10-25-2016

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Abstract

Background: The aim of our study was to compare spatiotemporal parameters and lower limb and pelvis kinematics during the walking in patients with hallux valgus before and after surgery and in relation to a control group.

Methods: Seventeen females with hallux valgus, who underwent first metatarsal osteotomy, constituted our experimental group. The control group consisted of thirteen females. Kinematic data during walking were obtained using the Vicon MX system.

Findings: Our results showed that hallux valgus before surgery affects spatiotemporal parameters and lower limb and pelvis kinematics during walking. Hallux valgus surgery further increased the differences that were present before surgery. Specifically after hallux valgus surgery, the walking speed decreased even more ($p = 0.09$, $\eta2 = 0.19$) while step time increased ($p = 0.002$, $\eta2 = 0.44$) on both legs. The maximum ankle plantar flexion of the operated leg during toe-off decreased to a greater extend ($p = 0.03$, $\eta2 = 0.26$). The asymmetry in the hip and the pelvis movements in the frontal plane (present preoperatively) persisted after surgery.

Interpretation: Hallux valgus is not an isolated problem of the first ray, which could be just surgically addressed by correcting the foot's alignment. It is a long-term progressive malfunction of the foot affecting the entire kinematic chain of the lower extremity.

Keywords:

Foot, Walking, Surgery, Biomechanics, Locomotion

1. Introduction

The hallux valgus (HV) deformity affects 23% of adults aged 18– 65 years and 35.7% of elderly aged over 65 years (Nix et al., 2010). The patients usually complain of pain, difficulties during walking and problems with the selection of shoes. Menz and Lord (2005) identified significantly reduced walking speed and step length in patients with HV as compared to patients without HV or mild HV. In addition, Deschamps et al. (2010) reported a reduced duration of the stance phase and stride time during walking in patients with HV. In severe stages of this deformity, surgery is required; however, if surgery actually improves walking mechanics remains unclear.

In the available literature N 400 surgical procedures were described, correcting the axis of the first ray (Dungl, 2005). Their effectiveness is evaluated in most cases by radiological examination, the American Orthopaedic Foot and Ankle Society (AOFAS) scores and subjective feelings of the patient (Baba et al., 2009; Carr and Boyd, 1968; Deenik et al., 2008; Flamme et al., 1998; Glazebrook and Copithorne, 2008; Kilmartin et al., 1992, 1994; Kleinberg, 1932; Kristen et al., 2002; Mauldin et al., 1990; McBride, 1939; O'Donnell et al., 2009; Orzechowski et al., 2008; Perugia et al., 2003; Pressman et al., 1986; Resch et al., 1994; Saragas, 2009; Saro et al., 2007b,c; Yucel et al., 2010). However, these outcome measures are either static or subjective, and thus objective evaluation during dynamic conditions (i.e. walking) of the HV surgical procedures is seriously lacking.

There are a few studies that have evaluated changes in gait after HV surgery, but their assessment is limited to the pressure distribution under the foot (Bryant et al., 2005; Dhukaram et al., 2006; Milani and Retzlaff, 1995; Nyska et al., 1998; Saro et al., 2007a; Stokes et al., 1979). However an HV deformity can influence not only foot loading, but also gait kinematics, because an individual with HV has a different lower limb alignment compared to the normal population (Steinberg et al., 2013). For example, a consistent coupling relationship was found between hallux plantar/dorsiflexion and hindfoot inversion/eversion (Dubbeldam et al., 2013). Significant correlations between movements of various body segments were also found not only within the foot, but also across the entire lower limb and pelvis. Foot alignment in the frontal plane (calcaneal valgus) correlates with hip rotation and pelvic tilt (Svoboda et al., 2014). Further it has been shown that a reduced arch height index is associated with increased pelvic retraction and increased knee valgus in midstance (Kothari et al., 2016), while significant correlation exists between foot rotation and hip and pelvis rotations (Gaston et al., 2011). These findings suggest that foot alignment as well as an HV deformity can influence movement of the entire lower limb and pelvis.

However, and to our knowledge, there are no studies that have assessed how HV surgery, which attempts to correct foot alignment, affects spatiotemporal parameters and lower limb and pelvis kinematics during walking. This is of great importance considering that surgical treatment is a crucial part of the HV medical management.

Therefore, the aim of our study was to compare spatiotemporal parameters and lower limb and pelvis kinematics during the gait cycle in patients with HV before and

after surgery and in relation to a control group. We hypothesized that the presence of HV negatively affects not only spatiotemporal parameters and foot kinematics during walking, but also knee, hip and pelvis kinematics compared to healthy controls. We also hypothesized that HV surgery will now affect spatiotemporal parameters and lower limb kinematics during walking in a lesser degree and will eliminate differences found before surgery.

2. Methods

2.1. Patients and procedure

Twenty eligible patients (19 women and 1 men) met our inclusion criteria: age 40–70 years, mild to moderate deformity HV (classification according to American Orthopaedic Foot & Ankle Society), without metabolic and neurological diseases and an ischemic disease of lower limb. However, only seventeen of them agreed to participate on this study. Seventeen females with clinical and x-ray diagnosed HV deformity constituted our experimental group (mean (SD)): age = 51.5 (11.4) years, weight = 69.2 (10.9) kg, height = 165.2 (5.9) cm, BMI = 25.5 (4.9). Exclusive representation of females in the experimental group was purely accidental. Meta-analysis of 24 studies showed a higher prevalence of HV in females [30% (CI: 22 to 38)] (23 studies) compared to males [13% (CI: 9 to 17)] (22 studies) (Nix et al., 2010). Our patients were indicated for HV surgery, specifically osteotomy of the first metatarsal. The control group consisted of thirteen females without HV deformity: age = 47.4 (7.1) years, weight = 70.5 (11.2) kg, height = 166.4 (3.7) cm, BMI = 25.42 (3.5). All participants that had a previous surgery on their lower limbs or any presence of pain were excluded from the study.

The preoperative examination contained a clinical orthopedic and x-ray examination (anteroposterior and lateral oblique projection). It also included a detailed gait analysis in a biomechanics laboratory. In the control subjects the preferred foot was determined by having to answer the following questions: Which foot would you use to kick a stationary ball at a target straight in front of you; If you wanted to pick up a marble with your toes, which foot would you use; Which foot would you use to stomp on a fast-moving bug; If you had to step up onto a chair, which foot would you place on the chair first. A limb was considered as preferred if the subject chooses this limb in at least three questions.

All patients then underwent first metatarsal osteotomy. Immediately after surgery, as well as six weeks and three months after surgery, all patients underwent a control x-ray and clinical orthopedic examination. The postoperative gait analysis evaluation took place four months post-operatively. After the surgery a gypsum fixation were used for 4–6 weeks, which was followed by physical therapy, including balneotherapy, soft tissue techniques and exercise of the operated segment. If there were not any complications, the patient returned to work and activities of daily living. According to Kristen et al. (2002) the time from surgery to return to work is 5.8 weeks and to sports 8.4 weeks. This time table fits well with the time we identified for our post-operative gait analysis

evaluation. The design of this study was approved by the Ethics Committees of the university and teaching hospital. All patients participated voluntarily and gave their written informed consent prior to the study.

2.2. Measures

Kinematic data were obtained at 200 Hz using the Vicon MX system (seven infrared cameras, Vicon Motion Systems, Oxford, UK). Prior to the measurement, 16 reflective markers were placed on the subject's lower limbs and the pelvis using the Plug-In Gait model (Vicon, 2016) (Fig. 1). The reflective markers were placed always by the same investigator (an experienced physical therapist with 10 years of clinical practice) to minimize intra- and inter-subject variability due to marker placement. Patients were instructed to walk barefoot at their self-selected pace. A self-selected pace was used because we did not want to affect kinematics by using a pre-determined speed. In addition, speed was an outcome measure and we wanted to see if it will also improve post-surgery. Subjects performed several trials for familiarization and five trials for evaluation using the Vicon Nexus software. The kinematic data were filtered with a 10 Hz cut-off using procedures described by Woltring (1986). We then identified several spatiotemporal parameters of the gait cycle as well as the maximal and minimal peaks of the ankle, knee, hip and pelvis motions in the sagittal, frontal and transverse plane. For statistical comparison values from five trials were averaged.

2.3. Statistical analysis

Following a Shapiro-Wilk normality test which showed that our data were normally distributed, we used a two way repeated measures ANOVA where the two factors were: 1) operated versus non-operated leg and 2) before versus after surgery. Post-hoc analysis was performed using the Fisher's LSD test (Statistica 10.0, Stat-Soft, Inc., Tulsa, OK, USA). Kinematic data that were obtained before and after HV surgery were also compared with the control group using independent two-sample t-tests as follows: 1) operated leg versus non-preferred leg and 2) non-operated leg versus preferred leg. We selected to compare the operated leg with the preferred leg because the surgically repaired foot is functionally in worse condition than the foot without any deformity. The non-preferred leg in a healthy population is also generally less functional compared to the preferred leg. The level of statistical significance was set on 0.05. Moreover, the effect size was determined using the omega-squared ($\omega2$) for the ANOVA and the Hedges' g (g) for the t-test. A "rule of thumb" was employed; if it was N 0.01 was identified as a small effect, N0.06 as a medium effect and N0.15 as a large effect (Cohen, 1988).

3. Results

There were no significant differences with respect to the age, weight and height between the experimental and the control groups. Before the surgery all patients had foot pain and in most cases in the toe and metatarsals areas. Four months after surgery, 10 out of 17 patients had no pain.

3.1. Kinematic parameters before surgery

Patients with HV deformity walked significantly slower compared to the control group (CG) (p b 0.05, g = 0.7). Furthermore, the HV group exhibited significantly shorter stride length on both legs as compared to CG (p b 0.05, g = 0.9) (Table 1). The HV deformity most markedly changed the ankle kinematics during the gait cycle as compared to CG (Table 2, Fig. 2). In the patients with HV, we observed a smaller range of ankle movement in the sagittal plane on both legs (p b 0.05, g =0.8). They showed a smaller maximum of plantar flexion during toe-off (p b 0.001, g = 1.3) and a greater maximum of dorsal flexion at the end of the swing phase on both legs (p b 0.05, g = 0.9). The maximum of knee extension was bilaterally smaller during the swing phase in the patients with HV (p b 0.05, g = 1.0). Hip and pelvis kinematics was significantly asymmetric in the patients with HV (Table 2, Figs. 3 and 4). We found a smaller maximum of hip abduction at the beginning of the stance phase (p = 0.01, η2 = 0.1) and a greater maximum of hip adduction during the pre-swing phase in the patients with HV as compared to the controls (p = 0.01, η2 = 0.13). Regarding the pelvis kinematics, we found that the side where the HV deformity was present showed that the maximum of pelvis elevation was smaller at the beginning of stance phase (p = 0.02, η2 = 0.14) and the maximum of pelvis depression was greater during the pre-swing phase as compared to the side without the HV deformity (p = 0.02, η2 = 0.14).

1. Anterior Superior Iliac Spine (R, L)
2. Posterior Superior Iliac Spine (R, L)
3. mid-Thigh Stick (R, L)
4. Knee Joint (R, L)
5. mid-Shank Stick (R, L)
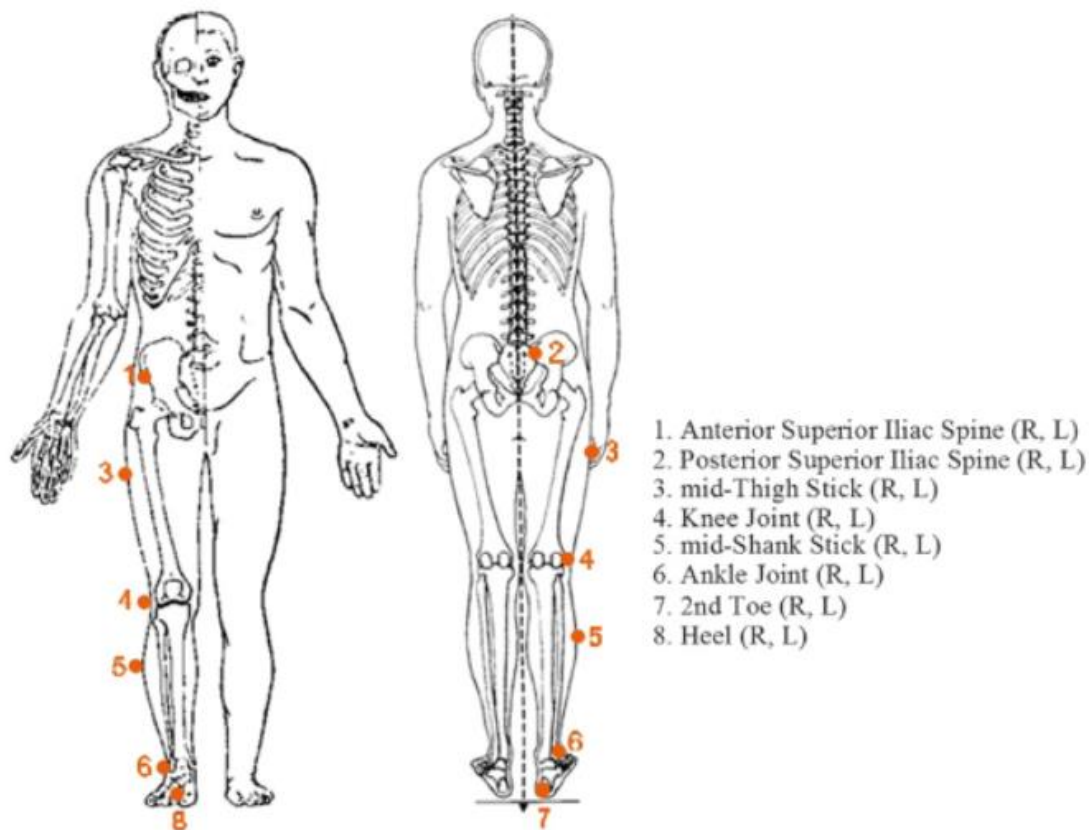6. Ankle Joint (R, L)
7. 2nd Toe (R, L)
8. Heel (R, L)

Fig. 1. Location of the reflective markers. Legend: R – right, L – left.

3.2. Kinematic parameters in the operated leg after surgery

HV surgery resulted in even greater decrease in the walking speed (p = 0.09, η2 = 0.19) while step time increased (p = 0.002, η2 = 0.44) (Table 1). HV surgery did not markedly influence the lower limb and pelvis kinematics (Table 2). However, we found that the maximum of plantar flexion during toe-off was even more decreased (p = 0.03, η2 = 0.26) (Table 2, Fig. 2). The surgery did not change the hip and pelvis kinematics. However, the asymmetry that was present in the hip and the pelvis movements in the frontal plane persisted (Table 2, Figs. 3 and 4). We found a smaller maximum of hip abduction with pelvis elevation at the beginning of the stance phase (p = 0.03, η2 = 0.13) and a greater maximum of hip adduction with pelvis depression at the end of stance phase in the operated leg as compared to the non-operated leg (p = 0.03, η2 = 0.12).

Table 1
Spatiotemporal parameters during the gait cycle in patients with HV before and after surgery as well as in healthy controls.

Group	HV				CG	
	nL		oL		pL	npL
	Before surgery	After surgery	Before surgery	After surgery		
Parameter	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Cadence [step/min]	112.65 ± 9.2	108.49 ± 9.5*	111.76 ± 10.3	108.53 ± 9.4	104.29 ± 22.2	104.32 ± 22.1
Walking speed [m/s]	1.15 ± 0.1†	1.07 ± 0.1*,†	1.14 ± 0.1†	1.07 ± 0.1†	1.25 ± 0.2	1.25 ± 0.2
Step length [m]	0.61 ± 0.0†	0.56 ± 0.1*,†	0.61 ± 0.1	0.61 ± 0.0#	0.66 ± 0.1	0.65 ± 0.1
Step time [s]	0.54 ± 0.0	0.54 ± 0.0*	0.54 ± 0.0†	0.57 ± 0.1*,#,†	0.50 ± 0.1	0.50 ± 0.1
Step width [m]	0.13 ± 0.0	0.13 ± 0.0	0.13 ± 0.0	0.13 ± 0.0	0.22 ± 0.2	0.22 ± 0.2
Stride length [m]	1.21 ± 0.1†	1.16 ± 0.1†	1.22 ± 0.1†	1.18 ± 0.1†	1.31 ± 0.1	1.31 ± 0.1
Stride time [s]	1.07 ± 0.1	1.11 ± 0.1	1.09 ± 0.1	1.11 ± 0.1	1.07 ± 0.1	1.07 ± 0.1
Double support [%]	22.59 ± 5.3	24.51 ± 5.1	23.46 ± 6.6	24.80 ± 5.2	24.46 ± 8.2	24.28 ± 8.0
FO [%]	60.65 ± 2.2	62.15 ± 2.1#	60.36 ± 2.9	59.82 ± 1.8#	63.30 ± 8.0	62.98 ± 7.4
Opposite FC [%]	49.84 ± 1.2	51.61 ± 1.5#,†	50.45 ± 2.2	48.55 ± 1.3#	46.97 ± 7.4	47.03 ± 7.7
Opposite FO [%]	10.46 ± 2.2	11.34 ± 2.4#	11.05 ± 3.1	10.58 ± 1.5#	12.95 ± 7.4	12.93 ± 6.9
Single support [%]	42.40 ± 3.7	44.88 ± 3.7*,#	41.95 ± 3.5	42.13 ± 2.6#	44.42 ± 4.8	44.37 ± 5.2

Legend: HV – experimental group with hallux valgus, CG – control group, nL – non-operated leg, oL – operated leg, npL – non-preferred leg, pL – preferred leg, SD – standard deviation, FC – foot contact, FO – foot-off.
† Differences between hallux valgus group and control group (non-operated leg versus preferred leg, operated leg versus nonpreferred leg) (t-test): significance at p < 0.05.
* Differences before and after hallux valgus surgery (two way ANOVA, LSD Fisher's post-hoc test): significance at p < 0.05.
# Differences between operated and nonoperated leg (two way ANOVA, LSD Fisher's post-hoc test): significance at p < 0.05.

Table 2
Kinematic parameters during the gait cycle in patients before and after HV surgery as well as in healthy controls (degrees).

Group	HV				CG	
	nL		oL		pL	npL
	Before surgery	After surgery	Before surgery	After surgery		
Parameter	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Ankle RoM in S	29.92 ± 6.23†	31.12 ± 4.61†	31.35 ± 5.68	32.04 ± 8.93	34.73 ± 6.46	36.88 ± 5.82
Plantar flexion (loading response)	−4.06 ± 4.6	−5.32 ± 4.3	−3.85 ± 3.5	−6.97 ± 6.9	−6.60 ± 8.0	−6.92 ± 5.9
Plantar flexion (toe-off)	−10.58 ± 7.7†	−12.45 ± 5.5†	−10.36 ± 5.3†	−6.72 ± 7.8*,#,†	−18.90 ± 4.6	−19.90 ± 4.4
Dorsal flexion (mid-stance)	19.18 ± 4.8†	18.60 ± 5.2	20.63 ± 5.9	22.24 ± 6.9#,†	15.49 ± 4.0	16.98 ± 5,2
Dorsal flexion (swing phase)	9.16 ± 4.9†	7.47 ± 4.3	9.53 ± 4.4†	6.99 ± 5.0	5.30 ± 4.2	4.96 ± 5.1
Knee RoM in S	58.92 ± 6.42	57.55 ± 5.65	58.21 ± 6.17	59.64 ± 7.21	60.75 ± 3.16	61.67 ± 3.29
Knee flexion (swing phase)	63.51 ± 5.35	60.86 ± 4.40	63.06 ± 5.83	63.74 ± 6.54	61.70 ± 4.22	62.94 ± 5.43
Knee extension (swing phase)	5.21 ± 4.26†	3.99 ± 3.55†	5.84 ± 5.75†	4.90 ± 3.64†	1.04 ± 3.32	1.38 ± 3.55
Hip adduction (stance phase)	11.89 ± 3.5	11.20 ± 4.1	8.23 ± 4.3#	8.28 ± 4.0#	9.48 ± 3.4	9.45 ± 4.6
Hip abduction (pre-swing phase)	−1.88 ± 4.4†	−1.98 ± 5.2†	−5.60 ± 4.5#	−4.95 ± 3.6#	−5.97 ± 1.9	−5.54 ± 4.6
Pelvis elevation (stance phase)	5.34 ± 2.5†	5.13 ± 2.2	2.84 ± 3.0#,†	2.86 ± 3.1#	4.62 ± 2.5	5.46 ± 1.8
Pelvis depression (pre-swing phase)	−2.96 ± 3.1	−2.91 ± 3.1†	−5.44 ± 2.6#	−5.08 ± 2.2#	−5.18 ± 1.5	−4.38 ± 2.7

Legend: HV – experimental group with hallux valgus, CG – control group, nL – nonoperated leg, oL – operated leg, npL – non-preferred leg, pL – preferred leg, SD – standard deviation; RoM – range of movement, S – sagittal plane, F – frontal plane.
† Differences between hallux valgus group and control group (non-operated leg versus preferred leg, operated leg versus nonpreferred leg) (t-test): significance at p < 0.05.
* Differences before and after hallux valgus surgery (two way ANOVA, LSD Fisher's post-hoc test): significance at p < 0.05.
# Differences between operated and nonoperated leg (two way ANOVA, LSD Fisher's post-hoc test): significance at p < 0.05.

3.3. Kinematic parameters in the non-operated leg after surgery

We observed similar changes in the non-operated leg as in the operated leg in the spatiotemporal parameters. HV surgery significantly decreased cadence (p = 0.01, η2 = 0.34) and walking speed (p = 0.006, η2 = 0.45). Step length of the non-operated leg became shorter (p = 0.008, η2 = 0.56) and took more time (p = 0.02, η2 = 0.31), which resulted in increased duration of single support (p = 0.004, η2 = 0.43) and double support phases (η2 = 0.19). However, there were no significant changes in lower limb and pelvis kinematics on non-operated leg after HV surgery.
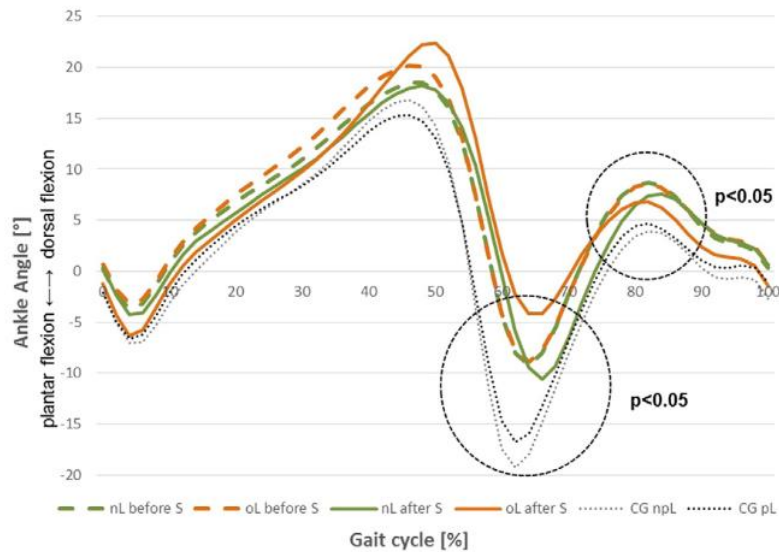

Fig. 2. Ankle movement in the sagittal plane before and after HV surgery. Legend: nL – nonoperated leg, oL – operated leg, S – hallux valgus surgery, CG – control group, npL – non-preferred leg, pL – preferred leg, p – level of statistical significance.

Fig. 3. Hip movement in the frontal plane before and after HV surgery. Legend: nL – nonoperated leg, oL – operated leg, S – hallux valgus surgery, CG – control group, npL – non-preferred leg, pL – preferred leg, p – level of statistical significance.

Fig. 4. Pelvis movement in the frontal plane before and after HV surgery. Legend: nL – nonoperated leg, oL – operated leg, S – hallux valgus surgery, CG – control group, npL – non-preferred leg, pL – preferred leg, p – level of statistical significance.
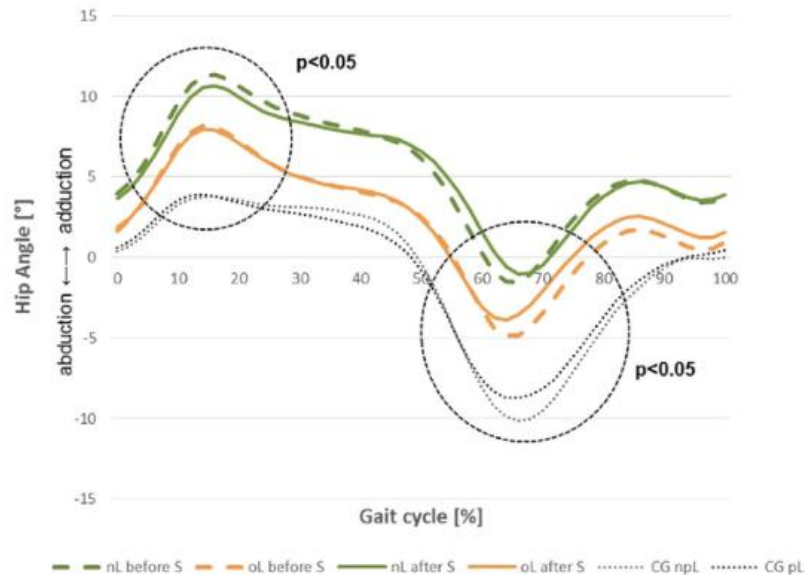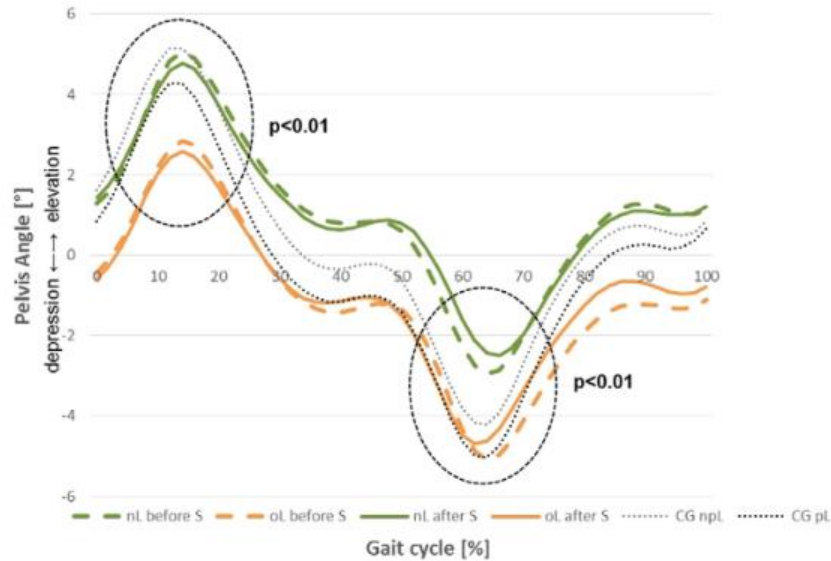
4. Discussion

Our results supported the first hypothesis that HV negatively affects spatiotemporal parameters, foot kinematics during walking and also knee, hip and pelvis kinematics compared to healthy controls. In addition, our results partially supported the second hypothesis as HV surgery does affect spatiotemporal parameters and lower limb kinematics during walking; however, minimal changes were found when comparisons were made between before and after surgery.

In general, values of our control group are similar with values found in the literature for healthy populations in both the spatiotemporal (Bohannon, 1997; Canseco et al., 2008; Kadaba et al., 1989; Kerrigan et al., 1998; Menz and Lord, 2005; Oberg et al., 1993) and the angular variables. For the HV group, spatiotemporal variables are comparable with other scientific studies that also evaluated populations with HV (Bohannon, 1997; Canseco et al., 2008; Kadaba et al., 1989; Kerrigan et al., 1998; Menz and Lord, 2005; Oberg et al., 1993). Regarding the kinematics of the HV group, we did not find any study that examined gait kinematics of the ankle, knee, hip and pelvis in subjects with HV deformity. Thus, we feel confident regarding our methodology and the accuracy and reliability of our data.

4.1. Gait parameters in patients with HV before surgery

With respect to our first hypothesis, we found similar changes in the spatiotemporal parameters in patients with HV as Canseco et al. (2010) in 33 patients and Menz and Lord (2005) in 71 patients. In these studies, the walking speed decreased, as well as stride length, in comparison with the healthy controls. A systematic review published in 2013 that included nine studies, showed no significant differences in spatiotemporal parameters in patients with HV compared to healthy

controls (Nix et al., 2013). However, only five studies included in this systematic review had analysis of spatiotemporal parameters and only two of them assessed the same parameters (walking speed and stride length) as our study. These two studies indicate that differences in spatiotemporal variables due to hallux valgus has a significant detrimental impact on gait patterns that may contribute to instability and risk of falling (Menz and Lord, 2005).

With respect to the lower limb kinematics, this research work is the first that has performed a comprehensive evaluation of the lower limb kinematics in patients with HV deformity and found that HV deformity affects ankle, knee, hip and pelvic kinematics during the gait cycle in comparison to healthy controls. Steinberg et al. (2013) also found different range of motion measured by goniometers for the hip, knee and ankle in subjects with HV compared to healthy controls. They suggested that a full kinematic evaluation of the entire lower limb is in order to comprehend the changes that occur. Other authors (Svoboda et al., 2014) showed an effect of foot alignment on the movement of the hip and even on the movement of the pelvis during gait. Thus it seems that changes at the foot due to HV are felt up in the kinetic chain and affect the mechanics even at the level of the pelvis. However, the majority of the previous scientists that have examined the HV deformity have focused on foot mechanics (Canseco et al., 2010, 2012; Deschamps et al., 2010). Truly, the most markedly (largest difference between the group means; see Table 2) changes were apparent in ankle kinematics at the end of stance phase during toe-off, as we found a smaller maximum of plantar flexion at the end of stance during toe-off in patient with HV compared to health controls. This difference was more pronounced in the leg with the HV deformity. Kozakova et al. (2011) reported greater maximum of plantar flexion during the loading response and a smaller maximum of the dorsiflexion during midstance in patient with HV compared to CG. We observed similar but not significant results in our experimental group. At the hip and the pelvis area, we found an important asymmetry in movement between the affected and the unaffected leg. This asymmetry is documented as follows. The values of the hip and pelvis kinematics in the frontal plane on the affected leg were similar with the healthy controls. However, the unaffected side had greater hip adduction and pelvis elevation at the beginning of the stance phase and smaller hip abduction and pelvis depression at the end of the stance phase as compared to the affected side and the healthy controls. This may indicate that compensations are taking place in the unaffected side to accommodate for the presence of the pathology. This serendipitous and novel finding deserves further study.

4.2. Gait parameters in patients with HV after surgery

Our results partially supported the second hypothesis. This is based on the fact that postoperatively, we found only slight changes in spatiotemporal parameters and ankle kinematics during walking. Interestingly, these changes were not positive but actually highlighted even more some of the differences found in the spatiotemporal parameters

and the lower limb kinematics that were present before surgery and were described above.

The HV surgery further reduced the walking speed, cadence, step time and step length and increase double support time. Paradoxically, even more changes were evident in the spatiotemporal parameters on the non-operated leg after HV surgery. The non-operated leg probably compensated even more for the decreased function of the operated leg during walking. Practically, these changes could be due to pain that is still present in the operated segment or due to the new movement pattern that is now used post-operatively.

We should reiterate here that the HV surgery did not markedly change the lower limb and pelvis kinematics; only made more pronounced the changes found in the ankle kinematics during the preswing phase. The decreased plantar flexion of the operated leg during toe-off is probably related to limited mobility and pain in the operated segment which does not allow sufficient dorsal flexion of the hallux that is needed for a more natural heel-off. A similar situation is described in the case of hallux limitus, which is defined as a limitation of the hallux motion in the first MTP joint during dorsal flexion. Hallux limitus according to Dananberg and Guiliano (1999) disrupts the stabilization of the first metatarsal and, consequently, the load transmission through the first ray. The limited dorsal flexion of the operated segment decreased probably even more the plantar flexion during the preswing phase. The plantar flexion of the foot at the end of stance phase precedes, according to Kirtley (2006), the dorsal flexion at the metatarsophalangeal joints, which is post-operatively limited. During propulsion and according to Frank et al. (2012) approximately 65° of dorsal flexion at the first metatarsophalangeal joint is necessary, however, only 20–30° of the hallux dorsal flexion is actually available. Therefore the additional 40° of the required motion is provided by the plantar flexion of the first metatarsal at the sesamoid complex. Consequently the toe-off at the end of stance phase could not be performed effectively.

The asymmetry found in the hip and pelvis kinematics in the frontal plane before surgery, persisted after surgery. The fact there are no other studies that have evaluated the effect of HV surgery on the hip and pelvis kinematics, signifies the importance of further studies to confirm this result. However, we should mention here that our examination showed that in most patients from our experimental group there was a positive Trendelenburg sign both before and after the surgery. A positive Trendelenburg sign is characterized by muscle imbalance between the abductor and adductor muscles. Dananberg (1993a,b) and Dananberg and Guiliano (1999) previously described that a malfunction of the first ray is related to postural disorders. They pointed out the relationship between functional hallux limitus and chronic postural ailments, including overloading structures in the lumbar spine and low back pain. HV is certainly a complex foot deformity and is closely related with foot dysfunction, which means disruption of the basal support during standing, shock absorption and loading transmission during

walking (Kozáková et al., 2010; Lorimer et al., 2006). Our results provide further support to these propositions.

Between other factors which can influence gait variables is also pain. In the present study, all patients with HV deformity complained about the pain. The pain was one of the main indication for surgery. After HV surgery, almost 60% of patients still reported the pain. Menz et al. (2015) showed that foot pain is significantly associated with difficulty performing various weight-bearing activities such as: remaining balanced while standing, standing for ≥ 15 min, getting in and out of a car, getting in and out of bed, getting in and out of a chair, walking two to three blocks, walking across a small room and walking up and down a flight of stairs.

A limitation of this experimental study is that recruitment of patients into experimental and control groups was carried out based on availability. However, both experimental and control groups has the similar baseline characteristic, such as age, weight, height, etc. In case of kinematic analysis, we should consider the inter- and intra-individuality performance of palpation when placing reflective markers on the skin. Inter-individual variability at multiple measurement is associated with higher risk of error than intra-individual variability (Leardini et al., 2006; Piazza and Bansal, 2003). Intra-individual variability, we could not eliminate due to repeated measurements before and after surgery HV, however, placement of reflective markers were done by one experienced physical therapist. Also accurate palpation is according to Lewit (2009) affected by "palpable illusion" caused by physiologically changing consistency and tension of a soft tissues. However, kinematic analysis is a according to Kadaba et al. (1989), Piazza and Bansal (2003) and Robertson et al. (2004) a reliable method for motion analysis. The whole measurement of kinematic parameters of the gait cycle was done by one researcher. All participants were measured at the same conditions and environment.

5. Conclusions

In conclusion, our study showed that the hallux valgus deformity is not only a problem of the foot's structure and function but also affects the entire lower limb and even the pelvis motion during walking. Surgical correction of the deformed segment itself could only correct skeletal alignment. However, does not solve functional related problems that occur during walking that are probably related with the cause of the problem or with the learned aspect of motor behavior.

Conflict of interest

There is no conflict of interest.

Acknowledgements

analysis" (University of Nebraska at Omaha, NE, USA) and of the research grant from Czech Science Foundation (grant no. 15–13980S).

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