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Research article

Evaluation of atraumatic hip instability measured by triaxial accelerometry during walking

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ABSTRACT

Hip joint instability has been targeted as an important issue that affects normal hip function. The diagnosis of hip instability could be very challenging and currently, there is no definitive diagnostic test. Hip instability results in an excessive amount of translation of femoroacetabular articulation, leading to changes on the dynamic loading of the hip. These changes in femoroacetabular translation could be evaluated by human movement analysis methods. The purpose of this study was to describe the triaxial and overall magnitude of acceleration in patients diagnosed with hip instability during gait cycle and compare those results with a control group. Our hypothesis was that acceleration values obtained from the instability group would be higher than asymptomatic controls. Ten patients with previously diagnosed hip instability were included and 10 healthy and asymptomatic subjects were enrolled as control group. Triaxial accelerometers attached bilaterally to the skin over the greater trochanter were used to record acceleration during walking on a treadmill. The overall magnitude of acceleration and the axial, anteroposterior and mediolateral accelerations ($x/y/z$) were obtained during gait. Mean overall magnitude of acceleration was higher in the hip instability group compared with the control group, 1.51 g (SD: 0.23) versus 1.07 g (SD: 0.16) ($P = 0.022$). The axial, anteroposterior and mediolateral accelerations significantly differed between the two groups. The axial and mediolateral accelerations showed to be higher for the hip instability group while the anteroposterior axis acceleration was lower.

INTRODUCTION

Hip joint stability is achieved mainly by the contribution of static stabilizers [1]. The high anatomical congruence between the femoral head and the acetabulum has been described as the most important static stabilizer [2]. This bony congruence allows the hip joint to achieve large range of motion in three different axes [3]. Moreover, the soft tissue structures consisting of acetabular labrum, ligamentum teres and the capsuloligamentous complex enhance the hip joint stabilization [4–6]. In addition, the surrounding musculature contributes to dynamic hip stabilization during movements [7]. Thus, the integration of both static and dynamic (i.e. hip musculature) stabilizers allows normal joint kinematics and normal distribution of the hip compression forces [8]. Nevertheless, changes in joint stability modify hip contact mechanism, inducing abnormal stresses of joint surface and leading to hip joint instability [9]. These changes can be associated with traumatic or atraumatic events and can result in joint degeneration and the presence of pain during daily activities [10].

Hip joint instability has been targeted as an important issue that affects normal hip function [10, 11]. Furthermore, hip instability is a relatively new and commonly underdiagnosed clinical entity [12]. Philippon *et al.* showed that

almost 35% of the patients that underwent a hip arthroscopy revision had undiagnosed hip instability [13]. Hip instability is commonly classified into six categories based on underlying cause: significant bony abnormalities or developmental dysplasia of the hip (DDH), connective tissue disorders, post-traumatic, athletics/microtrauma, iatrogenic and idiopathic [12]. Atraumatic hip instability has been targeted as chronic overuse injury, associated with motion patterns that results in microinstability [14, 15].

The diagnosis of hip instability could be very challenging and should include patient's history, physical exam, available radiographic imaging and even dynamic radiographic evaluation or examination under anesthesia. Currently, there is no definitive test that can be used to diagnose hip instability [12].

Independently of hip instability etiology, it results in an excessive amount of translation of femoroacetabular articulation, leading to changes on the dynamic loading of the hip [8]. These changes in femoroacetabular translation could be evaluated by human movement analysis methods.

The three-dimensional human movement analysis continues to be the gold standard method to study movement patterns [16, 17]. Parameters such as hip joint kinematics and kinetics can be obtained. However, this technology is an expensive method that requires highly qualified personnel and many hours of data processing [16]. Therefore, there have been recent advances in the human movement analysis. One of them are accelerometers that are portable devices which are placed on body segments, allowing to measure segmental acceleration and evaluating human movement, especially during gait [18, 19]. Previous studies have used accelerometry to evaluate the effects of periacetabular osteotomy in instability of dysplastic hips [20, 21]. An accelerometer attached over the greater trochanter was used to record triaxial acceleration during walking. In both studies, accelerometry has shown high reliability in detecting changes on hip stability. Thus, the use of triaxial accelerometry seems to be useful for the assessment of hip instability.

The objective of this study was to describe the triaxial and overall magnitude of acceleration in patients diagnosed with hip instability during gait cycle and comparing those results with a control group. Our hypothesis was that acceleration values obtained from the instability group would be higher than asymptomatic controls. This information may contribute to a better understanding and diagnosis of hip instability.

MATERIALS AND METHODS

Participants

A retrospective review from June 2016 to June 2017 was performed. Patients with diagnosis of hip instability and a complete biomechanical hip analysis, including triaxial accelerometry, were included. Three different fellowship trained hip surgeons, with vast experience in arthroscopic and open hip preservation surgery, did the diagnosis of hip instability. Diagnosis was based in patient's history, physical exam and dynamic radiographic evaluation. In all the cases dynamic radiographic evaluation showed easy manual distraction of hip joint accompanied by discomfort or pain.

Exclusion criteria were defined as follow: (i) radiographic findings of DDH, (ii) patients with body mass index (BMI) >25 kg/m^2, (iii) leg length difference >1.5 cm and (iv) history of functional, neurological or morphological disorders that affects gait. Ten patients were included in the hip instability group.

The control group was prospectively enrolled and included healthy subjects with no history of hip pain or pathology who had a medical interview and physical examination to rule out any confounding factor. Exclusion criteria for the control subjects were defined as follow: (i) history of functional, neurological or morphological disorders that affects gait, (ii) history of hip, knee or ankle surgery, (iii) leg length difference >1.5 cm and (iv) subject with BMI >25 kg/m^2. BMI was added as exclusion criteria to avoid bias in the accelerometry measurement. Ten subjects were included in the control group.

All participants provided a signed informed consent before participating in the study, which was approved by the Bioethics Committee of our Institution and conducted in accordance with the Declaration of Helsinki.

Analysis with the accelerometer

Previous studies have used an accelerometer to measure hip instability during gait [20, 21]. A triaxial accelerometer (Trigno Wireless System, Delsys, Inc., Boston, MA, USA) was used to record acceleration during walking on a treadmill (*x*-axis: axial direction, *y*-axis: anteroposterior direction and *z*-axis: mediolateral direction) (Fig. 1A). The accelerometers were attached bilaterally to the skin with adhesive tape over the greater trochanter. To exclude the influence of pelvic movement, another two sensors were attached bilaterally to the skin over the anterior superior iliac spine as references points to exclude the influence of pelvic movement [20]. To identify the different gait cycles, two accelerometers were attached over each calcaneal tuberosity. During heel-strike a characteristic morphology curve is observed, and it was used to identify the initial phase of gait [19]. The sampling frequency was 148 Hz for all the accelerometers used. The accelerations were measured in g, which represents the normal gravity vector (1 g = 9.81 m/s^2).

Subjects were instructed to walk on a treadmill at their usual speed (ranging from 3 to 4 km/h) and wearing their own shoes for 10 min to ensure familiarization. After the adaptation process, data were collected while the subject walked at the same previous speed. Each subject completed three trials of 1 min of walking to ensure a homogeneous gait pattern. In the hip instability group, only the injured limb was selected for analysis. In the control group the test limb was randomly selected to obtain 10 samples.

Data analysis (signal processing)

Data of the three trials were visually inspected to determine the more consistent signal. Once the trial signal was determined, 10 gait cycles were selected for the analysis. The raw peak acceleration of each of the 10 cycles was averaged for the three axes. The overall magnitude of the acceleration was calculated to evaluate hip instability, obtained by the following equation: $|a| = \sqrt{ax^2 + ay^2 + az^2}$ (Fig. 1B). The mean magnitude of each direction (axial, anteroposterior and mediolateral axes) and the mean magnitude of overall acceleration were compared with the control group.

Statistical analysis

Statistical analyses were performed using SPSS 20.0 software. For all the outcomes measurements, Shapiro–Wilk test was applied to determine the normality of the data. An unpaired *t*-test was used for the comparison between groups. The level of significance was set at $\alpha < 0.05$.

RESULTS

Ten subjects with diagnosed hip instability (height: 1.66 ± 0.10 m, weight: 65.27 ± 13.40 kg, BMI = 22.91 ± 2.84 kg/m^2 and Age: 28.77 ± 8.18 years) and 10 healthy control subjects (height: 1.61 ± 0.08 m, weight: 57.16 ± 8.56 kg, BMI = 21.93 ± 1.61 kg/m^2 and Age: 24.42 + 2.68 years) were recruited for this study. There was no statistical significant difference between demographics data in both groups and none of the patients included had evidence of femoroacetabular impingement.

The mean overall magnitude of acceleration was higher in the hip instability group compared with the control group, 1.51 g (SD: 0.23) versus 1.07 g (SD: 0.16), respectively. A statistically significant difference was found between groups ($P = 0.022$) (Fig. 2A and Table I).

The results for the mean axial, anteroposterior and mediolateral accelerations differed between the two groups. Axial and mediolateral accelerations were higher in the instability group and anteroposterior acceleration was lower, details are shown in Fig. 2B and Table I. Statistical analysis showed that differences found in the three axes between groups were significant (Table I). Individual mean overall magnitude of acceleration for every subject in the study is found in Fig. 3.

DISCUSSION

The aim of our study was to describe the triaxial accelerometry during the gait cycle while walking on a treadmill in patients diagnosed with hip instability and to compare the obtained accelerations values with a control group. The results showed a higher overall acceleration in subject with hip instability compared with control subjects. Analysis by axes exhibited that hip instability subjects had higher accelerations in the axial and mediolateral axes compared with the control group. Conversely, there was a lower

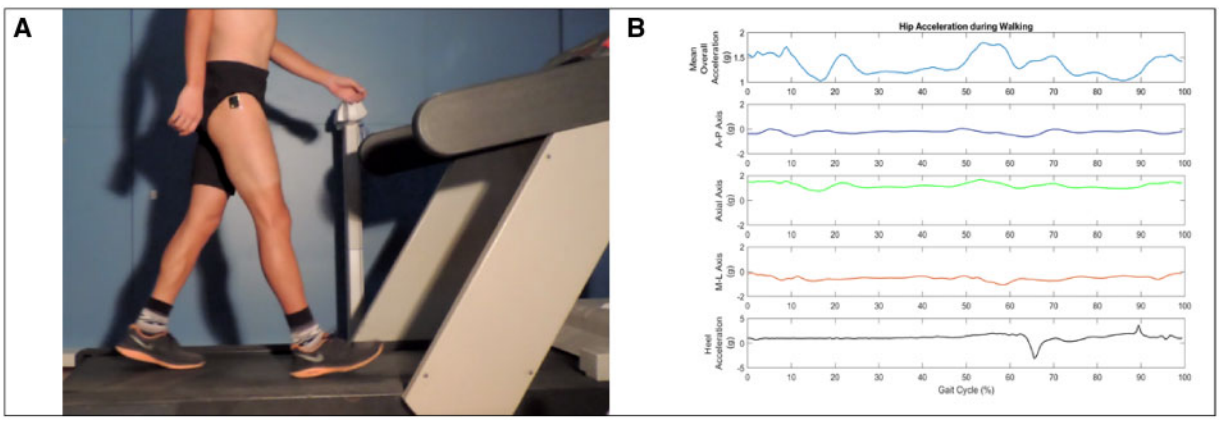

Fig. 1. Assessment with the accelerometer. (**A**) The accelerometer attached to the greater trochanter for quantifying the acceleration in the three axes during walking. Two accelerometers placed over each heel can be observed for quantifying the gait cycle. (**B**) Above, the overall magnitude of acceleration obtained by the described equation during a completed gait cycle. Below the accelerations of the three-different axes during a complete gait cycle and the heel acceleration.

acceleration in the anteroposterior axis in the hip instability subjects compared with the control group.

A previous study using the same method showed similar results in patients with hip instability due to dysplastic hips. In their study Maeyama *et al.*, showed a significantly higher mean overall acceleration in the dysplastic hips of 24 patients compared with their asymptomatic contralateral side [20]. Although the results are not equal in magnitude, they are concordant with the increment of acceleration in the unstable hip. We are not aware of any other study analysing triaxial accelerometry in normal asymptomatic population.

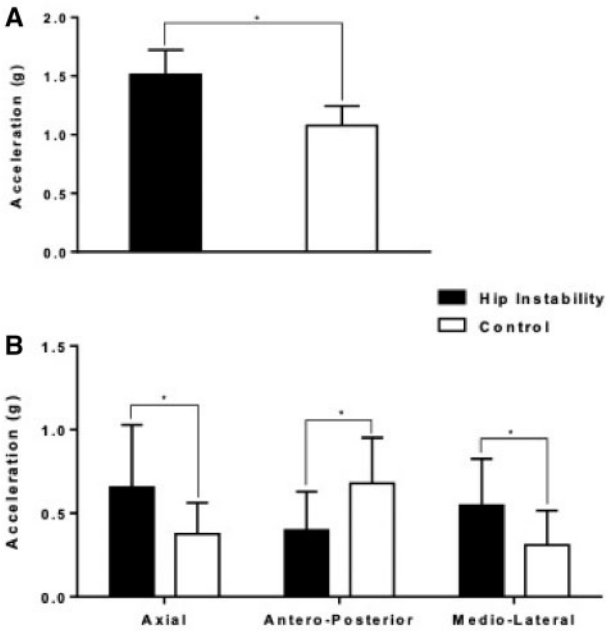

Fig. 2. Results for mean overall magnitude and triaxial acceleration. (**A**) Mean overall acceleration for both groups. (**B**) Axial, anteroposterior and mediolateral accelerations for both groups. Significant differences between groups (*$P < 0.05$) can be observed.

Hip instability is characterized by changes in capsuloligamentous stability, either if is traumatic or atraumatic [9, 10, 14, 15]. Particularly, atraumatic hip instability has been associated with overuse and repetitive motions. This may result in injury of the femoroacetabular ligaments and labrum, causing abnormal joint force distribution [14]. Once this capsuloligamentous injury is established, the dynamic stabilizers (i.e. surrounding hip musculature) play a key role in maintaining hip stability [9]. Thus, patients with hip instability continue performing their daily activities mainly by the stabilization provided by hip musculature. However, the long-standing nature of these compensations produces muscle dysfunction that finally leads to an impairment of hip function. Consequently, during walking or other daily activity patients may present symptoms characterized by pain, giving-away episodes and muscle alteration patters [11, 22] which causes excessive amount of translation of the femoroacetabular articulation during walking. Therefore, the higher overall magnitude of acceleration values found in the hip instability group may be explained by these progressive changes in femoroacetabular translation.

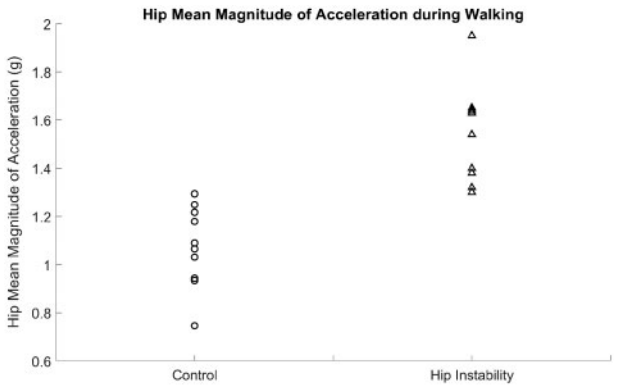

Fig. 3. Individual overall magnitude of acceleration of control v/s instable hips.

Table I. Axial, anteroposterior, mediolateral and overall magnitudes of accelerations for both groups are shown as mean (standard deviation)

	Hip instability, g // m/s²	*Control group, g // m/s²*	P *value*
Axial (g)	0.65 (0.37) // 6.37 (3.63)	0.37 (0.18) // 3.63 (1.765)	0.001*
Anteroposterior (g)	0.39 (0.23) // 3.82 (2.26)	0.67 (0.27) // 6.57 (2.65)	0.014*
Mediolateral (g)	0.54 (0.27) // 5.30 (2.65)	0.31 (0.20) // 3.04 (1.96)	0.016*
Mean overall (g)	1.51 (0.20) // 14.81 (1.96)	1.07 (0.16) // 10.50 (1.57)	0.022*

Significant differences between groups (*$P < 0.05$) can be observed.

The hip instability group showed higher accelerations in the axial and mediolateral directions. However, the anteroposterior axis showed to be higher in the control group, which was an unexpected finding. The hip joint capsule comprises three ligaments: the iliofemoral, ischiofemoral and pubofemoral [23]. These ligaments limit hip rotation, translation and distraction [24]. Biomechanical studies have shown that the iliofemoral ligament is the strongest ligament, limiting anterior translation of the hip and providing stability during movement [23, 25]. In addition Myers *et al.* have shown with fluoroscopy that anterior translation of the hip increased after sectioning the iliofemoral ligament [26]. Therefore, taking into account only the capsuloligamentous structures and based in previous literature, it should be expected to have an increased acceleration in every axis in the hip instability group. However, it must be noted that all the biomechanic evidence we have regarding the role of hip ligaments comes from *in vitro* studies. Thus, the finding of lower anteroposterior acceleration in the instability group, which seems to be in conflict with our previous biomechanical knowledge, could be explained because these measurements were performed *in vivo*. During the *in vivo* setting of our study other factors, previously not taken into account by *in vitro* studies, such as gait kinematics, dynamic hip load and dynamic stabilization by muscular forces where acting on the hip. We know that the role of musculotendinous structures about the hip in instability of the joint has not been elucidated and it is believed that most of the muscles that crosses the hip provide compression of the femoral head into the acetabulum moreover, special attention should be given to the iliopsoas because based on its anatomical location it could provide additional stability to resist anterior femoral head translation [27, 28]. In addition, we should take into consideration possible contributions as stabilizers of less studied muscles like the iliocapsularis, as it has been seen in borderline dysplastic hips [29]. Our hypothesis is that the finding of a decreased anteroposterior translation in the hip instability group could be due to dynamic redistribution of muscular forces around the hip, in the setting of a hypermobile and poorly constrained by ligaments joint. Although, further *in vivo* studies and a better understanding of the role of muscles as stabilizers around the hip are needed to prove this point.

Our study has some limitations. First, it is a retrospective series with a relatively small number of patients, mainly for the difficulty in recruiting hip instability patients. Second, hip instability has no conclusive criteria for diagnosis in the literature, therefore in our series the diagnosis of hip instability was based mainly in the clinical experience of the hip surgeons. Finally, as accelerometer indirectly evaluates femoral head movement and to be more accurate with the measurements, only patients with a BMI <25 kg/m^2 were included.

Nevertheless, this study showed a non-invasive and useful method to evaluated hip instability, and provided normal data from an asymptomatic population. We believe that triaxial accelerometry is a valuable exam to indirectly assess translation of hip joint and may be useful in better defining hip instability. Future studies may be needed to compare different data analysis protocols, and to obtain hip acceleration values from different normal populations to help us to better define hip instability.

CONCLUSIONS

Hip instability subjects had higher overall magnitude of acceleration during walking compared with controls. The axial and mediolateral accelerations showed to be higher for the hip instability group while the anteroposterior axis acceleration was lower in the same group. These changes in accelerations may be explained as redistribution of hip intra-articular translations.

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CONFLICT OF INTEREST STATEMENT

None declared.

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