Evaluation of the hip joint contact force in subjects with Perthes

Mohammad Taghi Karimi[1], Lanie Gutierrez-Farewik[2], Anthony McGarry[3]

[1]Rehabilitation Sciences Research Center, Shiraz University of Medical Sciences, Shiraz Iran.

[2]Department of Mechanics, KTH University, Stockholm Sweden

[3]Department of Biomedical Engineering, University of Strathclyde, Glasgow, UK.

Correspondence author:

Mohammad Taghi Karimi, Rehabilitation Sciences Research Center, Shiraz University of Medical Sciences, Shiraz Iran.

Tel: 009871136271552

Fax: 009871136272495

Email: mt_karimi@sums.ac.ir

The head of femoral bone is deformed in the subjects with Leg Calve Perthes disease (LCPD). This may be due to the excessive loads applied on it. There are no studies that report the hip joint contact force in subjects with LCPD. Therefore, the aim of this study was to evaluate the hip joint contact force in subjects with Perthes disease. Ten typically-developing (TD) children and 10 children with LCPD were recruited in this study. The kinematics and kinetics of the subjects were evaluated in 3D motion analysis. The hip joint contact force was approximated using OpenSIM software. Differences were determined with an independent t-test. There was a significant difference between walking speed of TD and Perthes subjects 63.8 (±8.1) and 57.4 (±7.0) m/min, respectively). The first peak of hip joint contact force was 4.8 (±1.7) N/BW in Perthes subjects, compared to 7.6 (±2.5) N/BW in TD subjects (p=0.004). The peak hip joint contact force in mediolateral and anteroposterior directions was significantly lower in Perthes subjects (p<0.05). The hip joint excursion was 40.0 (±5.6) and 46.4 (±8.5) degrees in Perthes and normal subjects, respectively (p=0.03). The hip joint contact forces were lower in the

subjects with Perthes disease. Therefore, it can be concluded that the strategies used by LCPD subjects were successful to decrease hip joint contact force.

Key words: Gait, hip joint contact force, OpenSIM

Introduction

Leg Calve Perthes disease (LCPD) is defined as a disease in which the blood supply of femoral head is disconnected and the femoral head temporarily dies [25]. Although the first description of this disease dates to more than 100 years ago, the cause of the disease is still debated. It has been reported that it occurs mostly in children between 5 and 12 years old with incidence varying in different countries, of between 0.45 and 10.8 per 100,000 [2,15,17,18]. Subjects with LCPD suffer from pain, limited range of motion especially in abduction and medial rotation, and usually have a deviating walking pattern [21,24]. Based on available evidence, three stages can be defined including avascular necrosis, fragmentation and healing phase [20]. Most of treatment methods used for LCPD focus on relief of weight bearing and increase femoral head containment [9]. Use of bed rest with or without orthosis, Snyder sling, Birmingham splint and Ischial weight bearing orthosis are the most common methods to remove the weight applied through the femoral head [3,8,9,12,13].

The theory behind containment was described by Craig and Bobeck between 1957 and 1968 [3]; and was supported by animal experiments performed on pigs. Based on this theory the deformity of the femoral head was less in the subjects with femoral head containment than in those with less containment [11,19]. Various types of orthoses and surgical methods have being used to increase containment of the femoral head within the acetabulum[3,9,13]. Various studies have, however, reported no differences between the outcome (femoral head deformation based on the Mose scale) of treatment approaches (use of orthosis, surgery or no treatment) [9]. It should be emphasized that the main treatment aim of LCPD is to decrease the deformation of femoral head [1,10]. There are three main factors which influence the outcome of treatment: the magnitude of applied force on femoral head, containment of the femoral head within acetabulum and density of the femoral head [9,12]. Although there are a few studies reporting gait patterns in the subjects with Perthes disease using 3D motion analysis, none of them have reported the estimated hip contact forces [8,16,21,24,26]. In a study by Westhoff et al., the patterns of hip joint kinetics and kinematics was evaluated in the subjects with Perthes disease [24]. The result of their study showed that the subjects with unilateral LCPD had two distinct pattern of gait depends on trunk lean to ipsilateral and contralateral sides [24]. In another study by Westhoff et al on the subjects with unilateral LCPD, it was speculated that range of hip motions in the affected side decreased as a compensatory mechanism to reduce the loads applied on the hip joint [23]. Therefore, the main aim of this study was to evaluate the joint contact forces in the subjects with LCPD. The main hypothesis associated with this study was that the joint contact force in the subjects with Perthes disease increases compared to typically-developing subjects.

Method

Ten children with unilateral LCPD and 10 typically-developing (TD) children participated in this quasi-experimental study. An overview of participant characteristics is provided in Table 1. Ethical approval was obtained from Isfahan University of Medical Sciences, Ethical Committee. A consent form was signed by the participant's parents before data collection. The severity of LCPD was scored using the classification recommended by Mose et al. based on the latest follow up X-ray [14]. The severity of this disease was scored as 'fair' for all subjects. The main inclusion criteria to select the Perthes subjects included, having unilateral LCPD with severity not more than 'fair' based on the Mose score with no other musculoskeletal disorders which influenced ability to stand and walk. The normal subjects were matched with LCPD subjects based on their weight and height. It should be also emphasized that the Perthes subjects had no history of surgery before the test, were pain free and on no medication.

A motion analysis system with 7 high speed cameras (Qualysis, Gothenburg, Sweden) was used to record the motions of the body during walking. A force plate (Kistler, Winterthur, Switzerland) was used to measure the ground reaction forces. The locations of the markers were recorded by Tract Manager Software. The calculation of joint angles, moment transmitted through the joints and hip joint contact forces were done by Use of OpenSIM software (SimTK and Stanford University, USA) [4,5]. A set of 23 markers (14 mm diameter) were attached bilaterally to the anterior superior Iliac spine, posterior superior iliac spine, medial and lateral malleoli, iliac crest, acromioclavicular joints, medial and lateral femoral condyles, first and fifth metatarsal heads, head, sacrum and C7. Moreover, five marker clusters comprising of 4 markers were attached on the anterolateral surfaces of thighs, calves and trunk by use of extensible Velcro straps. The subjects were asked to walk at a comfortable speed until 5 gait trials with full kinematic and kinetic information per side were collected. The kinematic and kinematic data were collected with frequency of 100 Hz. The collected data were filtered with a Butterworth low pass filter with cut-off frequency of 10 Hz.

OpenSIM (version 3.2) was used for neuromuscular modeling in order to measure kinematics and joint moments and to estimate muscles forces and joint contact forces [4]. In the software, joint contact forces were computed as a sum of joint reaction forces and forces due to muscle tension. The biomechanical model used in this study was normal gait model (2392) developed by Delph et al [4]. However, it should be emphasized that it was scaled based on static trial of the participants. Figure 1 shows the procedures used to calculate joint contact force by use of Motion analysis system, Mokka and OpenSIM softwares.

The output of the OpenSIM approach for estimation of muscles forces and joint reaction forces depended mostly on the optimization procedure. The characteristics of biomechanical simulation models are not often well suited to the formalized solution techniques for optimal control theory. Creation of models and performed stimulation required an extensive experience. In OpenSIM muscles forces are determined by implementation of a computed muscle control algorithm, which reduces the forward dynamic simulation time [6,22]. It is based on two assumptions which include: Resulting joint moments distributed to individual muscle forces according to minimizing role and also, the time varying ground reaction force at foot floor interface is known ahead of time [22]. The computed muscles control algorithm is comprised of four stages (desired accelerations, static optimization, excitation controller, and forward dynamics). The full description of optimization approach and the equations used in Open SIM can be found in the relevant literature [22].

Temporospatial gait parameters (walking speed, stride length, and cadence), and peak vertical, anteroposterior and mediolateral joint contact forces were obtained and used for final analysis. Normal distribution of the parameters was evaluated by a Shapiro-Wilk test. One-way ANOVA was used to determine the difference between the mean values of the parameters between normal and the subjects with history of Perthes disease. The interclass correlation coefficient (ICC) was calculated to assess reliability of the data collections. Though the ICC values of all variables were >0.7 and therefore all measures were reliable, the mean value of five measurements of each variable was calculated.

Results

Table 2 shows the mean values of temporospatial gait parameters and kinematic of hip joint of TD and LCPD groups. The mean value of walking speed of TD subjects was 63.8(6.9) m/min compared to 57.4(6.9) for LCPD subjects. There was a significant difference between stride length of TD and LCPD subjects (1.23(0.15) vs 1.06(0.21) m, respectively, p=0.05). The hip joint range of motion in all three anatomical planes was significantly lower in subjects with LCPD, compared to TD subjects ($p<0.05$). The mean value of pelvic range of motion of LCPD subjects were 10.26(3.6), 8.25(4.45), and 18(6.48) degrees in sagittal, frontal and transverse planes, respectively. The range of motion of pelvic in LCPD subjects differed significantly from normal subjects (p-value<0.05). The range of motion of trunk in three planes were also collected in this study. As can be seen from table 3, there was a significant difference between both groups regarding trunk range of motions.

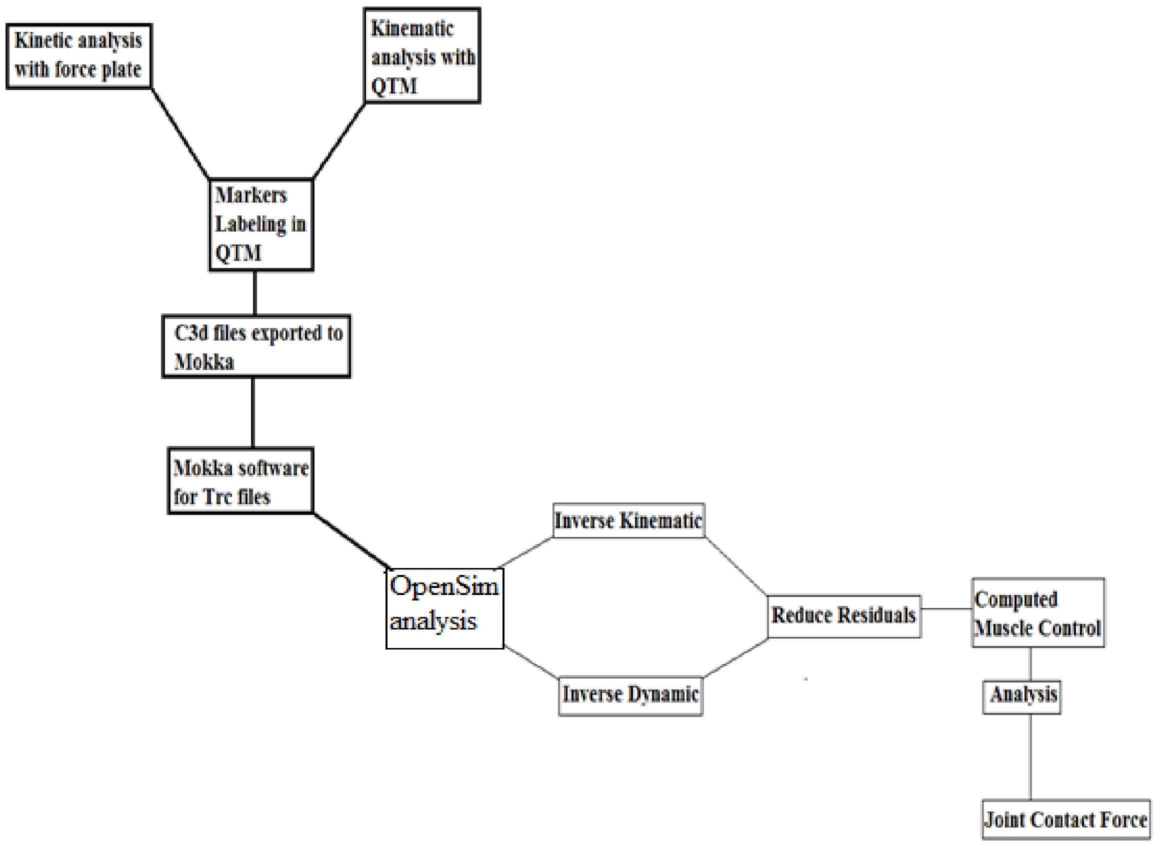

Figure 1: The procedures used to calculate joint contact force in OpenSIM

The first peak of vertical hip joint contact force was significantly lower in LCPD subjects than in TD subjects (4.8(1.7) N/BW vs 7.6(2.5), p=0.0, Table 4). The peak anteroposterior hip joint contact force was also significantly lower in LCPD than in TD subjects (1.95(1.4) vs. 3.6(2.4), p=0.0).

The mean values of hip joint flexion and extension moments of normal subjects were 1.06(0.48) and 0.54(0.22) Nm/BM, respectively compared to 0.59(0.36) and 0.43(0.27) in LCPD subjects. There was a significant difference between the peak of hip joint adduction moment of TD and LCPD subjects (p=0.034). Table 5 summarizes the magnitudes of the moments applied on the hip joint in two groups of participants.

Discussion

LCPD influences the abilities of the subjects during standing and walking [7,21]. Although various treatment approaches have being used to protect the femoral head and to decrease the deformation, the treatment outcome have not yet been entirely successful [9]. Various treatment approaches including use of orthosis, surgery and non-treatment have been used for this group of subjects. The first hypothesis is that the force applied on femoral head increased during walking. Therefore, the aim of this study was to evaluate the hip joint contact force in Perthes subjects.

Results from this study suggest that subjects with LCPD had lower hip joint contact force than TD children, Table 4. This can be attributed in part to their lower walking velocity, which in turn was largely due to their lower stride length and lower sagittal plane hip range of motion, Table 2. This correlates to the results of the findings by Westhoff et al [23], who observed reduction of hip joint motion. The lower hip joint contact forces can also be attributed to the lower hip extension and hip abduction moments during the first vertical contact peak and lower hip flexion and hip abduction moments during the second vertical contact force peak, Table 5. The trunk kinematics indicates that the subjects with LCPD lean to the stance leg on the affected side, reducing the hip abduction moments, Tables 3 and 5. This type of compensation using the upper body to reduce loading at the hip has been reported as compensation for hip abductor weakness, joint pain and joint instability [16,23]. Results also support the assumption that subjects with Perthes disease use some compensatory mechanisms to decrease the moment required to stabilize the hip joint in sagittal and frontal planes. As a result, they have an increased in range of flexion/ extension and abduction/adduction of pelvic and trunk, Table 3. LCPD Participants had weakness of the hip joint musculature, Table 5. Mean values of all moments of hip joint decreased significantly in LCPD subjects suggesting that subjects have to use the compensatory mechanism to provide stabilization of the hip joint. Due to this weakness, exercises to strengthen hip joint muscles is recommended.

It should be emphasized that the hip joint contact force reduced in LCPD subjects compared to TD children. This is due to some compensatory mechanisms used by subjects to decrease loads applied on the hip joint and to increase joint containment. The results of this study, summarized in tables 4 and 5, support that use of this mechanism is successful. However, it should be emphasized that a decrease in joint contact force may also be due to weakness of hip joint muscles.

Although there were a few published studies using gait analysis in subjects with LCPD, none have previously reported the estimated hip joint contact force [8,12,21,23,24]. Westhoff et al also showed that the subjects with Perthes have two distinct pattern of walking, depends on trunk lean to Perthes side or contralateral side [23]. They concluded that due to the change in adductor moment, the loads applied on the hip joint will be decreased or increased significantly. Results from this current study confirm that the moments applied on the hip joint and joint contact force decreased significantly in LCPD subjects.

There is no doubt that those with LCPD have some hip joint deformation. The deformation of femoral bone may be due to decrease in bone mineral density, an increase in joint contact forces and/ or decrease in hip joint containment [10]. Based on the results of the previous studies, the BMD of femoral bone did not differ significantly from that of normal subjects. The results of the current study also did not support the deformation of femoral bone due to increase in joint contact forces. Therefore, it can be concluded that the deformation of femoral bone in LCPD subjects may be due to decrease in joint containment. These subjects had to use some strategies to compensate a decrease in joint containment. They have to move the trunk and pelvic significantly in sagittal and frontal planes to increase joint containment of hip joint and to increase joint stability [23,24]. Therefore it may be concluded from the results of this study that increase in joint containment should be considered in this group of subjects which can be done by surgical approaches or use of especial conservative treatment. The LCPD subjects participated in this study have some degrees of hip joint deformation which was measured based on Mose method.

There are some limitations which should be acknowledged in this study. The main limitation is that the LCPD participated in this study had some degree of hip joint deformation. The second limitation was that the normal model of OpenSIM was scaled and used in this study. Therefore, it is recommended that the hip joint model used in future analysis will be produced based on model of the subjects developed in Mimics of NMS builder.

Conclusion

The walking strategy observed in subjects in this study should be considered a compensatory mechanism that decreases the loads applied on hip joint. Those with LCPD move the trunk and pelvis in sagittal and frontal planes more than normal subjects to stabilize the hip joint and to increase joint containment while walking. This also may be due to weakness of muscles of the hip joint. Based on the results of this study the deformation of femoral head may not be due to increase in joint contact force. It is recommended that the strength of hip joint muscles should be improved in this group of the subjects.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

Funding: There is no funding source.

Ethical approval: An ethical approval was obtained from Isfahan University of Medical Sciences, Ethical committee.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Tables

Table 1: The characteristics of the subjects in this study

Participants	Number of subjects	Age (years) Mean (SD)	Weight (N) Mean (SD)	Height (m) Mean (SD)
LCPD	10	9.1(2.1)	468(175.3)	1.43(0.119)
Typically-developing	10	8.5(2.3)	422(134)	1.51(0.2)
p- value	--	0.08	0.28	0.168

Table 2: The temporospatial gait parameters in walking of TD and LCPD subjects

Participants	Walking speed (m/min) Mean (SD)	Stride length (m) Mean (SD)	Cadence (steps/min) Mean (SD)	Flexion/ extension excursion (degrees) Mean (±SD)	Abduction /adduction excursion (degrees) Mean (SD)	Rotation (degrees) Mean (SD)
LCPD	57.4(6.97)	1.06(0.21)	107.6(12.8)	40.0(5.6)	13.0(2.3)	14.7(12.2)
TD	63.79(8.1)	1.23(0.15)	103.5(7.7)	46.4(8.5)	16.9(9.3)	23.6(8.8)
Mean square	82.9	0.033	72.73	92.93	15.95	78.16
P-value	0	0.05	0.64	0	0	0

Table 3: The mean values of pelvic and trunk range of motion in walking of TD and LCPD subjects

Participants	Flexion/ extension excursion Pelvic (degrees) Mean (±SD)	Abduction /adduction excursion Pelvic (degrees) Mean (SD)	Rotation Pelvic (degrees) Mean (SD)	Flexion/ extension excursion Trunk (degrees) Mean (±SD)	Abduction /adduction excursion Pelvic (degrees) Mean (SD)	Rotation Pelvic (degrees) Mean (SD)
LCPD	10.26 (3.6)	8.25 (4.45)	18 (6.48)	11.12 (1.87)	14.04 (3.12)	16.85 (1.1)
TD	7.83 (3.21)	10.25 (4.2)	21 (10.46)	9.34 (3.52)	12.6 (3.82)	22.55 (3.33)
Mean square	12.14	7.5	109.13	42.6	17.64	9.25
P-value	0	0	0	0	0	0

Table 4: The peaks of hip joint contact force in TD and LCPD subjects (FZ=Vertical force, 1 and 2 indicate first and second peaks), (FX=anteroposterior force), (FY=Mediolateral force).

Participants	FZ1 (N/BW)	FZ2 (N/BW)	FX (N/BW)	FY (N/BW)

	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Perthes	4.8(1.7)	4.3(1.7)	1.95(1.4)	1.2(1.1)
Normal	7.6(2.5)	6.5(4.0)	3.6(2.4)	2.4(0.7)
Mean square	8.89	18.76	6.58	0.472
P-value	0	0	0	0

Table 5: The mean values of the moments applied on the hip joint in TD and LCPD subjects (Mx1= flexion moment, Mx2=extension moment, My1=first peak of adduction moment, My2=second peak of adduction moment, Mz1= internal rotation moment, Mz2= external rotation moment)

Participants	Hip Mx1 Mean (SD)	Hip Mx2 Mean (SD)	Hip My1 Mean (SD)	Hip My2 Mean (SD)	Hip Mz1 Mean (SD)	Hip Mz2 Mean (SD)
Normal	1.06(0.48)	0.59(0.36)	0.95(0.658)	1.02(0.9)	0.15(0.11)	0.17(0.05)
Perthes	0.54(0.22)	0.43(0.27)	0.54(0.2)	0.56(0.21)	0.097(0.054)	0.01(0.077)
Mean square	0.263	0.15	0.516	1.04	0.015	0.027
P-value	0	0	0	0	0	0

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