Research Report

Rehabilitation After Hallux Valgus Surgery: Importance of Physical Therapy to Restore Weight Bearing of the First Ray During the Stance Phase

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Background. Operative treatment of people with hallux valgus can yield favorable clinical and radiographic results. However, plantar pressure analysis has demonstrated that physiologic gait patterns are not restored after hallux valgus surgery.

Objective. The purpose of this study was to illustrate the changes of plantar pressure distribution during the stance phase of gait in patients who underwent hallux valgus surgery and received a multimodal rehabilitation program.

Design. This was a prospective descriptive study.

Methods. Thirty patients who underwent Austin (n=20) and scarf (n=10) osteotomy for correction of mild to moderate hallux valgus deformity were included in this study. Four weeks postoperatively they received a multimodal rehabilitation program once per week for 4 to 6 weeks. Plantar pressure analysis was performed preoperatively and 4 weeks, 8 weeks, and 6 months postoperatively. In addition, range of motion of the first metatarsophalangeal joint was measured, and the American Orthopaedic Foot and Ankle Society (AOFAS) forefoot questionnaire was administered preoperatively and at 6 months after surgery.

Results. The mean AOFAS score significantly increased from 60.7 points (SD=11.9) preoperatively to 94.5 points (SD=4.5) 6 months after surgery. First metatarsophalangeal joint range of motion increased at 6 months postoperatively, with a significant increase in isolated dorsiflexion. In the first metatarsal head region, maximum force increased from 117.8 N to 126.4 N and the force-time integral increased from 37.9 N·s to 55.6 N·s between the preoperative and 6-month assessments. In the great toe region, maximum force increased from 66.1 N to 87.2 N and the force-time integral increased from 18.7 N·s to 24.2 N·s between the preoperative and 6-month assessments.

Limitations. A limitation of the study was the absence of a control group due to the descriptive nature of the study.

Conclusions. The results suggest that postoperative physical therapy and gait training may lead to improved function and weight bearing of the first ray after hallux valgus surgery.

Hallux valgus deformity remains one of the most common and disabling pathologies of the foot. A myriad of potential therapeutic interventions have been described for treating people with symptomatic hallux valgus, including bracing, soft-tissue procedures, and a number of different osteotomies.[1–3] The purpose of operative correction of the deformity by an osteotomy of the first metatarsal is to reduce the malalignment of the first ray, thereby restoring its function in weight bearing and ambulation.[4] Operative correction has yielded good to excellent results.[5–12]

However, recent plantar pressure distribution analyses indicate that, despite improvement of clinical and radiographic parameters, restoration of function of the first ray and great toe does not occur.[8,13–17] Kernozek and Sterikker[17] found decreased 1-year peak pressures and force-time integrals (impulse) in the great toe region compared with the preoperative values. They concluded that physical therapy may help to restore great toe function after the Austin procedure. In a prospective pressure distribution study, Bryant et al[13] found decreased load beneath the hallux 1 year after the Austin procedure compared with preoperative levels. They did not find any changes of plantar pressure parameters on the second, third, and fourth metatarsals after surgery. Guesgen et al[18] reported that, at a mean of 3 years after chevron osteotomy, 56% of the patients did not use their great toe for push-off. Jones et al[8] found decreased peak pressures 20 months after scarf osteotomy in the region of the first metatarsal head compared with the preoperative values. Dhukaram et al[15] found decreased load under the hallux after scarf and Mitchell osteotomies compared with individuals with absence of any foot pathology.

Because the first ray is the most heavily loaded structure of the foot during gait, proper weight bearing is essential for physiologic gait patterns.[19,20] Lateral deviation of the great toe and subluxation of the sesamoids represent pathomorphologic characteristics of hallux valgus deformity.[21] These changes alter kinematics of the first metatarsophalangeal (MTP) joint, leading to reduced strength (force-generating capacity) of the plantar flexors.[22] Plantar pressure studies revealed that the great toe assumes a diminishing role in weight bearing of the forefoot. In addition to the lateral transfer of forces, the center of pressure shifts laterally.[23–25] Therefore, several authors[26–28] have mentioned decreased weight bearing of the great toe during gait as the reason for lesser toe metatarsalgia. The results of plantar pressure distribution assessments performed after hallux valgus surgery suggest that structural correction of the pathobiomechanics alone is not sufficient to restore forefoot function.[8,13,15,16–18]

Postoperative physical therapy is a well-established method to restore function after surgical intervention for disorders of the musculoskeletal system. The benefits of postoperative physical therapy have been reported for nearly all orthopedic surgery subspecialties.[29–33] More applicable to this report, it has been shown that postoperative physical therapy for hindfoot surgical procedures improves postoperative function.[34] However, there is a paucity of literature describing the effect of physical therapy on the functional outcome of forefoot surgery. Shamus et al[35] reported good functional improvement in patients with hallux limitus when they underwent a special physical therapy program including sesamoid mobilization, flexor hallucis muscle strengthening, and gait training. These results indicate that physical therapy and gait training help to restore physiologic kinematics in the affected first MTP joint. Therefore, we hypothesized that physical therapy would improve function following surgical correction of symptomatic hallux valgus.

The purpose of this prospective descriptive study was to illustrate the changes of plantar pressure distribution during the stance phase of gait in patients who underwent hallux valgus surgery and received a multimodal rehabilitation program.

Method

Participants

Prospective participants were referred to the study by a fellowship-trained foot and ankle surgeon on the basis of mild to moderate hallux valgus deformity without radiographic signs of osteoarthritis of the first MTP joint. Between October 2006 and December 2007, 30 patients were included in this study. All patients complained of pain in the region of the first MTP joint. Demographics of the participants are shown in Table 1. None of the participants had evidence of lower-extremity malalignment (eg, genu valgum, genu varum) or any other pathologic conditions on the musculoskeletal system that might influence gait patterns (eg, low back pain; disk herniations; spondyloar-

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- eAppendix: Rehabilitation Program After Hallux Valgus Surgery
- The Bottom Line clinical summary
- The Bottom Line Podcast
- Audio Abstracts Podcast

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Table 1.
Demographic Characteristics of the Participants (N=30)

Characteristic	Measurement
Sex	
Male	2
Female	28
Type of osteotomy	
Austin	20
Scarf	10
Age (y)	
$\bar{X}$	58.4
SD	13.8
Range	22–79
Height (cm)	
$\bar{X}$	166.3
SD	0.1
Range	152.0–178
Weight (kg)	
$\bar{X}$	64.8
SD	8.9
Range	49–88
Body mass index[a]	
$\bar{X}$	23.4
SD	2.9
Range	17.8–31.6
Foot size (French)	
$\bar{X}$	38.5
SD	1.3
Range	36–42

[a] Body mass index calculated as weight in kilograms divided by the square of the height in meters.

thritis or osteoarthritis of the hip, knee, ankle, subtalar, transverse tarsal, or Lisfranc joints).

The operations were performed by a single surgeon (H.J.T.), as previously described by Kristen et al[9] and Trnka et al,[12] in an ambulatory surgery center setting. Briefly, the Austin osteotomy is a distal V-shaped osteotomy of the first metatarsal combined with a release of the contractile aspects of the lateral joint capsule of the MTP joint.[36] The operative area is explored through a median skin incision at the medial aspect of the first MTP joint, as well as a dorsal skin incision at the first web space. The V-shaped osteotomy is performed with a sagittal oscillating saw, and afterward the distal fragment is shifted laterally to realign the first metatarsal. In the present study, fixation was performed by inserting an oblique compression screw (Charlotte Multi Use Compression Screw*) from dorsomedial to plantarlateral.

The scarf osteotomy is a diaphyseal Z-shaped osteotomy of the first metatarsal shaft.[7–9,37,38] The operative area is explored through the same incisions as described for the Austin osteotomy. The osteotomy is performed using the oscillating saw. Correction of the deformity is provided by pushing the distal fragment laterally. Fixation was performed with the same screw used for the Austin osteotomy. This screw was inserted in a dorsal to plantar direction.

Participants underwent the scarf osteotomy when their intermetatarsal angle was more than 16 degrees and underwent the Austin osteotomy when it was less than 16 degrees. The intermetatarsal angle is measured on weight-bearing anterior-posterior radiographs of the foot. The intermetatarsal angle was determined from the longitudinal axes of the first and second metatarsals. This angle is the main indicator of the degree of the deformity.[3,21,39] To avoid the specific influence of a single surgical method, patients with both operations were included in this study.

Measurements

Prior to collecting data, all participants signed an informed consent form approved by the Foot and Ankle Center Vienna Institutional Review Board. The rights of the participants were protected all the times.

All measurements were taken by an independent observer who was neither the operating surgeon nor a physical therapist. The measurements included pedobarographic analysis and functional assessment using the metatarsophalangeal-interphalangeal score of the American Orthopaedic Foot and Ankle Society (AOFAS), as well as measurements of range of motion (ROM) of the first MTP joint according to the criteria of the AOFAS.[39,40] The AOFAS score and ROM of the first MTP joint were evaluated preoperatively and 6 months after surgery. Plantar pressure analyses were performed preoperatively and 4 weeks, 8 weeks, and 6 months after surgery.

Plantar Pressure Analysis

The plantar loading parameters were assessed using a capacitive pressure measurement platform (emed-at platform†). The platform has a total area of 610 × 323 mm enclosing a 240- × 380-mm sensor area. It includes a total of 1,760 sensors, providing a resolution of 2 sensors per square centimeter. The sampling rate of the platform was fixed at 60 Hz and automatically triggered upon first contact. The pressure threshold is 10 kPa, with plantar pressures ranging up to 1,270 kPa. The platform has a maximum measurable force of 67,000 N, with a hysteresis of <3%. Because of the 18-mm depth of the platform, the test arrangement enclosed the whole platform in the center of a polyethylene ramp with a length of 7 m. Participants were able to cross the platform in both directions. The validity, reliability, and repeatability of the EMED system† have been investigated previously.[41–43] According to Hughes et al,[41] the coefficients of reliability (Pearson *r*)

* Wright Medical Technology Inc, 5677 Airline Rd, Arlington, TN 38002.

† Novel GmbH, Ismaniger Strasse 51, 81675 Munich, Germany.

range from .914 to .988 for the parameters that were evaluated in the present study if 5 steps are recorded. In order to provide valid and reliable results, the mid-gait method was chosen for this study. This method requires the individual to walk across a walkway while pressure data are collected from a single foot contact over the sensor platform. This method allows recording of measurements during free movement and thus ensures that the effect of acceleration and deceleration at the start and end of each walk is minimized.

Putti et al[42] investigated the repeatability of measurements of the EMED system by having patients walk at normal speed on 2 separate occasions, approximately 12 days apart. In the present study, the participants were told to walk at normal speed and to keep their speed constant. Data were collected and stored for analysis. Analysis of the records was performed with the emed/D software.[†,44] An average of the 5 data sets was calculated by the software, and the foot was divided into geometric regions of interest according to the anatomical areas of the great toe, second toe, first metatarsal head, and second metatarsal head, as well as the total foot (Fig. 1). The following variables for each region were generated by the software: peak pressure (in kilopascals), maximum force (in newtons), contact area (in square centimeters), contact time (in milliseconds), and force-time integral (in newtons per second).

Measurements of plantar pressure provide an indication of foot and ankle function during gait. Data obtained from plantar pressure assessment can be used for the evaluation and treatment of patients with foot disorders. In the present study, plantar pressure measurements were performed to investigate changes in gait before and in the postoperative pe-

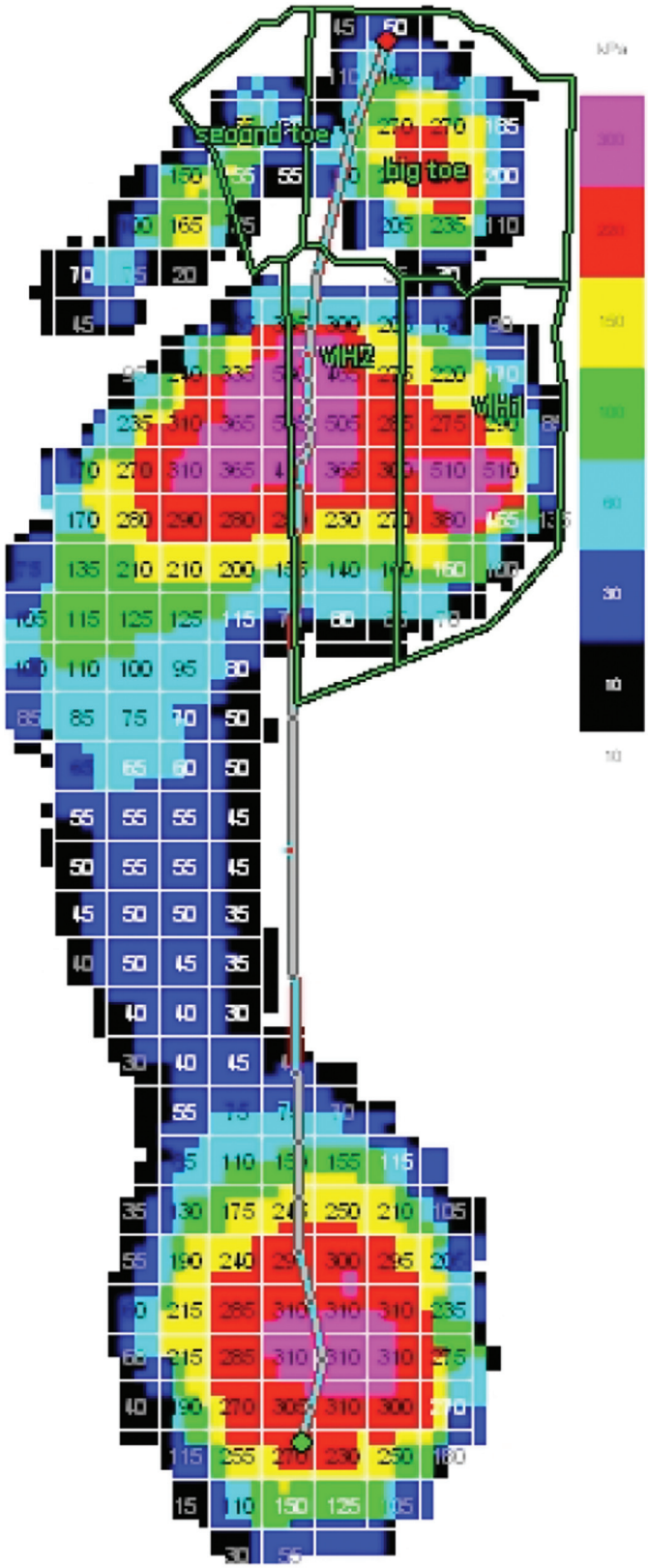

Figure 1.
Plantar pressure image with regions of interest: total foot, first metatarsal head (MH1), second metatarsal head (MH2), big toe, and second toe.

riod after hallux valgus surgery with respect to the functional restoration of the operated area.[45]

Pressure (measured in pascals) is defined as force (measured in newtons)/area (measured in square meters).[46] *Peak pressure* in the assessment of dynamic plantar pressure distribution is defined as the greatest pressure that is applied to the ground during the stance phase of gait. *Maximum force* is defined as the greatest vertical force that acts on a certain area and indicates its load.[46] In the present study, maximum force was measured to determine the load changes of certain regions of interest.

The *force-time integral (impulse)* is the area under the curve of a force (ie, time curve).[45] These parameters are appropriate for describing the overall loading effects of the foot during the stance phase of gait. *Contact time* reveals the time of ground contact of either the total foot or certain regions of interest during the stance phase. *Contact area* is the area of contact of the foot to the supporting surface during the stance phase. The data were not normalized to foot size and weight. The standard deviation reflects between-subject variations.

Rehabilitation Program

An Aircast cryo-cuff[‡] was applied for 8 hours starting immediately after surgery on the day of the operation and on the first postoperative day. This intervention was conducted as an inpatient treatment. Postoperatively, participants were placed in the Rathgeber postoperative shoe[§] for 4 weeks. This shoe allows weight bearing of the operated limp while reducing stress in the forefoot region. Participants also received a special sock (Gilofamed[‖]) that reduces swelling and the need for dressing changes. The first session of the physical therapy program started 4 weeks after surgery, with one session per week. Physical therapy treatment was performed by 3 licensed physical therapists following the same treatment protocol.

In the first session, elevation of the leg, lymphatic drainage, activation of the muscle pump, and cryotherapy (cool packs) were used to reduce the swelling. Participants were told to perform these actions at home once a day for 20 minutes.

During gait training, physiologic gait patterns were achieved. The stance phase was trained by performing a heel-strike in its physiological position at the lateral aspect of the heel,[47] followed by weight bearing of the first metatarsal during midstance and terminal stance, with training of active push-off by the great toe flexors, the flexor digitorum longus and brevis muscles, and the lumbrical muscles.

Selective strengthening of the peroneus longus muscle also was performed. The function of this muscle is to pronate the midfoot.[20,48,49] Pronation is essential for ground contact of the first ray, the most heavily loaded structure of the foot during gait.[19] If the peroneus longus muscle is too weak, people compensate by pushing the knee into a valgus position to achieve midfoot pronation. In addition, fascial release techniques for the peroneal muscles as well as to decrease of the tone (velocity-dependent resistance to stretch) of the tibialis anterior muscle were performed to improve the interaction of those antagonists.

‡ DonJoy Orthopaedics, ORMED GmbH, Merzhauser Strasse, 112D-79100 Freiburg, Germany.

§ OFA Bamberg GmbH, Laubanger 20, Bamberg 96052, Germany.

‖ OFA Austria, Franz-Ofner Strasse, 6620 Salzburg, Austria.

Figure 2.
Manual therapeutic intervention at the first metarsophalangeal joint.

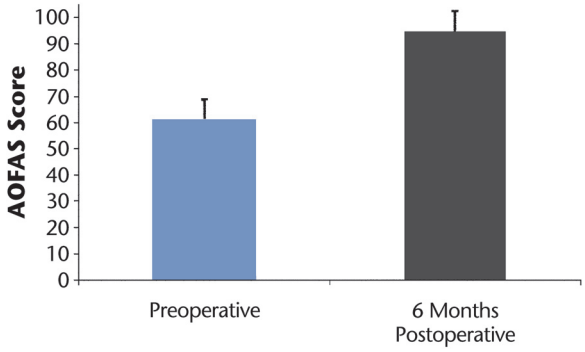

Figure 3.
Preoperative and postoperative means of the American Orthopaedic Foot and Ankle Society (AOFAS) score. The error bars indicate the standard deviation.

Manual therapeutic interventions were performed for all MTP joints. These manipulations focused on an improvement of flexion and included caudal sliding of the proximal phalanx to improve flexion and dorsal sliding of the proximal phalanx to improve extension (Fig. 2). In addition, oscillating traction was performed to activate the mechanoreceptors that inhibit the afferent pain sensors.

The treatment protocol also included mobilization of the first MTP, Lisfranc, transverse tarsal, subtalar, and ankle joints. Concentric strengthening exercises of the great toe flexors and extensors were performed as well.

The participants received a mean of 4.4 treatment sessions (range=3–6) based on their individual findings. The sessions took place once a week for 3 to 6 weeks. The duration of the sessions ranged from 35 to 45 minutes. The participants also were instructed to do a marble pick-up exercise, apply cold packs, and do strengthening exercises and gait training at home. A more-detailed description of the rehabilitation program is included in the eAppendix (available at www.ptjournal.org).

Data Analysis

Student *t* tests were used to determine whether there was a significant difference between the preoperative and postoperative AOFAS scores and MTP ROM measurements. Repeated-measures analyses of variance and Tukey *post hoc* analyses were used to investigate the changes in plantar pressure parameters at the different time points. Statistical analysis was performed using SPSS version 11.3[#] as well as Excel for Macintosh.[**] The level of significance was defined as $\alpha<.05$.

Results

Twenty-eight patients were available for a complete follow-up. One patient was excluded from the 6-month follow-up examination because of a recent myocardial infarction. Another patient was not able to participate in the 6-month follow-up examination because of a work-related change of his living area.

AOFAS Score

The mean AOFAS score increased from 60.7 (SD=11.9) preoperatively to 94.5 (SD=4.5) 6 months after surgery ($P<.001$) (Fig. 3).

[#] SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.
[**] Microsoft Corp, One Microsoft Way, Redmond, WA 98052-6399.

Pedobarographic Analysis

The results of the plantar pressure assessment are summarized in Table 2 and are illustrated in Figure 4.

Total Foot

The total foot area maximum force, contact time, and force-time integral did not show significant changes between the different examinations. Mean peak pressure decreased from 714.8 kPa (SD=195.8) preoperatively to 622.4 kPa (SD=228.0) 4 weeks postoperatively ($P=.003$). Six months postoperatively, it reached 687.8 kPa (SD=218.7), which was not statistically different from the preoperative value ($P=.896$). The contact area decreased from a preoperative mean value of 118.1 cm^2 (SD=13.3) to 107.7 cm^2 (SD=19.5) 4 weeks postoperatively ($P=.023$). Likewise, the contact area demonstrated a statistically significant increase to 118.0 cm^2 (SD=14.8) 8 weeks after surgery ($P=.048$). By 6 months after surgery, the mean total foot contact area of 119.0 cm^2 (SD=12.8) was not significantly different from the preoperative value ($P=.960$).

First Metatarsal Head

Contact time did not show any significant changes for the first metatarsal head. Mean maximum force decreased from 117.8 N (SD=48.0) preoperatively to 77.3 N (SD=41.9) 4 weeks postoperatively ($P=.001$) and increased to 123.7 N (SD=40.6) 8 weeks after surgery ($P<.001$). Mean peak pressure decreased in the same period from 288.9 kPa (SD=181.7) to 146.6 kPa (SD=73.5) ($P=.001$). Between the preoperative investigation and the assessment 6 months postoperatively, there was no statistically significant difference either for maximum force or for peak pressure ($P=1.0$). Mean contact area decreased between the preoperative assessment and the evaluation 4 weeks after surgery from 11.4 cm^2 (SD=1.8) to 10.04

Table 2.
Results[a] of Plantar Pressure Assessments for Maximum Force (MF), Peak Pressure (PP), Contact Time (CT), Contact Area (CA), and Force-Time Integral (FTI)

Parameter	Preoperative	4 Weeks Postoperative	8 Weeks Postoperative	6 Months Postoperative
Total foot				
MF (N)	722.1±101.5 (690.3–766.1)	710.5±94.1 (670.7–750.2)	728.3±99.6 (694.1–767.5)	719.0±87.0 (686.0–753.7)
PP (kPa)	714.8±195.8[b] (649.9–805.7)	622.4±228.0 (429.7–600.0)	630.9±230.6 (534.0–710.8)	687.8±218.7 (603.0–772.5)
CT (ms)	818.4±181.7 (768.0–905.3)	934.1±132.5 (878.1–990.1)	894.7±131.0 (847.5–943.7)	891.1±137.7 (837.9–944.5)
CA (cm^2)	118.1±13.3[b] (114.7–124.8)	107.7±19.5 (99.4–115.9)	118.00±14.77 (113.2–123.9)	119.0±12.8 (116.7–126.8)
FTI (N·s)	430.6±93.1 (404.6–480.8)	439.8±81.3 (405.5–474.1)	439.5±73.2 (415.2–473.8)	431.2±82.6 (408.5–480.3)
First metatarsal head				
MF (N)	117.8±48.0[b] (105.6–142.2)	77.3±41.9[c] (59.6–95.0)	123.7±40.6 (110.8–142.0)	126.4±40.2 (131.2–162.0)
PP (kPa)	288.9±181.7[b] (220.2–350.9)	146.6±73.5 (115.6–177.7)	207.2±60.8 (189.9–242.8)	287.4±153.0 (228.0–346.7)
CT (ms)	613.5±134.2 (574.6–675.4)	661.2±188.0 (581.8–740.6)	661.3±133.2 (612.5–709.9)	661.6±135.6 (609.1–714.2)
CA (cm^2)	11.4±1.8 (10.9–12.2)	10.04±3.43[c] (8.6–11.5)	12.1±2.2 (11.4–13.0)	12.1±1.6 (11.4–12.7)
FTI (N·s)	37.9±17.5 (34.2–49.5)	31.8±21.0[c] (22.9–40.6)	47.5±19.5 (40.8–55.1)	55.6±22.3 (46.9–64.3)
Second metatarsal head				
MF (N)	169.4±37.1[b,d] (157.4–188.9)	118.1±51.0[c] (96.5–139.6)	173.1±54.0 (154.3–193.7)	185.8±41.9 (169.6–202.1)
PP (kPa)	614.2±217.1[b] (536.3–719.3)	325.8±212.7[c] (236.0–415.6)	519.0±255.2 (423.9–614.7)	584.4±246.2 (488.9–679.7)
CT (ms)	685.0±150.1 (638.6–751.6)	736.8±135.3 (670.7–793.9)	689.4±119.2 (647.0–736.0)	661.6±135.6 (578.1–1,019.1)
CA (cm^2)	9.6±1.3 (9.3–10.2)	8.6±2.4 (7.6–9.7)	9.9±1.7 (9.3–10.5)	10.3±1.4 (9.8–10.7)
FTI (N·s)	62.4±16.7 (58.0–73.5)	50.3±21.1[c] (41.4–59.2)	71.1±22.8 (62.2–79.7)	74.7±21.1 (66.5–82.9)
Big toe				
MF (N)	66.1±33.2[b] (57.0–83.2)	28.4±31.5 (15.1–51.7)	51.7±47.3[e] (33.2–67.6)	87.2±37.3 (72.8–101.7)
PP (kPa)	357.9±198.7[b] (301.4–451.2)	114.9±131.0 (59.6–170.2)	190.0±200.1 (117.9–265.4)	322.4±200.6 (244.6–400.0)
CT (ms)	548.8±138.3[b] (516.0–633.4)	363.7±262.3 (253.0–474.5)	437.7±201.0 (346.7–504.3)	533.6±161.8 (470.8–596.3)
CA (cm^2)	7.3±2.1[b,d] (6.7–8.3)	5.09±3.1[c] (3.8–6.4)	7.4±2.4[e] (6.5–8.2)	9.2±1.5 (8.6–9.7)
FTI (N·s)	18.7±10.7[b] (16.0–25.6)	7.4±10.6 (2.9–11.9)	16.6±11.3[e] (6.7–17.0)	24.2±13.7 (18.9–29.5)
Second toe				
MF (N)	23.6±15.4[b] (18.3–31.1)	10.4±11.2 (5.7–15.2)	15.5±12.1 (11.4–22.3)	20.8±16.6 (14.4–27.2)
PP (kPa)	150.6±83.2[b] (122.8–188.2)	68.9±56.8 (44.6–92.8)	103.5±66.5 (80.1–136.0)	135.7±90.0 (101.0–170.4)
CT (ms)	445.9±131.4 (417.4–522.9)	396.9±241.8 (294.9–499.0)	398.0±138.1 (361.2–466.0)	408.0±160.5 (345.8–470.3)
CA (cm^2)	3.4±1.4[b] (3.0–4.0)	2.3±1.3 (1.7–2.8)	2.8±1.2 (2.4–3.3)	3.1±1.1 (2.7–3.5)
FTI (N·s)	5.8±3.9 (4.6–7.7)	2.5±3.7[c] (1.1–5.3)	3.9±3.9 (2.7–5.7)	5.3±5.5 (3.0–7.3)

[a] Results are expressed as mean±SD, with confidence interval (CI) in parentheses.
[b] Statistically significant change at $P<.05$, preoperative assessment to 4-week postoperative assessment.
[c] Statistically significant change at $P<.05$, 4-week assessment to 8-week postoperative assessment.
[d] Statistically significant change at $P<.05$, preoperative assessment to 6-month postoperative assessment.
[e] Statistically significant change at $P<.05$, 8-week assessment to 6-month postoperative assessment.

cm^2 (SD=3.43) (P=.08) and increased to 12.1 cm^2 8 weeks after surgery (P=.06). The force-time integral increased from a mean of 31.8 N·s 4 weeks postoperatively to 47.5 N·s 8 weeks postoperatively (P=.026). It increased from 37.9 N·s preoperatively to 55.6 N·s 6 months after surgery (P=.062). However, this increase was not statistically significant.

Second Metatarsal Head

Maximum force, peak pressure, and force-time integral showed statistically significant decreases between the preoperative evaluation and the assessment 4 weeks after surgery ($P<.001$, $P<.001$, P=.047, respectively) and significant increases between the evaluation 4 weeks after surgery and the assessment 8 weeks after surgery ($P<.001$, P=.021, P=.003, respectively).

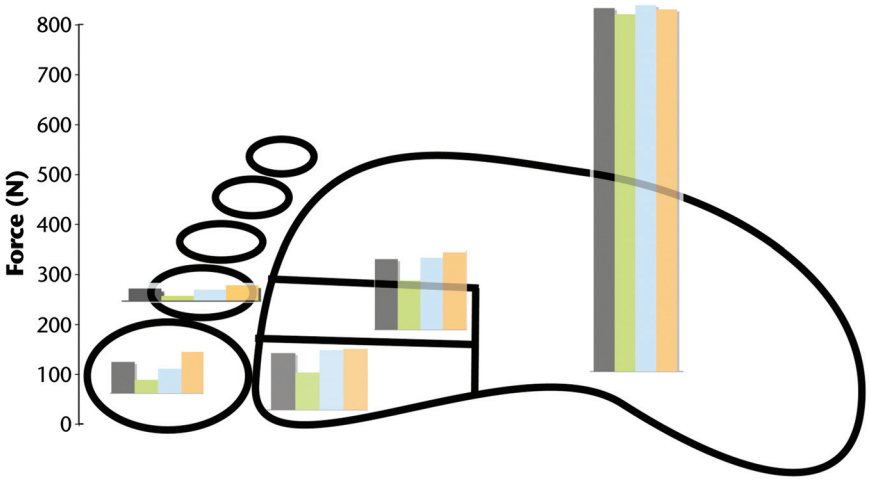

Figure 4.
Regional force changes in the treated feet: preoperative (gray), 4 weeks postoperative (green), 8 weeks postoperative (blue), and 6 months postoperative (orange).

Great Toe

In the great toe, maximum force, peak pressure, contact area, and force-time integral decreased significantly between the preoperative evaluation and the assessment at 4 weeks following surgery ($P \leq .001$). The mean contact area showed a statistically significant increase from 5.09 cm^2 (SD=3.1) 4 weeks after surgery (P=.001) to 7.4 cm^2 (SD=2.4) 8 weeks after surgery (P=.003) and 9.2 cm^2 (SD=1.5) 6 months after surgery (P=.017). The difference between the preoperative examination and the assessment 6 months after surgery was statistically significant (P=.034).

Mean values for maximum force were 66.1 N (SD=33.2) preoperatively and 87.2 N (SD=37.3) 6 months after surgery (P=.320). Average force-time integral was 18.7 N·s (SD=10.7) before surgery and reached 24.2 N·s (SD=13.7) (P=.752) 6 months postoperatively.

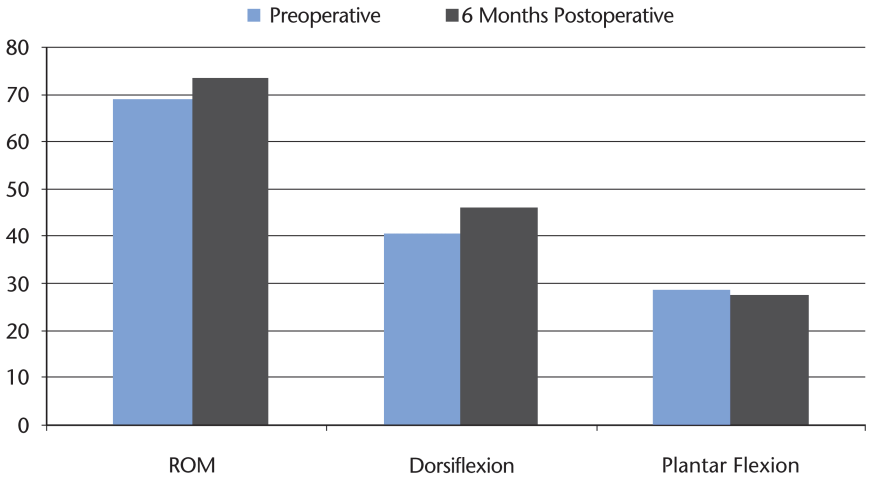

Figure 5.
Range of motion (ROM) assessment: changes (in degrees) in plantar flexion, dorsiflexion, and overall ROM of the first metarsophalangeal joint.

Contact time did not show any statistically significant changes.

Second Toe

In the second toe, the maximum force, peak pressure, and contact area decreased significantly between the preoperative evaluation and the assessment 4 weeks after surgery (P=.005, P=.001, P=.003, respectively). There were no statistically significant changes for force-time integral or contact time.

First MTP Joint ROM

Mean total ROM of the first MTP joint increased from 68.9 degrees (SD=11.9, range=40–90) preoperatively to 73.3 degrees (SD=21.4, range=30–150) 6 months after surgery. This improvement was not statistically significant (P=.31). However, mean dorsiflexion significantly increased from 40.4 degrees (SD=9.0, range=25–60) preoperatively to 45.9 degrees (SD=14.0, range=20–80) 6 months after surgery (P<.05). Mean plantar flexion was 28.5 degrees (SD=6.9, range=15–40) preoperatively and 27.4 degrees (SD=11.5, range=5–45) 6 months after surgery. This difference was not statistically significant (P=.44) (Fig. 5).

Discussion

In our study, plantar pressure distribution was assessed in patients who underwent hallux valgus surgery and received postoperative physical therapy and gait training. In general, loading parameters in the great toe region and the region of the first metatarsal head did not decrease between the preoperative examination and the assessment at 6 months after surgery. Several authors[8,13–17] have studied changes in plantar pressure distribution after hallux valgus surgery and found decreased loading parameters in the hallux and the first metatarsal head region after surgery. To the best of our knowledge, the postoperative regimens in those

studies did not include physical therapy and gait training, although Kernozek and Sterriker[17] concluded that the inclusion of physical therapy and gait training would improve the functional outcome.

Plantar pressure distribution measurements are a proper method to assess the functional outcome of hallux valgus surgery. This method was first recommended in 1956 by Barnett.[50] Henry et al, in 1975, were the first authors to report the results of plantar pressure distribution analysis.[26] They studied 170 feet retrospectively and found that 50% underwent resection arthroplasty according to Keller or arthrodesis of the first MTP joint for treatment of hallux valgus deformity. They showed that patients who underwent resection arthroplasty did not use their great toe for push-off. In addition, metatarsalgia showed a significantly higher incidence in the resectional arthroplasty group. Henry et al concluded that the higher incidence was attributable to the higher pressure distribution on the lateral aspects of the forefoot due to load shift. Even though both methods that were investigated in that study are joint-sacrificing methods rather than joint-preserving methods, which are able to restore physiological joint biomechanics as well as joint kinematics, the results indicate that the use of the great toe for push-off and weight bearing of the first ray is important to avoid metatarsalgia due to load shift after hallux valgus surgery. Therefore, a great deal of attention should be drawn to the restoration of physiologic gait patterns after such operations.

In agreement with Henry and colleagues' results,[26] Stokes et al[27] found no increase of plantar pressure patterns beneath the great toe region in 40 feet of patients who underwent a resectional arthroplasty or Wilson osteotomy. In addition, they investigated the plantar pressure distribution of 64 individuals (128 feet) with absence of any foot pathology and compared the results with the results of the hallux valgus group. On the lateral aspects of the foot, the hallux valgus group showed higher load before as well as after surgery compared to the control group. Stokes et al also concluded that this load shift may cause metatarsalgia. This was the first study that revealed pathologic plantar pressure distribution after hallux valgus surgery with a joint-preserving method.

Feet affected with hallux valgus deformity show a load shift to the lateral aspects of the foot and decreased weight bearing of the great toe.[22,24,26–28] In a kinematic study, Mitternacht and Lampe[22] found that, due to the lateral shift of the tendons of the extrinsic muscles of the great toe, a decrease in plantar-flexion moment of the great toe can be identified. Recently, Putti et al[42] performed a plantar pressure distribution assessment in 53 subjects who were healthy and used the force-time integral to describe the overall loading effect. The force-time integral is appropriate for describing the overall loading effect because it takes into account the amplitude and duration of load application.[45] The study by Putti et al revealed mean force-time integrals of 26 N·s for the hallux region and 52 N·s for the first metatarsal head region. In our study, we found mean preoperative force-time integrals of 37.9 N·s for the first metatarsal head region and 18.7 N·s for the first metatarsal head region. These measurements indicate a decreased load of the first ray in patients with hallux valgus deformity. Six months after surgery, the mean values for these regions reached 25.2 N·s for the big toe region and 55.6 N·s for the first metatarsal head region. These findings indicate increased weight bearing of the first ray and an almost physiological plantar pressure distribution. In addition, there were significantly decreased plantar pressure parameters in the region of the first and second metatarsal heads 4 weeks after surgery compared with the preoperative assessment. Considering the total foot region, no statistically significant changes for maximum force and force-time integral were observed. These results indicate the possibility of a load shift from the medial aspect of the forefoot to the lateral aspects of the forefoot.

Our patients were placed in a postoperative shoe for 4 weeks after surgery. To ensure bone healing, the postoperative shoe should decrease the load in the traumatized region.[2,3] The first ray is the most heavily loaded structure of the foot during gait.[19] Therefore, the shoe is designed to shift the load from the medial aspect to the lateral aspect of the forefoot during propulsion. We believe that one reason for the decreased load in the great toe region and the region of the medial forefoot 4 weeks after surgery is the pathologic gait pattern that is necessary in the early postoperative period. However, a multimodal rehabilitation program seems to be important for the patient to eliminate these pathologic gait patterns and to restore the function of the operated structures.

Recent plantar pressure distribution analysis with an intermediate-term follow-up revealed a decreased load in the region of the first MTP joint as well as in the great toe area after hallux valgus surgery. Kernozek and Sterricker[17] found decreased peak pressure and force-time integral in the great toe region 1 year after surgery compared with the preoperative examination in a prospective study of 25 patients who underwent the Austin procedure for correction of hallux valgus deformity. They concluded that physical therapy may

help to improve the functional outcome of this procedure.

Bryant et al[13] investigated 31 subjects (44 feet) before and after an Austin osteotomy. They also assessed the plantar pressure distribution in 36 control subjects. They found a decreased load beneath the hallux 1 year after the Austin procedure compared with preoperative levels.

In a retrospective analysis, Guesgen et al[18] measured plantar pressure distribution in 60 patients (66 feet) who underwent a chevron osteotomy, with a mean follow-up of 3 years. Thirty-four percent of the patients with a postoperative hallux valgus angle smaller than 20 degrees and 56% of the patients with a postoperative hallux valgus angle greater than 20 degrees did not use their great toe during propulsion. These results suggest that a total of 45% of the patients had pathologic gait patterns after surgery. Jones et al[8] investigated 24 patients (35 feet) who underwent a scarf osteotomy prospectively. They found a decrease in the peak pressure of the first metatarsal after a mean follow-up of 20 months. Dhukaram et al[15] investigated 28 patients who underwent a Mitchell or scarf osteotomy, with a mean follow-up of 3 years. They also measured plantar pressure distribution in 15 individuals who were healthy. They found deficient load bearing of the hallux for both groups.

In this study, plantar pressure patterns in the great toe region decreased significantly 4 weeks after surgery compared with the preoperative assessment. Maximum force, peak pressure, contact area, and force-time integral showed statistically significant increases between the fourth and the eighth weeks postoperatively. For the great toe region and the region of the first metatarsal head, maximum force and force-time integral showed increases compared with the preoperative values. This tendency was statistically nonsignificant. The changes concerning the plantar pressure distribution indicate that there is improved weight bearing of the first ray and the great toe. This finding indicates that there is a functional improvement after hallux valgus surgery, which does not correspond to the pedobarographic results reported by other authors.[8,13–15,17,18] Based on those results, we believe that this functional improvement is based on the physical therapy interventions.

In agreement with other authors, the AOFAS score improved significantly and reached 94.5 points at 6 months after surgery. Cancilleri et al[51] investigated 30 patients after an Austin osteotomy and found a mean AOFAS score of 81.9 points at a mean of 37 months after surgery. Trnka et al,[11] in 2- and 5-year follow-up assessments of 66 patients after a modified chevron (Austin) osteotomy, found a mean AOFAS score of 91 points. Aminian et al[52] studied the clinical results of the scarf osteotomy in 27 patients and found that the mean AOFAS score increased from 54.5 points preoperatively to 86.5 points at an average follow-up of 16.1 months. Kristen et al,[9] in 89 patients (111 feet) who underwent a scarf osteotomy, reported that the mean AOFAS score increased from 50.1 points preoperatively to 91 points postoperatively at a mean follow-up of 34 months. Perugia et al[10] investigated 33 patients (45 feet) after a scarf osteotomy and reported a mean increase in AOFAS score from 35.7 points preoperatively to 89.8 points postoperatively. Jones et al,[8] in 24 patients (35 feet) who underwent a scarf osteotomy, found the mean AOFAS score increased from 52 points preoperatively to 89 points at a mean of 22 months after surgery. Buchner et al,[6] in 29 patients who underwent a scarf osteotomy, found an increase in mean AOFAS score from 45 points preoperatively to 75 points at an average follow-up of 6 months. Crevoisier et al[53] found in 84 feet an increase in mean AOFAS score from 43 points preoperatively to 82 points at a mean follow-up of 22 months. In the present study, patients had a relatively high AOFAS score in comparison with these other investigations, even though surgery was just 6 months prior.

The total ROM improved from 68.8 degrees preoperatively to 73.3 degrees by 6 months after surgery. This improvement did not show statistical significance, but isolated dorsiflexion significantly improved from 40.4 to 45.9 degrees. It is difficult to compare the results of ROM measurements in our study with those of other studies because of the different methods used for the assessment of first MTP joint ROM. However, during propulsion, the first MTP joint has been reported to dorsiflex between 40 and 60 degrees during typical gait.[54] Plantar flexion of only a few degrees is necessary to allow physiologic gait. The improvement of dorsiflexion also may help to restore physiological gait patterns.

Weaknesses of this study include, due to its descriptive nature, the absence of a control group that did not receive physical therapy after hallux valgus surgery. A randomized controlled design would improve the level of evidence. Further research is necessary to determine whether there is a beneficial effect of a multimodal rehabilitation program on the restoration of physiological plantar pressure patterns. Further research should focus on performing a randomized controlled trial addressing this question. Gait speed seems to affect plantar pressure distribution.[55] In the present study, plantar pressure assessment was performed using the mid-gait method because it is the most favorable way to represent normal gait patterns.[42,45] Partic-

ipants were instructed to walk at a normal speed and to keep their speed constant. Putti et al[42] showed that this method produces repeatable results. However, gait speed was not recorded. Therefore, it is impossible to analyze the influence of gait speed on the plantar pressure distribution in the patients in this study.

The strengths of this study include its prospective nature and a systematic plantar pressure assessment. In addition, to the best of our knowledge, this is the first study determining plantar pressure changes after hallux valgus surgery and postoperative physical therapy.

Conclusion

Numerous authors[13,15–18,22,24,26–28] have reported pathologic gait patterns after hallux valgus surgery. We found that there was an increase in plantar pressure parameters in the region of the great toe and the first ray after hallux valgus surgery in patients who received physical therapy as well as gait training in the postoperative period. Therefore, we believe that postoperative physical therapy helps to restore function in weight bearing and ambulation after hallux valgus surgery.

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References

1 Easley ME, Trnka HJ. Current concept review: hallux valgus, part II: operative treatment. *Foot Ankle Int*. 2007;29:748–758.

2 Robinson AH, Limbers JP. Modern concepts in the treatment of hallux valgus. *J Bone Joint Surg Br*. 2005;87:1038–1045.

3 Coughlin MJ. Instructional course lectures, the American Academy of Orthopaedic Surgeons: hallux valgus. *J Bone Joint Surg Am*. 1996;78:932–966.

4 Sammarco VAJ. Stability and fixation techniques in first metatarsal osteotomies. *Foot Ankle Clin*. 2001;6:409–432.

5 Barouk LS. Scarf osteotomy of the first metatarsal in the treatment of hallux valgus. *Foot Disease*. 1995;2:35–48.

6 Buchner M, Schulze A, Zeitang F, Sabo D. Pressure distribution after scarf osteotomy for hallux valgus surgery [in German]. *Z Orthop Ihre Grenzgeb*. 2005;143:233–239.

7 Dereymaeker G. Scarf osteotomy for correction of hallux valgus: surgical technique and results as compared to distal chevron osteotomy. *Foot Ankle Clin*. 2000;5:513–524.

8 Jones S, Al Hussainy HA, Ali F, et al. Scarf osteotomy for hallux valgus: a prospective clinical and pedobarographic study. *J Bone Joint Surg Br*. 2004;86:830–836.

9 Kristen KH, Berger C, Stelzig S, et al. The SCARF osteotomy for the correction of hallux valgus deformities. *Foot Ankle Int*. 2002;23:221–219.

10 Perugia D, Basile A, Gensini A, et al. The scarf osteotomy for severe hallux valgus. *Int Orthop*. 2003;27:103–106.

11 Trnka HJ, Zembsch A, Easley ME, et al. The chevron osteotomy for correction of hallux valgus: comparison of findings after two and five years of follow-up. *J Bone Joint Surg Am*. 2000;82:1373–1378.

12 Trnka HJ, Zembsch A, Wiesauer H, et al. Modified Austin procedure for correction of hallux valgus. *Foot Ankle Int*. 1997;18:119–127.

13 Bryant AR, Tinley P, Cole JH. Plantar pressure and radiographic changes to the forefoot after the Austin bunionectomy. *J Am Podiatr Med Assoc*. 2005;95:357–365.

14 Dhanendran M, Pollard JP, Hutton WC. Mechanics of the hallux valgus foot and the effect of Keller's operation. *Acta Orthop Scand*. 1980;51:1007–1012.

15 Dhukaram V, Hullin MG, Senthil Kumar C. The Mitchell and Scarf osteotomies for hallux valgus correction: a retrospective, comparative analysis using plantar pressures. *J Foot Ankle Surg*. 2006;45:400–409.

16 Kernozek TW, Roehrs T, McGarvey S. Analysis of plantar loading parameters pre and post surgical intervention for hallux vargus. *Clin Biomech (Bristol, Avon)*. 1997;12:S18–S19.

17 Kernozek TW, Sterriker SA. Chevron (Austin) distal metatarsal osteotomy for hallux valgus: comparison of pre- and post-surgical characteristics. *Foot Ankle Int*. 2002;23:503–508.

18 Güsgen C, Walther M, Wölfel R, Vispo-Seara JL. The distal chevron osteotomy for hallux valgus: a medium-term retrospective clinical, radiographic and pedobarographic analysis [in German]. *FuβSprung*. 2005;3:164–171.

19 Jacob HAC. Forces acting in the forefoot during normal gait: an estimate. *Clin Biomech (Bristol, Avon)*. 2001;16:783–792.

20 Rodgers MM. Dynamic biomechanics of the normal foot and ankle during walking and running. *Phys Ther*. 1988;68:1822–1830.

21 Myerson MS. The etiology and pathogenesis of hallux valgus. *Foot Ankle Clin*. 1997;2:583–598.

22 Mitternacht J, Lampe R. Calculation of functional kinetic parameters from the plantar pressure distribution measurement [in German]. *Z Orthop Ihre Grenzgeb*. 2006;144:410–418.

23 Grieve DW, Rashdi T. Pressures under normal feet in standing and walking as measured by foil pedobarography. *Ann Rheum Dis*. 1984;43:816–818.

24 Hutton WC, Dhanendran M. The mechanics of normal and hallux valgus feet: a quantitative study. *Clin Orthop Relat Res*. 1981;(157):7–13.

25 Sanders M. Conservative treatment and shoewear options for hallux valgus. *Foot Ankle Clin*. 1997;4:639–649.

26 Henry AP, Waugh W, Wood H. The use of footprints in assessing the results of operations for hallux valgus: a comparison of Keller's operation and arthrodesis. *J Bone Joint Surg Br*. 1975;57:478–481.

27 Stokes IA, Hutton WC, Stott JR, Lowe LW. Forces under the hallux valgus foot before and after surgery. *Clin Orthop Relat Res*. 1979;(142):64–72.

28 Waldecker U. Metatarsalgia in hallux valgus deformity: a pedographic analysis. *J Foot Ankle Surg*. 2002;41:300–308.

29 Malone TB, Blackburn TA, Wallace LA. Knee rehabilitation. *Phys Ther*. 1980;60:1602–1610.

30 Beynnon BD, Johnson RJ, Fleming BC. The science of anterior cruciate ligament rehabilitation. *Clin Orthop Relat Res*. 2002;(402):9–20.

31 Chen B, Zimmerman JR, Soulen L, DeLisa JA. Continuous passive motion after total knee arthroplasty: a prospective study. *Am J Phys Med Rehabil*. 2000;79:421–426.

32 Hodgson S. Proximal humerus fracture rehabilitation. *Clin Orthop Relat Res*. 2006;442:131–138.

33 Theiler R, Schmid C, Risler R, Moser L. Postoperative physiotherapy in acute care: when, what and how much [in German]? *Orthopade*. 2007;36:552, 554–559.

34 Shaffer MA, Okereke E, Esterhai JL Jr, et al. Effects of immobilization on plantarflexion torque, fatigue resistance, and functional ability following an ankle fracture. *Phys Ther*. 2000;80:769–780.

35 Shamus J, Shamus E, Gugel RN, et al. The effects of sesamoid mobilization, flexor hallucis strengthening, and gait training on reducing pain and restoring function in individuals with hallux limitus: a clinical trial. *J Orthop Sports Phys Ther*. 2004;80:769–780.

36 Austin DW, Leventen EO. A new osteotomy for hallux valgus: a horizontally directed "V" displacement osteotomy of the metatarsal head for hallux valgus and primus varus. *Clin Orthop Relat Res*. 1981;(157):25–30.

37 Barouk LS. Scarf osteotomy for hallux valgus correction: local anatomy, surgical technique, and combination with other forefoot procedures. *Foot Ankle Clin*. 2000;5:525–558.

38 Jarde O, Trinquier-Lautard JL, Gabrion A, et al. Hallux valgus treated by Scarf osteotomy of the first metatarsus and the first phalanx associated with an adductor plasty: apropos of 50 cases with a 2-year follow up [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 1999;85:374–380.

39 Smith RW, Reynolds JC, Stewart MJ. Hallux valgus assessment: report of research committee of American Orthopaedic Foot and Ankle Society. *Foot Ankle*. 1984;5:92–103.

40 Kitaoka HB, Alexander IJ, Adelaar RS, et al. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. *Foot Ankle Int*. 1994;15:349–353.

41 Hughes J, Pratt L, Linge K, et al. Reliability of pressure measurements: the EMED F system. *Clin Biomech (Bristol, Avon)*. 1991;6:14–18.

42 Putti AB, Arnold GP, Cochrane LA, Abboud RJ. Normal pressure values and repeatability of the Emed ST4 system. *Gait Posture*. 2008;27:501–505.

43 van der Leeden M, Dekker JH, Siemonsma PC, et al. Reproducibility of plantar pressure measurements in patients with chronic arthritis: a comparison of one-step, two-step, and three-step protocols and an estimate of the number of measurements required. *Foot Ankle Int*. 2004;25:739–744.

44 Metaxiotis D, Accles W, Pappas A, Doederlein L. Dynamic pedobarography (DPB) in operative management of cavovarus foot deformity. *Foot Ankle Int*. 2000;21:935–947.

45 Orlin MN, McPoil TG. Plantar pressure assessment. *Phys Ther*. 2000;80:399–409.

46 Barnes SZ, Berme N. Measurement of kinetic parameters technology. In: Craik RL, Oatis CA, eds. *Gait Analysis: Theory and Application*. St Louis, MO: Mosby-Year Book Inc; 1995:239–251.

47 Cheung RTN, Gabriel YF. Influence of different footwear on force of landing during running. *Phys Ther*. 2008;88:620–628.

48 Perry J. *Gait Analysis: Normal and Pathologic Function*. Thorofare, NJ: Slack Inc; 1992.

49 Riegger CL. Anatomy of the ankle and foot. *Phys Ther*. 1988;68:1802–1814.

50 Barnett CH. Phases of human gait. *Lancet*. 1956;22:617–621.

51 Cancilleri F, Marinozzi A, Martinelli N, et al. Comparison of plantar pressure, clinical, and radiological changes of the forefoot after biplanar Austin osteotomy and triplanar Boc osteotomy in patients with mild hallux valgus. *Foot Ankle Int*. 2008;29:817–824.

52 Aminian A, Kelikian A, Moen T. Scarf osteotomy for hallux valgus deformity: an intermediate follow-up of clinical and radiographic outcomes. *Foot Ankle Int*. 2006;27:883–886.

53 Crevoisier X, Mouhsine E, Ortolano V, et al. The scarf osteotomy for the treatment of hallux valgus deformity: a review of 84 cases. *Foot Ankle Int*. 2001;22:970–976.

54 Hetherington VJ, Johnson RE, Albritton JS. Necessary dorsiflexion of the first metatarsophalangeal joint during gait. *J Foot Surg*. 1990;29:218–222.

55 Rosenbaum D, Hautmann S, Gold M, Claes L. Effects of walking speed on pressure distribution patterns and hindfoot angular motion. *Gait Posture*. 1994;2:191–197.