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# Motion of the Multisegmental Foot in Hallux Valgus

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## Abstract

*Background:* Hallux valgus is a common condition characterized by lateral deviation of the large toe and medial deviation of the first metatarsal. While some gait analyses of patients with hallux valgus have been performed using plantar pressures, very little is known about the kinematics of gait in this population. The purpose of this study was to evaluate triplanar kinematics in patients with hallux valgus using a multisegmental foot model. *Materials and Methods:* A 15-camera Vicon Motion Analysis System was used to evaluate the gait of 38 feet in 33 patients with mild to severe hallux valgus. The Milwaukee foot model was used to characterize dynamic foot and ankle kinematics and temporal-spatial parameters. Values were compared with normal subjects. Outcomes were evaluated using the SF-36 assessment tool. *Results:* Patients with hallux valgus showed

significantly decreased velocity and stride length and prolonged stance. Significant alterations in gait kinematics were observed in various planes in all segments (hallux, forefoot, hindfoot, and tibia) of the foot and ankle, particularly in the ranges of motion of the hallux and the forefoot. *Conclusion:* The results demonstrate significantly altered kinematic and temporal-spatial parameters reflective of reduced ambulatory function in patients with hallux valgus. As reports describing multisegmental foot and ankle kinematics in this population are limited, this study is valuable in characterizing gait in patients with hallux valgus. *Clinical Relevance:* A better understanding of altered gait dynamics of the multisegmental foot in patients with hallux valgus provides valuable insight on how distal pathology affects proximal segments.

## Keywords
Motion Analysis, Kinematics, Gait, Hallux Valgus, Multisegmental Foot Model, Foot and Ankle

## Introduction
Hallux valgus (HV) is a common condition affecting the first metatarsophalangeal (MTP1) joint and is characterized by lateral deviation of the large toe and medial deviation of the first metatarsal.[2,8] Patients typically present with a bunion, pronated hallux, and hammering of the second toe due to large toe abutment. Progressive subluxation of the MTP1 joint is common, resulting in attenuation of the medial soft tissues and contracture of the lateral soft tissues. The deformity displaces the flexors of the great toe and the sesamoid complex laterally, thereby increasing the valgus moment at the MTP1 joint. As the displaced flexors pull the great toe into abduction, the deformity and subluxation of the great toe worsens, resulting in articular incongruity. The consequent pathologic anatomy of this condition leads to biomechanical dysfunction and impairment.[25]

Current literature investigating dynamic segmental foot characteristics in the HV population is limited. Alterations in plantar loading patterns and gait kinematics have been reported.[3,6,18,29] In an early study using force plates to evaluate ground reaction force in postoperative patients, Merkel et al. found decreased cadence, stride, step length, and stance phase time subsequent to a Mitchell osteotomy.[19] This data is supported in a later study by Vittas et al. which looked at pre and postoperative hallux valgus patients.[28] Gait analysis has also suggested a mechanism for continued dysfunction even after surgical treatment, although the work only employed a single segment foot model.[24] In studies of plantar pressures in conservatively managed patients, Blomgren et al. found decreased and more proximally located first metatarsophalangeal joint pressures than controls, suggesting avoidance of this area.[3] This data is supported by Yamamoto et al. in conservatively managed patients and by Dhukaram et al. in postoperative patients treated with an osteotomy.[9,30] However, Lorei et al. reported improvement in first metatarsal pressure subsequent to scarf osteotomy.[16]

While pressure studies and early kinetic investigations provide relevant data, triplanar multisegmental investigations are scarce. There are no current reports in which anatomically indexed multisegmental foot models have been used to characterize gait in this patient population. Several authors have investigated triplanar hallux kinematics in healthy ambulators[7,10,15,17,20,26] and some consensus has emerged among these authors regarding motion in the sagittal and transverse planes.[7,10,15,20] These studies provide a framework for established normal values of hallux motion.

Hwang et al. employed a segmental model in a limited study of two subjects with stage II hallux valgus.[10] Bone based referencing was not employed, and there was no information on system validation. The authors found significantly less sagittal and coronal plane hallux range of motion when compared to controls. The study also reported excessive hindfoot eversion and external rotation in early stance. Clinical interpretation of the data was not provided.

The current study used both a radiographic bone-based referencing system and a larger patient population to describe segmental foot and ankle kinematics in a population of patients with HV. Our hypothesis was that in addition to significantly increased hallux transverse plane abduction, a decrease in hallux range of motion would occur in the sagittal and transverse planes. We also hypothesized that kinematics of the hindfoot of HV patients would differ significantly from those of controls. The findings of the study may prove helpful in better understanding kinematic segmental interaction of this condition.

# Materials and Methods

This study was approved by the Institutional Review Board at the Medical College of Wisconsin. This was a prospective study involving 38 feet in 33 adult patients (31F, 2M) with a primary complaint of a symptomatic hallux valgus deformity ("HV" group) and 25 healthy subjects ("Control" group) with no prior surgical treatment to the foot or any known foot pathology which would interfere with gait. Exclusion criteria from the HV group included prior surgical treatment to the foot that may have altered its anatomy or function, or other pathology which would interfere with gait. All patients were recruited from the Foot and Ankle Clinics at the Medical College of Wisconsin from 2000 through 2007. Twenty-eight patients presented with unilateral HV while five had bilateral HV. Mean age at the time of testing was 51.9 years (range, 24 to 72 years). Patients' hallux valgus ranged from mild to severe based on hallux valgus angle. Full demographic data are listed in Table 1.

**Table 1:** Subject Demographics

| | **HV** | **Controls** | ***p*** |
|---|---|---|---|
| Number of Subjects | 33 | 25 | |
| Age (years) | 51.9 (range, 24 to 72) | 41 (range, 27 to 73) | |
| Gender | 31 females, 2 males | 12 females, 13 males | |
| BMI (kg/m2) | 26.3 ± 4.7 | 26.1 ± 3.7 | 0.95 |
| Height (m) | 1.7 ± 0.1 | 1.7 ± 0.1 | 0.17 |
| Weight (kg) | 71.4 ± 12.7 | 77.8 ± 13.2 | 0.12 |

## Motion analysis

Foot and ankle motion studies were conducted in the Motion Analysis Laboratory at the Medical College of Wisconsin. Motion data were collected using a 15 camera 120 Hz Vicon 524 Motion Analysis System (Vicon Motion Systems, Inc.; Lake Forest, CA). Data were collected during walking trials at self-selected speed along a 6-meter walkway and processed using the Milwaukee Foot Model (MFM). The MFM is a four-segment model of the foot and ankle which has been validated for adult and pediatric populations.[13,20] The MFM allows three-dimensional evaluation of the tibia, hindfoot, forefoot, and hallux, and uses weightbearing radiographs to index marker position to underlying bony anatomy.[12,13]

## Statistics

Minimum, maximum and range values during the seven phases of gait as described by Perry[21] were compared between the HV group and the Control group. Temporalspatial parameters (cadence, stride length, stance duration, and walking speed) were also compared. For each segment in each plane, we tested the null hypothesis that the ROM measured between the HV and Control groups was similar during each gait phase using unpaired parametric methods (Wilcoxon test). A Bonferroni correction was used to assure 5% overall error rate with a significance level of $p \leq 0.002$ for joint kinematics and $p \leq 0.05$ for temporalspatial parameters.

## Outcomes assessment

The SF-36 Health Survey was administered to evaluate functional levels in patients with hallux valgus. Specific subscale scores of interest included physical functioning (extent to which health interferes with physical

activities), role functioning-physical (extent to which physical health interferes with work and daily activities), bodily pain (intensity and effect of pain on work), and general health (personal evaluation of health).

# Results

## Subject comparison

The HV group consisted of 33 patients, five of which had bilateral hallux valgus. A nonparametric comparison between unilateral and bilateral hallux valgus demonstrated no statistical difference in the kinematic (i.e., position, range of motion) or temporal-spatial (i.e., walking speed, cadence, stride length, stance/swing duration) parameters. Based on this, all 38 feet were grouped together to form the HV group. Mean height was 1.65 m for the HV group, which was not significantly different from the Control group (1.70 m). The HV group had an average weight of 71.4 kg while the controls had 77.8 kg. The difference was not significant ($p = 0.12$). Their Body Mass Indices were likewise not significantly different at 26.3 kg/m$^2$ (HV) and 26.1 kg/m$^2$ (Controls).

## Temporal-Spatial parameters

Results showed significantly slower walking speed (Control: 1.12 m/s; HV: 1.01 m/s; $p = 0.0018$) and decreased stride length (Control: 1.29 m; HV: 1.14 m; $p < 0.0001$) in patients with hallux valgus. Stance phase duration was significantly prolonged (Control: 62.3% gait cycle; HV 64.1%; $p = 0.0103$). The decrease in cadence was not statistically significant.

## Hallux kinematics

The hallux demonstrated a significant valgus position ($p < 0.0001$) throughout the gait cycle (Figure 1). Decreased transverse range of motion (ROM) was seen from terminal swing through terminal stance. Sagittal range was also significantly limited from terminal swing through midstance ($p \leq 0.0018$). In the coronal plane, hallux pronation was observed from preswing through initial swing, shifting to supination at terminal swing. Coronal range of motion was significantly increased from preswing to midswing ($p \leq 0.0004$).

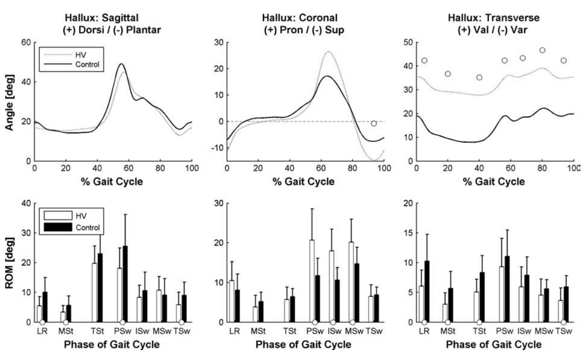


**Fig. 1:** Upper: Average hallux kinematics during complete gait cycle (HV vs. Control). Circles denote phases of gait cycle with significantly different minimum and maximum positions. Lower: hallux ROM (average ± 1SD). Circles denote phases of gait cycle with significantly different ROMs. Note: Hallux kinematics were calculated relative to forefoot.

## Forefoot kinematics

The forefoot demonstrated a less plantarflexed position throughout the gait cycle (Figure 2). In the coronal plane, diminished forefoot varus was observed throughout the gait cycle and was found significant from terminal stance through initial swing ($p \leq 0.0006$). Sagittal and transverse ROMs were significantly diminished from preswing through midstance ($p \leq 0.0013$). Coronal range was decreased from midstance through terminal stance and midswing through terminal swing ($p \leq 0.0007$).

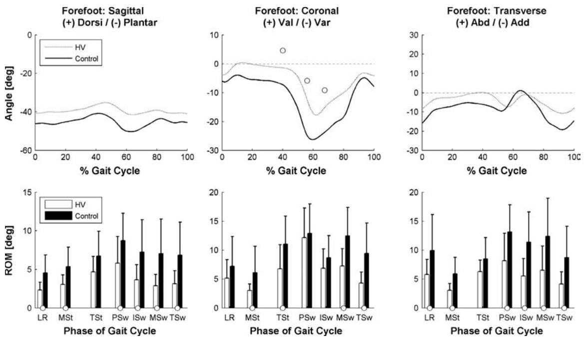


**Fig. 2:** Upper: average forefoot kinematics during complete gait cycle (HV vs. Control). Circles denote phases of gait cycle with significantly different minimum and maximum positions. Lower: forefoot ROM (average ± 1SD). Circles denote phases of gait cycle with significantly different ROMs. Note: Forefoot kinematics were calculated relative to hindfoot.

## Hindfoot kinematics

In general, hindfoot positions were not significantly different from healthy ambulators. However, there was a noticeable decrease in dorsiflexion and eversion throughout the gait cycle (Figure 3). Significant ROM differences were found in all planes ($p \leq 0.0015$). Hindfoot transverse ROM was significantly diminished from midswing through load response and a significantly decreased coronal range was noted from midswing through midstance. Sagittal ROM was significantly decreased at load response and at midswing.

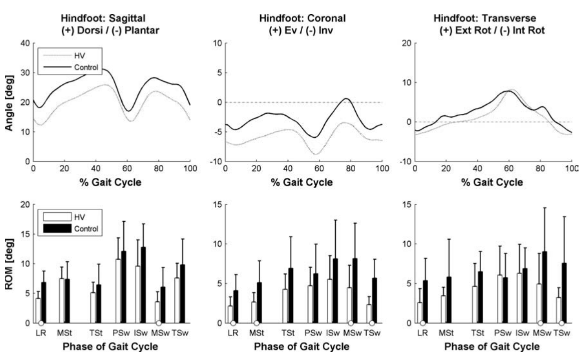


**Fig. 3:** Upper: average hindfoot kinematics during complete gait cycle (HV vs. Control). Circles denote phases of gait cycle with significantly different minimum and maximum positions. Lower: hindfoot ROM (average ± 1SD). Circles denote phases of gait cycle with significantly different ROMs. Note: Hindfoot kinematics were calculated relative to tibia.

## Tibia kinematics

The most noticeable difference in tibial kinematics was a shift towards internal rotation throughout the gait cycle (Figure 4). This shift was most notable from heel strike through midstance. There were significant ROM differences noted in various phases in three planes ($p \leq 0.0018$).

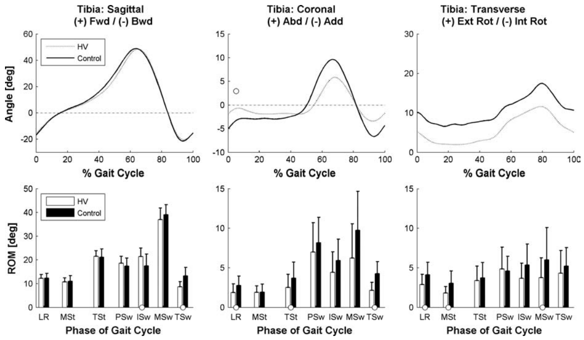


**Fig. 4:** Upper: average tibia kinematics during complete gait cycle (HV vs. Control). Circles denote phases of gait cycle with significantly different minimum and maximum positions. Lower: tibia ROM (average ± 1SD). Circles denote phases of gait cycle with significantly different ROMs. Note: Tibia kinematics were calculated relative to laboratory global.

## Outcomes assessment

Twenty-six members of the HV group provided a response to the SF-36 outcomes assessment. These data are presented in Table 2. Compared to age-matched normative values,[5] significant decreases were seen in "Physical Function" ($p = 0.0188$) and "Bodily Pain" ($p = 0.0004$) subscales.

**Table 2:** SF-36 results. Values are scaled to a 100-point scale

| | Mean and Standard Deviation |
|---|---|
| Physical Function | 79.8 ± 14.2 |
| Role-Physical | 84.6 ± 27.4 |
| Bodily Pain | 63 ± 21.6 |
| General Health | 76.4 ± 17.6 |

# Discussion

This study aimed to characterize multisegmental foot and ankle kinematics in a population of patients with hallux valgus. Five of the 33 patients exhibited bilateral hallux valgus. To ensure that there were no differences in gait between bilateral and unilateral hallux valgus, a nonparametric comparison was conducted. The HV group was compared to a previously tested population of healthy ambulators with comparable height and weight.

This study found altered gait in patients with hallux valgus when compared to healthy ambulators. Patients walked slower (walking speed, $p = 0.0018$) and had shorter strides (stride length, $p < 0.0001$). Stance phase of gait was also prolonged in patients with hallux valgus which may reflect the inability of the hallux to effectively push off during the third rocker. The findings of reduced velocity and stride length and prolonged stance in patients with HV are consistent with previous reports in the literature.[10,18,28] These alterations may be due in part to displacement of the flexor complex which diminishes the great toe's ability to bear weight, provide stability, and push off at terminal stance.[8,22] These observations are supported by previous studies which have shown that isometric strength of the hallux is decreased by 50% and peak force generation is decreased by about 37% in hallux valgus.[22]

While the HV and Control groups did not differ in height or weight, they did differ in age. Previous authors have demonstrated that temporal/distance parameters stabilize by age 20 and remain largely unchanged throughout most of adult life.[11,23] Based on age-stratified temporal parameters[11], and given the ages of the two groups in the study, differences of 2.5% in walking speed and 1% in stance duration are expected. The larger changes measured in this study (−9.8% walking speed, +1.83% stance duration) may be attributed to a pathologic cause.

In the transverse plane, the HV group demonstrated excessive valgus position of the hallux throughout the gait cycle. This was expected due to the excessive valgus noted on clinical exam and radiographs; however, this positional abnormality was accompanied by diminished varus-directed motion from swing to midstance, as demonstrated by the Control group. This may be the result of the plantarward displacement of the abductor hallucis tendon, normally located medially, leaving the capsule as the only medial restraint.[8] Contraction of the nondisplaced abductor hallucis longus pulls the great toe medially away from the second ray. Likewise, the nondisplaced flexor complex of the great toe in healthy individuals enables the hallux to effectively push off the ground. The displaced pull of the flexor complex in HV may account for the increased hallux pronation from preswing through initial swing in our population of patients. Changes in hallux position have been shown to alter joint axes and moment vectors at the MTP1 joint.[22] This may be the reason for the altered hallux sagittal and coronal ranges of motion. This may also occur with soft tissue (capsule and ligaments) and articular pathologies.[10,25] Our range of motion findings corroborate results originally reported by Hwang et al.

Sagittal plane abnormalities in position and ROM of the forefoot suggest flattening of the longitudinal arch. This finding agrees with the association of hallux valgus with pes planus in the literature.[1,8,25] The forefoot valgus shift on plantar loading is consistent with this sagittal deformity and possibly results from a valgus moment as the forefoot bears weight on the lateral aspect. Numerous studies have noted that in HV, plantar pressures are typically transferred from the first metatarsal to the lesser toes, frequently resulting in metatarsalgia.[3,6,18,29] This has been attributed to displacement of the flexors, reduced flexor function and decreased great toe load at toe off, thus transferring stress to the lateral metatarsals.

Plantar load shifting laterally is also supported by hindfoot inversion, hindfoot internal rotation, and the decrease in tibial external rotation throughout gait. These findings are consistent with previous work in the orthopedic literature demonstrating lateral shift of weightbearing.[4,14,16] This may also account for the reduced velocity and stride length and prolonged stance phase in patients with HV as seen in this study and other investigations.[10,18,25,28] Hwang et alreported excessive hindfoot eversion and external rotation in early stance which agrees with a radiographic study by Tanaka et al. and the pedobarographic study by Yamamoto et al.[27,30]

The results of the current study are indicative of significant kinematic changes and altered temporal-spatial parameters reflective of reduced ambulatory function in patients with HV. Physical Functioning and Bodily Pain subscale scores from the SF-36 support these findings. The HV group had significantly poorer scores in these categories compared to age-matched normative values.[5] While nine subjects demonstrated medical comorbidities (asthma, heart disease, hypertension, endometriosis, depression, and Crohn's disease), their Physical Functioning and Bodily Pain subscale scores were wide-ranging within the HV group as a whole. One of these subjects also presented with bilateral first tarsometatarsal joint arthritis. The current study effectively described triplanar changes that occur in the proximal segments of the foot and ankle in a population of patients with HV. This study covered a wide range of disease severity, though the majority of those tested presented with moderate HV.

Ongoing and future work will establish larger pools of subjects with mild and severe HV, with the goal of assessing variations in kinematic abnormalities as disease severity increases. Postoperative assessment is also ongoing to investigate how kinematic deficits in more proximal segments are affected by surgical intervention. Initial findings in 10 subjects show significantly improved hallux positions in all three planes but temporal-spatial parameters and range of motion did not exhibit similar improvements. Continued postoperative assessment with a larger population is suggested. Further improvements in future studies should include prospective longitudinal studies of persons with risk factors for hallux valgus.

## Acknowledgements

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