THE INFLUENCE OF DIGITAL STABILIZATION ON METATARSALGIA

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ABSTRACT

This study quantitatively determines the influence of digital stabilization on plantar weightbearing pressures in patients with mechanically induced lesser metatarsalgia and associated hammertoes. It is generally accepted that a contracted digit creates retrograde metatarsophalangeal joint (MTPJ) plantar buckling, which in turn causes plantar protrusion of the corresponding metatarsal head, with or without corresponding plantar hyperkeratosis. Prior reports indicate alleviation of subjective complaints following surgical correction of contracted lesser digits by means of proximal interphalangeal joint (PIPJ) fusion, usually in conjunction with MTPJ relocation. Two patients were evaluated using the Musgrave Footprint™ in an effort to objectively quantify the effectiveness of lesser digital stabilization on the reduction of plantar-directed pathological pressures in the ball of the foot.

SPECIFIC AIMS

This study was designed to objectively quantify the effectiveness of PIPJ fusion and MTPJ relocation on the reduction of plantar-directed pressures in the ball of the foot. Data on two patients is presented. A quantitative weightbearing pressure test, based upon the Musgrave Footprint™, was used to compare preoperative and postoperative values for these individuals and to objectively assess the changes in the metatarsal ball region of the operated foot. The following hypothesis was tested:

"If lesser digital stabilization reduces retrograde plantar buckling of the MTPJ, then quantitative plantar pressures as measured by the Musgrave Footprint™ will be decreased throughout the ball of the foot following surgery."

BACKGROUND AND SIGNIFICANCE

Lesser metatarsalgia is commonly induced by pathological plantar-directed retrograde forces secondary to abnormally contracted digits, usually hammertoes or clawtoes. This condition is a frequent cause of pedal symptomatology, and often correlates with plantar hyperkeratoses in the ball of the foot. When this pathologic relationship between the digits and metatarsus exists, treatment of the lesser metatarsalgia should entail correction of the associated digital deformity. In many cases, lesser metatarsalgia is adequately alleviated following correction of the digital deformity without the need for traditionally accepted lesser metatarsal osteotomy. Many different lesser metatarsal osteotomy techniques have been described for the treatment of metatarsalgia, and unfortunately postoperative complications associated with these techniques are not uncommon. Despite a relatively high rate of postoperative complication, most notably the development of transfer lesion or recurrence of symptomatology, lesser metatarsal osteotomy techniques persist to be the mainstay of surgical management for the treatment of lesser metatarsalgia recalcitrant to conservative care.

A variety of analytical techniques have been described for evaluating weightbearing forces sustained by the plantar aspect of the foot. Scranton[1] used pressure-sensitive cholesterol crystal force plates to measure sub-metatarsal forces following metatarsal osteotomy. Grundy et al.[2] used highly sensitive piezoelectric force plates with simultaneous filming of the sole of the foot to assess the centers of weightbearing pressure. This type of piezoelectric force plate data provides a representation of the total ground reactive force passing through the entire extremity, however very limited information is gained regarding pressures sustained by discrete points on the sole of the foot. Pressure-sensitive films, upon which the subject walks, provide crude comparative data relating to weightbearing pressures and specific anatomic parts. Currently, pedobarographic technology provides useful information for accurate, simultaneous and reproducible measurements of plantar weightbearing pressure at many discrete points on the sole of the foot.[3,4,5]

The Musgrave Footprint™ measures pressure almost simultaneously from 2048 distinct sensors, and provides two- and three-dimensional representation of the distribution of plantar foot pressures, with the instantaneous center of pressures superimposed. Moreover, special 1:1 aspect ratio two-dimensional pressure images can be superimposed upon pedal radiographs, thereby allowing direct correlation between pressure measurements and osseous structures. Application of the Musgrave Footprint™ has proven useful in assessing pressures related to metatarsalgia associated with digital deformities.

EXPERIMENTAL DESIGN AND METHODS

To date, two subjects have been evaluated to determine the influence of digital stabilization on metatarsalgia. These subjects were evaluated to ascertain the presence of contracted intermediate lesser digit or digits, with associated metatarsalgia with or without concomitant plantar hyperkeratosis. Each deformed digit was classified as either a hammertoe or clawtoe. Digital and metatarsophalangeal joints were characterized as flexible, semi-rigid, or rigid; and radiographs were obtained for skeletal assessment (routine preoperative studies).

Local and systemic signs and symptoms of metatarsalgia were evaluated in an effort to rule-out the presence of Morton's neuroma, neoplasm, acute fracture or dislocation, metabolic arthritis, blood dyscrasia, peripheral vascular disease, peripheral neuropathy, and other nonmechanical causes of lesser metatarsalgia. The degree of metatarsalgia was assessed using a standardized subjective clinical scale. Sub-metatarsal hyperkeratoses, if present, were identified with respect to etiology, exact location, diameter, thickness, and degree of tenderness to deep palpation. Following appropriate preoperative evaluation, the patients were scheduled for digital stabilization for correction of the contracted intermediate digits. Prior to surgery, preoperative plantar foot pressure measurements were obtained using the Musgrave Footprint™. The following additional inclusion criteria were also met: 1) the subject had signed the informed consent to participate in the study, 2) the subject could ambulate freely without walking aids, and 3) the digital deformities warranted surgical correction following failure to satisfactorily respond to non-surgical therapy.

Plantar foot pressure measurements were obtained by having each subject walk barefoot at a self-selected, comfortable cadence, across the Musgrave Footprint™ within two weeks prior to the planned surgery. Plantar pressure measurements were obtained and stored. Two and three dimensional images, as well as center of pressure plots and enhanced sensitivity plots for the sub-metatarsal region of the affected foot were produced. The sensors activated by plantar pressure were printed on a 1:1 aspect ration transparency and overlayed with a transverse plane radiograph of the foot. The individual metatarsal heads and corresponding digits, lateral and medial columns of the arch, and lateral and medial aspects of the calcaneus were identified and the corresponding pressures tabulated by plantar region. Specifically, the average of peak pressure values for four adjacent sensors approximately ascribing the area of contact of a metatarsal head were calculated and stored.

Each involved digit was stabilized by means of proximal interphalangeal arthrodesis with Kirschner wire fixation, using standard techniques of sequential reduction. Routine postoperative management was subsequently provided. At approximately three months following surgery, when each subject was ambulating well in normal shoe gear, the subject was again asked to subjectively rank the degree of metatarsalgia. Moreover, the presence or absence of sub-metatarsal hyperkeratosis was noted. Each patient then walked barefoot, at a self-selected and comfortable cadence, across the Musgrave Footprint™ and postoperative plantar foot pressure measurements were obtained. After analyzing the preoperative and postoperative plantar foot pressure data, a quantitative assessment was made as to whether or not digital stabilization improved the subject's status regarding plantar pressure in the sub-metatarsal head region of the foot. An analysis of variance (ANOVA) with paired t-tests determined if there were statistically significant differences between the preoperative and postoperative parameter measurements. Each subject served as their own control in this single-subject design. The direction of the statistically significant changes in the mean parameter values was used to infer if the expected outcome (i.e. plantar pressure reduction following digital stabilization) had resulted. After comparing the qualitative subjective clinical findings and quantitative objective pressure findings in both the preoperative and postoperative states, a correlation was made relating to the influence of digital stabilization on lesser metatarsalgia.

RESULTS AND DISCUSSION

Two representative subjects examined preoperatively were found to have metatarsalgia and hammertoe deformities affecting the right foot. Figure 1A shows color-coded two and three dimensional plots of patient V.C.'s plantar foot pressures. The color-coded pressure scale ranges from 0-16 kg/cm^2, and plantar pressures in excess of 10 kg/cm2 are considered potentially pathological (especially in the insensitive foot)[6,7] Figure 1B represents the same patient's postoperative Musgrave Footprint™ plots, showing marked decreases in the pressures sustained plantar to the metatarsal heads. Figures 2A- 2D show preoperative and postoperative two and three dimensional plots for patient W.M. Note that in the second and third metatarsal regions, where the subject complained of pain and displayed a thick tyloma, there were high preoperative pressures in the metatarsal head region ranging from 11.2 to 15.9 kg/cm^2. Figures 2B and 2C represent a 1:1 aspect ratio comparisons of an outline of the subject's

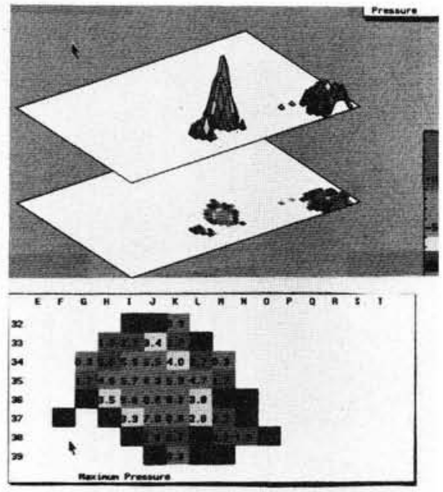

Fig. 1A. Preoperative Plantar Aspect Pressures.

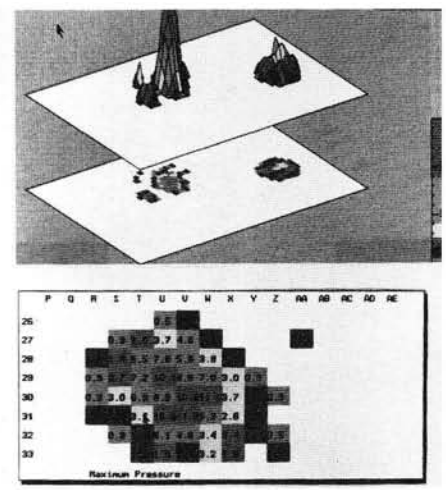

Fig. 1B. Postoperative Plantar Aspect Pressures.

DP radiograph and the color-coded plot of the patient's foot in propulsion, for both the pre- and postoperative phases. Once again, note that the sensors corresponding to the area of the second and third metatarsal heads, indicate excessively high preoperative pressures and significant reductions following surgery for digital stabilization and MTPJ relocation.

Figure 3 displays the statistical analysis of the preoperative and postoperative data for these two patients, and indicates a statistically significant (probability less than .05) reduction in plantar pressures for V.C., and a clinically significant reduction for W.M. Both of these patients displayed the following improvements following digital stabilization: 1) plantar pressures associated with metatarsalgia were reduced, 2) complaints of metatarsalgia were significantly reduced

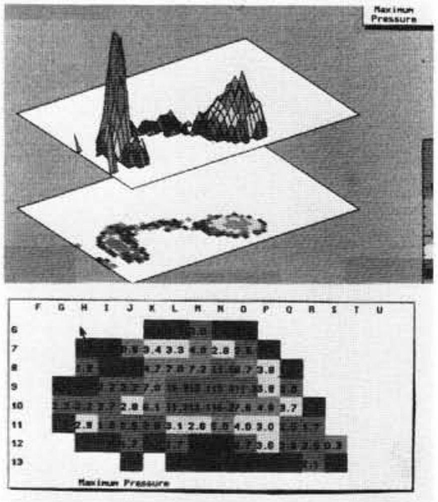

Fig. 2A. Preoperative Plantar Aspect Pressures.

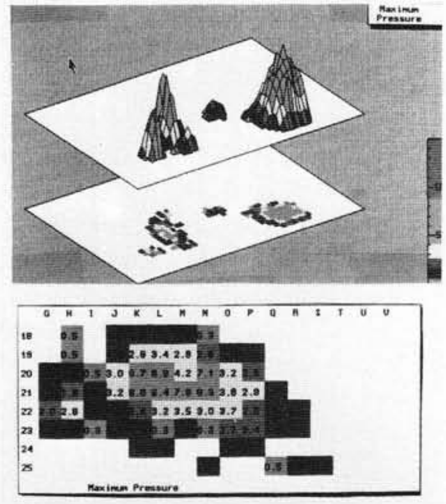

Fig. 2B. Postoperative Plantar Aspect Pressures.

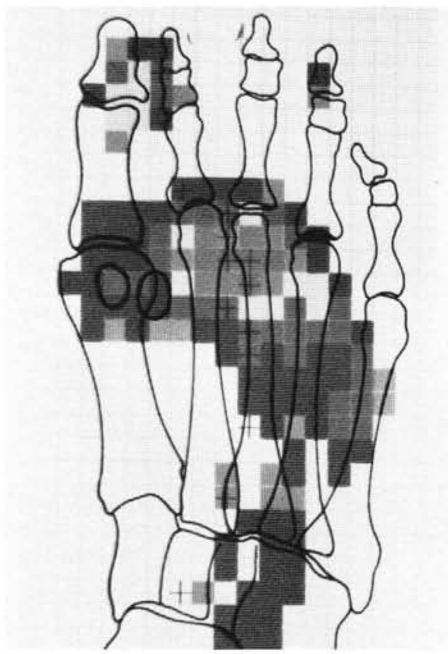

Fig. 2C. Preoperative 1:1 ratio comparison of the D.P. radiograph and the color coded plot.

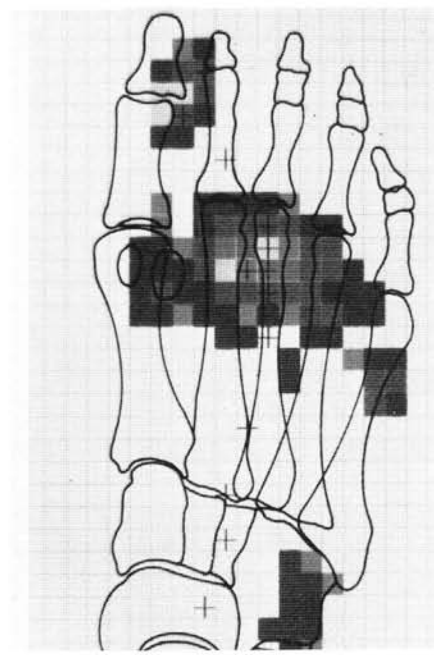

Fig. 2D. Postoperative 1:1 ratio comparison of the D.P. radiograph and the color coded plot.

or eliminated, and 3) subjects had no plantar pressures greater than 10 kg/cm^2 after digital stabilization.

The authors have developed a simple static equilibrium model for the midstance and propulsion phases of healthy and hammertoe digits. Figure 4A represents the healthy digit in midstance and propulsion. In this model the following assumptions are made:

1. The digit is represented as a solid beam.
2. The extensor tendons are represented as T_{EXT}.
3. The flexor tendons are represented as T_{FLEX}.
4. The MTPJ is considered mechanically grounded via the flexor plate.
5. The metatarsal declination angle in midstance is 21 degrees and 21 degrees + *theta* in propulsion.
6. The plantar MTPJ pressure results from the normal force at the MTPJ applied through the area of the flexor plate.

Figure 4B represents the hammertoe deformed digit in midstance and propulsion, and the following additional assumption is made:

PRE-OP/POST-OP SINGLE SUBJECT DESIGN ANOVA

SUBJECT	PRE-OP	POST-OP	PROBABILITY
V.C.(right Met 3)	9.62 Kg/sq. cm	6.45 kg/sq.cm	0.0076
W.M.(right Met 3)	10.78 Kg/sq.cm	8.67 kg/sq.cm	0.0746

Note: Based upon a four sensor average of the peak plantar pressures throughout stance under the anatomical lesion.

Fig. 3.

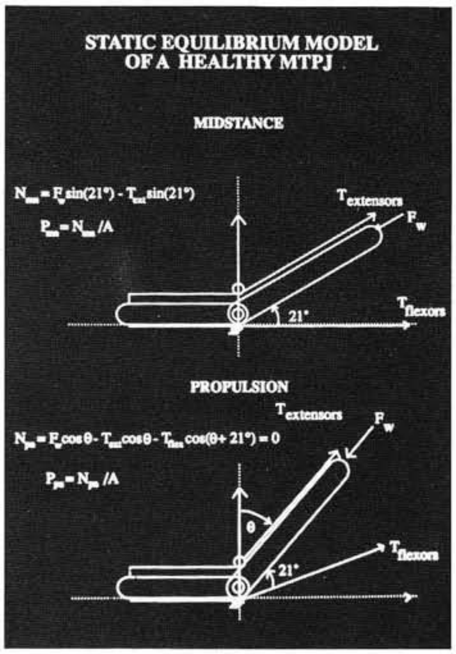

Fig. 4A.

The hammering or clawing phenomenon is modeled as the raising of the forward beam by an angle *phi*.

Due to the additional force applied to the dorsal aspect of the metatarsal head by the retrograde buckling of the hammertoe, or raising the distal beam phi degrees, it can be shown that the plantar pressure beneath the metatarsal head in propulsion is greater in the case of a hammertoe deformity than in the case of a healthy, or straight digit.

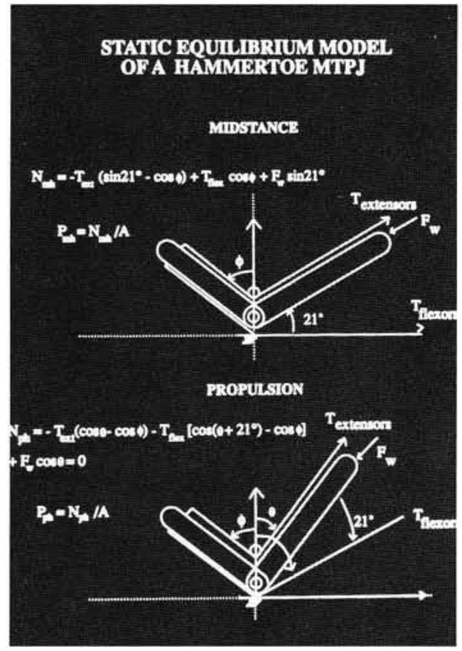

Fig. 4B.

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