the foot, or any part of the foot, is angulated in a sagittal plane away from the tibia. Rotation occurs about the frontal axis (17:16).

Plantarflexion of the First Ray. Plantarflexion of the first ray exists when the plantarflexion measurement exceeds that of dorsiflexion. Eversion accompanies this condition (17:86).

Postural Stability. Postural stability occurs when the structures located above the subtalor joint are maintained in a position perpendicular to those structures below the subtalor joint (14:117).

Pronation. Pronation occurs when the foot, or any part of the foot, is abducted, everted and dorsiflexed simultaneously (17:18).

Structural Stability. Structural stability occurs when the bones and ligaments located below the subtalor joint cause the foot to become a rigidly fixed base throughout which body-weight is supported in a definite ratio of distribution (14:115).

Subtalor Joint. The subtalor joint is the juxtaposition of three articulations of the talus and calcaneus (17:36).

Supination. Supination occurs when the foot acts simultaneously in the direction of inversion, adduction and plantarflexion (17:18).

Valgus. Valgus is an everted structural position of the foot, or any part of the foot, occurring solely in the frontal position (17:22).

Varus. Varus is a congenitally inverted structural position of the foot, or any part of the foot, occurring in the frontal plane (17:22).

Delimitations

The study was delimited to forty-six Bozeman, Montana runners who exercised regularly and ran a minimum of five miles each week and who had no history of orthopedic or surgical trauma to the hip, knee, leg, ankle or foot occurring within the past five years. The study was also delimited to the previously stated eighteen biomechanical measures, four radiographic and dynamic weight distribution measures.

Limitations

With the exception of controlling locations, instruments, methods, techniques and technicians employed in the examination of all subjects, no other controls were imposed. Therefore the following limitations existed.

Data collection occurred at various times of the day during the weeks of May 16 - June 8, 1977. Therefore, the time and type of activity, in addition to running, in which the subjects participated

before or after the examination could not be controlled. In addition, neither the number of miles run per day, per week, the type of shoes worn, nor the type of surface on which all running took place were held constant.

The limited number of subjects per group did not provide a significant base for study.

Although Morton believed that Morton's Foot syndrome became symptomatic no earlier than the age of thirty, no attempt was made to delimit this study to only those subjects who were thirty years or older.

Further, no attempt was made to delimit the actual difference in length of the outwardly appearing long second toe to the first toe in the selection of subjects among those runners having an outwardly appearing long second toe who experienced no complaints, who experienced complaints slight in nature, who experienced complaints of moderate severity, and who experienced complaints severe in nature.

Chapter 2

REVIEW OF RELATED LITERATURE

Review of Research

Biomechanical examination of lower extremity alignment factors in athletes has become a fast growing area of research. Investigations were performed to determine the relationship of lower extremity alignment factors to overuse complaints experienced by athletes. Lillstvedt (11) found several of these factors to be significant in the prediction of pain related to the shin splint syndrome. Further, Courtney (2) found that lower extremity alignment factors served as contributing factors in the occurrence of achilles tendonitis.

Morton (14), using a Staticometer, determined the metatarsus distribution of weight in the normal foot to be of equal ratio on metatarsals II through V with metatarsal I taking on two times that of the others. In addition, he investigated the dynamic weight distribution of African men as they walked across a kinetograph. His findings indicated that the head of metatarsal II showed the greatest concentration of weight on feet having an outwardly appearing long second toe whereas greatest weight concentration occurred on metatarsal I in feet having a longer first toe.

Schuster (21) examined an extensive number of feet in an attempt to determine whether or not a short first metatarsal was a causative

factor of orthopedic foot difficulties. Schuster found that the greatest incidence of a short metatarsal I, ranging from minus 2mm to minus 6mm, occurred in the patient group. Thus, he concluded that a short metatarsal I "must be one of the etiological factors in mechanical foot difficulties" (21:41).

To this investigator's knowledge, little or no research has been conducted with specific relevancy to pain associated with Morton's Foot syndrome and athletics.

Overuse Syndrome

Morton's Foot syndrome falls under the umbrella term, "overuse syndrome". Subotnick defines it as:

> "... a gradual accumulation of micro trauma resulting in, at first, minor injuries which become progressively more severe. The overuse syndrome is usually secondary to a combination of 3 factors: 1) conditioning, 2) training, 3) biomechanical structure of the lower extremity. Thus, overuse injuries may be a combination of overtraining plus feet and legs that have intrinsic or extrinsic imbalance problems. Intrinsic deformities are those which are in the foot structure itself. Extrinsic deformities occur where a bend in the legs places the foot at an improper angle to the running surface." (31:37)

In running, the feet support the entire body weight while in contact with the running surface. This impact occurs approximately 1000 times per mile (20:69). Since the biomechanical alignment of the lower extremity affects the runner's ability to accomodate this accumulative shock, even slight imbalances could result in overstress

on these body parts (33). "Overstress leads to the overuse syndrome" (33:108), therefore, it is important that the runner maintain postural and structural stability.

Lower Extremity Postural and Structural Analysis

Postural stability relates to the structures found above the subtalor joint. With the foot providing a stable base of support and the body weight distributed throughout the plane of balance, the muscles of the leg maintain the leg's position in relation to the foot as a fixed base of support (14:117).

In order to maintain stability, the normal position of the leg must be such that its alignment will see the hip, thigh, distal 1/3 of the lower leg and calcaneus perpendicular to the supporting surface (30:7; 17:34). This allows external and internal rotation of the femur at the hip joint to be equal within an acceptable variance of 15° (23:154). Hip extension is affected by the soft tissues around the joint while hip flexion is affected by the length of the hamstring muscles. Therefore, it is necessary for the hamstring muscle group to have a minimum of 12° and a maximum of 20° flexion when measured with the subject supine and the hip flexed to 90° (15). Since such hip alignment and flexibility of the hamstring muscle group permit the knee to sufficiently extend during the stance phase of gait, the distal 1/3 of the tibia would then be made vertical

within an acceptable varum or valgus variance of 2° (17:131).

Normalcy of the ankle joint has been discussed under postural stability since the talus moves according to the motion of the tibia and fibula and is, therefore, considered to be a part of the lower leg (22:38). During midstance and prior to toe-off in gait, the talus moves backward to allow the ankle joint to dorsiflex a minimum of 10° (17:130; 22:38). When ankle dorsiflexion is within normal limits at the contact phase, the heel is allowed to meet the ground first to permit shock absorption and foot position for proper support throughout the stance phase. If proper foot positioning is achieved in stance, the foot is then ready to function effectively during the propulsive phase (28:66-67).

In the normal lower extremity the subtalor joint lies in a neutral position with "the calcaneus perpendicular to the ground and parallel to the distal one-third (1/3) of the leg" (17:130).

When the range of motion of the subtalor joint is normal, the rearfoot functions properly at heel strike, thus allowing the lower leg to rotate internally causing the subtalor to evert (pronate). During the mid-support phase, the lower leg rotates externally to cause the subtalor joint to roll through its neutral position, and continue laterally to an inverted (supinated) position to allow the midtarsal joint to do its part in causing the foot to become a rigid lever for propulsion (22:86).

Structural stability relates to those bones and ligaments located below the subtalor joint which make the foot a rigidly fixed base of support. This rigidly arched contour is the means by which the body weight is supported in a definite ratio of distribution to areas of bone and ground contact (14:115).

The normal foot is found to be of three toe length structures: the Greek foot, in which the great toe is shorter than the second toe; the Egyptian foot, in which the great toe is longer than the second toe; and the squared foot, in which both the great toe and the second toe are of equal length. Any one of these structures may be found in combination with either of three metatarsal structures: the "index plus minus" type in which metatarsals I and II are equal in length; the "index minus" type in which metatarsal I is shorter than metatarsal II; and the "index plus" type in which metatarsal I is longer than metatarsal II (34:165-167). However, the ideal foot is believed to be of the Greek toe type (great toe is shorter than the second toe) with the "index plus" (metatarsal I is longer than metatarsal II) or the "index plus minus" (metatarsal I and metatarsal II are equal in length) metatarsal structure (34:165-167).

Balanced weight-bearing is achieved by the grasping action of the toes, parabolic weight-bearing angle created by the metatarsal alignment and the relative range of motion of the metatarsal-midtarsal joints.

The grasping action of all five toes provides firm and constant support of the metatarsal heads on the supporting surface (34:168). All metatarsal heads sustain weight when they lie in a transverse plane parallel to the supporting surface (34:168; 17:34). The ranking of lengths of the metatarsals exist in two specific combinations, 2>3>1>4>5 or 2>1>3>4>5 (7:105; 13:334). These metatarsal length patterns form a weight-bearing parabolic angle (Figure 1). Meschen cites the normal angle to be 136° (13:136). Gamble states that the normal parabolic angle of 142.5° in combination with the 2>1>3>4>5 metatarsal length pattern maintains a balanced weight transfer throughout the metatarsal-phalangeal joints, thus minimizing any pivotal action which would cause any one particular metatarsal head to bear excessive weight (6:126-127). Thus, a parabolic angle less than "normal", i.e. 136° or 142.5° creates less weight-bearing stability. It must be noted here that in the "normal" foot, as defined by Gamble, the lateral four metatarsals bear weight equally with the first metatarsal sustaining double that weight (6:123).

In the normal foot, equal weight distribution is achieved when the foot is stable. Stability is achieved when the subtalor joint is in a neutral position and the forefoot is perpendicular to the rearfoot. This allows the midtarsal joint to be fully pronated causing it to lock with the first ray. Such locking permits the first ray and hallux to become active as the prime propulsive

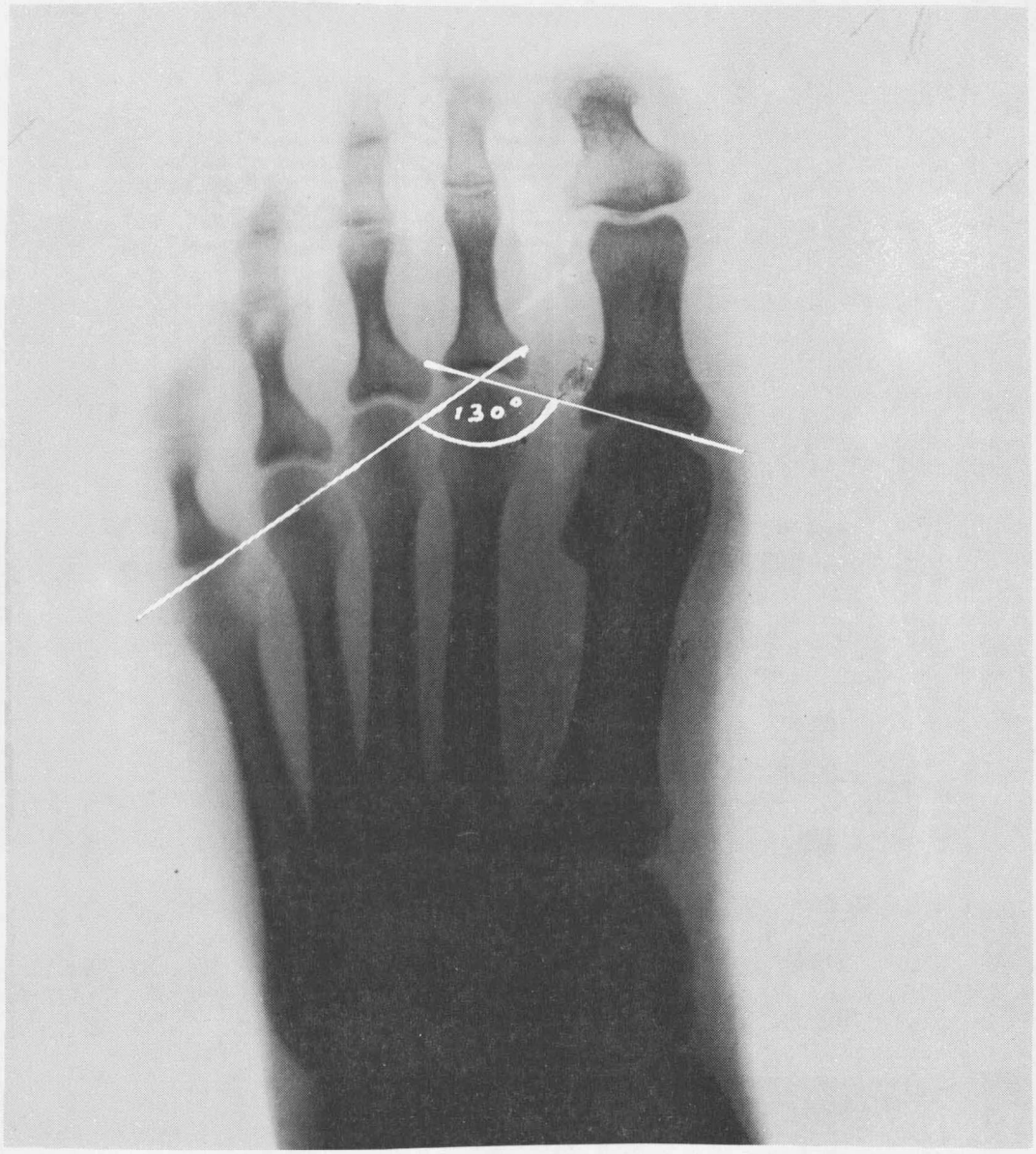


Figure 1. Weight-Bearing Parabolic Curve Angle Formed by the Heads of Metatarsals I-V

mechanisms of the foot (32:93).

Morton noted that as weight is distributed throughout the normal foot, it flows through the axis of balance located between the heads of metatarsals II and III. As the supination of the subtalor joint causes the midtarsal to maximally pronate thus locking against the first ray, weight is transferred to the heads of metatarsals I and II. These heads act as the fulcrum of leverage axis during propulsion (14:180).

Gait Pathology

When malfunctioning of the subtalor joint is present, supination causes the forefoot to invert (forefoot varus), and conversely, pronation causes the forefoot to evert (forefoot valgus) (22:86). Both conditions result in the unlocking of the midtarsal joint thus causing the foot to be a "loose bag of bones" (hypermobile) (22:92). This lack of perfect fore-rearfoot alignment results in disproportionate weight distribution throughout the metatarsus, first ray insufficiency (dorsiflexed first ray), firsty ray overload (plantarflexed first ray) and callus formation (34:169-172).

Problems arise when metatarsal I is shorter than metatarsal II and/or when the first ray is hypermobile (dorsiflexed or plantarflexed). Morton theorized that when metatarsal I is shorter than metatarsal II, it fails to assume its normal share of weight, causing

the longer metatarsal II to assume excessive weight thus becoming the sole fulcrum during toe-off (14:180, 189). Gamble notes that observations have been recorded when excessive weight force is assumed by metatarsal III rather than by the longer metatarsal II, thus seemingly contradicting Morton's theory.

Definition of Morton's Foot Syndrome

Morton's Foot syndrome is a structural abnormality characterized by: an inherited short first metatarsal and a longer second metatarsal; an outwardly appearing long second toe and a short great toe; dorsiflexion or plantarflexion of the first ray segment; rearwardly displaced sesamoid bones; thickening of the cortical walls of the second metatarsal; calluses at the head of the second and occasionally the third metatarsals; discomfort at the base of the second cuneiformmetatarsal joint; and evidence of greater weight-bearing at the head of the second metatarsal acquired through dynamic foot imprints (14:9; 21; 12).

For purposes of this study, the presence of rearwardly displaced sesamoid bones and thickening of the cortical walls of the second metatarsal were not examined since suggested methods used to measure these factors seemed too unreliable to the investigator.

Controversy exists as to whether or not the structural characteristics noted earlier are the etiological basis of foot complaints. In question is just what is considered to be an abnormally short first metatarsal. Morton believed that the "normal foot" was one

in which the distal most points of the heads of metatarsals I and II are even, thereby making any metatarsal I that varied by minus 1mm an abnormally short structure. Wood Jones, on the other hand, stated emphatically that "the first metatarsal is always the shortest member of the series" (9:370). Schuster considered the first metatarsal to be abnormally short when it was found to be 2mm or more shorter than the second metatarsal (21:38). In contrast, Viladot (34) saw the "normal" foot as having three structural types of metatarsal formations: the "index plus minus" type in which metatarsals I and II are equal in length; the "index minus" type in which metatarsal I is shorter than metatarsal II; and the "index plus" type in which metatarsal I is longer than metatarsal II.

In addition to the length variance of metatarsals I and II, there existed disagreement regarding the methods used to determine this length difference. Morton's method (14) consisted of drawing lines tangent to the distal most points on the arc formed by the heads of metatarsals I and II as seen in the weight-bearing dorso-plantar radiographic view. A millimeter rule was used to measure the distance between the two lines (Figure 2). Schuster (21) felt that this method did not allow for a varus or valgus slant of the metatarsals. In an attempt to account for this, he scribed an arc from the distal most point of metatarsal II to the medial border of metatarsal I. The radius for this arc was determined by placing the

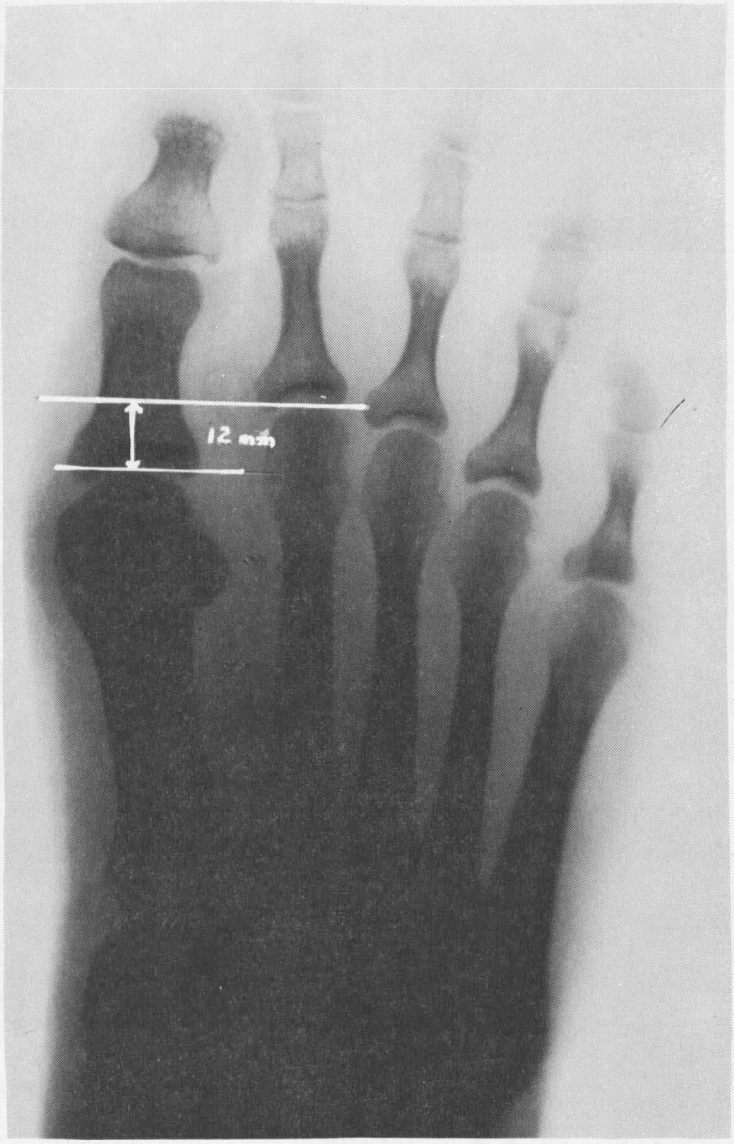


Figure 2. Morton's Method of Measuring the Length Difference of Metatarsal I to Metatarsal II

compass axis at the posterior most portion of the calcaneus and by placing the compass point at the distal most aspect of metatarsal II. A millimeter rule was placed perpendicular to the distal most aspect of metatarsal I and extended through the arc. The distance between both the distal point of metatarsal I and the intersecting point on the arc was then noted in order to determine the difference in length of metatarsal I to metatarsal II (Figure 3). Sheer (26) also attempted to account for a varus or valgus slant of the metatarsals by employing a completely different approach. He suggested that the percent difference of the actual lengths of metatarsals I and II be used to determine a short first metatarsal. This percentage was to be determined by measuring the actual lengths of each metatarsal (Figure 4). In addition, he suggested that a 20 percent or greater difference would be accompanied by a Hallux Abductus Valgus condition.

Hallux Abductus Valgus is a deformity of the metatarsal-phalangeal joint in which the hallux becomes deviated laterally on the transverse plane. Such a deformity is caused by "the imbalance of the extrinsic and intrinsic muscles and tendons of the foot" (5:19) which is directly related to abnormal pronation of the subtalor and midtarsal joints and the resultant hypermobility of the first ray (5:19-20). The normal metatarsal-phalangeal joint is said to be congruent. The deformed metatarsal-phalangeal joint is known either as deviated, or if more severe in nature, subluxed (Figure 5). In

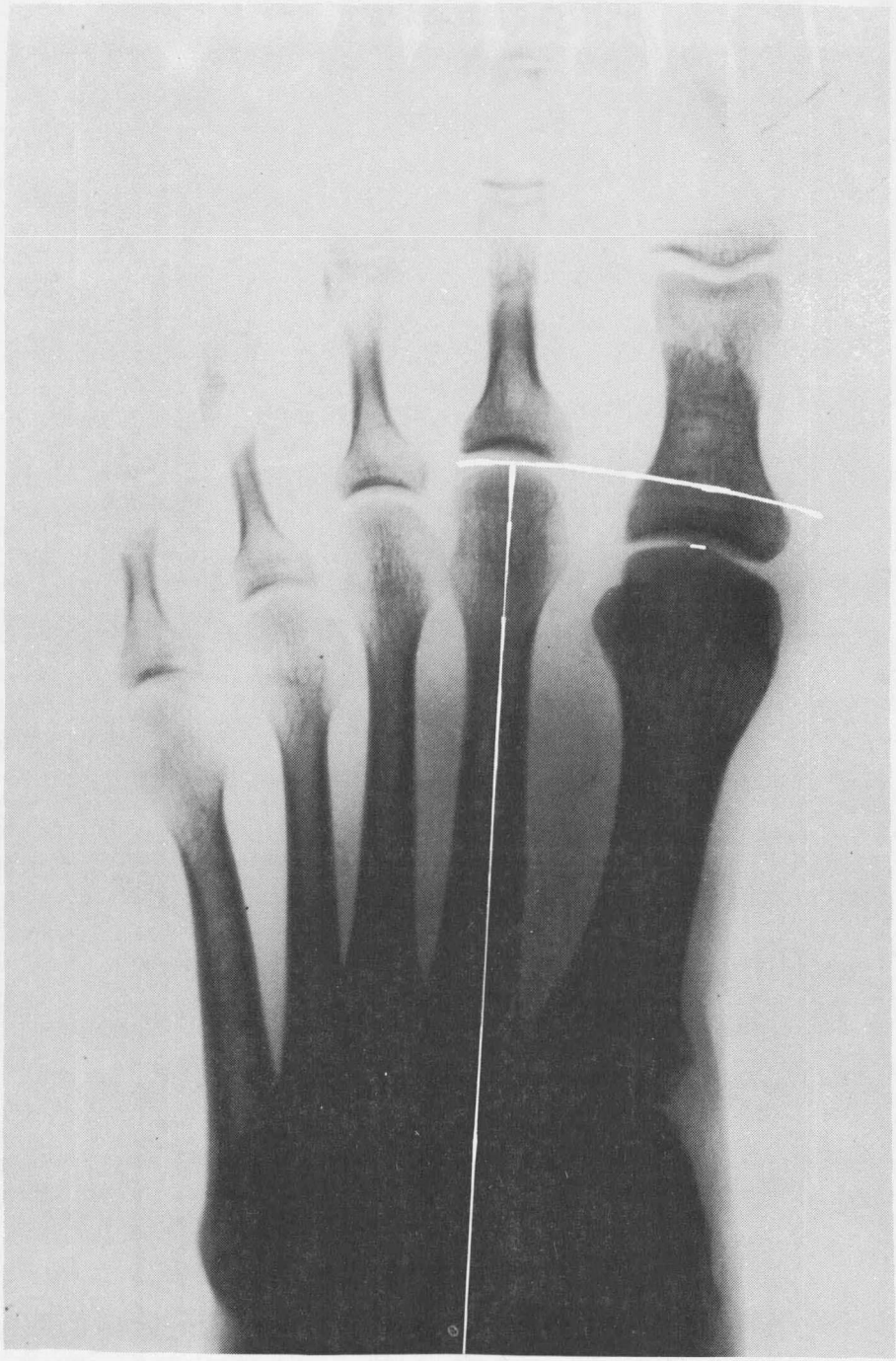


Figure 3. Schuster's Method of Measuring the Length Difference of Metatarsal I to Metatarsal II.

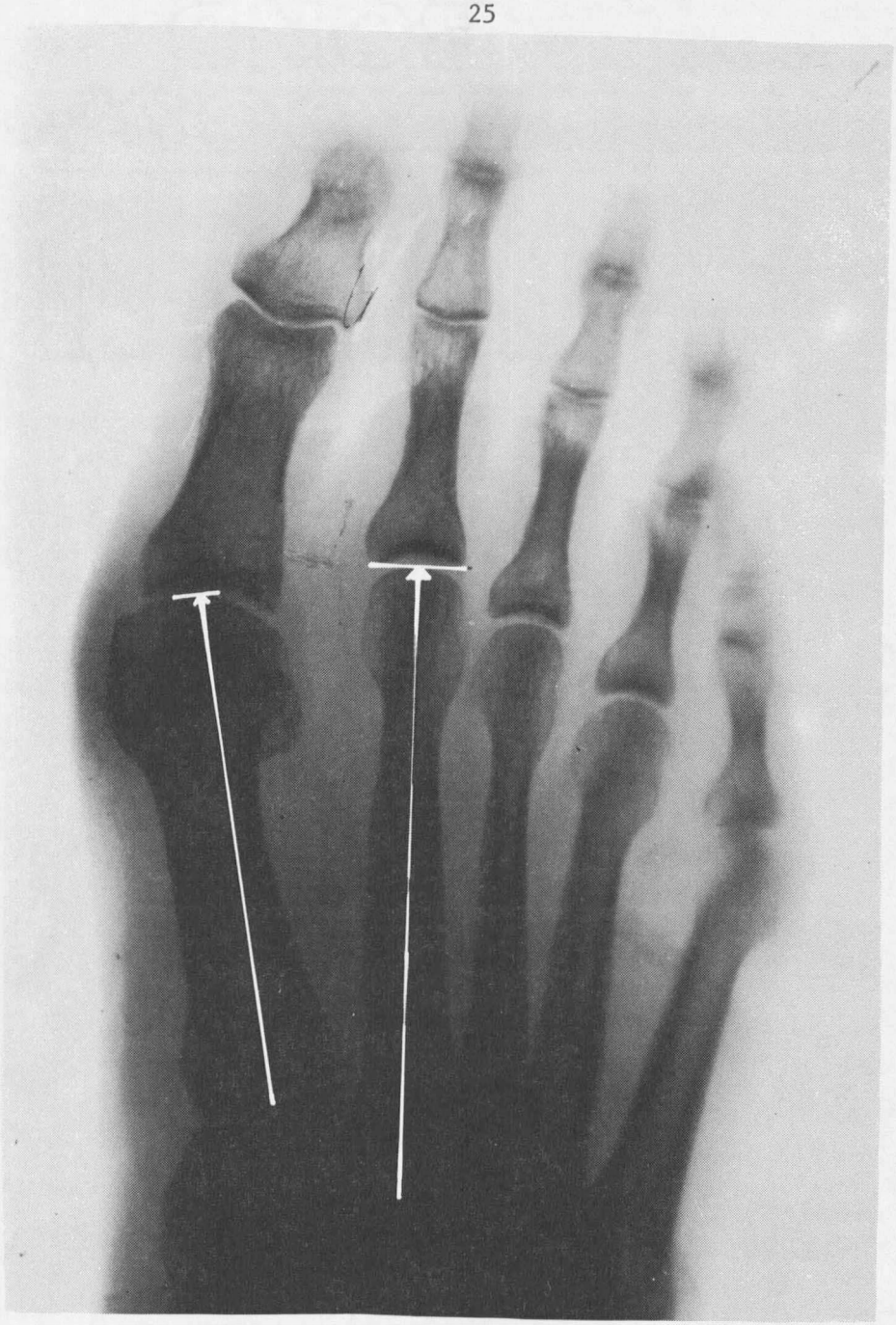


Figure 4. Sheer's Method of Measuring the Length Difference of Metatarsal I to Metatarsal II
Figure 5. Hallux Abductus Valgus of the Metatarsal-Phalangeal Joint

order to determine the severity of the Hallux Abductus Valgus condition, it was necessary to be able to radiographically observe the cartilage articulations at the base of the hallux and at the head of metatarsal I. Since such radiographic evidence was unavailable, examination of this condition was impossible.

Hypermobility of the First Ray

Hypermobility of the first ray increases the chance of disproportionate weight-bearing throughout the metatarsus. Hypermobility occurs as either an insufficiency syndrome (dorsiflexion) or as an overload syndrome (plantarflexion). The presence of either syndrome results in the failure of the first ray and the hallux to bear its normal weight load, thus forcing the neighboring metatarsal heads to compensate (14:189; 22:94).

The dorsiflexed first ray is due to the "relaxation of the capsuloligamentous structures" (34:169) of the first metatarsal. When the head of metatarsal I contacts the ground and weight is put on it, the laxity of the ligaments permits the metatarsal (I) to continue in an upward direction (dorsiflex) thus providing no support and resulting in a medial roll (pronation) of the forefoot (Figure 6). This roll now causes metatarsal II to assume the weight. The abnormal pronation of the forefoot also results in tibial varus, thus causing the medial ankle muscles to assume greater stress and strain (14:157).

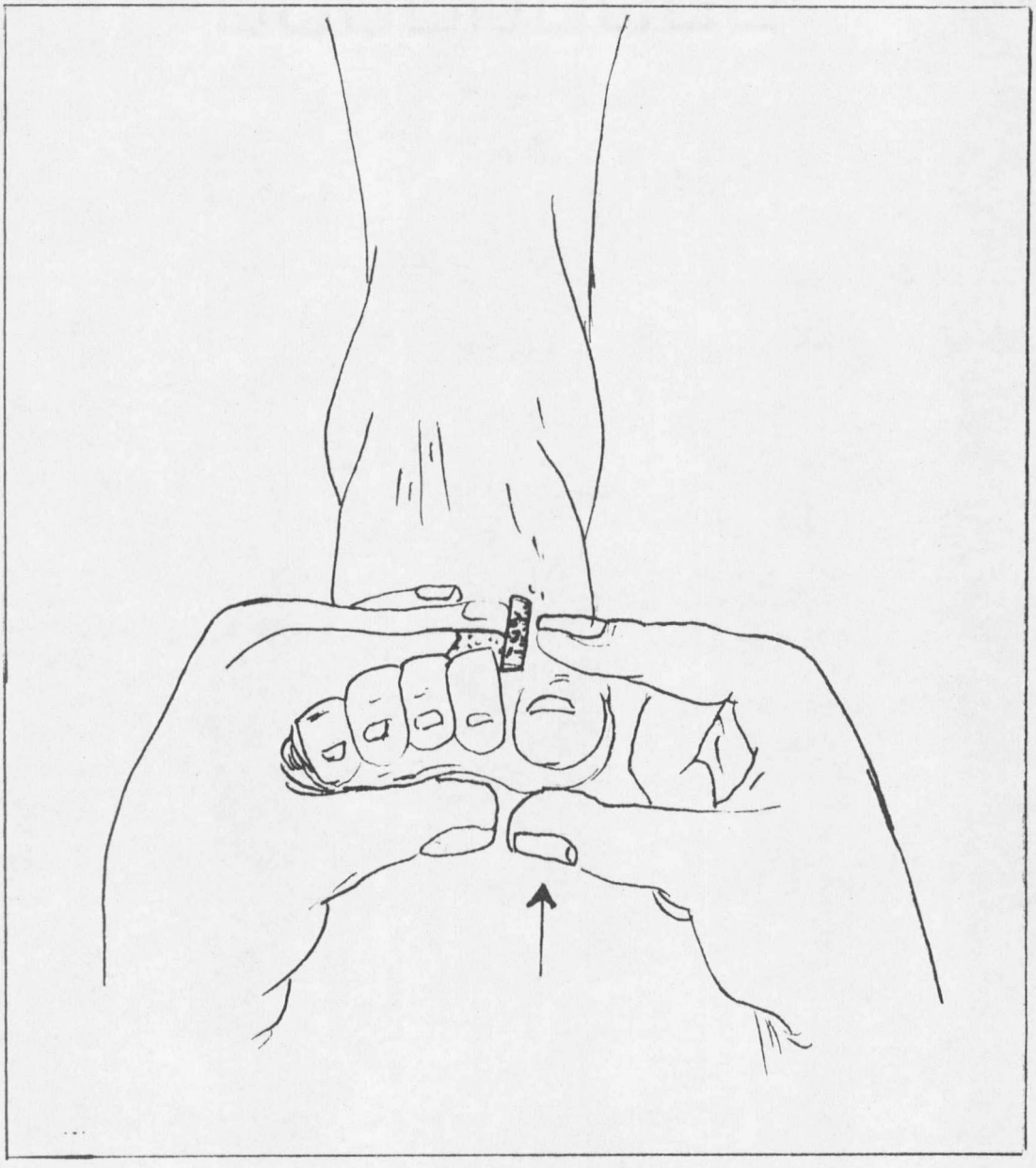


Figure 6. Dorsiflexion of the First Ray

The plantarflexed first ray is due to contraction of the peroneus longus muscle which creates a plantarflexing force thus causing the head of the first metatarsal to move in a plantarward direction (22:261) (Figure 7). It must be remembered that pronation of the subtalor joint prior to forefoot contact (22:86), alone or in combination with contraction of the peroneus longus muscle, causes the first ray to prematurely assume greater body weight stress. The first ray, unstable at this time, dorsiflexes, while at the same time, causes the forefoot to move in the opposite direction on the transverse plane. This movement places the forefoot in an inverted (varus) position to the rearfoot. Hence, body weight is sustained by the lateral metatarsals since the first ray is hypermobile (22:94).

Hyperkeratosis (Calluses)

When weight distribution is disproportionate throughout the metatarsus, excessive stress is assumed by some of the metatarsal heads and not by others. Biomechanically, three types of stress forces are simultaneously generated at the plantar sites of this excessive body weight. They are: tension stress, which distends or separates the tissue; compression stress, a force which resists other pressing forces; and sheer stress, a force which is generated by a 45° angle to compression and tension stresses and often causes

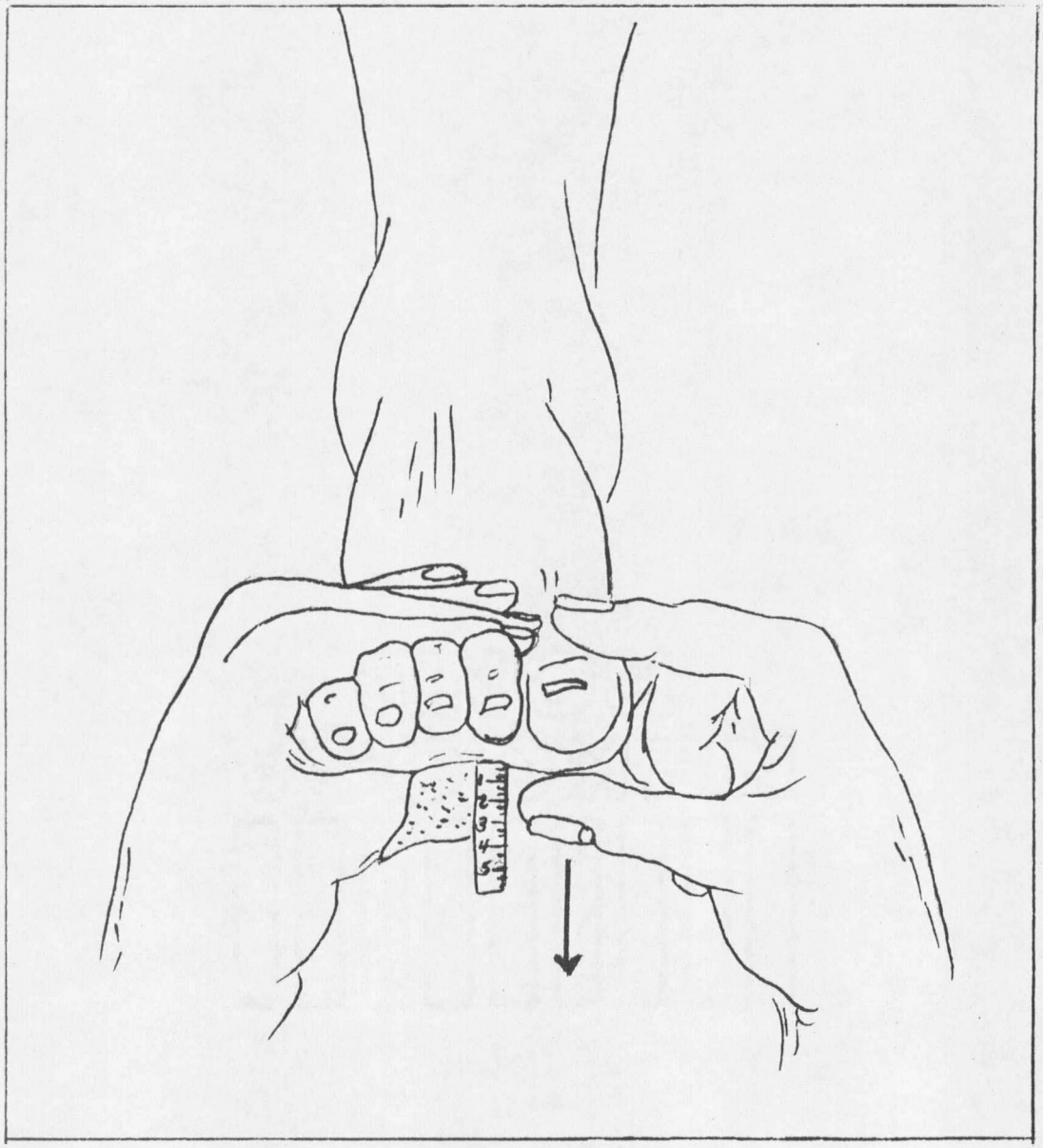


Figure 7. Plantarflexion of the First Ray

tearing of the tissue (22:49). Tissue growth, commonly referred to as a callus, is often found beneath any of the metatarsal heads (22:86). Calluses most often occur as a result of these stress forces brought on by excessive weight-bearing at that particular site. Morton notes that the resultant weight concentration on the head of metatarsal II and sometimes metatarsal III, due to a short metatarsal I, produces calluses at these sites (14:181).

Chapter 3

METHODS AND PROCEDURES

Instrumentation

Four instruments were used to collect data pertinent to this study: a manual biometer, a thimble-rule, a pedograph, and individual radiographs.

The biometer, developed by Phillips (15), consisted of various types of protractors designed to measure the range of motion of the various joints and segments of the lower extremity (Figure 8). A straight-edged rule was used to bisect the posterior lower leg and calcaneus areas, respectively, to determine their neutral alignment planes. All measures obtained with the biometer were taken by Courtney (3).

The thimble-rule, developed by the researcher, was used to measure the dorsiflexion, plantarflexion and normal ranges of motion of the first ray. It consisted of a rubber thimble with a millimeter ruler cemented to its end (Figure 9).

A pedograph instrument, designed by the researcher, was used to obtain dynamic (walking) weight distribution foot imprints (Figure 10). Indications of the size of the longitudinal arch could also be observed from the impression. The instrument consisted of a wood framed rubber mat composed of closely located

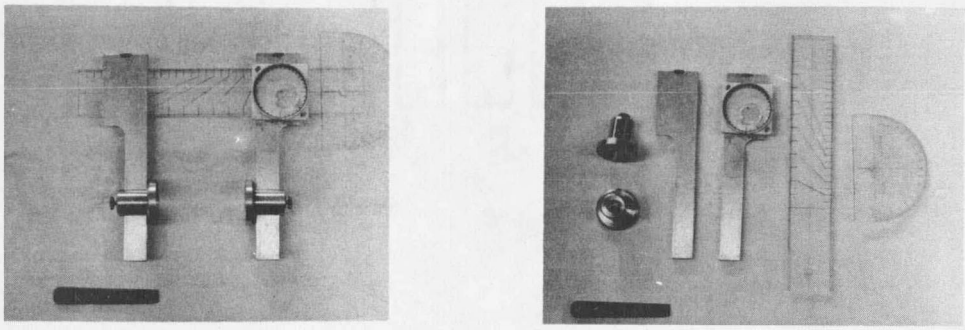


Figure 8. Biometer Shown Intact (Left) and in Separate Parts (Right)

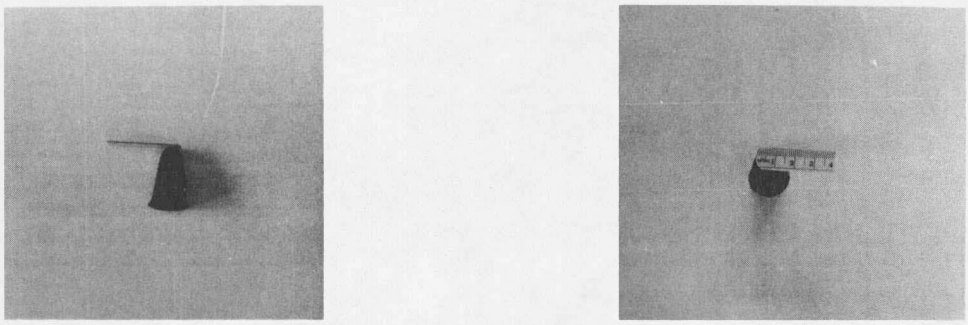
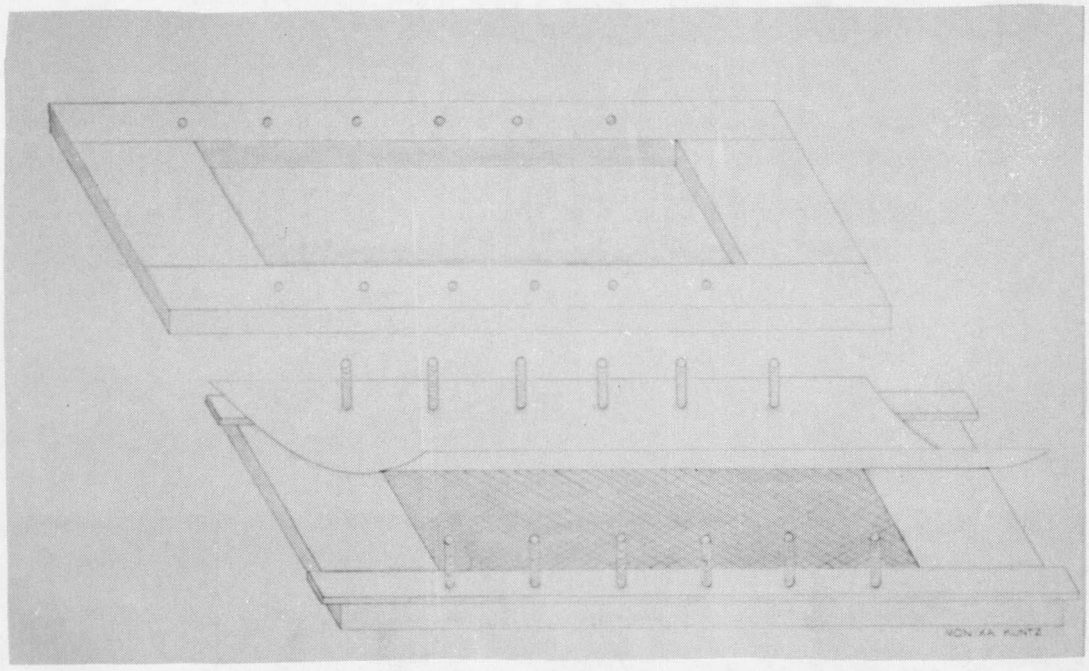
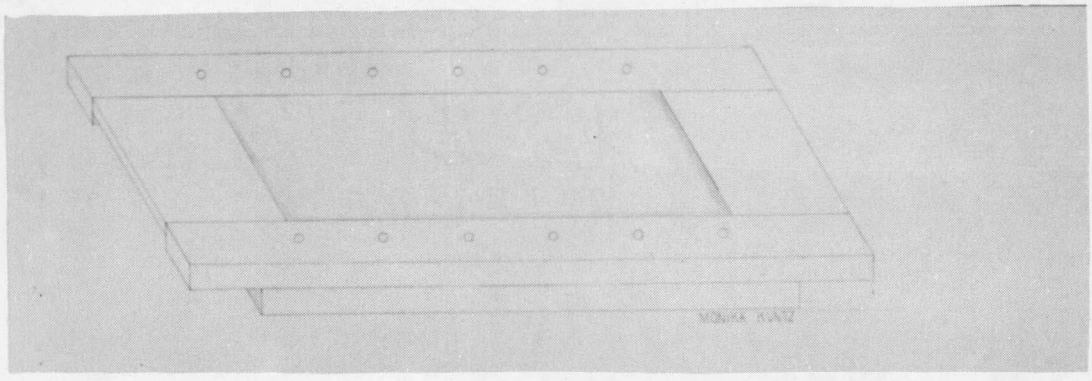


Figure 9. Thimble-Rule: Side View (Left); Top View (Right)



TOP



Bottom

Figure 10. Pedograph Shown Complete (Bottom) and in Separate Parts (Top)

cone shaped nubs (a rubber welcome mat), which was subsequently inked with Carter's Black Stamp Pad Ink No. 412. A roller type paint brush, rolled across an inked plexiglass board to ensure even saturation, was used to apply the ink to the mat. Frosted Mylar was used to retain the impression.

The Picker Econilex IV System, located at the Montana State University Student Health Center, was used to take all radiographs used in this study.

The validity of the above instruments was accepted at face value.

Data Collection Techniques

Techniques used to collect data pertinent to the biomechanical alignment measures of the lower extremity (ranges of motion of the first ray, inversion and eversion of the subtalor joint, tibial varus and/or valgus with the subtalor joint in neutral and static position, inversion and eversion of the calcaneus with the subtalor joint in static and neutral positions, hamstring muscle flexibility, dorsiflexion of the ankle joint with the knee both flexed and extended, forefoot varus and/or valgus positions, and internal and external rotation of the femur with the hip both flexed and extended) were those implemented by Lilletvedt (11) and Courtney (2) and performed by Courtney (3).

First ray mobility measurement techniques were conducted with the subject in an L-seat position on a table. The subtalor joint was placed in the neutral position with the midtarsal joint fully pronated. The heads of metatarsals II, III, IV, and V were stabilized by the researcher's index finger and thumb. The index finger and thumb of the other hand were placed on the head of metatarsal I.

When measuring dorsiflexion of the first ray, the thimble-rule was worn on the index finger of the stabilizing hand. The placement of the nail of the index finger of the opposite hand, in regard to the ruler, was noted. The head of metatarsal I was then pushed upward as far as possible, and the new placement of the nail so noted. The difference of the two measures was then accepted as the measurement for dorsiflexion (Figure 6; p. 26).

Plantarflexion of the first ray was taken with the thimble-rule worn on the thumb of the stabilizing hand. The placement of the thumbnail of the opposite hand on the ruler was noted. The head of metatarsal I was then pushed downward as far as possible with the new nail placement noted. The difference of the two measures was accepted as the measurement for plantarflexion (Figure 7; p. 28).

Five measures were taken for each directional range of motion. The mode figure was then accepted as the reliable measure for that direction (dorsiflexion or plantarflexion). The range of motion of

the first ray was considered to be normal when the dorsiflexion measure equalled the plantarflexion measure. The first ray was considered to be dorsiflexed when the mode measure was 1mm or more greater than the plantarflexion measure and, inversely, the first ray was considered to be plantarflexed when the mode measure was 1mm or more greater than the dorsiflexion measure.

Dynamic weight distribution foot impressions were acquired with the pedograph. The subject walked onto a section of the frosted Mylar which had been placed over the frame and held above the inked mat by tightening the wingnut-held frame. Care was taken to ensure that a normal walking gait was achieved.

Weight concentration was observable by the difference in the size of the dots made by the cone shaped nubs. The diameter of the dots was measured in millimeters. Those areas consisting of the largest dots were designated as bearing the greatest dynamic force. The foot imprint was then placed over the radiograph in order to determine the location of the greatest concentration of weight bearing on the metatarsus (Figure 11).

Bilateral radiographs were taken in the weight bearing dorsiplantar view of the foot with the subject in a normal angle and stance of gait. The center beam was aimed 15° from vertical with the central ray directed at the first cuneiform (Figure 12) (15). Separate exposures were taken of each foot.

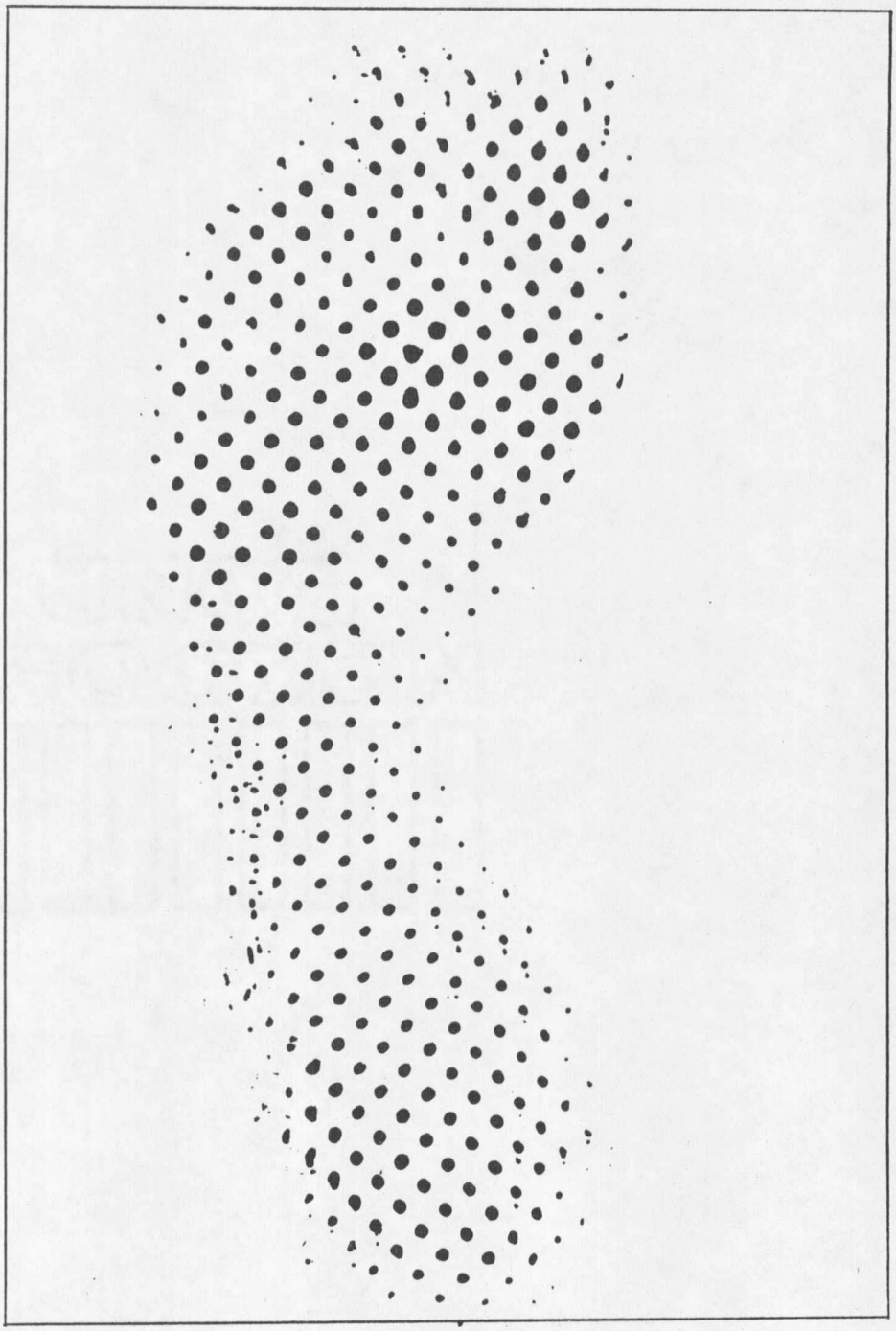


Figure 11. Foot imprint acquired by pedograph. Larger dots denote area of greatest concentration of dynamic weight-bearing

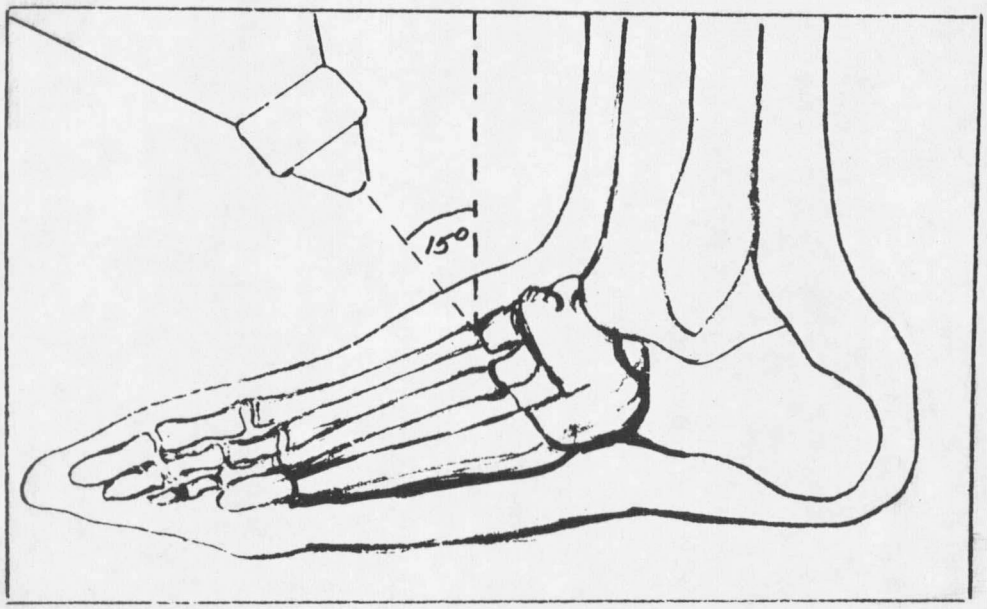


Figure 12. Method Used to Acquire Bilateral Radiographs

Three methods were applied to determine the relative lengths of metatarsals I and II; Morton's, Schuster's and Sheer's (14, 21, 26).

Morton's (14) method consisted of drawing lines tangent to the distal most point of the heads of metatarsals I and II. The difference of these two lines was then measured in millimeters (Figure 2; p. 22).

Schuster (21) attempted to consider the possibility of a varus or valgus slant of the metatarsals by using an arc, instead of Morton's tangential lines. Schuster's method was employed with a slight adaptation made by the researcher. Due to the blending of the leg and heel portions of the radiograph, the posterior aspects of the os calcis was not definable. Therefore, the axis point was determined to be one-half the transverse plane of the widest medial and lateral borders of the os calcis. A line was then drawn connecting this point with the distal point of metatarsal II. This line was used as the radius by which the arc was scribed. The compass axis was placed at the center of the os calcis with the graphite placed at the distal most point of metatarsal II. An arc was then scribed toward and beyond the medial border of metatarsal I. A millimeter rule was placed perpendicular to the distal most aspect of metatarsal I and extended through the arc. The distance between both the distal point of metatarsal I and the intersecting point on the arc was then noted in order to determine the difference in

length of metatarsal I to metatarsal II (Figure 3; p. 24).

Sheer (26) also in an attempt to consider a varus or valgus slant of the metatarsals, suggested the percent difference of metatarsal I to metatarsal II be determined. This was accomplished by measuring the length of each metatarsal by drawing a longitudinal line from the distal border of the head to the proximal border of the base. This line was placed one-half the transverse plane of the head and base of said metatarsals. Measurements of the line were then taken in millimeters for each metatarsal (Figure 4; p. 25).

The above measures were then applied to the formula:

$$\text{Percent difference of I to II} = \frac{\text{length of II} - \text{length of I}}{\text{length of II}} \times 100$$

All data obtained were recorded on the evaluation form provided by Phillips (15) (Appendix A).

Measurement Reliability

Courtney's reliability for all measures taken with the biometer was established ($p < .05$) (2).

Since a minimal range of five numbers existed with the measures for dorsiflexion and plantarflexion of the first ray, respectively, coefficients of reliability could not be determined; therefore, in an attempt to establish reliability for these measures, five separate measurements for each directional range of motion on each foot were taken. The mode measurement was then accepted to be the reliable

figure.

Subject Selection

All subjects were runners acquired from the Big Sky Winddrinker's Association, physical education activity classes and volunteers from Montana State University in Bozeman, Montana, who were selected on the basis of a questionnaire (Appendix B).

Persons whose second toe outwardly appeared to be longer than the first toe were selected for study regardless of the existence or non-existence of varying degrees of pain, ache or soreness in their legs and/or feet. Persons whose second toe was not outwardly longer than the first toe and who experienced no pain, ache or soreness in their legs and/or feet were selected as control subjects.

Subjects who were known to have had sprains, fractures and/or surgery on one or both limb(s) within the last five years had that limb(s) eliminated from the study.

Subject Description

Forty-six Caucasian male and female runners from Montana State University and the Big Sky Winddrinker's Association of Bozeman, Montana participated in this study. They ranged from nineteen to sixty-two years of age, from 5'3" to 6'4" in height and from 115 pounds to 200 pounds in weight. The miles covered by each runner ranged from 5 to 70 miles per week with 54 percent run on pavement,

21 percent run on dirt, 3 percent run on grass and 22 percent run on wood.

Complaints of varying degrees of severity experienced by the subjects with an outwardly appearing long second toe were 9 knee problems, 11 anterior leg problems, 9 posterior leg problems, 12 forefoot problems and 5 ankle problems.

In addition, it was noted that such complaints experienced by seven runners often occurred in only one foot and/or leg and not the other, while eleven other runners suffered the symptoms in both feet and/or legs. No such problems were evidenced in twenty-seven feet and/or legs.

Subject Classification

The legs and/or feet of all subjects were classified according to relative lengths of first and second toes and the existence of pain. The degree of pain used as the basis of classification was determined by the subject's own observations and response to the questionnaire. For the purpose of correlations and a stepwise regression analysis, the classifications were as follows:

Group I - No Long Second Toe, No Foot and/or Leg Complaints: Legs and/or feet whose second toe did not outwardly appear to be longer than the first toe and had no foot and/or leg complaints were assigned to Group I (N = 22).

Group II - Long Second Toe, No Foot and/or Leg Complaints: Legs and/or feet having an outwardly appearing long second toe which experienced no foot and/or leg complaints were assigned to Group II (N = 23).

Group IIIA - Long Second Toe, Slight Complaints: Legs and/or feet having an outwardly appearing long second toe which experienced slight annoyance were assigned to Group IIIA (N = 17).

Group IIIB - Long Second Toe, Moderate Complaints: Legs and/or feet having an outwardly appearing long second toe which experienced complaints moderate in severity were assigned to Group IIIB (N = 14).

Group IIIC - Long Second Toe, Severe Complaints: Legs and/or feet having an outwardly appearing long second toe which experienced chronically severe complaints that disabled the runner to the point of stopping all running in order to lessen the problems were assigned to Group IIIC (N = 12).

It was possible for an individual to have each lower extremity placed in a different group. For example, an individual might have one foot with no long second toe while the other foot had a long second toe. If the former foot also had no pain, ache or soreness in the entire extremity, it was placed in Group I, whereas the latter foot was assigned to either of the remaining groups according to the degree of severity of complaints. In addition, those extremities which were known to have experienced sprains, fractures

and/or surgery within the last five years were eliminated from the study.

Statistical Treatment of Data

The data were programmed by Dr. A. Suvak, the testing advisor, for treatment on the Sigma Seven computer system on the Montana State University campus, Bozeman, Montana.

An analysis of variance was applied to the data of each of the 20 lower extremity alignment measurements and foot characteristics in an attempt to determine which, if any, of the biomechanical, radiographic and weight-bearing measures would best describe any of the specific groups. The analysis of variance was computed among: Group I - no outwardly appearing long second toe and no pain, and Group II - an outwardly appearing long second toe and no pain; Group I - no outwardly appearing long second toe and no pain, and the combined Groups III A, B and C - an outwardly appearing long second toe and experiencing pain slight, moderate and severe in nature; and Group II - an outwardly appearing long second toe and no pain, and the combined Groups III A, B and C - an outwardly appearing long second toe and experiencing pain slight, moderate and severe in nature.

A step-wise regression analysis was applied to determine the relationship of the 20 biomechanical, radiographic and

weight-bearing measures to the degree of severity of the complaints cited. The analysis was also employed to determine which, if any, of these measures could best predict the occurrence of pain as related to Morton's Foot syndrome. The analysis was performed according to the increase in the degree of severity of the complaints on Groups I (no outwardly appearing long second toe, no pain), II and III A, B and C (an outwardly appearing long second toe, no complaints and complaints slight, moderate and severe in nature).

The Pearson product moment correlation coefficient was performed to determine correlations among the 20 selected measures among Groups I, II and the combined Groups III A, B and C.

Hand calculations were made by the researcher on data collected among Groups I, II, IIIA, IIIB, IIIC, the combined Groups III A, B and C, and the combined Groups II, III A, B and C in order to determine: the mean, mode and median differences in length of metatarsal I to metatarsal II acquired by Morton's, Schuster's, and Sheer's methods; the group means for the parabolic weight-bearing curve angle; the relationship of the length difference of metatarsal I to metatarsal II acquired by Morton's, Schuster's and Sheer's methods to the metatarsus location of the greatest concentration of dynamic weight distribution; the metatarsal location of greatest weight-bearing and calluses with and without first ray consideration; and the first ray range of motion and metatarsal location of greatest concentration of

dynamic weight-bearing and calluses.

Chapter 4

RESULTS

Relationship of Biomechanical, Radiographic and Weight-Bearing Measures

Statistical treatments were applied to data obtained from the biomechanical, radiographic and weight-bearing measures performed on the subjects studied. The legs and/or feet of all subjects were classified according to the relative lengths of the first and second toes and the existence of pain. The classifications were as follows: Group I (N = 22), no outwardly appearing long second toe, no pain; Group II (N = 23), an outwardly appearing long second toe, no pain; Group IIIA (N = 17), an outwardly appearing long second toe, pain slight in nature; Group IIIB (N = 14), an outwardly appearing long second toe, pain moderate in nature; and Group IIIC (N = 12), an outwardly appearing long second toe, pain severe in nature.

Measures Descriptive of Morton's Foot Syndrome

An analysis of variance was applied to the data of each of the 20 lower extremity alignment measurements and foot characteristics in an attempt to determine which, if any, of the biomechanical, radiographic and weight-bearing measures would best describe any of the specific groups. The analysis of variance was computed between: Group I, no outwardly appearing long second toe, no pain,

and Group II, an outwardly appearing long second toe, no pain; Group I, no outwardly appearing long second toe, no pain and the combined Groups III A, B and C, an outwardly appearing long second toe and experiencing pain slight, moderate and severe in nature; and Group II, an outwardly appearing long second toe, no pain, and the combined Groups III A, B and C, an outwardly appearing long second toe and experiencing pain slight, moderate and severe in nature.

Results of the data analyzed showed no significant differences among any of the 20 variables between each of the groups examined.

The results of the analysis of variance are summarized in Table 1. There was insufficient evidence to indicate rejection of the null hypotheses. The null hypotheses stated that there would be no significant difference in the characteristics of the lower extremity as described by the selected biomechanical, radiographic and weight-bearing measures among runners with no outwardly appearing long second toe who experienced no complaints, those runners with an outwardly appearing long second toe who experienced no complaints, and those runners with an outwardly appearing long second toe who experienced complaints slight in nature, who experienced complaints of moderate severity and who experienced complaints severe in nature. It was also hypothesized that no significant difference would be found among the ratio of difference in length of metatarsals I and II, the existence or non-existence of an outwardly appearing

long second toe, the parabolic weight-bearing curve, nor the evidence of metatarsus location of the greatest concentration of dynamic weight-bearing distribution. Thus, it was not possible to determine those biomechanical, radiographic and weight-bearing measures that best describe the Morton's Foot syndrome.

Table 1

Least Squares Analysis
of Variance

Source	D.F.	Sum of Squares	Mean Square	F
Total	1848	8356610048.000000		
Total Reduction	63	4267875328.000000	67744048.000000	29.575
Mu - Y	1	384134656.000000	384134656.000000	167.700
Var	20	3707099392.000000	185354960.000000	80.920*
Gr	2	3464176.000000	1732088.000000	.756
Var x Gr	40	94214976.000000	2355374.000000	1.028
Remainder	1785	40887334720.000000	2290607.000000	

*Significant beyond the $p < .05$ level. (The significance found among the variables is due to the differences of the types of variables studied.)

Correlations of Measures

The Pearson product moment correlation coefficient was performed to determine correlations among the 20 selected measures according to

the severity of pain. Significant correlations were found beyond the $p < .05$ level for the following:

1. ranges of internal rotation of the femur with the hip straight correlated with inversion of the subtalor joint ($r = .453$);
2. dorsiflexion of the ankle joint with the knee straight correlated with dorsiflexion of the ankle joint with the knee flexed ($r = .788$);
3. ranges of internal rotation of the femur with the hip flexed correlated with internal rotation of the femur with the hip straight ($r = .846$);
4. ranges of external rotation of the femur with the hip flexed correlated with external rotation of the femur with the hip straight ($r = .842$);
5. the three methods used to determine the difference in length of metatarsal I to metatarsal II (Morton's, Schuster's and Sheer's) correlated; Schuster to Morton ($r = .931$); Sheer to Morton ($r = .610$); Sheer to Schuster ($r = .661$);
6. the weight-bearing parabolic curve angle formed by the heads of metatarsals I through V correlated to the difference in length of metatarsal I to metatarsal II: to Morton's method ($r = .783$); to Schuster's method ($r = .820$); to

Sheer's method (r = .601).

The results are summarized in Table 2.

Measures Predictive of Pain Associated with Morton's Foot Syndrome

A step-wise regression analysis was applied to determine the relationship of the 20 biomechanical, radiographic and weight-bearing measures to the degree of severity of the complaints cited. In addition, this analysis was employed to determine which, if any, of these measures could best predict the occurrence of pain as related to Morton's Foot syndrome. The analysis was performed on Group I, no outwardly appearing long second toe and no pain, Group II, an outwardly appearing long second toe and no pain, and Groups III A, B and C, an outwardly appearing long second toe and pain slight, moderate and severe in nature, according to the increase in the degree of severity of the complaints. Results of the step-wise regression analysis are summarized in Table 3.

The regression analysis indicated that five measures were significant in the prediction of pain related to Morton's Foot syndrome. They were Sheer's method measuring the percent difference of the actual length of metatarsal I to the actual length of metatarsal II, the ranges of internal rotation of the femur with the hip straight, the metatarsus location of the greatest concentration of dynamic weight distribution, eversion of the subtalor joint and the ranges

Table 2

Summary of Correlated Measures Among
Groups II, IIIA, IIIB, IIIC

Correlated Measures	Correlation Coefficient
Internal rotation of femur, hip straight, to inversion of subtalor joint	r = .453*
Ankle dorsiflexion, leg straight, to ankle dorsiflexion, knee flexed	r = .788*
Internal rotation of femur, hip flexed, to internal rotation of femur, hip straight	r = .846*
External rotation of femur, hip flexed, to external rotation of femur, hip straight	r = .842*
Schuster's method of measure, to Morton's method of measure	r = .931*
Sheer's method of measure, to Morton's method of measure	r = .610*
Sheer's method of measure, to Schuster's method of measure	r = .661*
Weight-bearing parabolic curve angle to Morton's method of measure	r = .783*
Weight-bearing parabolic curve angle to Schuster's method of measure	r = .820*
Weight-bearing parabolic curve angle to Sheer's method of measure	r = .601*

*Significant beyond the $p < .05$ level.

Table 3

Summary of the Step-Wise Regression Analysis Performed
On Groups I, II, IIIA, IIIB, IIIC

Step Number	Variable Entered	Multiple R.	RSQ.	Increase In RSQ	F Value to Enter or Remove
1.	Sheer's Measure	.3649	.1332	.1132	13.2118*
2.	Internal rotation, legs straight	.4827	.2330	.0998	11.0603*
3.	Metatarsal location of weight concentration	.5310	.2820	.0490	5.7296*
4.	Eversion of Subtalor joint	.5577	.3110	.0291	3.5051**
5.	External rotation, hip straight	.5897	.3477	.0367	4.6127*
6.	Inversion of Subtalor joint	.6019	.3623	.0146	1.8545
7.	Metatarsal Parabolic Angle	.6093	.3713	.0089	1.1363
8.	Calcaneal Inversion, Eversion in static stance	.6149	.3781	.0069	.8716
9.	First Ray ranges of motion	.6193	.3836	.0054	.6874
10.	Hamstring flexibility	.6245	.3900	.0064	.8119
11.	Forefoot varus, neutral, valgus	.6281	.3945	.0045	.5689
12.	Schuster's Measure	.6298	.3966	.0021	.2619
13.	Morton's Measure	.6385	.4077	.0111	1.3828
14.	External rotation, hip flexed	.6409	.4107	.0030	.3761
15.	Ankle dorsiflexion, knee flexed	.6422	.4125	.0017	.2136
16.	Calcaneal Inversion, Eversion in neutral stance	.6437	.4143	.0019	.2250
17.	Ankle dorsiflexion, leg extended	.6453	.4164	.0021	.2508
18.	Tibial varus, static stance	.6460	.4173	.0009	.1021
19.	Tibial varus, neutral, valgus in neutral stance	.6463	.4177	.0004	.0493
20.	Internal rotation, hip flexed	.6465	.4179	.0002	.0222

*Significant beyond p < .01 level.
**Significant beyond p < .05 level.

of external rotation of the femur with the hip straight. The null hypotheses which stated that the biomechanical, radiographic and weight-bearing measures could not predict the occurrence of Morton's Foot syndrome was rejected for four of the five above mentioned measures beyond the $p < .01$ level of significance. The null hypotheses was rejected for eversion of the subtalor joint beyond the $p < .05$ level of significance. There was insufficient evidence to reject the null hypotheses for the remaining measures.

Metatarsus Weight-Bearing Angle

Table 4 is a summary of the means of the parabolic weight-bearing curve angle formed by the metatarsus among all groups studied. The findings are: Group I (N = 22), no outwardly appearing long second toe, no pain (139.68 degrees); Group II (N = 23), an outwardly appearing long second toe, no pain (134.61 degrees); Group IIIA (N = 17), an outwardly appearing long second toe with pain slight in nature (135.88 degrees); Group IIIB (N = 14), an outwardly appearing long second toe with pain moderate in nature (133.57 degrees); Group IIIC (N = 12), an outwardly appearing long second toe with pain severe in nature (135.5 degrees); the combined Groups III A, B and C (N = 43), an outwardly appearing long second toe with pain slight, moderate and severe in nature (135.02 degrees); and the combined Groups II, III A, B and C (N = 66), an outwardly

appearing long second toe with varying degrees of pain (134.81 degrees).

Table 4

Summary of Means of Parabolic Weight-Bearing Curve Angle Among All Groups

Group	N	Range (degrees)	X(degrees)	Meschen (136°)	Gamble (142.5°)
Group I	(N=22)	123-153	139.68	+3.68	-2.82
Group II	(N=23)	128-146	134.61	-1.39	-7.89
Group IIIA	(N=17)	129-143	135.57	-0.43	-6.93
Group IIIB	(N=14)	126-145	133.57	-2.43	-8.93
Group IIIC	(N=12)	129-142	135.5	-0.5	-7.00
Groups III A, B and C	(N=43)	126-145	135.02	-0.98	-7.48
Groups II, IIIA, B, C	(N=66)	126-146	134.81	-1.19	-7.69

The findings of mean deviations from Meschen's (12) suggested standard of normalcy (136 degrees) shows Group I, no outwardly appearing long second toe and no pain as having a greater parabolic angle mean deviation (+3.68 degrees) of metatarsus weight support than that suggested by Meschen. Those groups having an outwardly appearing long second toe with varying degrees of pain showed mean

deviations which were less than the suggested norm: Group II, -1.39 degrees; Group IIIA, -0.43 degrees; Group IIIB, -2.43 degrees; Group IIIC, -0.5 degrees; the combined Groups III A, B and C, -0.98 degrees; and the combined Groups II, III A, B and C, -1.19 degrees. When compared to Gamble's (6) suggested mean angle (142.5 degrees) the mean parabolic angle of all groups studied were found to be less than the suggested norm. Group I, no outwardly appearing long second toe and no pain showed the lowest mean deviation (-2.82 degrees). The remaining groups, those having an outwardly appearing long second toe and varying degrees of pain, showed relatively close mean deviations: Group II, -7.89 degrees; Group IIIA, -6.93 degrees; Group IIIC, -7.00 degrees; the combined Groups III A, B and C, -7.48 degrees; and the combined Groups II, III A, B and C, -7.69 degrees.

Length Differences of Metatarsal I to Metatarsal II

Table 5 summarizes the incidence of measures of length differences of metatarsal I to metatarsal II for all groups studied. Shown is a comparison of the mean, mode and median measures acquired by Morton's, Schuster's and Sheer's methods. The mean findings were: Group I (N = 22), (Morton, -2mm, Schuster, -2mm, Sheer, 18 percent); Group II (N = 23), (Morton, -5mm, Schuster, -3mm, Sheer, 19 percent); Group IIIA (N = 17), (Morton, -4mm, Schuster, -1mm,

Table 5

Mean, Mode and Median Comparison of Measures Acquired by Morton's, Schuster's and Sheer's Methods

	GROUP I			GROUP II			GROUP IIIA			GROUP IIIB		
	Morton	Schuster	Sheer	Morton	Schuster	Sheer	Morton	Schuster	Sheer	Morton	Schuster	Sheer
Mean	-2mm	-2mm	18%	-5mm	-3mm	19%	-4mm	-1mm	19%	-6mm	-4mm	21%
Mode	-3mm	0mm	18%	-5mm	-3mm	17,19%	-5mm, -6mm, -7mm	-1mm	19,20%	-5mm	-3mm	20%
Median	-1mm	-1mm	18%	-5mm	-3mm	19%	-5mm	-3mm	19%	-5mm	-3mm	20%

	GROUP IIIC			GROUP III A,B,C			GROUP II. III A,B,C		
	Morton	Schuster	Sheer	Morton	Schuster	Sheer	Morton	Schuster	Sheer
Mean	-5mm	-3mm	21%	-5mm	-3mm	20%	-5mm	-3mm	20%
Mode	-3mm	-3mm	17%	-5mm	-1mm	20%	-5mm	-3mm	19%
Median	-4mm	-2mm	20%	-5mm	-3mm	20%	-5mm	-3mm	20%

Sheer, 19 percent); Group IIIB (N = 14), (Morton, -6mm, Schuster, -4mm, Sheer, 21 percent); Group IIIC (N = 12), (Morton, -5mm, Schuster, -3mm, Sheer, 21 percent); the combined Groups III A, B and C (N = 43), (Morton, -5mm, Schuster, -3mm, Sheer, 20 percent); and the combined Groups II, III A, B and C (N = 66), (Morton, -5mm, Schuster, -3mm, Sheer, 20 percent). The mode findings were: Group I (Morton, -3mm, Schuster, 0mm, Sheer, 18 percent); Group II (Morton, -5mm, Schuster, -3mm, Sheer, 17 percent and 19 percent); Group IIIA (Morton, -5mm, -6mm and -7mm, Schuster, -1mm, Sheer, 19 percent and 20 percent); Group IIIC (Morton, -3mm, Schuster, -3mm, Sheer, 17 percent); the combined Groups III A, B and C (Morton, -5mm, Schuster, -1mm, Sheer, 20 percent); and the combined Groups II, III A, B and C (Morton, -5mm, Schuster, -3mm, Sheer, 19 percent). The median findings were: Group I (Morton, -1mm, Schuster, -1mm, Sheer, 18 percent); Group II (Morton, -5mm, Schuster, -3mm, Sheer, 19 percent); Group IIIA (Morton, -5mm, Schuster, -3mm, Sheer, 19 percent); Group IIIB (Morton, -5mm, Schuster, -3mm, Sheer, 20 percent); Group IIIC (Morton, -4mm, Schuster, -2mm, Sheer, 20 percent); the combined Groups III A, B and C (Morton, -5mm, Schuster, -3mm, Sheer, 20 percent); and the combined Groups II, III A, B and C (Morton, -5mm, Schuster, -3mm, Sheer, 20 percent).

The mean findings indicate that those runners having no outwardly appearing long second toe and no pain (Group I) experienced

the least length difference of metatarsal I to metatarsal II (mean acquired by Morton's method, -2mm). Groups II, III A, B and C, those runners having an outwardly appearing long second toe with varying degrees of pain, evidenced a greater but similar length difference of metatarsal I to metatarsal II (mean acquired by Morton's method, -5mm, -4mm, -6mm, -5mm, respectively). Sheer's mean measure among all groups evidenced only a 2 percent deviation with Group I, runners having no outwardly appearing long second toe and no pain having a mean of 18 percent, and Groups II, III A, B and C, runners having an outwardly appearing long second toe with varying degrees of pain having a mean of 20 percent.

Metatarsal Location of Dynamic Weight-Bearing

Those subjects in Group I (N = 22), having no outwardly appearing long second toe and no pain (Figure 13), showed evidence of weight-bearing by: two (9 percent) subjects on metatarsal II, alone; three (14 percent) equally on metatarsals I and II; six (27 percent) equally on metatarsals I, II and III; two (9 percent) equally throughout metatarsals I-IV; two (9 percent) equally throughout metatarsals I-V; three (14 percent) equally on metatarsals II and III; one (5 percent) equally throughout metatarsals II-IV; two (9 percent) equally throughout metatarsals II-V; and one (5 percent) equally throughout metatarsals III-V.

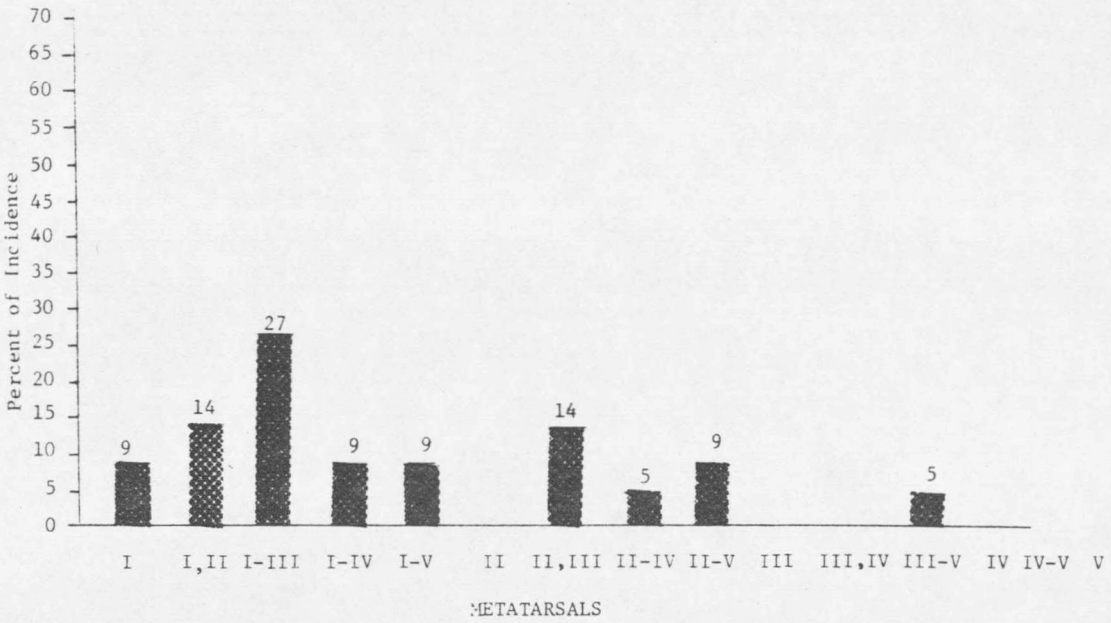


Figure 13. Group I (N = 22) Metatarsal Location of Greatest Dynamic Weight-Bearing

Figure 14 shows that of those subjects in Group II (N = 23), having an outwardly appearing long second toe and no pain, weight-bearing was assumed by: three (13 percent) on metatarsals I and II, equally; six (26 percent) equally on metatarsals I-III; one (4 percent) equally on metatarsals I-IV; two (9 percent) equally on metatarsals I-V; two (9 percent) equally on metatarsals II and III; three (13 percent) on metatarsals II-IV; three (13 percent) equally on metatarsals II-V; and three (13 percent) equally on metatarsals III-V.

In Figure 15, it can be seen that of those subjects in Group IIIA (N = 17), having an outwardly appearing long second toe and pain slight in nature, weight-bearing was assumed by: one (12 percent) equally on metatarsals I and II; four (24 percent) equally on metatarsals I-III; four (24 percent) equally on metatarsals I-IV; three (18 percent) equally on metatarsals II and III; one (6 percent) equally on metatarsals II-IV; two (12 percent) equally on metatarsals II-V; and one (6 percent) equally on metatarsals III-V.

Of those subjects in Group IIIB (N = 14), having an outwardly appearing long second toe and pain moderate in nature (Figure 16): weight-bearing was assumed by two (14 percent) equally on metatarsals I and II; weight-bearing was assumed by one (7 percent) equally on metatarsals I-IV; weight-bearing was assumed by two (14 percent) solely on metatarsal II; weight-bearing was assumed by five (36

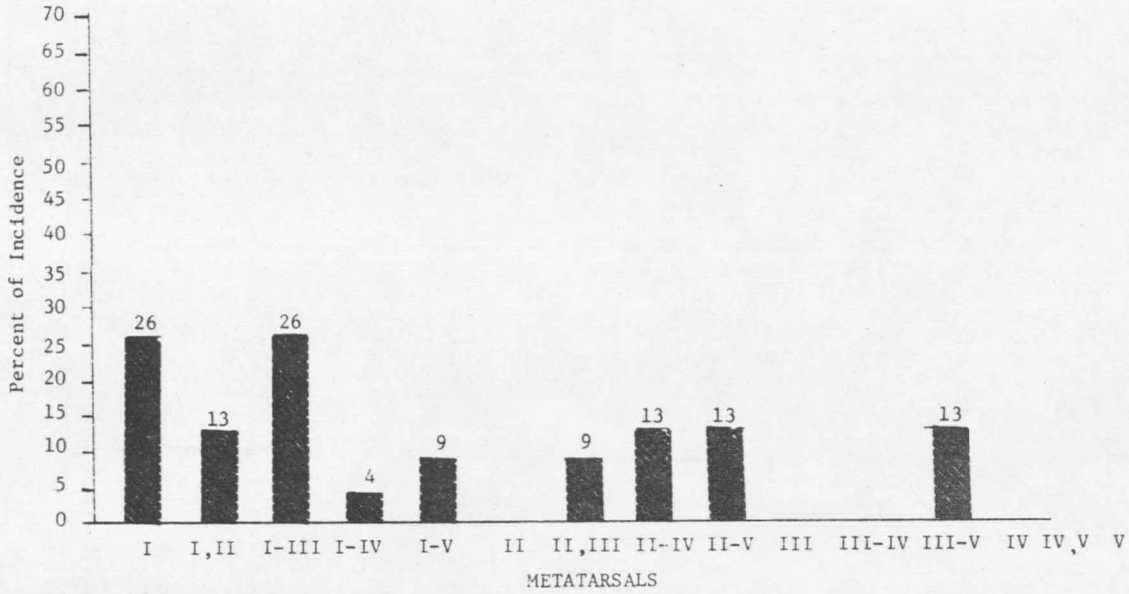


Figure 14. Group II (N = 23) Metatarsal Location of Greatest Dynamic Weight-Bearing

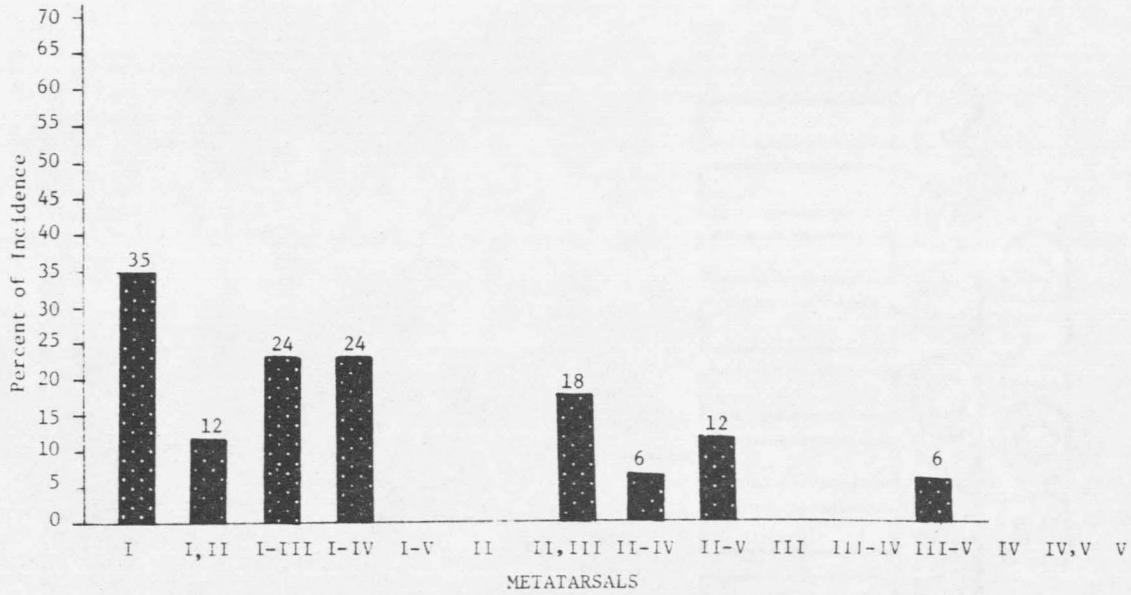


Figure 15. Group IIIA (N = 17) Metatarsal Location of Greatest Dynamic Weight-Bearing

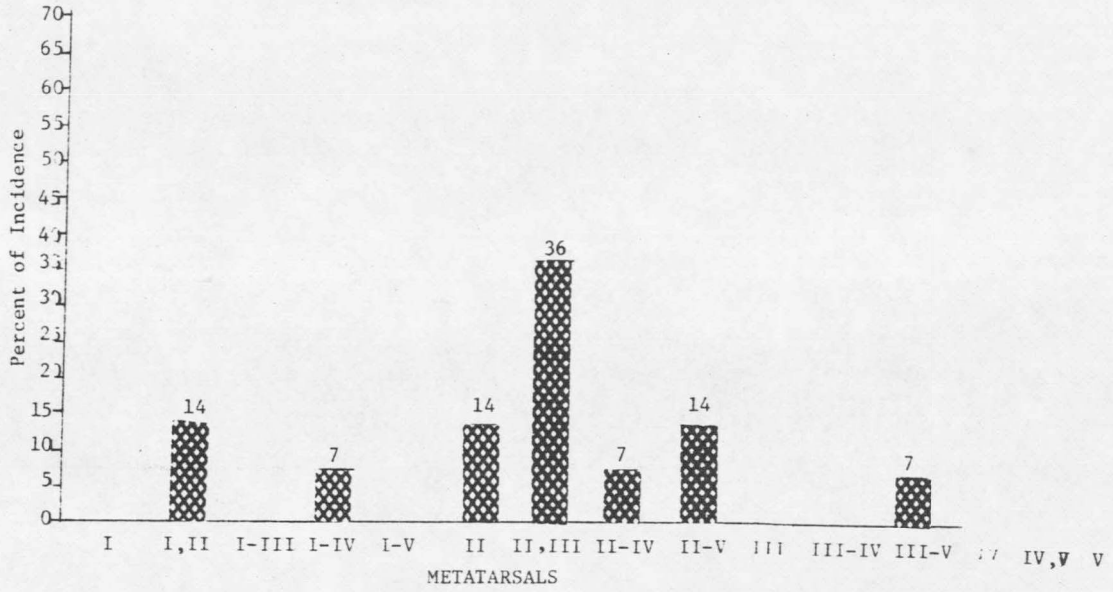


Figure 16. Group IIIB (N = 14) Metatarsal Location of Greatest Dynamic Weight-Bearing

percent) equally on metatarsals II and III; weight-bearing was assumed by one (7 percent) equally on metatarsals II-IV; weight-bearing was assumed by two (14 percent) equally on metatarsals II-V; and weight-bearing was assumed by one (7 percent) equally on metatarsals III-V.

Figure 17 shows that of those subjects in Group IIIC (N = 12), having an outwardly appearing long second toe and pain severe in nature, weight-bearing was assumed by: three (25 percent) equally on metatarsals I-III; one (8 percent) equally on metatarsals I-IV; seven (58 percent) equally on metatarsals II and III; and one (8 percent) equally on metatarsals II-IV.

Those subjects in the combined Groups III A, B and C (N = 43), having an outwardly appearing long second toe and pain slight, moderate and severe in nature (Figure 18) evidenced weight-bearing by: four (9 percent) equally on metatarsals I and II; seven (16 percent) equally on metatarsals I-III; six (14 percent) equally on metatarsals I-IV; two (5 percent) solely on metatarsal II; fifteen (35 percent) equally on metatarsals II and III; three (7 percent) equally on metatarsals II-V; and two (5 percent) equally on metatarsals III-V.

In Figure 19, it can be seen that of those subjects in the combined Groups II, III A, B and C (N = 66), having an outwardly appearing long second toe and varying degrees of pain, weight-bearing was assumed by: seven (11 percent) equally on metatarsals I and II;

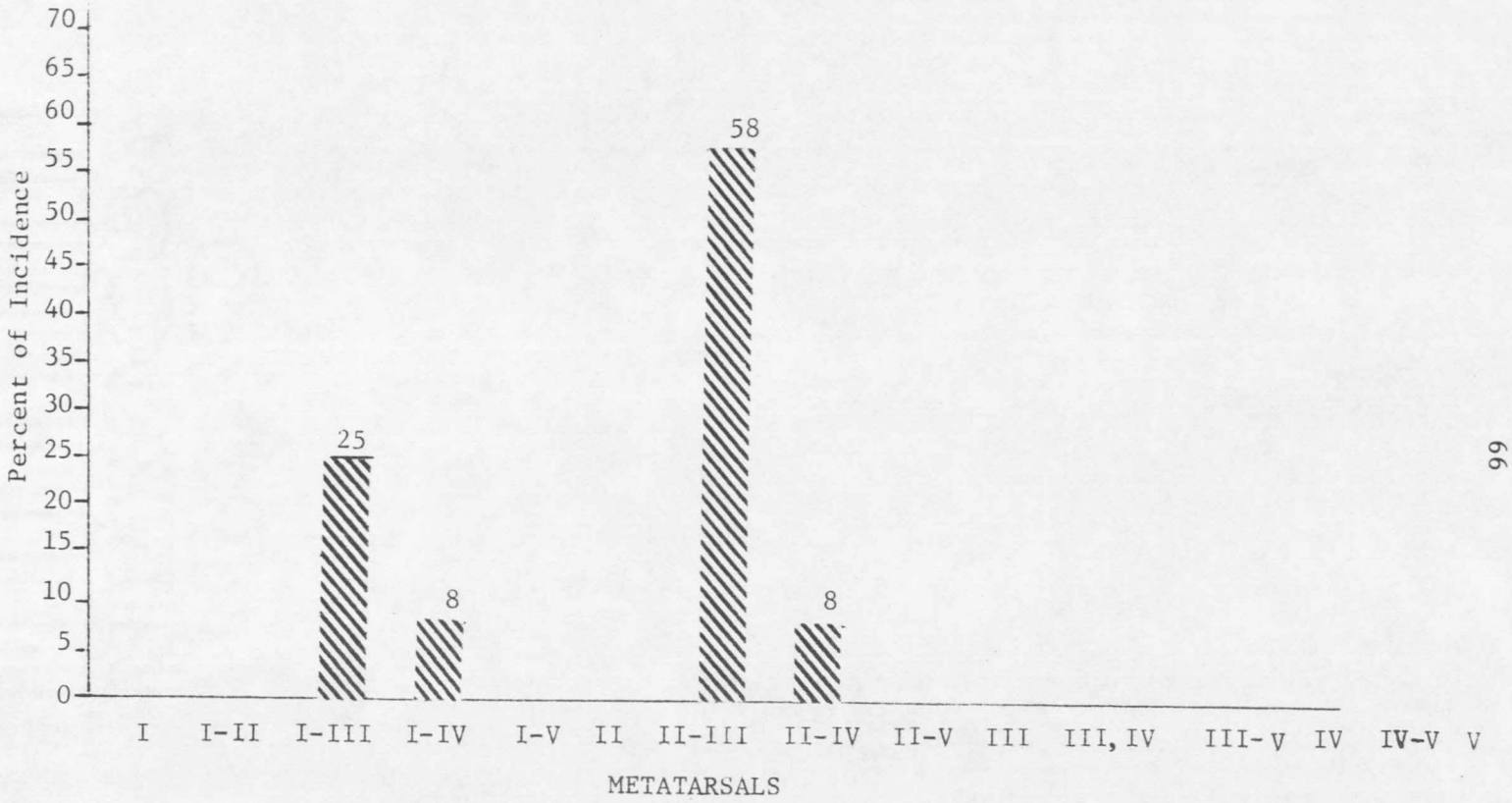


Figure 17. Group IIIC (N = 12) Metatarsal Location of Greatest Dynamic Weight-Bearing

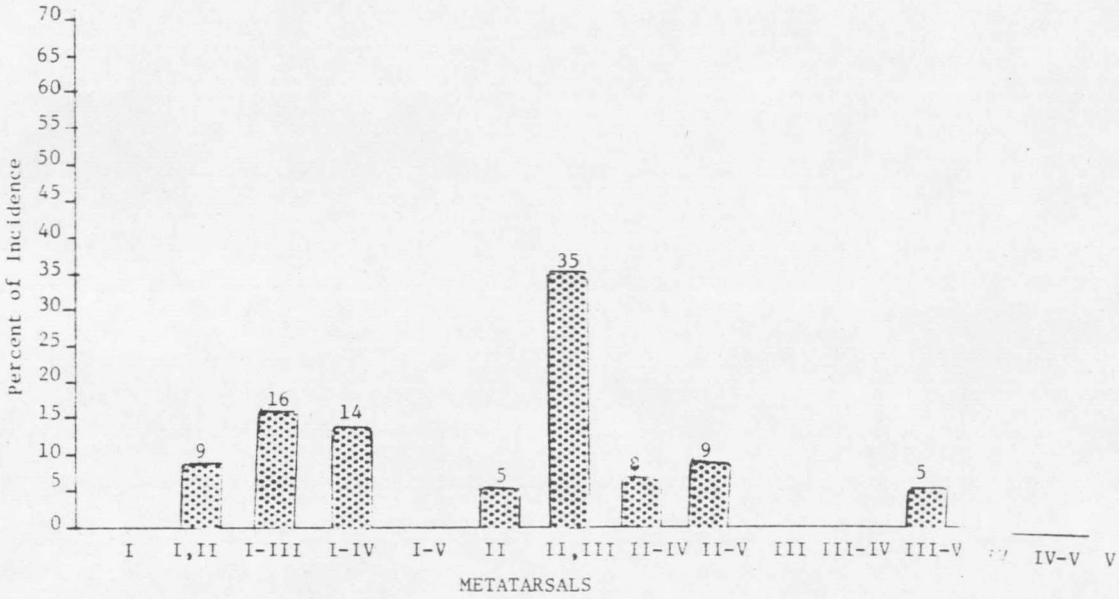


Figure 18. Combined Groups III A, B and C (N = 43) Metatarsal Location of Greatest Dynamic Weight-Bearing

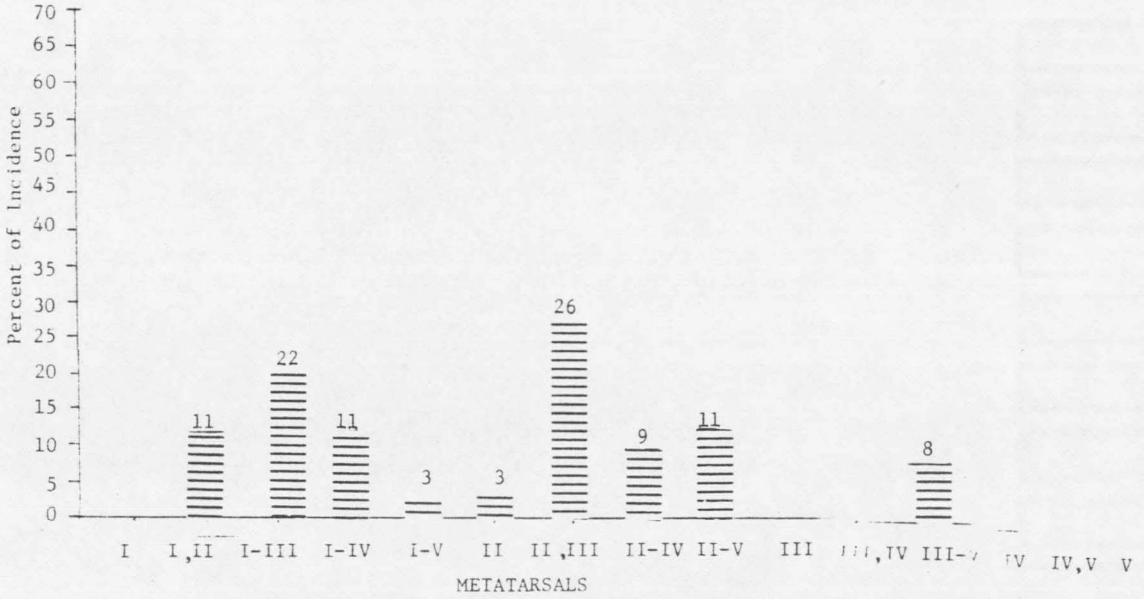


Figure 19. Combined Groups II, III A, B and C (N = 66) Metatarsal Location of Greatest Dynamic Weight-Bearing

thirteen (19 percent) equally on metatarsals I-III; seven (11 percent) equally on metatarsals I-IV; two (3 percent) equally on metatarsals I-V; two (3 percent) solely on metatarsal II; seventeen (26 percent) equally on metatarsals II and III; six (9 percent) equally on metatarsals II-IV; seven (11 percent) equally on metatarsals II-V; and five (8 percent) equally on metatarsals III-V.

Callus Formation Throughout the Metatarsus

Figure 20 shows that of those subjects in Group I (N = 22), having no outwardly appearing long second toe and no pain, calluses were evidenced by seven of the twenty-two subjects (32 percent): three (14 percent) on metatarsal I, alone; two (9 percent) on metatarsals I, II and III; one (5 percent) on metatarsals I-V; and one (5 percent) on metatarsals II and III.

Evidence shows (Figure 21) that of those subjects in Group II (N = 23), having an outwardly appearing long second toe and no pain, thirteen of the twenty-three subjects (57 percent) experienced callus formations: six (26 percent) solely on metatarsal I; one (4 percent) on metatarsals I and II; one (4 percent) on metatarsals I-III; one (4 percent) on metatarsals I-IV; three (13 percent) solely on metatarsal II; and one (4 percent) on metatarsals II and III.

Of those subjects in Group IIIA (N = 17), having an outwardly appearing long second toe and pain slight in nature (Figure 22),

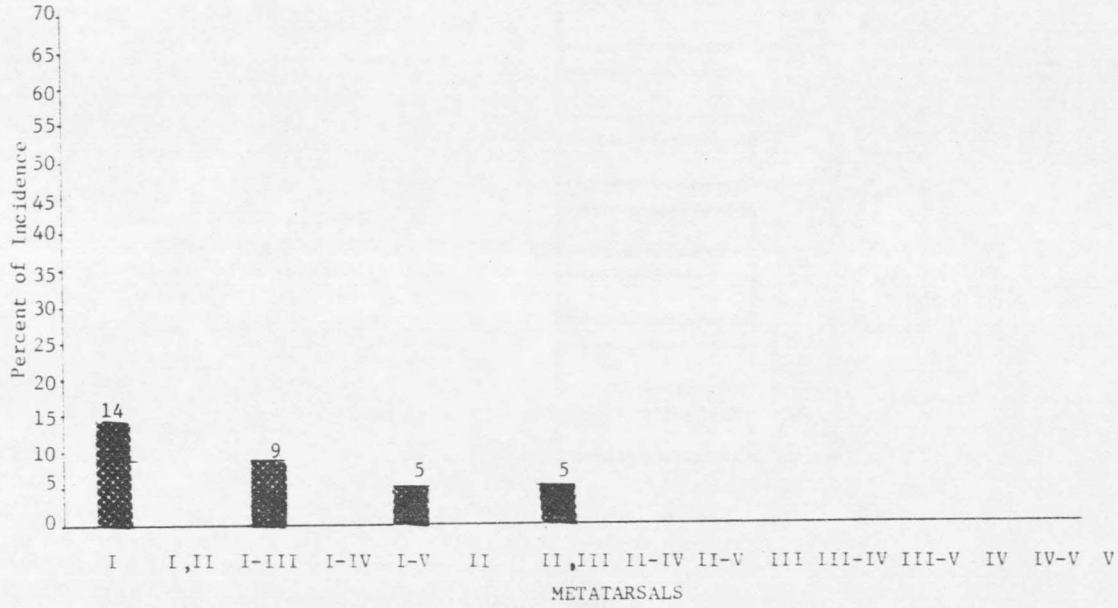


Figure 20. Group I (N = 22) Metatarsal Location of Calluses

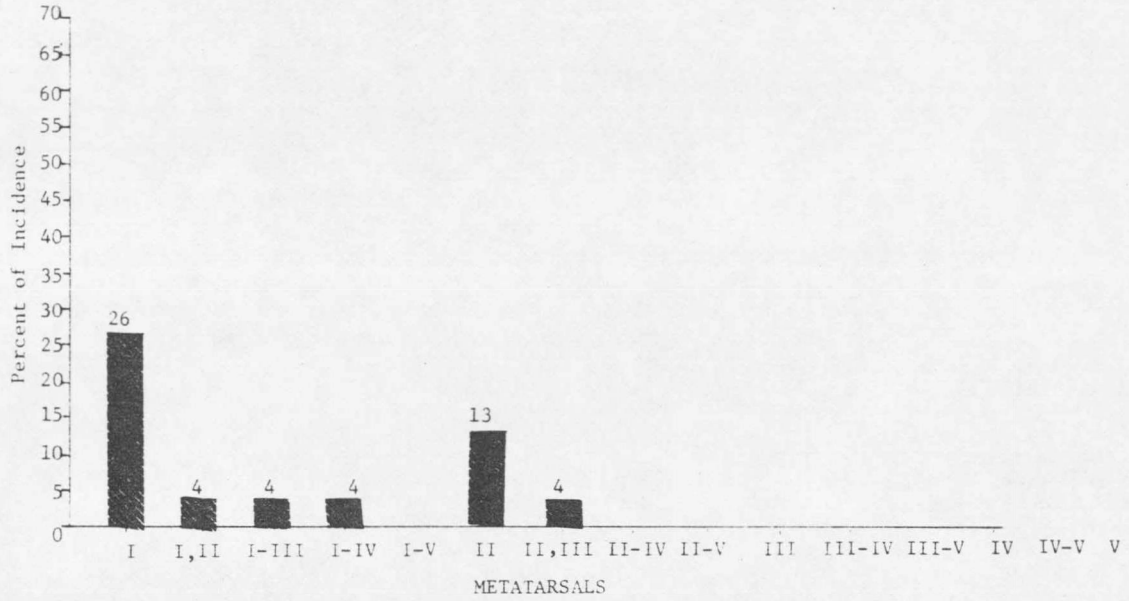


Figure 21. Group II (N = 23) Metatarsal Location of Calluses

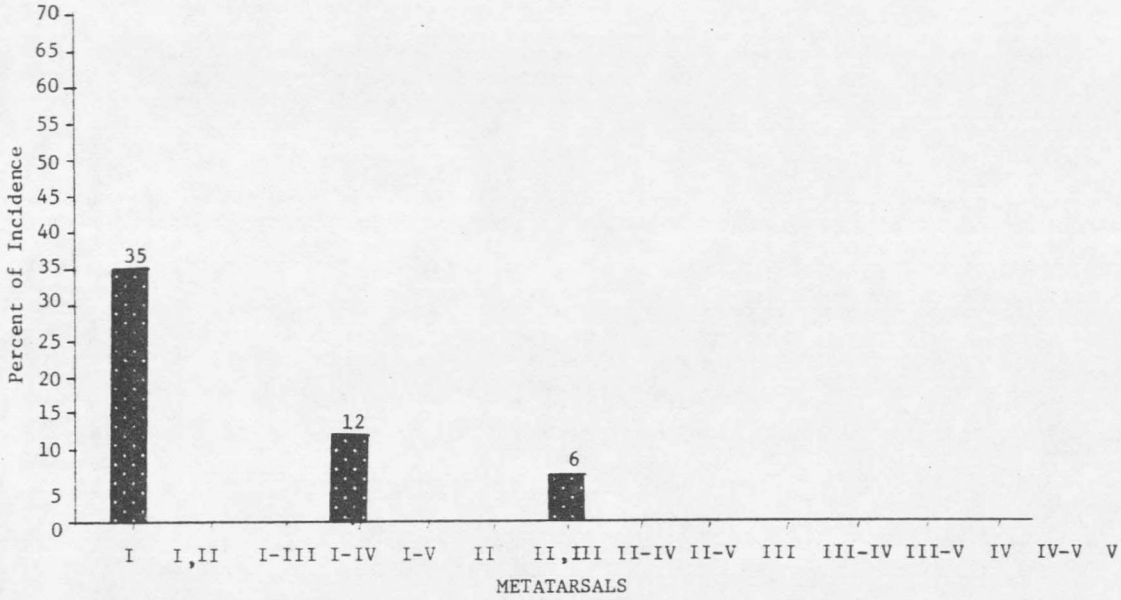


Figure 22. Group IIIA (N = 17) Metatarsal Location of Calluses

eight (47 percent) evidenced callus formations: six (35 percent) solely on metatarsal I; one (6 percent) on metatarsals I-IV; and one (6 percent) on metatarsals II and III.

Figure 23 shows that of the fourteen subjects in Group IIIB, having an outwardly appearing long second toe and pain moderate in nature, four (29 percent) evidenced callus formations: two (14 percent) on metatarsal I, alone; and two (14 percent) on metatarsals I and II.

In Figure 24, it can be seen that of the twelve subjects in Group IIIC, having an outwardly appearing long second toe and pain severe in nature, six (50 percent) evidenced callus formations: two (17 percent) solely on metatarsal I; two (17 percent) on metatarsals II and III; one (8 percent) on metatarsals II-V; and one (8 percent) on metatarsals III-V.

Evidence shows (Figure 25) that of the forty-three subjects in the combined Groups III A, B and C, having an outwardly appearing long second toe and pain slight, moderate and severe in nature, eighteen (42 percent) experienced callus formations: ten (23 percent) on metatarsal I, alone; two (5 percent) on metatarsals I and II; two (5 percent) on metatarsals I-IV; three (7 percent) on metatarsals II and III; and one (2 percent) on metatarsals II-V.

Of the sixty-six subjects in the combined Groups II, III A, B and C (Figure 26), having an outwardly appearing long second toe and pain

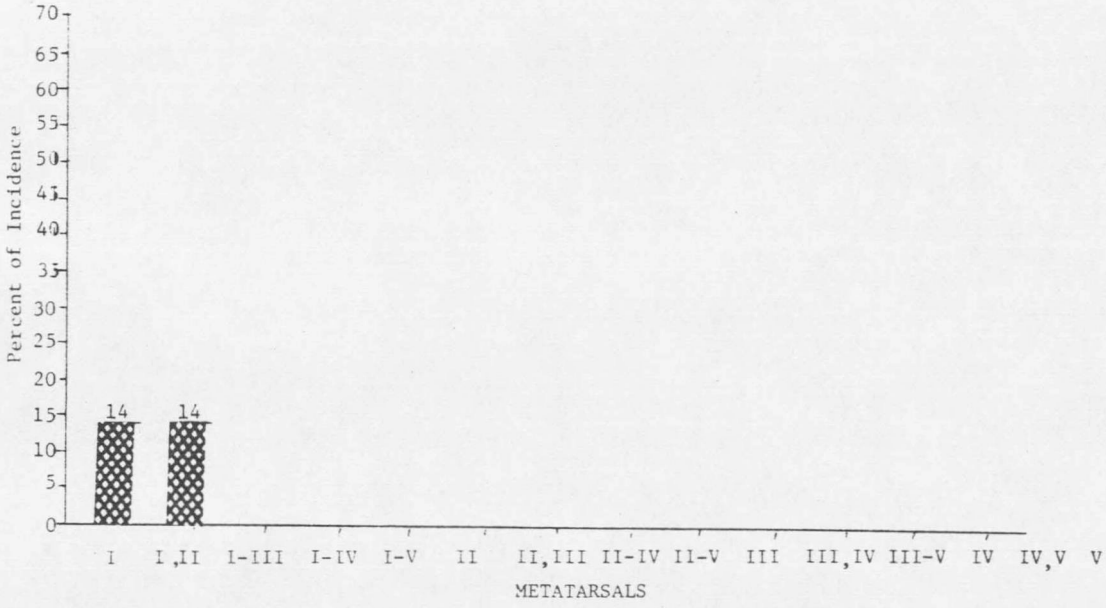


Figure 23. Group IIIB (N = 14) Metatarsal Location of Calluses

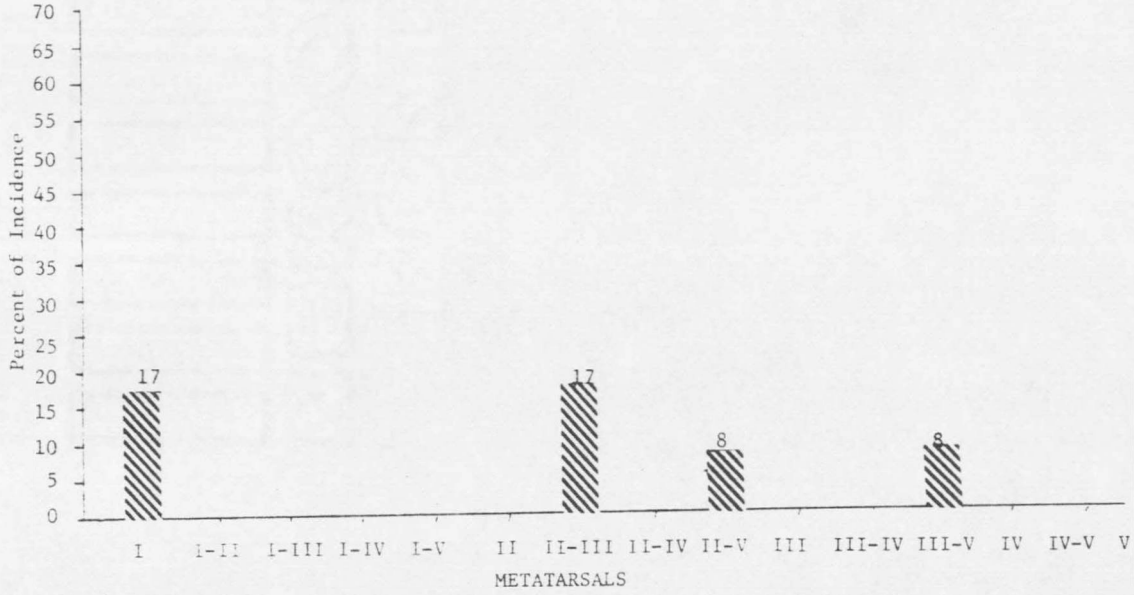


Figure 24. Group IIIC (N = 12) Metatarsal Location of Calluses

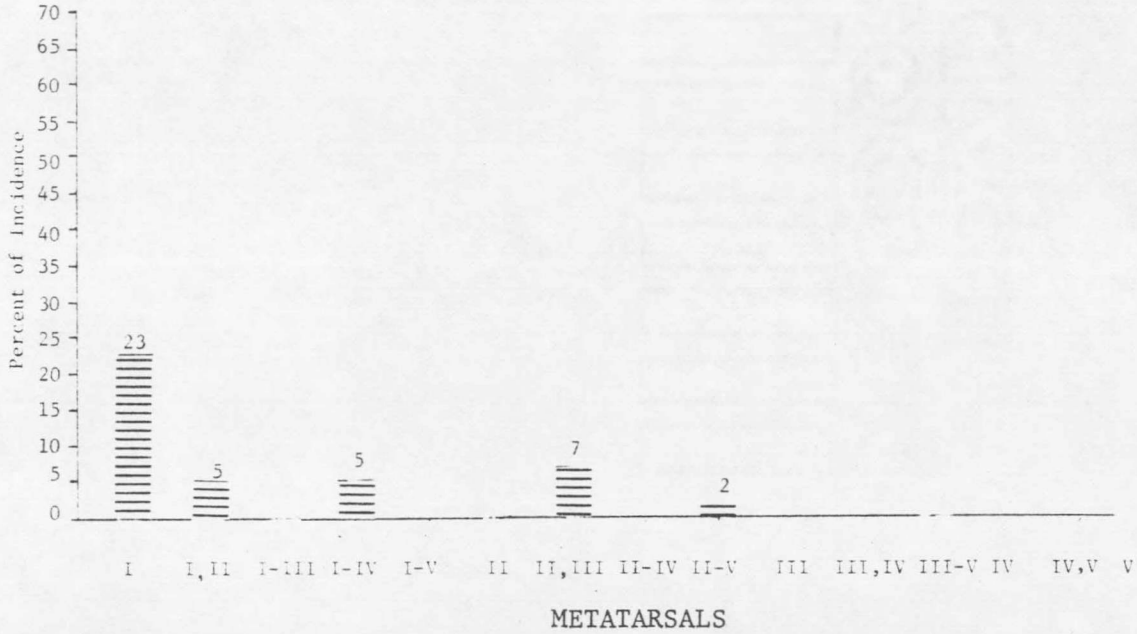


Figure 25. Combined Groups III A, B and C (N = 43)
Metatarsal Location of Calluses

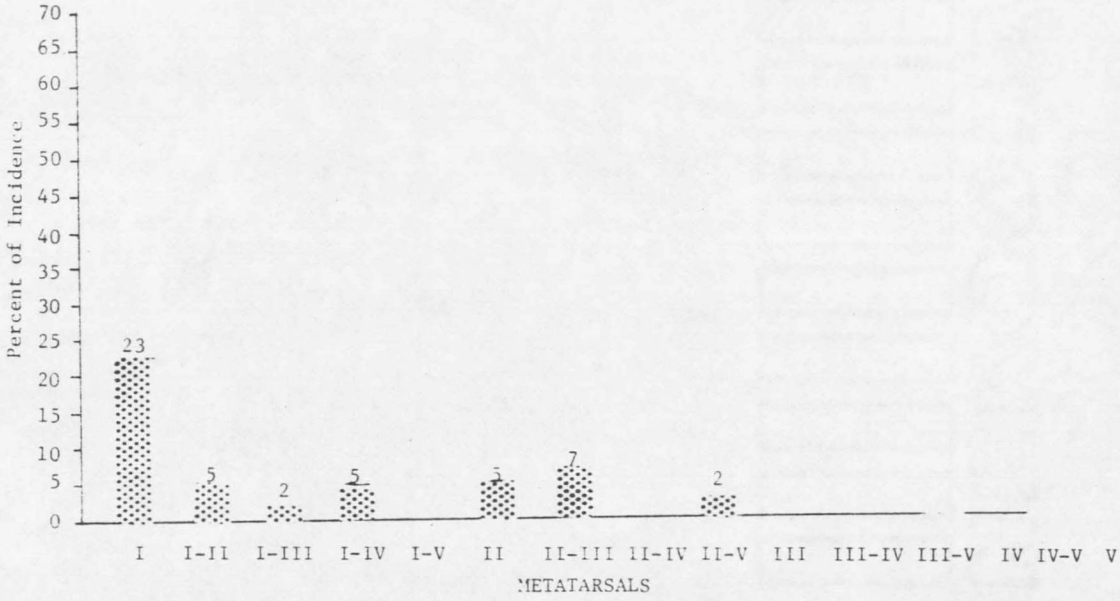


Figure 26. Combined Groups II, III A, B and C (N = 43)
Metatarsal Location of Calluses

of varying degrees, thirty-one (47 percent) evidenced callus formations: sixteen (23 percent) on metatarsal I, alone; three (5 percent) on metatarsals I and II; one (2 percent) on metatarsals I-III; three (5 percent) on metatarsals I-IV; three (5 percent) solely on metatarsal II; four (7 percent) on metatarsals II and III; and one (2 percent) on metatarsals II-V.

Metatarsal Length Differences and Location of Dynamic Weight-Bearing

Table 6 shows the incidence relationship of length differences of metatarsal I to metatarsal II, acquired by Morton's method, and the metatarsal location of the greatest concentration of dynamic weight-bearing among the subjects in Group I, no outwardly appearing long second toe, no pain. The greatest incidence in length differences was minus 3mm (f = 5; 23 percent). The greatest incidence of dynamic weight-bearing throughout the metatarsus occurred at the heads of metatarsals I, II and III (f = 6; 27 percent).

In comparison, Table 7 examines the incidence relationship of length differences of metatarsal I to metatarsal II, acquired by Morton's method, and the metatarsal location of the greatest concentration of dynamic weight-bearing among the combined subjects of Groups II, III A, B and C (N = 66), having an outwardly appearing long second toe and pain of varying degrees. The greatest incidence in length differences was minus 5mm (f = 15; 23 percent). The greatest

Table 6

Incidence Comparison of Length Difference of Metatarsal I to Metatarsal II (Morton) and Metatarsal Location of Greatest Concentration of Dynamic Weight-Bearing: Group I (N = 22)

Metatarsals	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	f	%
I			1				1											2	9
I-II				1		1				1								3	14
I-III				1	1		1		1						1		1	6	27
I-IV			1	1														2	9
I-V							1											1	5
II																			
II-III			1		1		1											3	14
II-IV		1																1	5
II-V				1			1	1										3	4
III																			
III-IV																			
III-V			1															1	5
IV																			
IV-V																			
V																			
f	0	1	4	4	2	1	5	1	1	1	0	0	0	0	1	0	1		
%		5	18	18	9	5	23	5	5	5					5		5		

Table 7

Incidence Comparison of Length Difference of Metatarsal I to Metatarsal II (Morton) and Metatarsal Location of Greatest Concentration of Dynamic Weight-Bearing: Groups II, III A, B, C (N = 66)

Metatarsals	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	f	%
I																			
I-II		1							3		3							7	11
I-III		1		1		1	3	3	2		2							13	20
I-IV						1	1		1	1	2		1					7	11
I-V									1				1					2	3
II									1		1							2	3
II-III				1		1		1	5	4	2	1	1		1			17	26
II-IV				1	1	1	1	3		1								8	12
II-V						2	1		1	1								5	8
III																			
III-V					1			2	1	1								5	8
IV																			
IV-V																			
V																			
f	0	2	0	3	2	6	6	9	15	8	10	1	3	0	1	0	0		
%		3		5	3	9	9	14	23	12	15	2	5		2				

incidence of dynamic weight-bearing throughout the metatarsus occurred simultaneously at the heads of metatarsals II and III (f = 17; 26 percent).

Table 8 illustrates the incidence relationship of length differences of metatarsal I to metatarsal II, acquired by Schuster's method, and the metatarsal location of the greatest concentration of dynamic weight-bearing among the subjects in Group I (N = 22), no outwardly appearing long second toe, no pain. The greatest incidence in length difference was 0mm (f = 7; 32 percent). The greatest incidence of dynamic weight-bearing throughout the metatarsus occurred at the heads of metatarsals I, II and III (f = 6; 27 percent).

In contrast, Table 9 examines the incidence relationship of length differences of metatarsal I to metatarsal II, acquired by Schuster's method, and the metatarsal location of the greatest concentration of dynamic weight-bearing among the combined subjects of Groups II, III A, B and C (N = 66), having an outwardly appearing long second toe and pain of varying degrees. The greatest incidence in length difference was minus 3mm (f = 15; 23 percent). The greatest incidence of dynamic weight-bearing throughout the metatarsus occurred at the heads of metatarsals II and III (f = 17; 26 percent).

Table 10 illustrates the incidence relationship of length differences of metatarsal I to metatarsal II, acquired by Sheer's

Table 8

Incidence Comparison of Length Difference of Metatarsal I to Metatarsal II (Schuster) and Metatarsal Location of Greatest Concentration of Dynamic Weight-Bearing: Group I (N = 22)

Metatarsals	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	f	%
I				1		1												2	9
I-II				1	1	1												3	14
I-III				1		3							1		1			6	27
I-IV				2														2	9
II																			
II-III				2			1											3	14
II-IV		1																1	5
II-V		1			1		1											3	14
III																			
III-IV																			
III-V		1																1	5
IV																			
IV-V																			
V																			
f	0	3	0	7	3	5	2	0	0	0	0	0	1	0	1	0	0		
%		14		32	14	23	9						5		5				

Table 9

Incidence Comparison of Length Difference of Metatarsal I to Metatarsal II (Schuster) and Metatarsal Location of Greater Concentration of Dynamic Weight-Bearing: Groups II, III A, B, C (N = 66)

Metatarsals	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	f	%
I																			
I-II	1			1		1		1	2		1							7	11
I-III		1		1	4	1	4		2									13	20
I-IV					1	1	1	3		1								7	11
I-V							1				1							2	3
II									1	1								2	3
II-III				1	1	1	4	2	5		2	1						7	26
II-IV				1	2		2		1									6	9
II-V					4	1	2											7	11
III																			
III-IV																			
III-V					1	2	1		1									5	8
IV																			
IV-V																			
V																			
f	1	1	0	4	13	7	15	6	12	2	4	1	0	0	0	0	0		
%	2	2		6	20	11	23	9	18	3	6	2							

Table 10

Incidence Comparison of Length Difference of Metatarsal I to Metatarsal II (Sheer) and Metatarsal Location of Greatest Concentration of Dynamic Weight-Bearing: Group I (N = 22)

Metatarsals	percent difference																		f	%
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28		
I						1	1												2	9
I-II					1		1		1										3	14
I-III					1			1	1		1	2							6	27
I-IV						1		1											2	9
I-V							1												1	5
II																				
II-III					1			2											3	14
II-IV								1											1	5
II-V			1			1							1						3	14
III																				
III-IV																				
III-V	1																		1	5
IV																				
IV-V																				
V																				
f	1	0	1	0	3	3	3	5	2	0	1	2	1	0	0	0	0	0		
%	5		5		14	14	14	23	9		5	9	5							

method, and the metatarsal location of the greatest concentration of dynamic weight-bearing among the subjects in Group I (N = 22), no outwardly appearing long second toe, no pain. The greatest incidence in length difference was 18 percent (f = 5; 23 percent). The greatest incidence of dynamic weight-bearing throughout the metatarsus occurred at the heads of metatarsals I, II and III (f = 17; 26 percent).

In contrast, Table 11 examines the incidence relationship of length differences of metatarsal I to metatarsal II, acquired by Sheer's method, and the metatarsal location of the greatest concentration of dynamic weight-bearing among the combined subjects of Groups II, III A, B and C (N = 66), having an outwardly appearing long second toe and pain of varying degrees. The greatest incidence in length difference was 19 percent (f = 12; 18 percent). The greatest incidence of dynamic weight-bearing throughout the metatarsus occurred at the heads of metatarsals II and III (f = 17; 26 percent).

First Ray Range of Motion

The ranges of motion of the first ray (dorsiflexion, normal and plantarflexion) for all groups studied are summarized in Table 12 and Figure 27. Hand calculations determined the percent incidence for each directional range of each group. Group I, no outwardly appearing

Table 11

Incidence Comparison of Length Difference of Metatarsal I to Metatarsal II (Sheer) and Metatarsal Location of Greater Concentration of Dynamic Weight-Bearing: Groups II, III A, B, C (N = 66)

Metatarsals	percent difference																			
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	f	%
I									1										1	2
I-II						1		1	2	1	1		1						7	11
I-III			1		3		4		3	1		1							13	20
I-IV						1			2	2	2								7	11
I-V							1											1	2	3
II														1					1	2
II-III						1	2	1	2	3	2	1	4					1	17	26
II-IV			1			1	1			1	1	1							6	9
II-V							1	3	1	1		1							7	11
III																				
III-IV																				
III-V	1							1	1	2		1							6	9
IV																				
IV-V																				
V																				
f	1	0	2	0	3	4	9	6	12	11	6	5	5	1	0	0	0	2		
%	2		3		5	6	14	9	18	17	9	8	8	2				3		

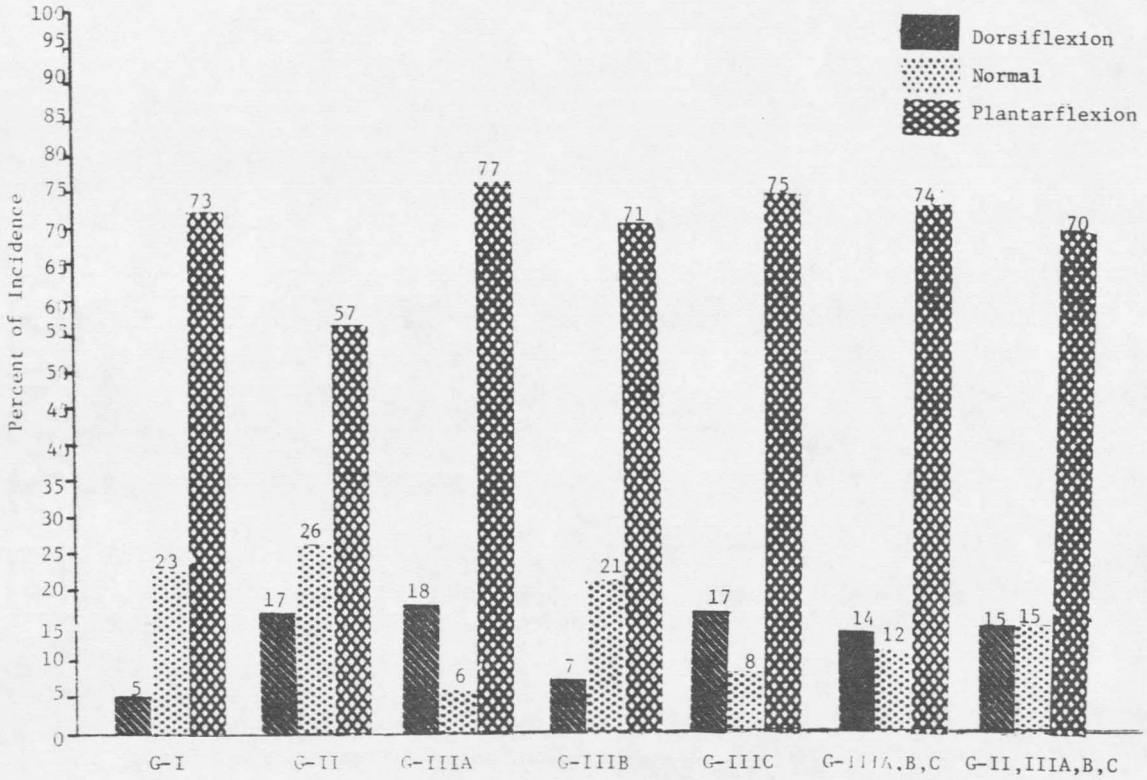


Figure 27. First Ray Ranges of Motion

long second toe and no pain, experienced 5 percent dorsiflexion, 23 percent normalcy and 73 percent plantarflexion. Group II, an outwardly appearing long second toe and no pain, experienced 17 percent dorsiflexion, 26 percent normalcy and 57 percent plantarflexion. Group IIIA, an outwardly appearing long second toe with pain slight in nature, experienced 18 percent dorsiflexion, 6 percent normalcy and 77 percent plantarflexion. Group IIIB, an outwardly appearing long second toe with pain of moderate severity, experienced 7 percent dorsiflexion, 21 percent normalcy and 71 percent plantarflexion. Group IIIC, an outwardly appearing long second toe with pain severe in nature, experienced 17 percent dorsiflexion, 8 percent normalcy and 75 percent plantarflexion. The combined Groups III A, B and C, an outwardly appearing long second toe with slight, moderate and severe pain, evidenced 14 percent dorsiflexion, 12 percent normalcy and 74 percent plantarflexion. The combined Groups II, III A, B and C, an outwardly appearing long second toe and varying degrees of pain, evidenced 15 percent dorsiflexion, 15 percent normalcy and 70 percent plantarflexion. Although plantarflexion of the first ray was the highest of the ranges of motion for all groups examined, the step-wise regression analysis (Table 3) did not find it to be a significant factor in the prediction of pain as related to the Morton's Foot syndrome.

Table 12

Summary of First Ray Ranges of Motion
Among All Groups

	Group I (N=22)		Group II (N=23)		Group IIIA (N=17)		Group IIIB (N=14)		Group IIIC (N=12)		Group IIIA,B,C (N=73)	
	N	%	N	%	N	%	N	%	N	%	N	%
Dorsi-flexion	1	5	4	17	3	18	1	7	2	17	6	14
Normal	5	23	6	26	1	6	3	21	1	8	5	12
Plantar-flexion	16	73	13	57	13	77	10	71	9	75	32	74

Metatarsal Location of Greatest Dynamic Weight-Bearing With First Ray Consideration

The percent incidence of metatarsal location of the greatest concentration of dynamic weight-bearing with consideration given to first ray ranges of motion are summarized in Figures 28-34.

Evidence shows (Figure 28) that those subjects in Group I (N = 22) no outwardly appearing long second toe and no pain, who have a dorsi-flexed first ray (N = 1) assumed an equal amount of dynamic weight-bearing (100 percent) on metatarsals I, II and III, with no assumption of weight on metatarsals IV and V. Of those subjects having a normal first ray (N = 5), one (20 percent) assumed weight equally on

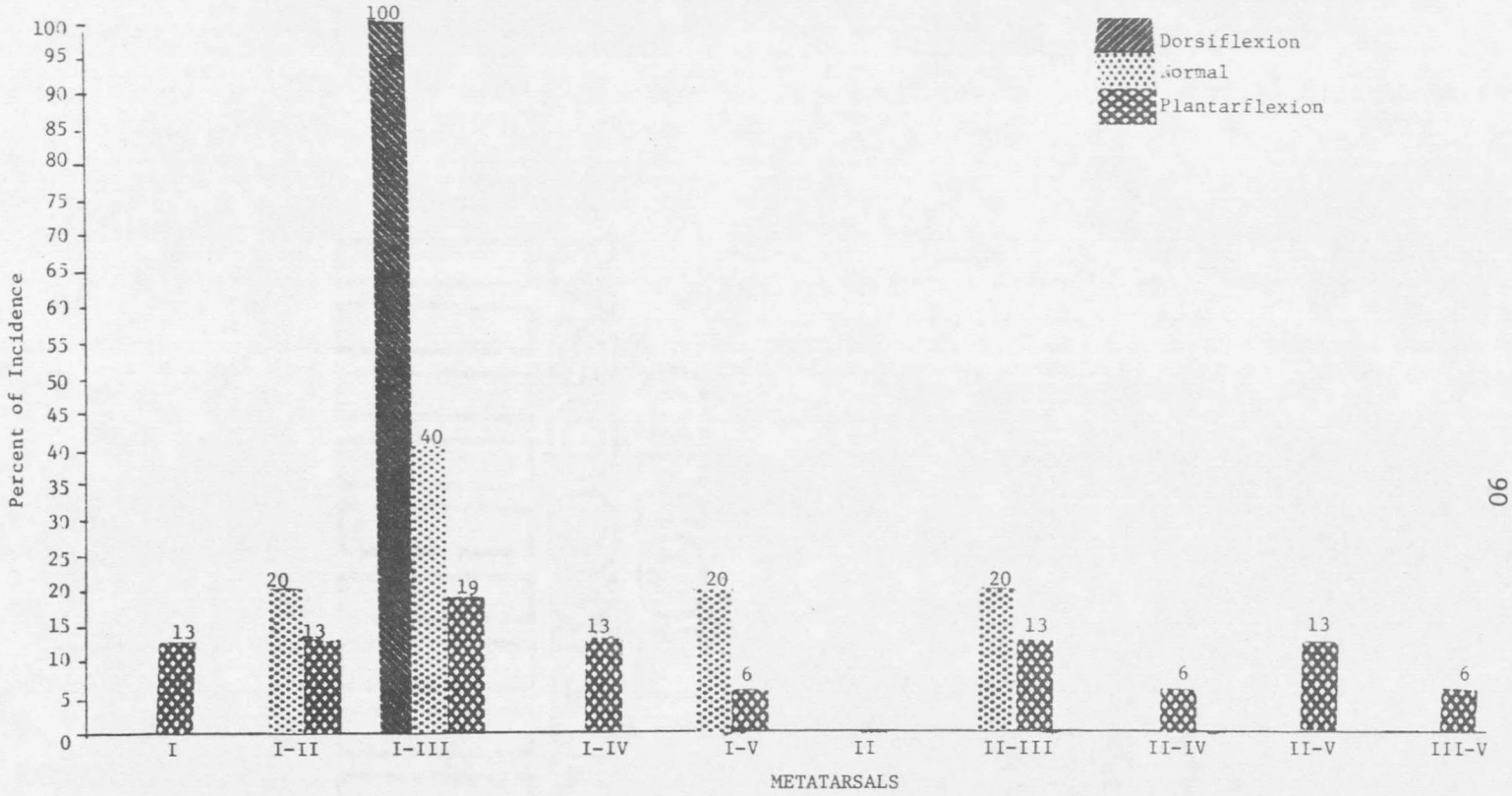


Figure 28. Group I (N = 22) Metatarsal Location of Greatest Dynamic Weight-Bearing With Consideration Given to First Ray Ranges of Motion

metatarsals I and II, two (40 percent) assumed weight equally on metatarsals I, II and III, one (20 percent) assumed weight equally on metatarsals I-V, and one (20 percent) assumed weight equally on metatarsals II and III. Sixteen (73 percent) subjects experienced plantarflexion of the first ray: two (13 percent) assumed weight solely on metatarsal I; two (13 percent) assumed weight equally on metatarsals I and II; three (19 percent) assumed weight equally on metatarsals I-III; two (13 percent) assumed weight equally on metatarsals I-IV; and one (6 percent) assumed weight equally on metatarsals I-V. Further, two (13 percent) subjects having a plantarflexed first ray assumed weight equally on metatarsals II and III; one (6 percent) assumed weight equally on metatarsals II-IV; two (13 percent) assumed weight equally on metatarsals II-V; and one (6 percent) assumed weight equally on metatarsals III-V.

Of those subjects in Group II (N = 23), an outwardly appearing long second toe and no pain (Figure 29), who had a dorsiflexed first ray (N = 4): one (25 percent) assumed weight equally on metatarsals I and II; one (25 percent) assumed weight equally on metatarsals I, II and III; one (25 percent) assumed weight equally on metatarsals II-V; and one (25 percent) assumed weight equally on metatarsals III-V. Of those subjects having a normal first ray (N = 6): one (17 percent) assumed weight equally on metatarsals I and II; two (33 percent) assumed weight equally on metatarsals I, II and III;

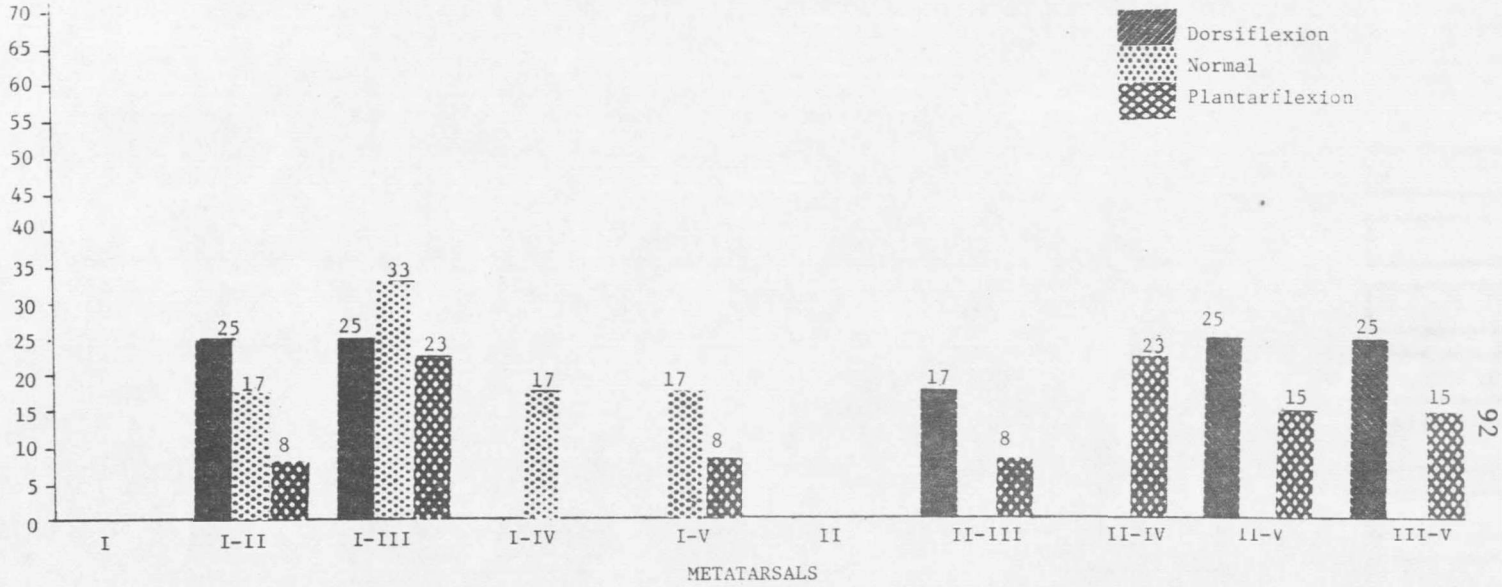


Figure 29. Group II (N = 23) Metatarsal Location of Greatest Dynamic Weight-Bearing With Consideration Given to First Ray Ranges of Motion

one (17 percent) assumed weight equally on metatarsals I-IV; one (17 percent) assumed weight equally throughout metatarsals I-V; and one (17 percent) assumed weight equally on metatarsals II and III. Of those subjects having a plantarflexed first ray (N = 13): one (8 percent) assumed weight equally on metatarsals I and II; three (23 percent) assumed weight equally on metatarsals I-III; one (8 percent) assumed weight equally on metatarsals I-V; one (8 percent) assumed weight equally on metatarsals II and III; three (23 percent) assumed weight equally on metatarsals II-IV; two (15 percent) assumed weight equally on metatarsals II-V; and two (15 percent) assumed weight equally on metatarsals III-V.

Evidence shows (Figure 30) that of those subjects in Group IIIA (N = 17), an outwardly appearing long second toe with pain slight in nature, who had a dorsiflexed first ray (N = 3), two (67 percent) assumed weight equally on metatarsals I and II, and one (33 percent) assumed weight equally on metatarsals I, II and III. Normal first ray ranges of motion were not observed. Of those subjects having a plantarflexed first ray (N = 13): three (23 percent) assumed weight equally on metatarsals I-III; three (23 percent) assumed weight equally on metatarsals I-IV; three (23 percent) assumed weight equally on metatarsals II and III; one (8 percent) assumed weight equally on metatarsals II-IV; two (15 percent) assumed weight equally on metatarsals II-V; and one (8 percent) assumed weight equally on metatarsals

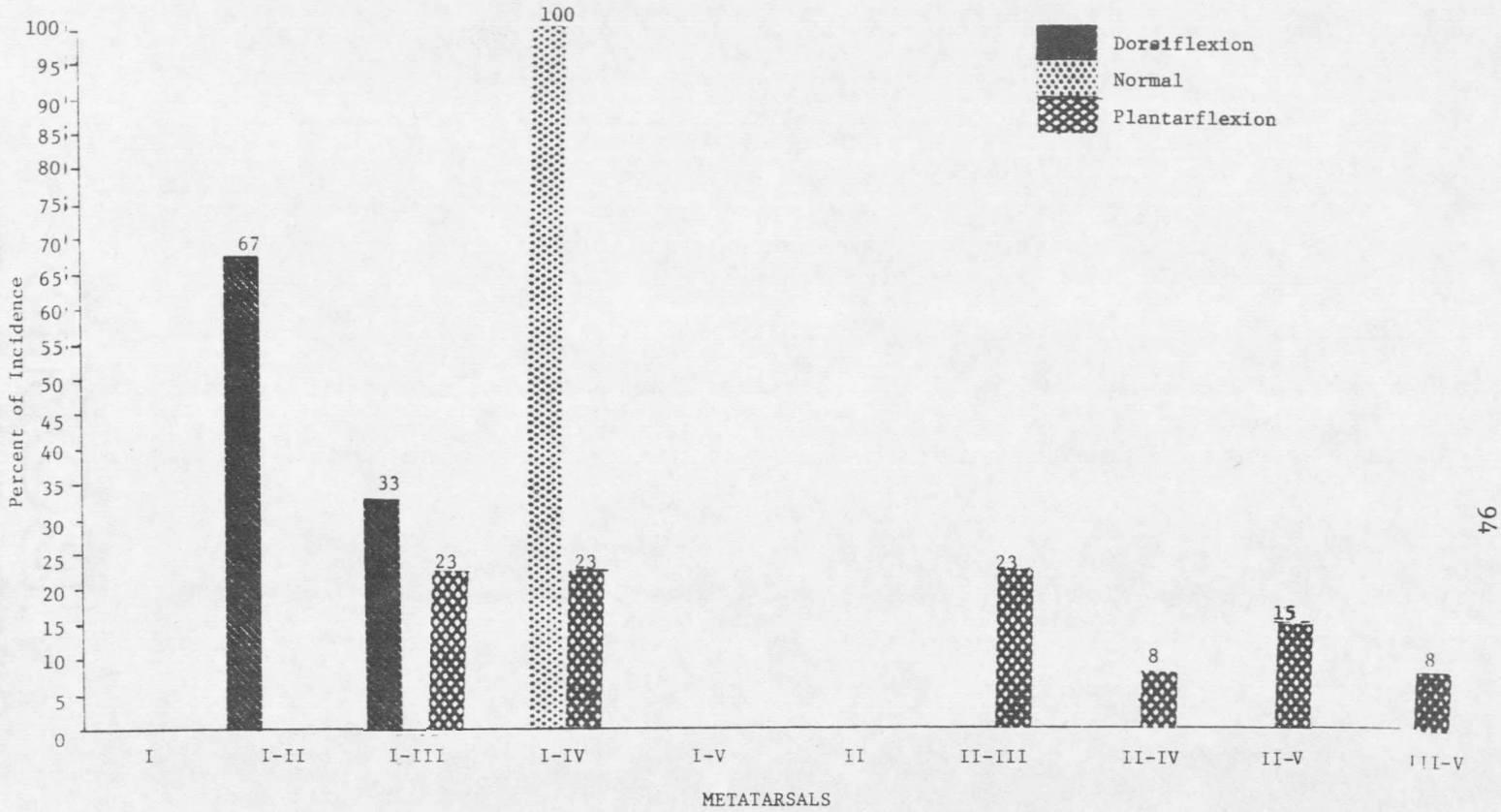


Figure 30. Group IIIA (N = 17) Metatarsal Location of Greatest Dynamic Weight-Bearing With Consideration Given to First Ray Ranges of Motion

III-V.

Of those subjects in Group IIIB (N = 14), an outwardly appearing long second toe with moderate pain (Figure 31), who had a dorsiflexed first ray (N = 1), one (100 percent) assumed weight equally on metatarsals II and III. Of those subjects having a normal first ray (N = 3); one (33 percent) assumed weight solely on metatarsal II, and two (67 percent) assumed weight equally on metatarsals II and III. Of those subjects having a plantarflexed first ray (N = 10): two (20 percent) assumed weight equally on metatarsals I and II; one (10 percent) assumed weight equally on metatarsals I-IV; one (10 percent) assumed weight solely on metatarsal II; two (20 percent) assumed weight equally on metatarsals II and III; one (10 percent) assumed weight equally on metatarsals II-IV; two (20 percent) assumed weight equally on metatarsals II-V; and one (10 percent) assumed weight equally on metatarsals III-V.

In Figure 32 it can be seen that of those subjects in Group IIIC (N = 12), an outwardly appearing long second toe and severe pain, who had a dorsiflexed first ray (N = 2), one (50 percent) assumed weight equally on metatarsals I-III and one (50 percent) assumed weight equally on metatarsals II and III. Only one (100 percent) subject had a normal first ray and assumed weight equally on metatarsals II and III. Of those subjects having a plantarflexed first ray (N = 9): two (22 percent) assumed weight equally on metatarsals I-III; one (11

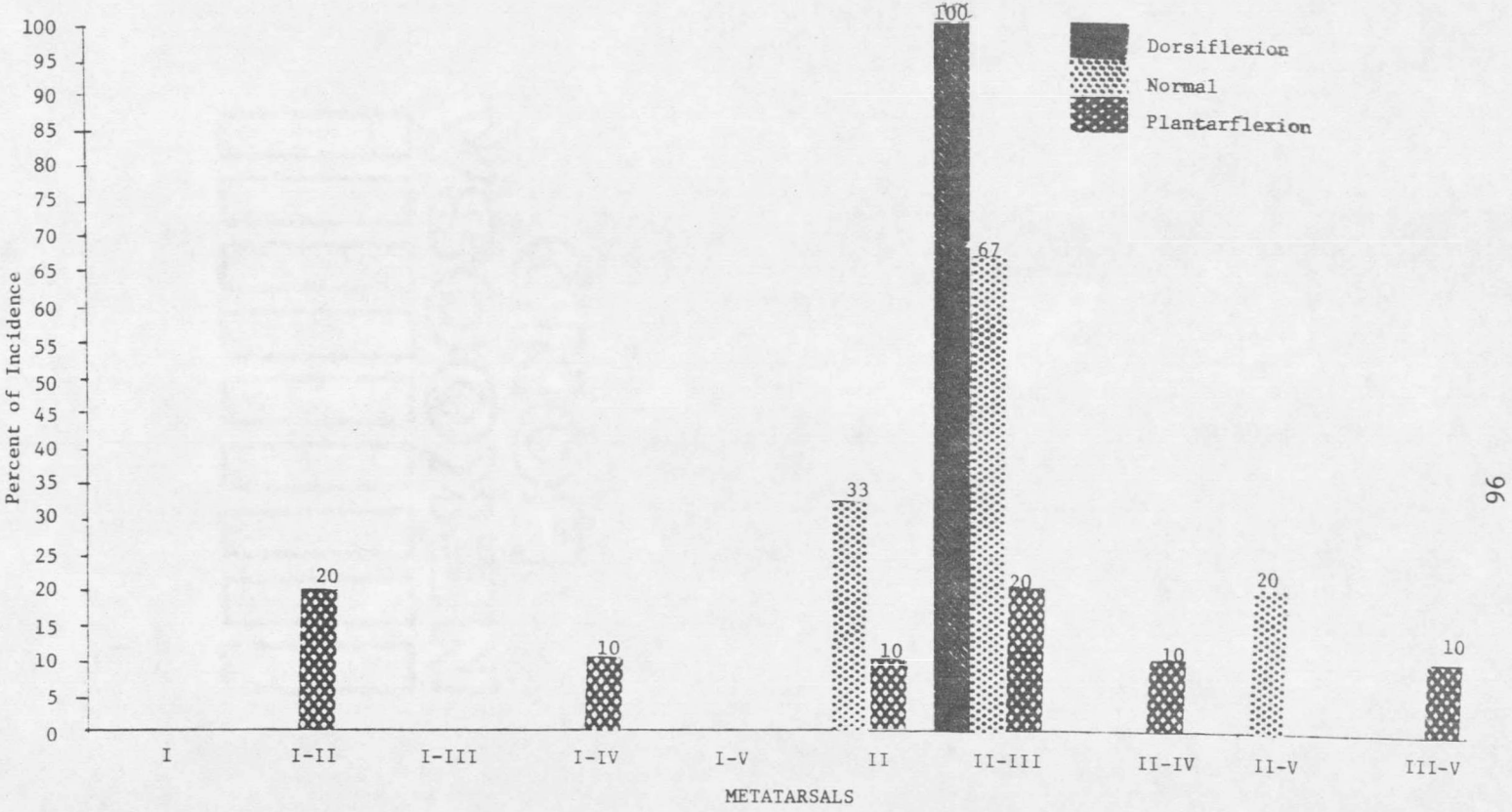


Figure 31. Group IIIB (N = 14) Metatarsal Location of Greatest Dynamic Weight-Bearing With Consideration Given to First Ray Ranges of Motion

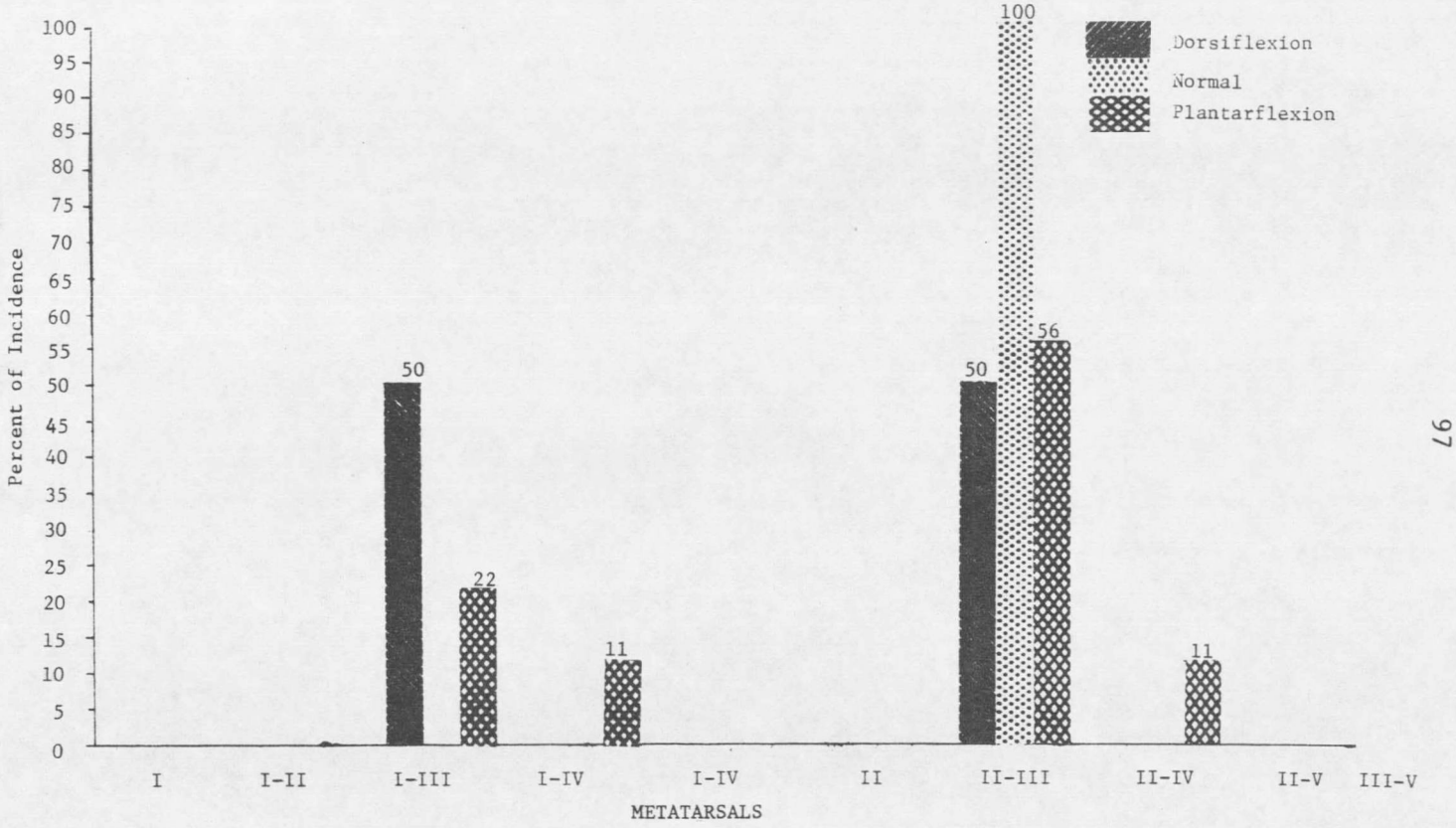


Figure 32. Group IIIC (N = 12) Metatarsal Location of Greatest Dynamic Weight-Bearing With Consideration Given to First Ray Ranges of Motion

percent) assumed weight equally on metatarsals I-IV; five (56 percent) assumed weight equally on metatarsals II and III; and one (11 percent) assumed weight equally on metatarsals II-IV.

Evidence shows (Figure 33) that of those subjects in the combined Groups III A, B and C (N = 43), an outwardly appearing long second toe with varying degrees of pain, who had a dorsiflexed first ray (N = 6): two (33 percent) assumed weight equally on metatarsals I and II; two (33 percent) assumed weight equally on metatarsals I-III; and two (33 percent) assumed weight equally on metatarsals II and III. Of those subjects having a normal first ray (N = 5): one (20 percent) assumed weight equally on metatarsals I-IV; one (20 percent) assumed weight solely on metatarsal II; and three (60 percent) assumed weight equally on metatarsals II and III. Of those subjects having a plantarflexed first ray (N = 32): two (6 percent) assumed weight equally on metatarsals I and II; five (16 percent) assumed weight equally on metatarsals I-III; five (16 percent) assumed weight equally on metatarsals I-IV; one (3 percent) assumed weight solely on metatarsal II; ten (31 percent) assumed weight equally on metatarsals II and III; three (9 percent) assumed weight equally on metatarsals II-IV; four (13 percent) assumed weight equally on metatarsals II-V; and two (6 percent) assumed weight equally on metatarsals III-V.

Figure 34 shows that of those subjects in the combined Groups II, III A, B and C (N = 66), an outwardly appearing long second toe and

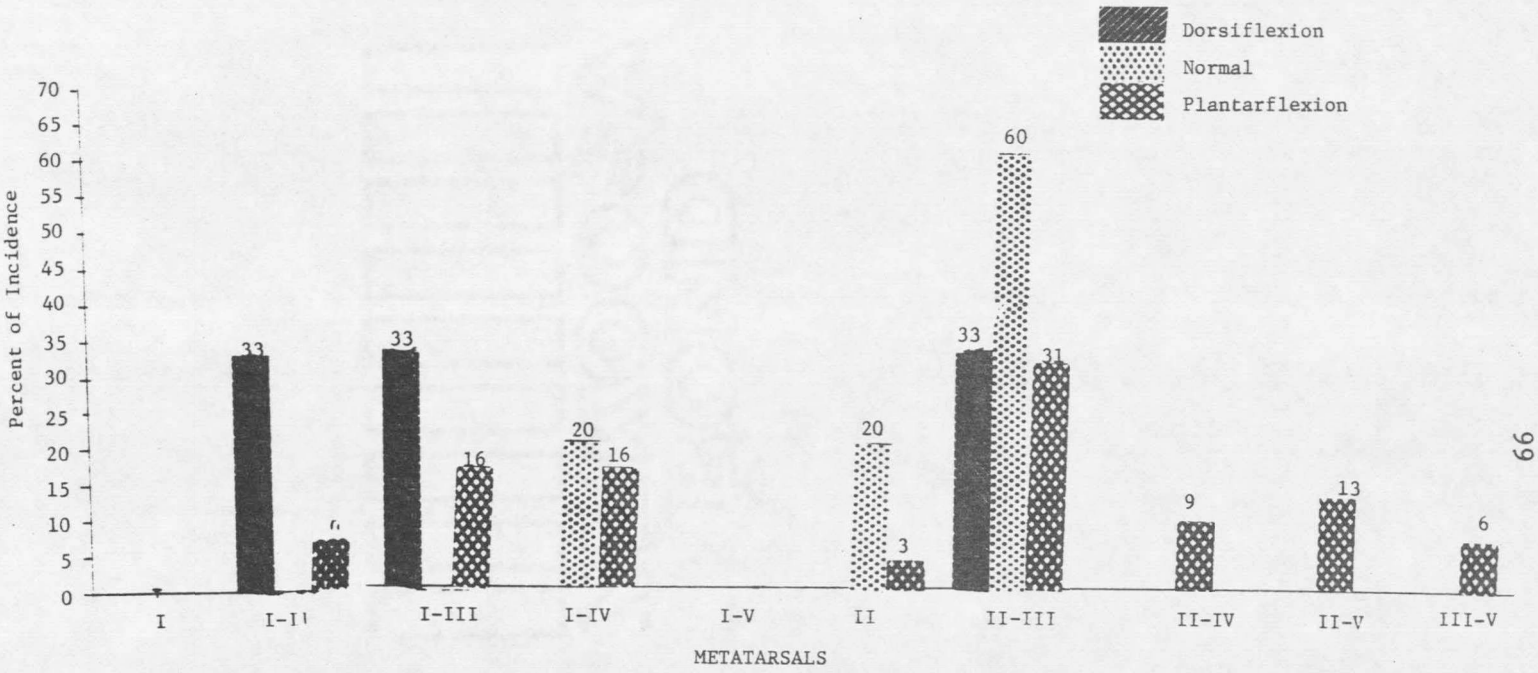


Figure 33. Combined Groups III A, B and C (N = 43) Metatarsal Location of Greatest Dynamic Weight-Bearing with Consideration Given to First Ray Ranges of Motion

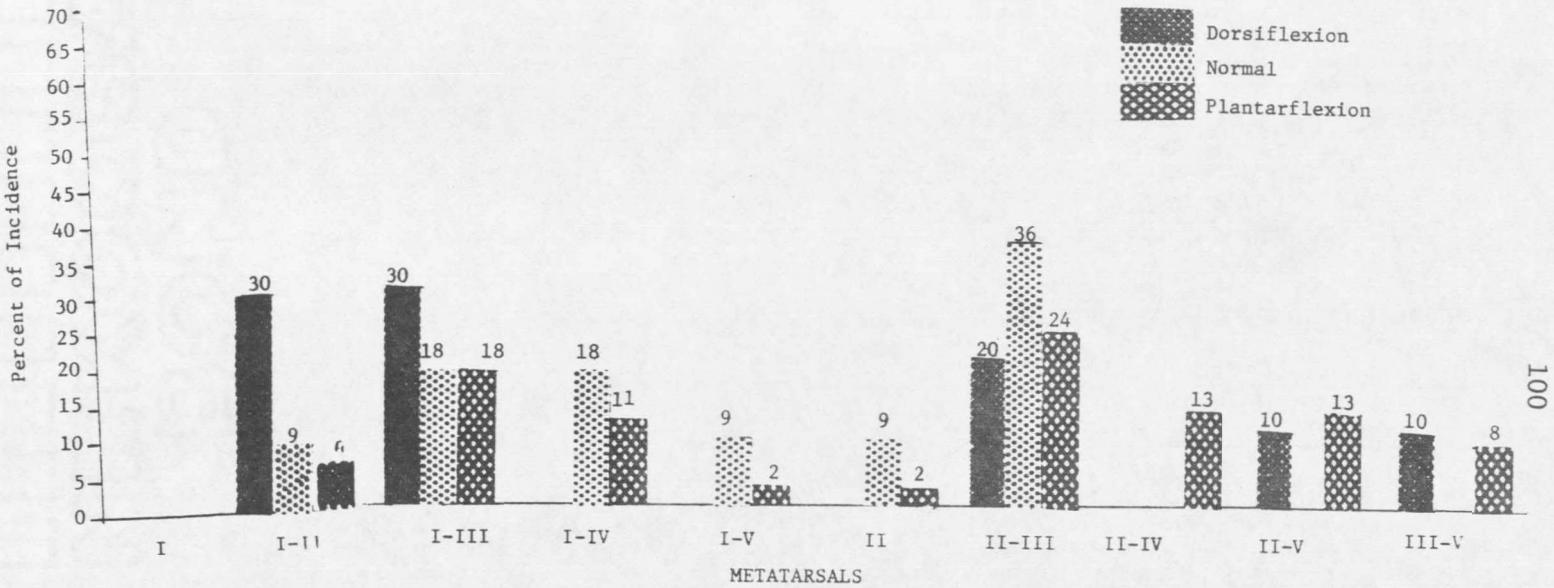


Figure 34. Combined Groups II, III A, B and C (N = 66) Metatarsal Location of Greatest Dynamic Weight-Bearing with Consideration Given to First Ray Ranges of Motion

varying degrees of pain, who had a dorsiflexed first ray (N = 10): three (30 percent) assumed weight equally on metatarsals I and II; three (30 percent) assumed weight equally on metatarsals I-III; two (20 percent) assumed weight equally on metatarsals II and III; one (10 percent) assumed weight equally on metatarsals II-V; and one (10 percent) assumed weight equally on metatarsals III-V. Of those subjects having a normal first ray (N = 11): one (9 percent) assumed weight equally on metatarsals I and II; two (18 percent) assumed weight equally on metatarsals I-III; two (18 percent) assumed weight equally on metatarsals I-IV; one (9 percent) assumed weight equally on metatarsals I-V; one (9 percent) assumed weight solely on metatarsal II; and four (36 percent) assumed weight equally on metatarsals II and III. Of those subjects having a plantarflexed first ray (N = 45): three (6 percent) assumed weight equally on metatarsals I and II; eight (18 percent) assumed weight equally on metatarsals I-III; five (11 percent) assumed weight equally on metatarsals I-IV; one (2 percent) assumed weight equally on metatarsals I-V; one (2 percent) assumed weight solely on metatarsal II; eleven (24 percent) assumed weight equally on metatarsals II and III; six (13 percent) assumed weight equally on metatarsal II-V; and four (8 percent) assumed weight equally on metatarsals III-V.

Metatarsal Location of Callus Formations with First Ray Consideration

In Figure 35 it can be seen that of those subjects in Group I (N = 22), no outwardly appearing long second toe and no pain, who had a dorsiflexed first ray (N = 1), one (100 percent) evidenced callus formations on metatarsals I-III. Of those subjects having a normal first ray (N = 5), only one (20 percent) evidenced callus formations, located on metatarsals II and III. Of those subjects having a plantarflexed first ray (N = 16): three (19 percent) evidenced calluses on metatarsal I, alone; one (6 percent) evidenced callus formations on metatarsals I, II and III; and one (6 percent) evidenced callus formations on metatarsals I-IV.

Evidence shows (Figure 36) that of those subjects in Group II (N = 23), an outwardly appearing long second toe and no pain, who had a dorsiflexed first ray (N = 4), two (50 percent) evidenced callus formations solely on metatarsal I, and one (25 percent) evidenced callus formations solely on metatarsal II. Of those subjects having a normal first ray (N = 6), one (17 percent) evidenced callus formations on metatarsals I and II. Of those subjects having a plantarflexed first ray (N = 13): four (31 percent) evidenced callus formations on metatarsal I, alone; one (8 percent) evidenced callus formations on metatarsals I and II; one (8 percent) evidenced callus formations on metatarsals I-III; one (8 percent) evidenced callus formations on metatarsals I-IV; and two (15 percent) evidenced callus

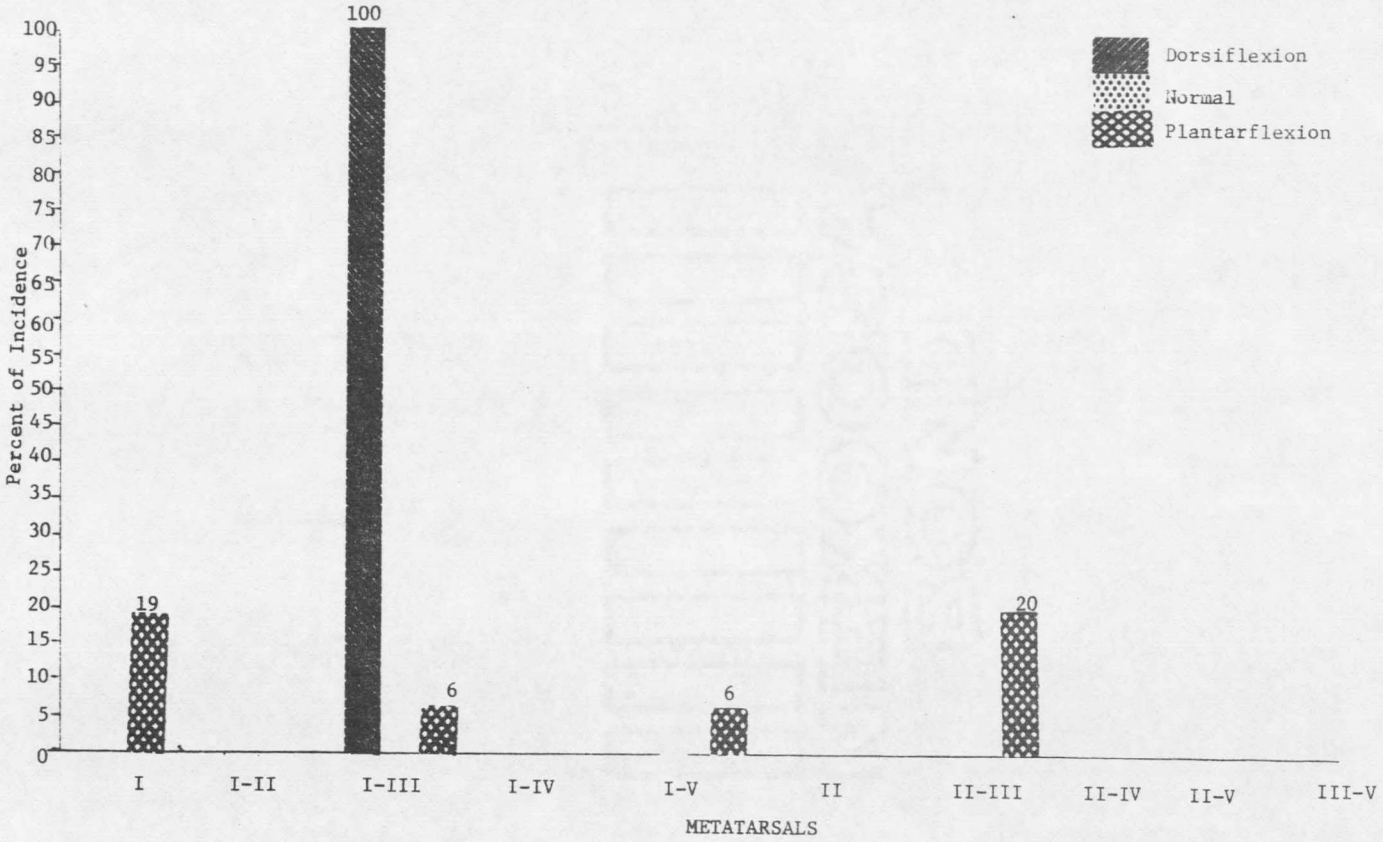


Figure 35. Group I (N = 22) Metatarsal Location of Calluses With Consideration Given to First Ray Ranges of Motion

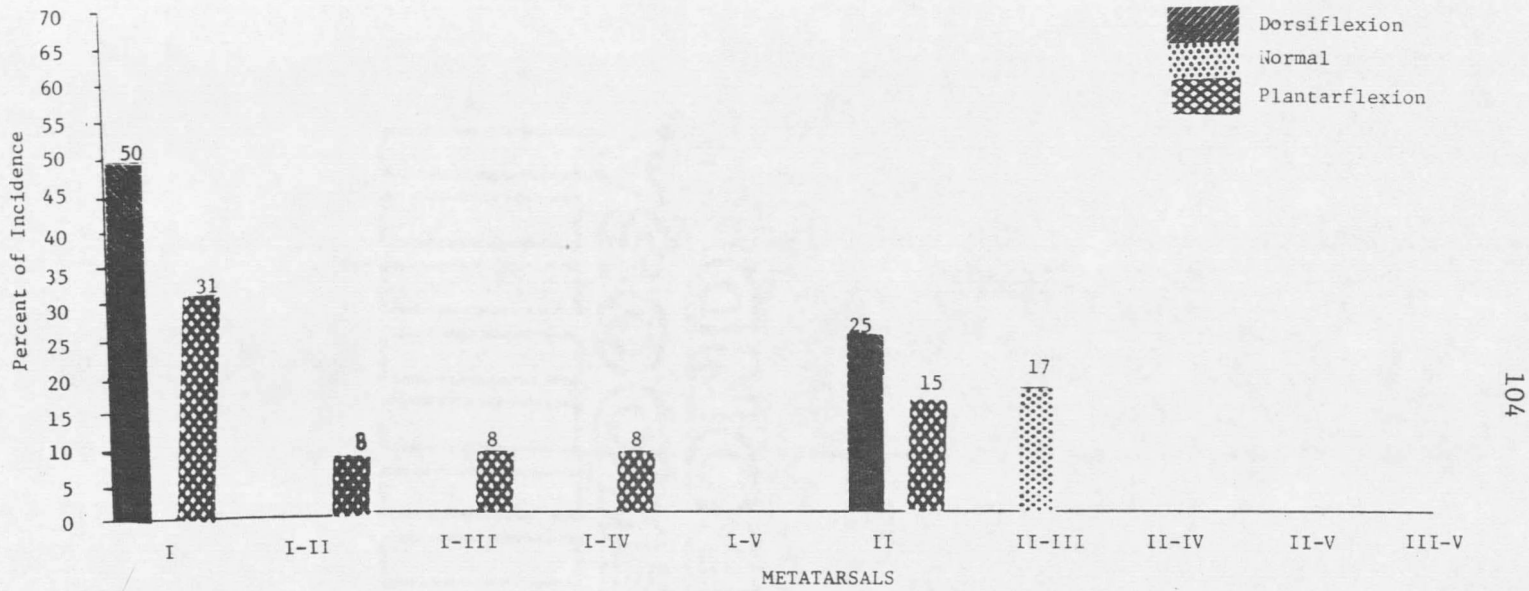


Figure 36. Group II (N = 23) Metatarsal Location of Calluses With Consideration Given to First Ray Ranges of Motion

formations on metatarsal II, alone.

Of those subjects in Group IIIA (N = 17), an outwardly appearing long second toe with slight pain (Figure 37) who had a dorsiflexed first ray (N = 3), only one (33 percent) evidenced callus formations on metatarsals I-IV. One subject had a normal first ray with no evidence of callus formations. Of those subjects having a plantarflexed first ray (N = 13): five (39 percent) evidenced callus formations solely on metatarsal I; one (8 percent) evidenced callus formations on metatarsals I-IV; and one (8 percent) evidenced callus formations on metatarsals II and III.

Figure 38 shows that of those subjects in Group IIIB (N = 14), an outwardly appearing long second toe with moderate pain, who had a dorsiflexed first ray (N = 1), no evidence of callus formations were observed. Of those subjects having a normal first ray (N = 3), one (33 percent) evidenced callus formations on metatarsals I and II. Of those subjects having a plantarflexed first ray (N = 10), two (20 percent) evidenced callus formations on metatarsal I, alone, and one (10 percent) evidenced callus formations on metatarsals I and II.

Of those subjects in Group IIIC (N = 12), an outwardly appearing long second toe with severe pain (Figure 39), who had a dorsiflexed first ray (N = 2), one (50 percent) evidenced callus formations on metatarsals III-V. One subject had a normal first ray with no evidence of callus formations. Of those subjects having a plantarflexed

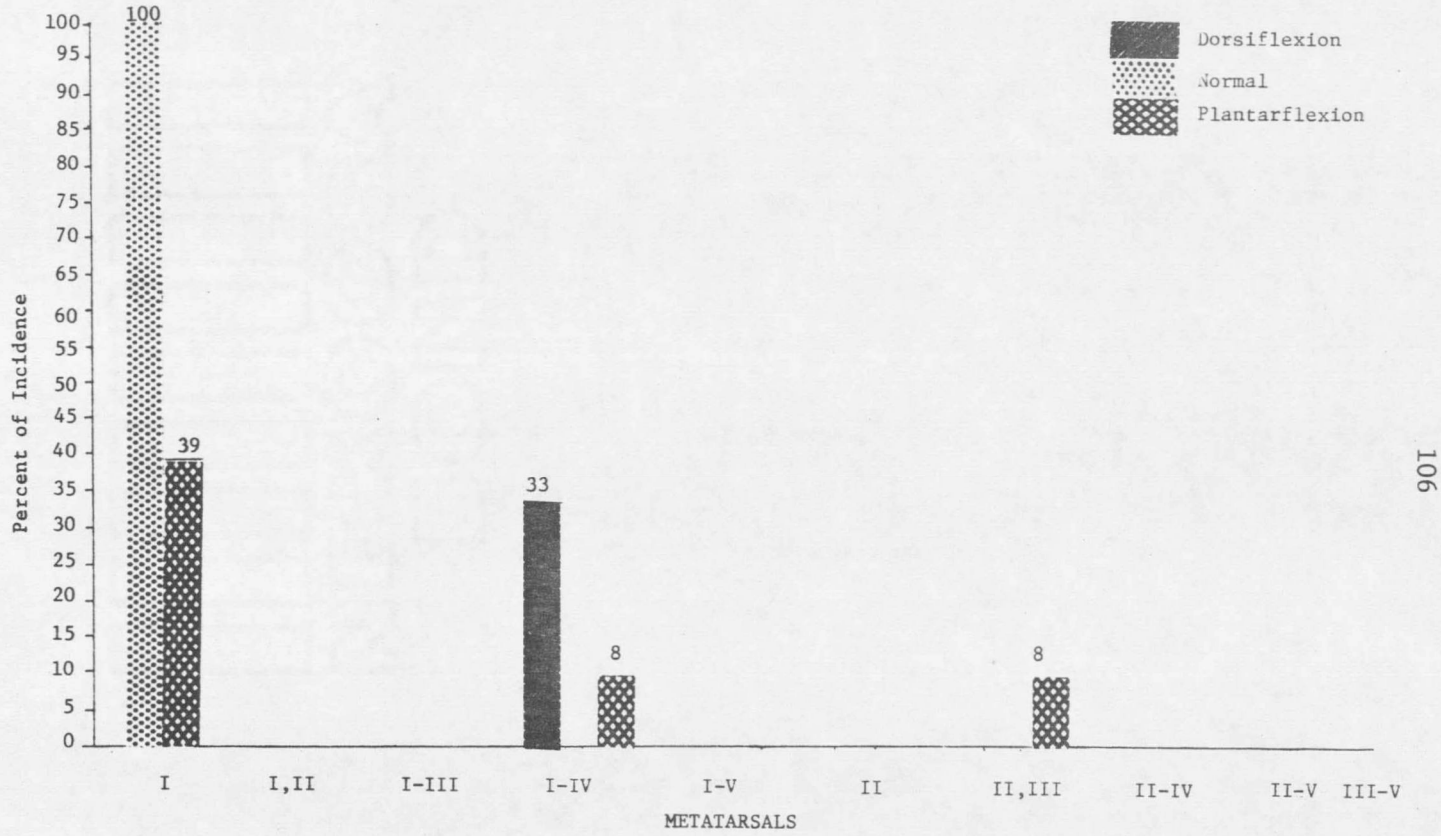


Figure 37. Group IIIA (N = 17) Metatarsal Location of Calluses With Consideration Given to First Ray Ranges of Motion

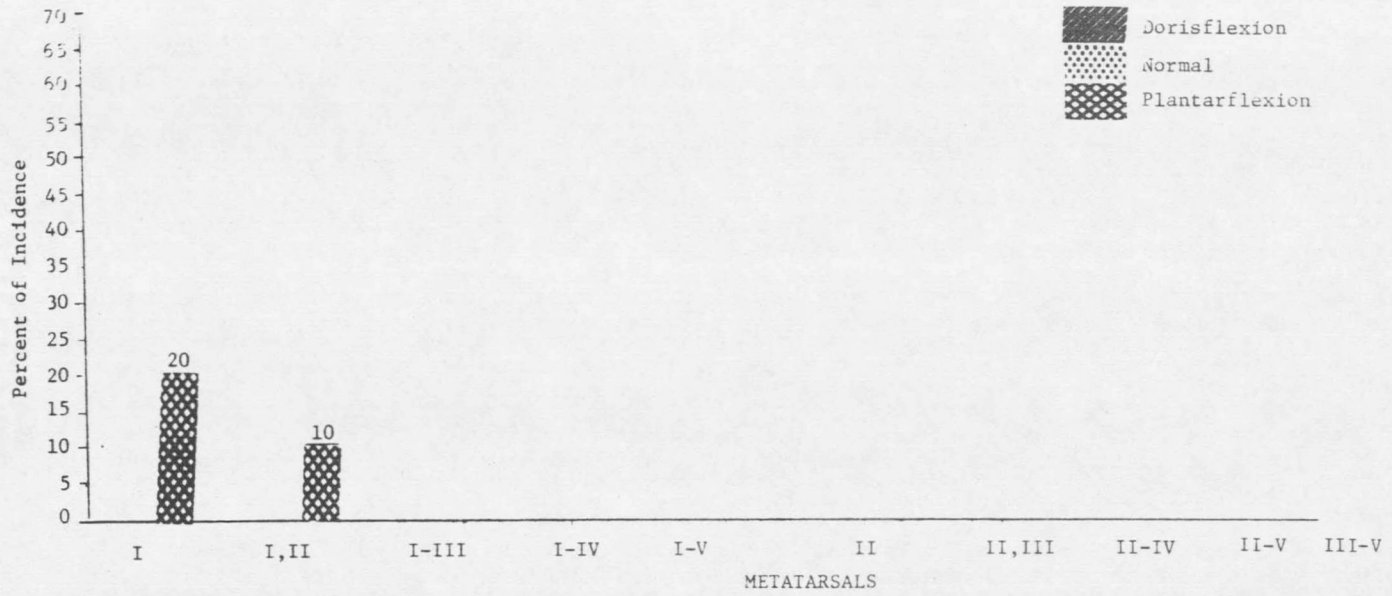


Figure 38. Group IIIB (N = 14) Metatarsal Location of Calluses With Consideration Given to First Ray Ranges of Motion

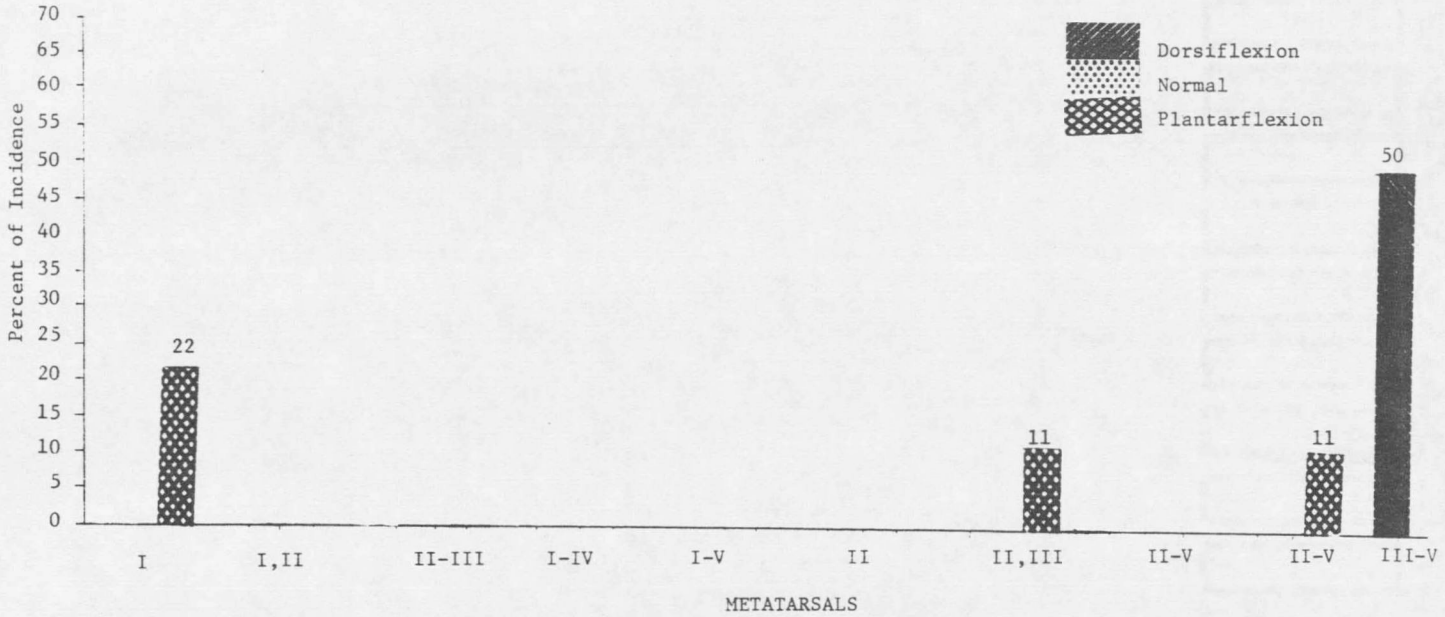


Figure 39. Group IIIC (N = 12) Metatarsal Location of Calluses With Consideration Given to First Ray Ranges of Motion

first ray (N = 9): two (22 percent) evidenced callus formations on metatarsal I, alone; two (22 percent) evidenced callus formations on metatarsals II and III; and one (11 percent) evidenced callus formations on metatarsals II-V.

In Figure 40 it can be seen that of those subjects in the combined Groups III A, B and C (N = 43), an outwardly appearing long second toe with pain slight, moderate and severe in nature, who had a dorsiflexed first ray (N = 6), one (17 percent) evidenced callus formations on metatarsals I-IV, and one (17 percent) evidenced callus formations on metatarsals III-V. Of those subjects having a normal first ray (N = 5), one (20 percent) evidenced callus formations on metatarsal I, alone, and one (20 percent) evidenced callus formations on metatarsals I and II. Of those subjects having a plantarflexed first ray (N = 32): nine (28 percent) evidenced callus formations on metatarsal I, alone; one (3 percent) evidenced callus formations on metatarsals I and II; one (3 percent) evidenced callus formations on metatarsals I-IV; three (9 percent) evidenced callus formations on metatarsals II and III; and one (3 percent) evidenced callus formations on metatarsals II-V.

Figure 41 shows that of those subjects in the combined Groups II, III A, B and C (N = 66), an outwardly appearing long second toe with varying degrees of pain, who had a dorsiflexed first ray (N = 10): two (20 percent) evidenced callus formations on metatarsal I,

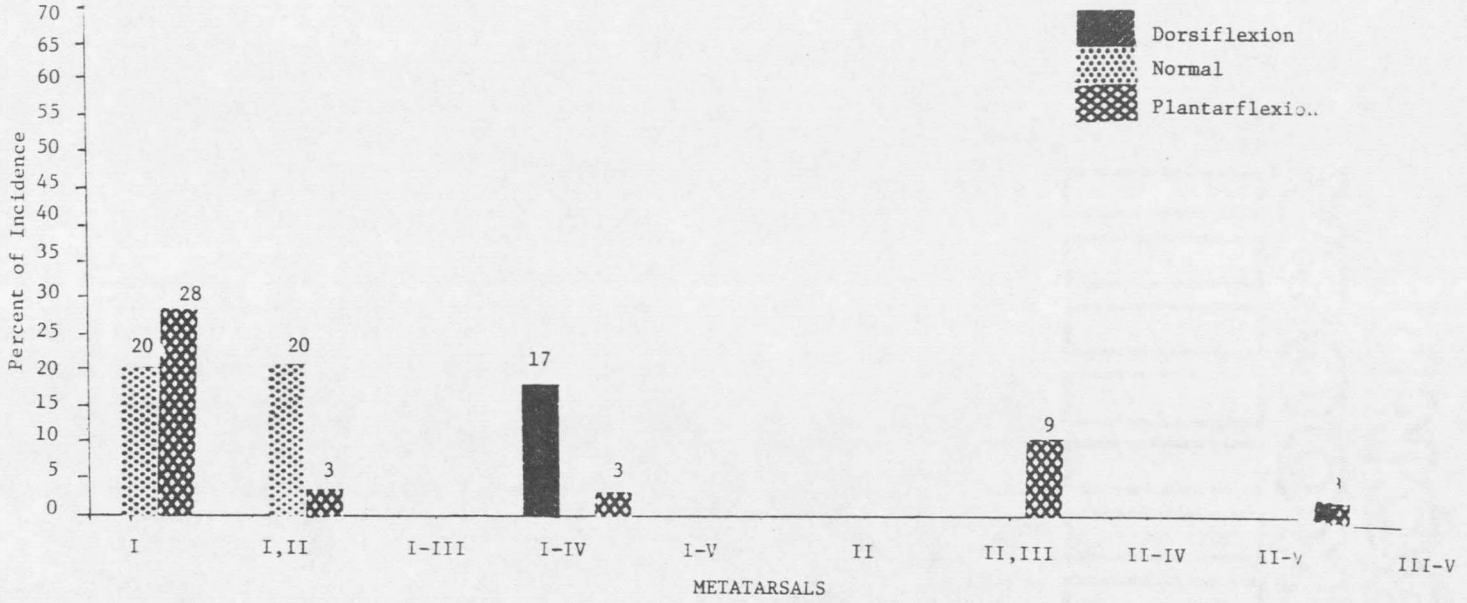


Figure 40. Combined Groups III A, B and C (N = 43) Metatarsal Location of Calluses with Consideration Given to First Ray Ranges of Motion

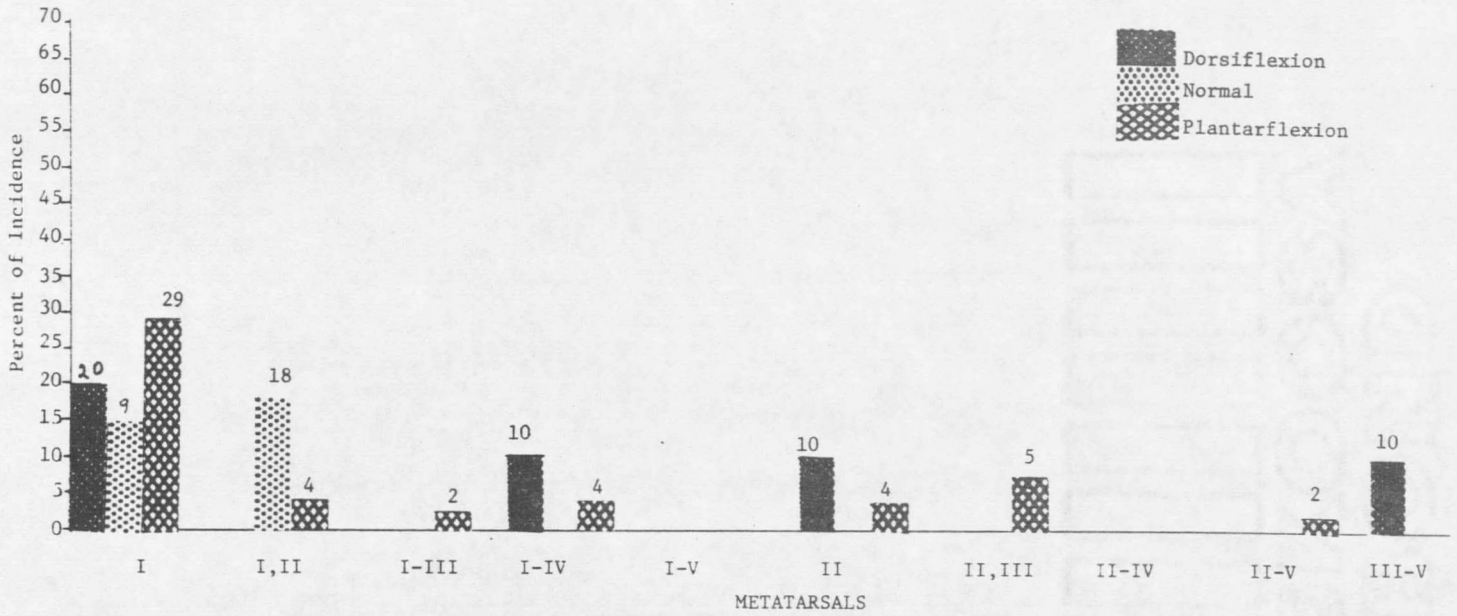


Figure 41. Combined Groups II, III A, B and C (N = 66) Metatarsal Location of Calluses with Consideration Given to First Ray Ranges of Motion

alone; one (10 percent) evidenced callus formations on metatarsals I-IV; one (10 percent) evidenced callus formations on metatarsal II, alone; and one (10 percent) evidenced callus formations on metatarsals III-V. Of those subjects having a normal first ray (N = 11), one (9 percent) evidenced callus formations on metatarsal I, alone, and two (18 percent) evidenced callus formations on metatarsals I and II. Of those subjects having a plantarflexed first ray (N = 45): thirteen (29 percent) evidenced callus formations on metatarsal I, alone; two (4 percent) evidenced callus formations on metatarsals I and II; one (2 percent) evidenced callus formations on metatarsals I-III; two (4 percent) evidenced callus formations on metatarsals I-IV; two (4 percent) evidenced callus formations on metatarsal II, alone; three (7 percent) evidenced callus formations on metatarsals II and III; and one (2 percent) evidenced callus formations on metatarsals II-V.

Chapter 5

DISCUSSION

Morton's Foot syndrome is a structural abnormality considered to be one of the causes of overuse complaints experienced by runners. Characterized by a short metatarsal I and hypermobile first ray, a Morton's foot is believed to cause an imbalance of dynamic body weight distribution throughout the metatarsus during weight-bearing. Because the foot is a vital part of the body's "link system", the lack of proper dynamic weight distribution within the foot, when subjected to constant impact with the supporting surface during running, is believed to be the etiological basis of chain-like biomechanical inefficiency of the lower extremity. Lilletvedt (11) and Courtney (2), in similar studies, found sufficient evidence to support theories that prediction of the occurrence of the shin splint syndrome and achilles tendonitis may be made on biomechanical malignment factors found in the lower extremity.

Analysis of Results

An analysis of variance showed no significant differences among the biomechanical, radiographic and dynamic weight-bearing characteristics between the following: Group I (N = 22) - runners having no outwardly appearing long second toe, no pain, and Group II

(N = 23) - runners having an outwardly appearing long second toe, no pain; Group I and the combined Groups III A, B and C (N = 43) - runners having an outwardly appearing long second toe with pain slight, moderate and severe in nature; and Group II and the combined Groups III A, B and C. Such a lack of significant evidence may be due to the method used in the selection and classification of the subjects studied. The criterion employed was the visible presence of a long second toe. A wide range of length differences of metatarsal I to metatarsal II existed eithin the groups studied, the greatest range of length difference occurring in Group I, runners having no outwardly appearing long second toe, no pain. When measured by Morton's method (14), the length difference of metatarsal I to metatarsal II for subjects in Group I ranged from an upper limit of plus 2mm to a lower limit of minus 7mm. By contrast, when Schuster's method (21) was applied, the length difference of metatarsal I to metatarsal II for the same subjects ranged from an upper limit of plus 3mm to a lower limit of minus 5mm. If one accepts Morton's theory that the normal foot is one in which the length of metatarsal I is equal to metatarsal II, and if one also accepts Schuster's theory that the pathological foot is one in which metatarsal I is greater than minus 2mm shorter than metatarsal II, then the findings appear to suggest that the outwardly appearing long second toe is not a sound basis for selection and classification.

Thus a more homogeneous grouping of subjects based on a criterion of metatarsal length difference as seen in the radiograph, in conjunction with accepted theories of normalcy and pathology, may be a better means of determining significant differences in the biomechanical, radiographic and dynamic weight-bearing characteristics among the groups studied.

A step-wise regression analysis was performed according to the increase in the severity of pain on Group I (N = 22), runners having no outwardly appearing long second toe, no pain; Group II (N = 23), runners having an outwardly appearing long second toe, no pain; Group IIIA (N = 17), runners having an outwardly appearing long second toe, slight pain; Group IIIB (N = 14), runners having an outwardly appearing long second toe, moderate pain; and Group IIIC (N = 12), runners having an outwardly appearing long second toe, severe pain. The results showed the following factors to be significant in the prediction of pain related to the Morton's Foot syndrome: percentage measurement (Sheer's method) of the length difference of metatarsal I to metatarsal II; the ranges of internal rotation of the femur with the hip straight; metatarsal location of the greatest concentration of dynamic body weight distribution; eversion (pronation) of the subtalor joint; and the ranges of external rotation of the femur with the hip straight.

The fact that the length difference of metatarsal I to

metatarsal II as determined by Sheer's method (26) appeared on step one in the regression analysis ($p < .01$ level of significance) seems to support the theories of Morton and Schuster that a short metatarsal I "must be one of the etiological factors in mechanical foot difficulties" (21:42). It must be noted that Morton's method (14) and Schuster's method (21) of measuring the length difference of metatarsal I to metatarsal II correlated beyond the $p < .05$ level of significance with Sheer's method (26), thus suggesting that any one of the three methods would be suitable for obtaining the same information.

Confusion exists as to the actual differences in length of metatarsal I to metatarsal II which may cause a structural imbalance. According to Morton (14), metatarsal I must be a minimum of 1mm shorter than metatarsal II in order for an imbalance to occur. Schuster (21) determined that problems occurred when metatarsal I was shorter than metatarsal II by a minimum of 2mm. According to the findings in this study, runners having no outwardly appearing long second toe and no pain (Group I), showed a mean of minus 2mm as determined by Morton's and Schuster's methods, whereas those runners having an outwardly appearing long second toe with varying degrees of pain (Groups II, III A, B and C) showed a mean of minus 5mm by Morton's method and a mean of minus 3mm by Schuster's method.

Confusion probably results from either one or both of the

following rationales: that the metric measures of mechanical difficulties as suggested by Morton and Schuster might be marginal measures, as they may vary slightly in either direction; and/or that the criterion of the outwardly appearing long second toe, as it was used as the basis for subject selection and classification in this study, appears to be invalid. Based on the findings of this study, Morton's (-1mm) and Schuster's (-2mm) suggested minimum limits of etiological length difference of metatarsal I to metatarsal II fall within the mean length difference of Group I which represented the normal group. The mean length difference (-3mm) for the experimental groups (Groups II, III A, B and C) acquired by Schuster's method is marginally related to the mean length difference (-2mm) of the normal group (Group I). The findings appear to suggest that Schuster's minimum limit (-2mm) of length difference is marginal. Thus the findings of this study, as acquired by Schuster's method, provide insufficient evidence to support his theory that problems occur when metatarsal I is shorter than metatarsal II by a minimum of 2mm. In contrast, the mean length difference (-5mm) for the experimental groups (Groups II, III A, B and C), acquired by Morton's method, does not appear to be marginally related to the mean length difference (-2mm) of the normal group (Group I). Therefore, it appears to be a fair assumption that an excessively short metatarsal I could be considered to be an etiological factor in

structural and biomechanical imbalance. Another possible cause of confusion may lie within the criterion of the outwardly appearing long second toe as it was used as the basis for subject selection and classification in this study. It must be remembered that a wide range of length differences of metatarsal I to metatarsal II existed within the groups studied. Since the upper limits of the ranges of length difference for all groups reached as high as plus 2mm, the mean values for all groups could probably be considered to be lower than that which should be expected. Lower mean values would then provide insufficient evidence for determining the actual length difference of metatarsal I to metatarsal II which may cause structural imbalance.

In normal gait the lower leg medially rotates prior to heel strike to cause the subtalor joint to pronate and thus, allow the foot to become a "mobile adaptor" (2:15). Thus, when internal rotation of the femur with the hip straight significantly exceeds normal ranges, prolonged pronation of the subtalor joint may occur. When in combination with a significantly excessive range of eversion (pronation) of the subtalor joint, the foot remains hypermobile throughout the stance phase of gait. In normal stance, external rotation of the femur with the hip straight causes the subtalor joint to rotate laterally through its neutral position to one of supination (inversion). Supination allows the midtarsal joint

to pronate maximally and thus lock against the first ray segment. Such action permits the first and second rays to act as a rigid lever for propulsion. Although external rotation of the femur with the hip straight was found to be significant in the prediction of pain related to Morton's Foot syndrome, its fifth step location in the regression analysis appears to indicate an insufficient influence in allowing the subtalor joint to supinate sufficiently for normal function of the midtarsal joint and first ray segment during propulsion. Since the subtalor joint remains pronated prior to forefoot contact during midstance, the midtarsal joint and first ray segment remain unlocked during the propulsive phase of gait. The result is a disproportionate distribution of dynamic body weight throughout the metatarsus.

Step three of the regression analysis shows the metatarsal location of dynamic weight-bearing to be significant beyond the $p < .01$ level in the prediction of pain related to the Morton's Foot syndrome. Morton's theory that a short metatarsal I causes a transfer of dynamic weight-bearing from the shorter metatarsal I to the longer metatarsal II during propulsion is supported by: the finding that the length difference if metatarsal I to metatarsal II is significant in the prediction of pain related to Morton's Foot syndrome; the finding that the metatarsal location of dynamic weight-bearing is significant in the prediction of pain related to Morton's Foot syndrome; the location of the greatest concentration

of dynamic weight-bearing on metatarsals I, II and III by runners having no outwardly appearing long second toe and no pain; and the location of the greatest concentration of dynamic weight-bearing on metatarsals II and III by runners having an outwardly appearing long second toe with varying degrees of pain.

The fact that 64 percent of those runners having no outwardly appearing long second toe and no pain showed evidence of participation of dynamic weight-bearing by metatarsal I appears to indicate that a slight length difference (mean, -2mm) does not act as a causative agent in disproportionate weight distribution. In contrast, the fact that 57 percent of those runners having an outwardly appearing long second toe with varying degrees of pain showed evidence of no participation of dynamic weight-bearing by metatarsal I, appears to indicate that an excessively short metatarsal I (mean, -5mm) fails to assume its normal share of weight, thus causing the longer metatarsal II to compensate.

Evidence of weight sharing by the neighboring metatarsals and the presence of dorsiflexion and plantarflexion of the first ray by all groups, appear to support Morton's theory that first ray hypermobility causes weight-bearing to be transferred from metatarsal I to its neighboring metatarsals. Hypermobility of the first ray is either dorsiflexed or plantarflexed in nature. In either instance the first ray, following contact, moves in a dorsal direction. Since

no stopping action is provided, the forefoot continues to roll medially. The neighboring metatarsals are then forced to compensate by assuming body weight during the propulsive phase of gait. Compensation of dynamic weight by the neighboring metatarsals may also be due to forefoot hypermobility. Excessive ranges of internal rotation of the femur with the hip straight and eversion of the subtalor joint produce prolonged pronation of the subtalor joint. When maintained prior to forefoot contact, prolonged pronation causes the midtarsal joint and the first ray segment to remain unlocked. Therefore, the first ray is unable to act as a rigid lever for propulsion.

The presence of hyperkeratosis (calluses) to further support normal versus disproportionate distributions of dynamic body weight was inconclusive.

Chapter 6

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

A study was conducted among forty-six runners from Bozeman, Montana, who were known to run from 5 to 70 miles per week. Based on the results of a questionnaire and the visual presence of a long second toe, the lower extremities of the subjects were classified as follows: Group I (N = 22), runners having no outwardly appearing long second toe, no pain; Group II (N = 23), runners having an outwardly appearing long second toe, no pain; Group IIIA (N = 17), runners having an outwardly appearing long second toe, pain slight in nature; Group IIIB (N = 14), runners having an outwardly appearing long second toe, pain moderate in nature; and Group IIIC (N = 12), runners having an outwardly appearing long second toe, pain severe in nature.

The general purpose of this study was to describe, compare and analyze biomechanical, radiographic and weight-bearing characteristics of the lower extremity of runners having Morton's Foot syndrome.

Specifically, this study attempted:

1. to examine variances of biomechanical, radiographic and weight-bearing measures among those runners having no

outwardly appearing long second toe who experienced no complaints, those runners having an outwardly appearing long second toe who experienced no complaints, those runners having an outwardly appearing long second toe who experienced complaints slight in nature, those runners having an outwardly appearing long second toe who experienced complaints moderate in nature, and those runners having an outwardly appearing long second toe who experienced complaints severe in nature.

2. to determine correlations among the methods used by Morton (14), Schuster (21), and Sheer (26) to measure the ratio of the length difference of metatarsal I with that of metatarsal II.
3. to examine differences among the following: the ratio of the length difference of metatarsals I and II; the existence or non-existence of an outwardly appearing long second toe; the parabolic weight-bearing curve created by the heads of all metatarsals; and the metatarsus location of the greatest concentration of dynamic weight distribution.
4. to determine if there existed a significant variance of the selected measures among the five groups investigated.
5. to determine which, if any, of the biomechanical,

radiographic and weight-bearing measures could best describe the Morton's Foot syndrome.

The basis for such determinations were the selected biomechanical, radiographic and weight-bearing measures of: dorsiflexion and plantarflexion ranges of motion of the first ray; inversion and eversion of the subtalor joint; dorsiflexion of the ankle with the knee both flexed and extended; flexibility of the hamstring muscle groups; internal and external rotation of the femur with the hip flexed and extended; position of the forefoot with the rearfoot; calcaneal position of the static angle of gait; frontal plane position of the tibia with the subtalor joint static; length of metatarsal I to metatarsal II; the angle of parabolic weight-bearing curve; and the metatarsus location of dynamic weight distribution.

The procedures employed included: methods by Morton (14), Schuster (21) and Sheer (26) to determine the length differences of metatarsal I to metatarsal II as seen in the radiograph; the biometer developed by Phillips (15) to examine lower extremity biomechanical alignment; the thimble-rule developed by the investigator to determine the ranges of motion of the first ray segment; and the pedograph developed by the investigator to determine the metatarsal location of the greatest concentration of dynamic weight distribution.

The data were treated by means of: an analysis of variance;

the Pearson product moment correlation; and a stepwise regression analysis. Hand calculations were made by the researcher on data collected among Groups I, II, IIIA, IIIB, IIIC, the combined Groups III A, B and C, and the combined Groups II, III A, B and C to determine: the mean, mode and median differences in length of metatarsal I to metatarsal II acquired by Morton's, Schuster's and Sheer's methods; the group means for the parabolic weight-bearing curve angle; the relationship incidence of the length of metatarsal I to metatarsal II acquired by Morton's, Schuster's and Sheer's methods to the metatarsus location of the greatest concentration of dynamic weight distribution; the metatarsal location of greatest weight-bearing and calluses with and without first ray consideration; and the first ray range of motion and metatarsal location of greatest concentration of dynamic weight-bearing and callus formations.

Conclusions

The results of the study showed the following:

1. The groups examined could not be independently described according to biomechanical, radiographic and dynamic weight-bearing characteristics.
2. Either method by Morton (14), Schuster (21) or Sheer (26) could be used to determine the length difference of metatarsal I to metatarsal II as seen in the radiograph.

3. Pain related to the Morton's Foot syndrome could best be predicted by: Sheer's method (correlated with Morton's and Schuster's) of determining the percentage of length difference of metatarsal I to metatarsal II; the ranges of internal rotation of the femur with the hip straight; the metatarsal location of the greatest concentration of dynamic weight distribution; eversion of the subtalor joint; and the ranges of external rotation of the femur with the hip straight.
4. Those runners having an outwardly appearing long second toe with varying degrees of pain tended to have a shorter metatarsal I (mean, -5mm) than did those runners having no outwardly appearing long second toe (mean, -2mm).
5. Those runners having an outwardly appearing long second toe (mean 134.81 degrees) showed a mean deviation (-1.19 degrees) which was less than Meschen's (12) suggested standard for a normal parabolic weight-bearing curve angle (136 degrees). Those runners having no outwardly appearing long second toe (mean 139.68 degrees) showed a mean deviation (+3.68 degrees) which was greater than Meschen's suggested standard of normalcy. When compared to Gamble's (6) suggested standard for a normal parabolic weight-bearing curve angle (142.5 degrees), those runners having

an outwardly appearing long second toe (mean 134.81 degrees) showed a greater mean deviation (-7.69 degrees), while those runners having no outwardly appearing long second toe (mean 139.68 degrees) showed a smaller mean deviation (-2.82 degrees).

6. Those runners having an outwardly appearing long second toe tended to bear the greatest weight on the heads of metatarsals II and III (26 percent), while those runners having no outwardly appearing long second toe tended to bear the greatest weight on the heads of metatarsals I, II and III (27 percent).
7. Comparison of the metatarsal location of the greatest concentration of dynamic weight distribution with and without consideration given to first ray ranges of motion appear to support the above findings (#6).
8. Comparison among all groups examined showed the first ray ranges of motion to be nearly equal in incidence.
9. Examination of hyperkeratosis (callus) formations relative to metatarsal location of dynamic weight distribution among all groups studied appeared to be inconclusive.

Recommendations

The results of the study suggest the need for further

investigation as related to runners having the Morton's Foot syndrome. Such investigations should involve:

1. Studies comprised of larger group populations.
2. A similar study of subjects selected and classified homogeneously according to the length difference of metatarsal I to metatarsal II as seen in the radiograph and determined by either Morton's, Schuster's, or Sheer's method.
3. A similar study conducted to examine the length difference of metatarsal I to metatarsal II as related to runners having specific types of overuse syndromes of the lower extremity.
4. A similar study conducted to examine the length difference of metatarsal I to metatarsal II, biomechanical characteristics of the lower extremity, the involvement of specific muscles of the lower extremity and the metatarsal location of dynamic body weight distribution by means of force plates, cinematography and electromyography in order to ascertain variances which may occur during actual running performance.

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APPENDICES

APPENDIX A

SUBTALAR JOINT:

LEFT		RIGHT
	INVERSION	
	EVERSION	
	VARUS	
	VALGUS	

SUPINATION
PRONATION
TOTAL R.O.M.
NEUTRAL POSITION

5	NORMAL
4	GOOD
3	FAIR
2	POOR
1	TRACE
0	ZERO

MIDTARSAL JOINT:

	VARUS	
	VALGUS	

EVALUATION
1st to 5th Ray

ANKLE JOINT:

	DORSIFLEXION	
	PLANTARFLEXION	
	DORSIFLEXION	
	PLANTARFLEXION	

RANGE OF DORSIFLEXION — c̄ KNEE FLEXED
RANGE OF DORSIFLEXION — c̄ KNEE EXTENDED

ANKLE TO KNEE:

	INTERNAL	
	EXTERNAL	
	INTERNAL	
	EXTERNAL	

MALLEOLAR TORSION
ABNORMAL TRANSVERSE KNEE ROTATION

HIP JOINT:

c̄ HIP EXTENDED	c̄ HIP FLEXED	EXTENDED	FLEXED

RANGE OF INTERNAL ROTATION
RANGE OF EXTERNAL ROTATION
TOTAL R.O.M.
NEUTRAL POSITION

GENU DEVIATION:

VARUM	VALGUM	RECURVATUM	VARUM	VALGUM	RECURVATUM

S	SPASM (CLONIC OR TONIC)
SS	SEVERE SPASM
C	CONTRACTURE
CC	SEVERE CONTRACTURE

T.M. DISTANCE ____ cm.

STANCE CORRELATION:

	ADDUCTION	
	ABDUCTION	
	VARUS	
	VALGUS	
	INVERTED	
	EVERTED	
	VARUS	
	VALGUS	
	INVERTED	
	EVERTED	
	PRONATION	
	SUPINATION	

ANGLE OF GAIT
FRONTAL PLANE POSITION OF TIBIA c̄ SUBTALAR JT. NEUTRAL
CALCANEAL POSITION TO FLOOR c̄ SUBTALAR JOINT NEUTRAL
FRONTAL PLANE POSITION OF TIBIA c̄ SUBTALAR JT. STATIC POSITION
CALCANEAL STANCE POSITION IN STATIC ANGLE OF GAIT
RESULTANT ABNORMAL SUBTALAR JOINT POSITION

LEFT			RIGHT
	HIP: FLEXORS	ILIOPSOAS	
	EXTENSORS	GLUT. MAX. HAMS.	
	ABDUCTORS	GLUT. MED & MIN.	
	ADDUCTOR GROUP		
	EXT. ROTATOR GROUP		
	INT. ROTATORS	GLUT. MIN. T.F.L.	
	SARTORIUS		
	KNEE: FLEXORS	HAMS	
	EXTENSORS	QUAD. FEM. GROUP	
	ANKLE: DORSIFLEXORS	E.D.L. E.H.L. ANT. TIB.	
	PLANTARFLEXORS	GASTROCNEMUS SOLEUS	
	FOOT: SUPINATORS	TIB. ANT. TIB. POST.	
	PRONATOR	PER. BR.	
	1ST RAY PLANTARFLEXOR	PER. LG.	
	HALLAX: M-P FLEXOR	F.H.B.	
	M-P EXTENSOR	E.H.B.	
	ADDUCTOR	ADD. H.	
	ABDUCTOR	ABD. H.	
	TOE (I-P) FLEXOR	F.H.L.	
	TOE (I-P) EXTENSOR	E.H.B. E.H.L.	
	DIGITS: M-P FLEXION	LUMBRICALES PLANTARFLEXION	
	M-P EXTENSION	LUMBRICALES PLANTARFLEXION / DORSIFLEXION / E.D.L. / E.D.B.	
	PROXIMAL I-P FLEXION	F.D.B.	
	DISTAL I-P FLEXION	F.D.L.	

Gait Analysis _____

Name _____

Case No. _____ Date _____ Age _____ Weight _____ Height _____ Examiner _____

APPENDIX B

SUBJECT SELECTION QUESTIONNAIRE

Name_____ Ht:_____Wt:_____

Address_____ Age:_____Sex_____

Telephone_____Occupation:_____

Do you run/jog on a regular basis?
If so: How far each day_____: each week_____

How long have you been running this distance?_____

What other activities are you participating in at present?_____

_____

What percentage of your workout is done on the following surfaces?

pavement_____; dirt road_____; grass_____

indoors_____

Were you an athlete previously? Yes_____ No_____

If so: What area? Basketball_____ Football_____

Track/Field_____ Volleyball_____

Other(s)_____

Morton's Foot

Does the second toe extend beyond the great toe?

right_____ left_____ both_____ neither_____

Have you ever experienced any pain, ache or soreness in your feet?

right_____ left_____ both_____ neither_____

Have you ever experienced any pain, ache or soreness in your legs?

right_____ left_____ both_____ neither_____

Do your feet tire easily?

right_____ left_____ both_____ neither_____

Have these problems prevented you from continuing your running at anytime?

Yes_____ No_____

How long have you had to rest?_____

How often has this occured?_____

Has your problem ever been diagnosed?

By whom (doctor, trainer)?_____

What was it diagnosed as?_____

Morton's Foot
Page 2

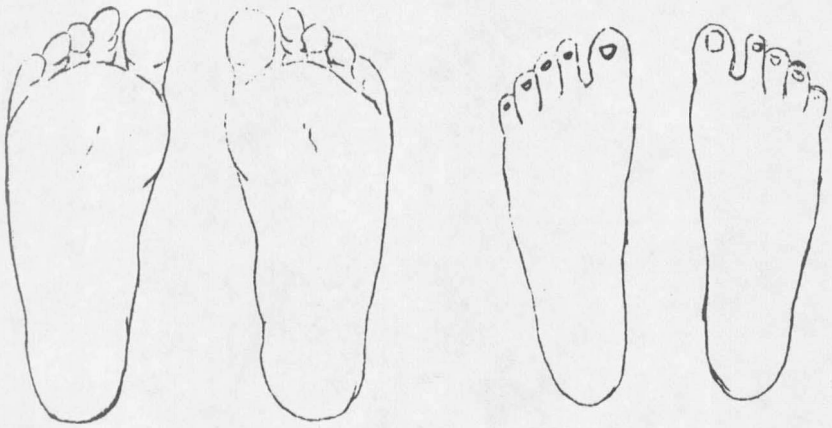
Symptoms experienced by you

Type of discomfort: slight annoyance _____;
pain on pressure_____

Severity: Slight_____; moderate_____; sharp_____

Frequency: intermittent_____; chronic_____; after hard workout?_____

Location: please indicate on diagram:



LEFT RIGHT LEFT RIGHT

SOLES TOP

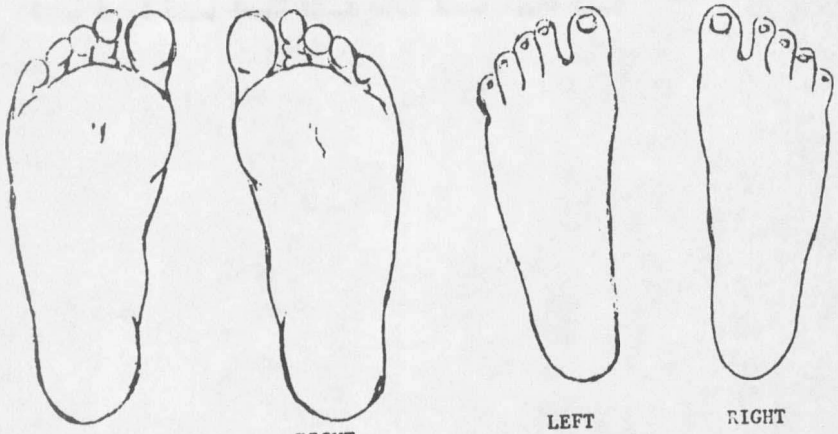
Location of pain in legs (describe)

Have you ever suffered recurring blisters and/or calluses

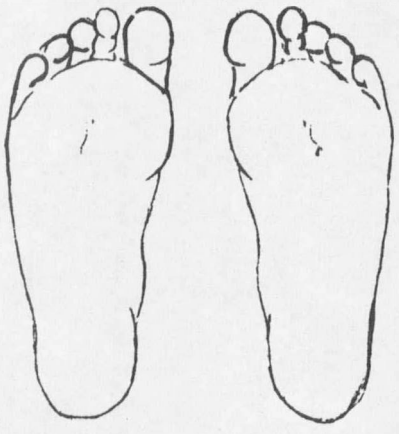
If so: When _____ 14-17 years of age
_____ 18-22 years of age
_____ 23-30 years of age
_____ 30 years and over
_____ at present

Morton's Foot
Page 3

Indicate location of <u>blisters</u> on diagrams:



Indicate location of calluses on diagram:



Would you be willing to have both feet x-rayed at the Student Health Center, at no cost to you Yes_____ No_____

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