Kinematic Analysis of Gait in Patients with Juvenile Hallux Valgus Deformity*

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Abstract
The juvenile form of hallux valgus (JHV) develops during the growth period of children and adolescents. The purpose of our study was to investigate the kinematic changes of the lower extremity segments during gait in subjects with and without JHV. Subjects diagnosed with JHV (n = 27, age = 20.5 ± 1.2 yrs, mass = 61.2 ± 10.1 kg) were compared to a healthy controls (n = 11, age = 21.5 ± 1.3 yrs, mass = 66.6 ± 12.5 kg). Spatial parameters along with 3-D video motion kinematic data were collected from the pelvis, hip, knee, and ankle of both lower extremities as the subjects walked at self-selected speeds. Results were analyzed with a two-factor ANOVA followed by Fisher LSD post hoc test. Maximum hip extension was smaller in the JHV groups (p<0.05) compared to the control group and maximal flexion at the hip that was greater in the JHV groups than in the control group (p<0.01). The one-sided JHV group walked with a shorter stance due to lack of full hip extension, contributing to a smaller knee extension range (p<0.01) at the late stance. In the JHV group the larger step coupled with increased plantar-flexion (p<0.01) may result from the greater hip flexion found during the loading response. These data suggest the influence of the JHV deformation on the kinematic parameters of the lower extremities during gait.

Key words: Juvenile Hallux Valgus, Gait, Kinematics

1. Introduction
The basic functions of the foot are energy absorption when the foot contacts the ground, stabilization of posture, and the transfer of muscle force following takeoff (1). Approximately 75% of the body mass is transferred to the calcaneus, and 25% is transferred to the metatarsals’ heads as a result of which 10% of this mass is transferred to the first metatarsal head (2). During the final contact stage of gait 40% of body mass is loaded on the hallux, the resultant force is about 600 N (3). These values show the importance of the first metatarso-phalangeal (MTP) joint and the hallux during the load transfer. Internal factors such as hormonal changes and nociceptive irritation along with external factors, including shape of the shoes and sports activities, can have a negative impact on the loading of the foot.
One of the most common deformities of the foot is hallux valgus (HV), which is a complex condition involving a number of deformities and severe dislocations. The typical deformity is the valgus of the hallux with increased varus of the first metatarsal, where the intermetatarsal angle measures more than 15 degrees. Part of this deformity is pronation of the hallux with plantar movement of the abductor hallucis tendon. The first MTP joint is predisposed to a HV by a planovalgus deformity, which is caused by knee valgus which leads to compensatory ankle or foot valgus, resulting in loss of the midfoot arch and soft-tissue weakness.

Reasons for the development of the HV differ; several associating factors cause this deformity. The primary cause of HV is the abnormal pronation in the subtalar joint. Additionally, the HV represents the consequence of the weakening of the abductor hallucis, which, when it is normally developed, supports the arch of the foot. Alternatively, Shine reported that the most important cause of HV is the use of the improperly fitting shoes. Finally, the overload of the foot with the static load plays an important role in the development of HV, along with genetic factors.

According to the National Center for Health Statistics, HV is a frequently seen condition. It is estimated that 1% of the U.S. adult population has HV, and the number of cases increases with age, with 16% of people over the age of 60 are affected. Adults are not the only ones affected; children suffer from the deformity, which is termed juvenile hallux valgus (JHV). To demonstrate the prevalence of JHV, Kilmartin et al. reviewed 6,000 radiographs of young subjects and found 60 cases of both-sided JHV, 36 cases of one-sided JHV.

JHV develops during the growth period of children and adolescents. It differs from adult HV in that there is a lower degree of valgus, there are no arthritic changes in the first MTP joint, and pain, chronic infection, and swelling of the bursa are usually absent. The pathomechanic etiology of JHV is great toe abduction that can be seen before the development of the metatarsus primus varus, which is medial deviation of the first metatarsal with an increased first-second metatarsal angle. The first stage of deformation starts with the lateral subluxation of the proximal phalange in the MTP joint. This abnormality is connected with the hypermobility of the first ray, which is the consequence of the calcaneal aversion in the foot adduction type. While the deformity can occur during the early stages of life, the symptoms usually do not manifest until adulthood.

The theories about the JHV origin are often mixed. One reason that has been posited for JHV development is based on the relationship to the postural ontogene, which looks at the overall balance between JHV and functional joint centralization (or decentralization). The loss of stabilization of one joint causes decentralization of other joints, subsequently affecting muscle synergies and therefore body posture. Another similar theory is the influence of the distal-proximal chain model, which suggests that a dysfunction in one endpoint of the joint leads to decentralization of the central core.

Biomechanical research suggests that during the terminal stance followed by pre-swing of normal gait the whole lower extremity (including the pelvis, femur, tibia, and talus) rotates outward, and at pre-swing phase the outward rotation is at the maximal degree. These mechanisms of gait allow for greater stability around the hip, knee, shank, and ankle joints. Foot deformity can negatively alter the phases of gait and conversely, changes in gait can cause foot deformity.

The purpose of this study was to investigate the kinematic changes of the lower extremity segments during gait in subjects with and without JHV.

2. Methods

Twenty seven subjects with JHV (mean age 20.5 ± 1.2 years, mean mass 61.2 ± 10.1
kg) were recruited and divided into two groups; (1) one-sided JHV (JHV1, n = 8, mean age 20.5 ± 1.0 years, mean mass = 67.3 ± 12.2 kg), (2) with both-sided JHV (JHV2, n = 19, mean age 20.5 ± 1.27 years, mean mass 58.6 ± 7.7 kg). A healthy control group consisted of 11 subjects (CON, mean age 21.5 ± 1.3 years, mean mass 66.6 ± 12.5 kg).

Three-dimensional (3D) video image data were collected by four 50 Hz video cameras (JVC GR-DVL9800). The video images of each marker placed on the subjects were digitized by the commercial software package APAS (Ariel Dynamics Inc, Trabuco Canyon, CA) with the quintic spline interpolation.

Prior to gait data collection radiograph examinations were done to observe forefoot to rearfoot relationships during load. Following the radiograph a qualitative clinical examination of the lower extremities and pelvis was performed.

While subjects were standing barefoot and wearing swimsuits a set of 17 external markers was attached (bilaterally) to significant anatomical locations of pelvis and both lower extremities: (1) anterior superior iliac spine (ASIS), (2) posterior superior iliac spine (PSIS), (3) capitulum fibulae, (4) greater trochanter, (5) lateral femoral condyle, (6) tibial tuberosity, (7) lateral malleolus, (8) the fifth metatarsal head. One final marker was placed on the spinus process (L5). After placement of the marker sets, subjects were then instructed to walk at a self-selected pace straight across a gait laboratory walkway. Each subject performed two practice walking trials to gain familiarity and five subsequent post-familiarity walking trials. As the subjects performed the walking trials they were video tapped.

From the 3D angular displacement the following dependent variables were quantified at gait cycle phases: The pelvis in the transverse (forward/backward rotation) and frontal (drop/rise) planes, hip in the sagittal (flexion/extension) and frontal (abduction/adduction) planes, knee in the sagittal (flexion/extension) plane, and ankle in the sagittal plane (plantar/dorsiflexion) (Fig. 1). The measured peak data were analyzed by using a two-factor ANOVA followed by Fisher LSD post hoc test (STATISTICA, version 6.0, Stat-Soft, Inc., Tulsa, Oklahoma, USA). P-values less than 0.05 were considered significant.

3. Results

The angular joint changes over the normalized gait cycle are illustrated in Figures 2-4. The patterns of the joint angular displacement of the measured groups showed no unusual features and are similar as common patterns of the hip, knee and heel in the sagittal plane. The CON group flexed the hip joint maximally later (90% of the normalized gait cycle) in comparison to the JHV groups (85-87% of the cycle) (p<0.05). The HV2 group achieved minimum knee flexion during the terminal stance (35% of cycle), there was significant...
difference found with the CON group (37% of cycle), HV1 injured leg (38% of cycle) and HV1 healthy leg (p < 0.05). The maximum dorsiflexion was reached by the HV1 groups at 46% of the walking cycle; the other two groups (HV2 and CON) showed this value between 43 and 44% of the gait cycle (p < 0.1).

Fig. 2  Hip flexion/extension angular position (in deg) during the gait cycle

Fig. 3  Knee flexion/extension angular position (in deg) during the gait cycle
3.1 Subjects with both-sided JHV

The following statistical differences are compared to the control group. The subjects demonstrated a greater range of motion (ROM) in the frontal plane during the pelvis drop and rise (p < 0.01) (Fig. 5), and a tendency to a decreased lower extremity abduction angular position during the gait cycle (p < 0.01) (Fig. 6). As the individuals stabilized their body weight at loading response their peak ankle plantar flexion was greater (p < 0.01) (Fig. 7). Additionally, the subjects experienced smaller peak hip extension (p < 0.05) at terminal stance (Fig. 8). When the foot advanced from its trailing position to a swing phase the peak knee flexion increased its angular value (p < 0.01) at initial swing (Fig. 9), and the peak hip flexion showed the statistical difference (p < 0.01) at terminal swing (Fig. 10).

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**Fig. 4**  Ankle plantar/dorsi flexion angular position (in deg) during the gait cycle

**Fig. 5**  Peak range of motion of the pelvis (in deg) in the frontal plane

**Fig. 6**  Minimum hip adduction (in deg) during the gait cycle
3.2 Subjects with one-sided JHV

A smaller ROM was found in the pelvis anterior/posterior rotation in the transverse plane (p < 0.01) compared to JHV2 and controls (Fig. 11). In order to preserve the gait progression during the beginning of the gait cycle, these subjects showed the larger peak plantar-flexion (p < 0.01) at loading response compared to healthy controls (Fig. 7). Then the body progressed beyond the supporting foot to terminal stance, and the minimum knee flexion was found greater (p < 0.05) compared to JHV2 subjects and controls (Fig. 12), and the peak hip extension decreased (p < 0.01) in comparison to control group (Fig. 8). The swing phase was characterized by increased peak knee flexion (p < 0.01) than control group at initial swing (Fig. 9), and the higher peak hip flexion (p < 0.01) at terminal swing compared to control subjects (Fig. 10).
4. Discussion

The pelvis and the joints of the lower extremity rotate outward at the terminal phase. This mechanism gives stability around the hip, knee, shank, and foot (19). It was found in the clinical examination that subjects with JHV show the opposite rotation at the hip and knee during the same phase (2). Based on the increased demands on pelvic stability, the muscle tension in the pelvis and hip adductors are increased (19). Our study showed a larger pelvic ROM in the frontal plane (drop and rise) in both-sided JHV subjects might be, besides others, caused by insufficient stabilization of the foot, which cannot adapt to the changing load.

4.1 Biomechanical instability in subjects with both-sided JHV

At loading response of the gait cycle the heel becomes the center of rotation around which the tibia and other foot segments rotate. This “heel rocker” functions as an absorption when the eccentric contraction of the tibialis anterior, extensor digitorum longus, and peroneus tertius prevents the plantar-flexion ankle moment (21). An excessive ankle plantar-flexion found in both JHV groups at loading response phase may be the result of muscle disorder co-activation in the region of the foot and shank, which affects dynamic stability of the ankle joint. Specifically, the weakness in the extensor hallucis longus causes the premature loading of the forefoot is followed by inadequate dorsiflexion at MP joint (22), which was not found in the present study. The decreased peak hip extension functions as a “set up” for the increased hip flexion found in the later phase.

The requirement of the correct function of the leg is the functional stability of the first MTP joint because it has a key role at the terminal stance of the gait cycle, and a disorder of MTP joint stability in JHV patients does not allow the optimum foot position at toe-off (23). The increased hip and knee flexion compensates the insufficient stability of hallux and helps the effective foot clearance during the following swing phase.

Tichy showed a reciprocal relationship between the hip flexion and extension with increased hip adduction and inward rotation as a functional joint blockade, which causes decentralization of the hip joint (24). This may create a movement variability of the hip, knee and ankle joints, and this phenomenon is considered as a mutual chain reaction in kinematics of gait.

4.2 Biomechanical instability in subjects with one-sided JHV

Some of the statistical differences found in JHV2 were also found in JHV1 group, i.e., increased plantar-flexion during the stance. This non-advancement over the forefoot rocker minimized the foot trailing motion and was combined with the reduced peak hip extension...
when the weight was transferred to the healthy leg at terminal stance. As a result of the latter reduction, the pelvis anterior/posterior range of motion (ROM) was lower during the whole gait cycle. To compensate for the insufficient hip extension during stance the plantar-flexed foot needed to be lifted and caused the observed excessive knee and hip flexion during swing phase. If the function of the foot (JHV1) is dysfunctional, the dynamic motion is transferred to the hip and knee.

When judging the results of our study we need to observe small sample size in the groups. Another of the limitations of our study was an execution of the gait cycle barefoot and without correction of the foot deformity. Further research should include the execution of the gait cycle with the improvement of the big toe deformity with correctors, orthotic devices, or functional tapping. It is therefore important to analyze gait during stepping on uneven surfaces and also involvement of upstairs and downstairs gait.

5. Conclusion

The data in our study suggest the influence of the JHV deformation on the kinematic parameters of the pelvis and the lower extremities during gait. It is necessary to regard JHV such a complex deformity, not only as localized foot problem. It needs to be perceived as an indication or a symptom of associated abnormal biomechanical function of the entire lower extremity. It is necessary to extend the search for etiology to include proximal-distal influences of chain functional failures in postural locomotor system and understand the concept of treatment and prevention of such deformity.

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References


