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Gait strategy in patients with Ehlers–Danlos syndrome hypermobility type: A kinematic and kinetic evaluation using 3D gait analysis

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ABSTRACT

The aim of this study was to quantify the gait patterns of adults with joint hypermobility syndrome/Ehlers–Danlos syndrome (JHS/EDS-HT) hypermobility type, using Gait Analysis. We quantified the gait strategy in 12 JHS/EDS-HT adults individuals (age: 43.08 + 6.78 years) compared to 20 healthy controls (age: 37.23 ± 8.91 years), in terms of kinematics and kinetics. JHS/EDS-HT individuals were characterized by a non-physiological gait pattern. In particular, spatio-temporal parameters evidenced lower anterior step length and higher stance phase duration in JHS/EDS-HT than controls. In term of kinematics, in JHS/EDS-HT patients the main gait limitations involved pelvis, distal joints and ankle joint. Conversely, hip and knee joint showed physiological values. Ankle moment and power revealed reduced peak values during terminal stance. Differences in stiffness at hip and ankle joints were found between JHS/EDS-HT and controls. JHS/EDS-HT patients showed significant decreased of Kh and Ka parameters very probably due to congenital hypotonia and ligament laxity. These findings help to elucidate the complex biomechanical changes in JHS/EDS-HT and may have a major role in the multi-dimensional evaluation and tailored management of these patients.

1. Introduction

Joint hypermobility syndrome (JHS) is a relatively common, although largely under diagnosed clinical entity, characterized by congenital contortionism and additional musculoskeletal complaints (Steinmann, Royce, & Superti-Furga, 2002). There is a significant clinical overlap with various heritable connective tissue disorders, mainly the Ehlers–Danlos syndrome(s) (EDS) (Grahame, Bird, & Child, 2000). These similarities are so similar that, recently, an international group of experts stated that JHS and EDS hypermobility type (EDS-HT) are the same clinical entity that should be distinguished from other types of EDS (Tinkle et al., 2009). Accurate prevalence data are still lacking for JHS/EDS-HT. However, this condition seems to affect no less than 1 in 10,000 in the general population (Steinmann et al., 2002) and is dramatically more common in women (Castori, Camerota, Celletti, Danese, et al., 2010). The diagnosis of JHS/EDS-HT is clinical in essence, as no validated genetic test is available yet (Callewaert, Malfait, Loeys, & De Paepe, 2008). Major features include joint hypermobility, joint complications and minor skin features (e.g., skin hyperextensibility), while the presence of additional cutaneous, vascular, skeletal and ocular findings moves towards the diagnosis of other EDS variants.

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Although laxity of tendons and ligaments is considered a major determinant for musculoskeletal complaints in JHS/EDS-HT, the muscle itself seems to be frequently affected in terms of hypotonia, muscle cramps and pain, fibromyalgia, and chronic fatigue (Voermans et al., 2009). Such widespread involvement coupled with impaired proprioception (Hall, Ferrell, Sturrock, Hamblen, & Baxendale, 1995; Sahin et al., 2008) contribute to posture anomalies in JHS, as recently demonstrated in a qualitative scoring study (Booshanam, Cherian, Joseph, Mathew, & Thomas, 2010). Poor postural control can be also affected by the frequent orthopedic complications involving the lower limbs in these patients (Galli, Rigoldi, et al., 2011; Galli, Cimolin, et al., 2011; Stanitski, Nadjarian, Stanitski, Bawle, & Tsipouras, 2000). However, quantitative data on lower limb (dys)function and kinematics in JHS/EDS-HT are still lacking.

The goal of this study was to quantitatively evaluate the gait in a group of JHS/EDS-HT patients compared with healthy age-matched controls by using three-dimensional multifactorial Gait Analysis (i.e., spatio-temporal, kinematics and kinetics) (3D-GA). We decided to use the 3D GA as it is considered the gold-standard for investigating the gait pattern in humans.

2. Patients and methods

2.1. Participants

Twelve adults (11 females, 1 male; age: 43.08 ± 6.78 years) with JHS/EDS-HT participated and established using published criteria for JHS/EDS-HT (Beighton, De Paepe, Steinmann, Tsipouras, & Wenstrup, 1998; Grahame, 2000). As JHS/EDS-HT is a diagnosis of exclusion, the absence of features suggestive of other heritable connective tissue disorders was assessed in a clinical genetics outpatient clinic. In order to collect homogeneous and reproducible data, these individuals were selected from a pool of more than 40 patients on the basis of age (more than 30 years) and the ability to walk without devices. 20 adult participants, age and sex matched, were recruited as healthy controls (Control Group; CG; 10 females, 10 males; mean age: 37.23 ± 8.91 years). Selection criteria for this group included no prior history of cardiovascular, neurological or musculoskeletal disorders. Participants showed negative Beighton score, normal muscle strength and no obvious gait abnormalities.

The study was approved by the Ethics Research Committee of the Institute and written informed consent was obtained by the patients.

2.2. Experimental set-up

The complete evaluation consisted of clinical examination and 3D GA. All patients were evaluated instrumentally using an optoelectronic system with passive markers (ELITE2002, BTS, Milan, Italy) with a sampling rate of 100 Hz, two force platforms (Kistler, CH) and 2 TV camera Video system (BTS, Italy) synchronized with the system and the platforms for videorecording.

To evaluate the kinematics of each body segment, passive markers were positioned on the participants' body, as described by Davis, Ounpuu, Tyburski, and Gage (1991). Participants were asked to walk barefoot at their own natural pace (self-selected and comfortable speed) along a walkway (10 m long) where the two force platforms were placed. At least six trials were collected for each individual in order to ensure the consistency of the data. All the acquisitions were acquired by the same operator with experience, so to assure reproducibility of the acquisition technique and to avoid the introduction of errors due to different operators.

2.3. Data analysis

All graphs obtained from GA were normalized as % of gait cycle and kinetic data were normalized for individual body weight. In order to define the gait pattern of JHS/EDS-HT patients and to quantify their deviations from normality, some parameters (time/distance parameters, angles joint values in specific gait cycle instant, peak values in ankle moment and power graphs) were identified and among them the followings were analysed.

2.3.1. Spatio-temporal parameters

(a) % stance: duration of the stance phase (as % of the gait cycle);
(b) velocity: mean velocity of progression (m/s);
(c) step length: longitudinal distance from one foot strike to the next one, normalized to participant's height;
(d) step width (m).

2.3.2. Kinematics

(a) the mean value of pelvis on the sagittal plane (Mean PT index), expressed in degrees;
(b) the values of angle of ankle (AIC index), knee (KIC index) and hip joint (HIC index) at the contact of the foot with the ground (i.e. initial contact or IC), expressed in degrees;

(c) the values of maximal ankle dorsiflexion during stance phase (AMSt index) and the maximal flexion of the knee (KMSw index) during swing phase, expressed in degrees;
(d) the values of minimal ankle dorsiflexion in stance phase (AmSt index), knee (KmSt index), and hip flexion (HmSt index) during the gait cycle, expressed in degrees;
(e) the range of motion of the pelvis on the coronal (PO-ROM index) and transversal (PR-ROM index) plane; the range of motion of hip on coronal (HAA-ROM index) and sagittal (HFE-ROM) plane; the range of motion of knee (KFE-ROM index) on sagittal plane; the range of motion of ankle on sagittal plane during stance phase (ADP-ROM index), expressed in degrees.

2.3.3. Kinetics

2.3.3.1. Ankle moment. (a) The peak of plantarflexion moment of ankle joint in the second half of stance (AMMax index), expressed in N m/kg.

2.3.3.2. Ankle power. (a) The maximum ankle power during terminal stance (maximum value of positive ankle power; APMax index), expressed in W/kg and the same index normalized to the velocity of progression (APMax norm index, m/s^2); this parameter represents the push-off capacity during walking and is related to the forward propulsive power during gait.

2.3.4. Joint stiffness

In order to evaluate the effect of ligament laxity and hypotonia on joint kinetics and kinematics, hip and ankle stiffness (hip stiffness: Kh index; ankle stiffness: Ka index) were expressed by plotting the values of the flexion–extension moment versus the flexion–extension angle over the gait cycle interval between 10% and 30%. The 10% to 30% interval (corresponding to the second rocker) of the gait cycle was selected and the linear regression was fitted. The angular coefficient of the linear regression corresponded to the joint stiffness index, as described in previous studies (Davis & De Luca, 1996; Frigo, Crenna, & Jensen, 1986). Knee stiffness was not included in this study due to the lack of linear relation between kinematics and kinetics.

2.4. Statistical analysis

All the previously defined parameters were computed for each participants and then the mean values and standard deviations of all indexes were calculated for JHS/EDS-HT GROUP and CG. The Wilcoxon Signed Ranks test for paired samples was used for testing the side to side difference in patients and the Mann–Whitney *U*-test was used for comparing the normal controls and pathological participants. A statistically significant difference was accepted as $p < 0.05$.

3. Results

In Table 1 the clinical characteristics of JHS/EDS-HT and CG are reported. Age was not significantly different among groups. Weight was similar but JHS/EDS-HT participants' height was significantly different from CG. In order to take in account the variability in height, stride length was normalized to the individual's height.

For gait parameters an initial comparison between right and left limb was made. As no statistical difference was found between the two limbs, the data from both sides were pooled. In Table 2 the mean values and standard deviations of the spatio-temporal and kinematic indices considered in this study for JHS/EDS-HT and CG are reported. As concerns spatio-temporal parameters in JHS/EDS-HT, the step length was significantly different from CG: patients walked with a reduced step length than CG. No statistical differences were evident in terms of the velocity of progression, duration of stance phase and of the step width. As for kinematic parameters, the pelvic tilt displayed a higher range of motion (PT-ROM index) than Control Group with a quite normal pelvic tilt mean value (Mean PT index); no abnormalities were present on frontal and transversal planes (PO-ROM and PR-ROM indices). The hip and knee joints were quite normal during the entire gait cycle (Hip: HIC, HmSt and HFE-ROM indices; Knee: KIC, KmSt, KMSw and KFE-ROM indices). Hip showed physiological gait strategy on the frontal plane (HAA-ROM index), too. The feet were in a plantarflexed position at initial contact (AIC index) and the ankles presented reduced dorsiflexion during stance phase (AMSt index) and in swing (AMSw index) if compared to CG; ankle joint excursion during stance phase (ADP-ROM index) was close to controls.

Table 1
Clinical characteristics of the study groups.

	JHS/EDS-HT GROUP	Control Group
Age (years)	43.08 (6.78)	37.23 (8.91)
Height (cm)	162.83 (4.80)*	173.3 (5.01)
Weight (kg)	64.33 (16.76)	66.9 (8.5)

Data are expressed as mean (standard deviation).
* $p < 0.05$, JHS/EDS-HT GROUP versus Control Group.

Table 2
Spatio-temporal and kinematic parameters of the study groups.

	JHS/EDS-HT GROUP	Control Group
Spatio-temporal parameters		
% stance (% gait cycle)	59.83 (3.42)	59.65 (3.19)
Anterior step length	0.34 (0.12)*	0.88 (0.21)
Step width (mm)	131.64 (42.42)	123.29 (27.84)
Velocity (m/s)	0.96 (0.25)	1.12 (0.18)
Pelvis (°)		
Mean PT	8.64 (4.99)	6.53 (6.97)
PT-ROM	6.20 (3.87)*	3.62 (0.86)
PO-ROM	7.58 (3.27)	6.01 (2.53)
PR-ROM	10.29 (4.41)	10.72 (5.32)
Hip joint (°)		
HIC	28.45 (8.35)	27.23 (9.57)
HmSt	−11.07 (7.90)	−14.83 (9.60)
HFE-ROM	40.37 (5.99)	43.52 (4.76)
HAA-ROM	11.82 (4.75)	10.71 (3.06)
Knee joint (°)		
KIC	4.07 (7.19)	4.39 (6.53)
KmSt	−2.44 (6.92)	0.12 (3.82)
KMSw	53.99 (9.23)	57.08 (6.36)
KFE-ROM	59.03 (7.44)	59.07 (6.31)
Ankle joint (°)		
AIC	−4.74 (5.53)*	1.81 (6.87)
AMSt	9.89 (4.79)*	21.04 (5.16)
AmSt	−13.79 (7.35)	−9.73 (9.40)
ADP-ROM	23.68 (6.74)	25.72 (6.56)
AMSw	3.02 (5.26)*	7.89 (9.93)

Data are expressed as mean (standard deviation).
ROM: range of motion; PT: pelvic tilt; PO: pelvic obliquity; HIC: hip at IC; HFE: hip flex-extension; HAA: hip ab-adduction; KIC: knee at IC; KFE: knee flex-extension; AIC: ankle at IC; ADP: ankle dorsi-plantarflexion; IC: initial contact; St: stance; Sw: swing; M: maximum value; m: minimum value.
* $p < 0.05$, JHS/EDS-HT GROUP versus Control Group.

Ankle moment showed a reduced peak of ankle plantarflexors moment during terminal stance (AMMax index; EDS: 1.17 ± 0.16 N m/kg; CG: 1.51 ± 0.18 N m/kg; $p < 0.05$). As concerns the ankle power plot, it revealed a lower maximum of the positive area during terminal stance (APMax index; EDS: 2.04 ± 0.83 W/kg; CG: 3.14 ± 0.88 W/kg; $p < 0.05$), representative of limited push-off ability, than CG mean value; the same results was obtained considering the APMax index normalized to the velocity of progression (APMax norm index; EDS: 1.88 ± 1.15 m/s^2; CG: 2.89 ± 0.93 m/s^2; $p < 0.05$), which was significantly reduced if compared to the controls.

Joint stiffness data are shown in Fig. 1. JHS/EDS-HT values were significantly different in terms of hip and ankle stiffness (Kh and Ka indices): patients showed mean values significantly lower than CG. An example of hip stiffness for a JHS/EDS-HT and a CG participant is shown in Fig. 2.

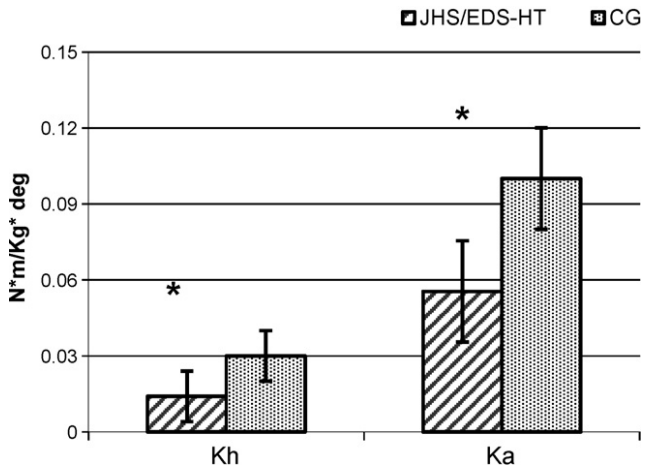

Fig. 1. Joint stiffness values of the study groups. Data are expressed as mean (standard deviation). *$p < 0.05$, JHS/EDS-HT GROUP versus Control Group. Kh: hip stiffness; Ka: ankle stiffness.

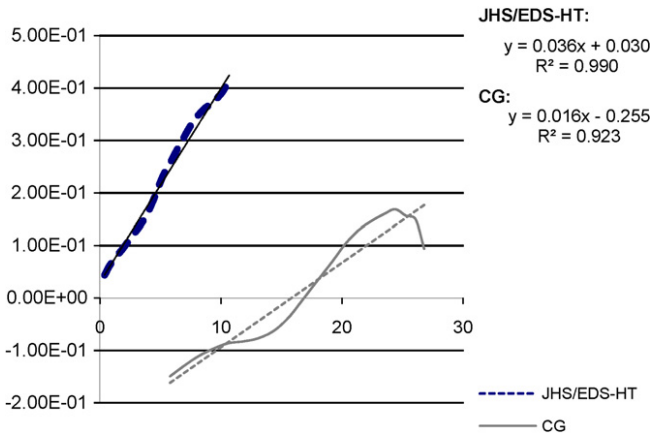

Fig. 2. An example of hip angle–moment plot cycle during second rocker for a participant with JHS/EDS-HT and one healthy individual is reported. The slope of the joint moment plotted as a function of joint angle during second rocker represents hip joint stiffness.

4. Discussion

Joint hypermobility is the key clinical feature of JHS/EDS-HT and, at the moment, its recognition is uniquely feasible by physical examination. This trait, which is universal in JHS/EDS-HT patients in the paediatric age, naturally decreases with age and progressively becomes more difficult to be ascertained in adults. On the other hand, the onset of associated symptoms is time-dependant and it is often inversely related to the residual joint hypermobility (Castori, Camerota, Celletti, Grammatico, & Padua, 2010). Hence, the practicing physician often encounters patients displaying a constellation of musculoskeletal complaints, but no longer showing overt joint hypermobility. This phenomenon often leads to a diagnostic conundrum and highlights the need of more reproducible and quantitative approach(es) to diagnose and assess JHS/EDS-HT. In fact, hypermobility not only determines passive hyperextension of joints but, more importantly, is likely to cause complex and still poorly understood biomechanical consequences on movement patterns. In line with this, some studies demonstrated impaired proprioception in various joints of JHS/EDS-HT patients (Hall et al., 1995; Mallik, Ferrell, McDonald, & Sturrock, 1994; Rombaut, Malfait, Cools, De Paepe, & Calders, 2010; Sahin et al., 2008). More interestingly, the entire postural control and balance seems disrupted in JHS (Booshanam et al., 2010).

These considerations emphasize the importance of a careful and precise evaluation of JHS/EDS-HT patients in terms of biomechanics. In fact quantitative analysis of walking yields crucial information in establishing the level of disability and in identifying the proper therapeutical program for JHS/EDS-HT patients.

JHS/EDS-HT individuals showed non-physiological gait pattern. Regarding spatio-temporal parameters, significant differences were evident in terms of anterior step length, which exhibited low values than healthy participants. Conversely, the other spatio-temporal parameters were close to normative data. In terms of kinematics, pelvic tilt showed high excursion during the gait cycle, with no differences in terms of pelvic position on the frontal and transversal plane. Hip and knee joint revealed physiological values. Conversely the ankle joint seems to be the less physiological lower limb joint. The feet were in a plantarflexed position at initial contact with a reduced dorsiflexion during stance and swing phase if compared to CG.

Peak plantarflexion moment and power generated at ankle joint in the terminal stance were also analysed. Limited muscle strength was probably the cause of the reduced values of these parameters. The reduced ability to generate ankle power during this phase of gait cycle is not connected to the velocity of progression. JHS/EDS-HT patients revealed a quite normal gait velocity and the APMax index normalization to the velocity of progression does not in fact change the results in terms of APMax index, which was lower than controls.

We found differences in both hip and ankle joint stiffness between JHS/EDS-HT and CG. JHS/EDS-HT patients revealed decreased values of Kh and Ka parameters if compared to controls. Hypotonia and ligament laxity, which are major features of JHS/EDS-HT are very probably the most important factors influencing reduced joint stiffness in our patients' cohort.

From a clinical perspective, quantitative characterization of gait patterns in JHS/EDS-HT is important to identify, develop and enhance the rehabilitative options. Quantification of their peculiar gait deficits in JHS/EDS-HT strongly supports the issue that these patients need tailored rehabilitation programs. Our results highlight that the main gait limitations in JHS/EDS-HT patients are present at pelvis, distal joint and ankle joint. The plantarflexion at initial contact and reduced dorsiflexion ability may suggest a tibialis anterior weakness; in addition, the non-physiological ankle kinetics, in terms of reduced ankle moment and ankle power generation, may be justified by reduced calf muscle strength. Improving pelvis and ankle strategy should represent a specific major goal to optimize gait pattern and prevent the onset of compensatory strategies in JHS/EDS-HT patients. In addition, also hypotonia and muscle strength during gait should be equally improved. A possible bias of our study is the relatively small sample size, resulting in limited strength of the clinical and statistical findings. However it represents a preliminary attempt to quantify the gait pattern in JHS/EDS-HT patients using 3D GA. In addition it should be reminded that JHS/EDS-HT is a relatively rare condition and large experimental groups are difficult to

gather. Further studies should be conducted to confirm these data considering larger groups of patients with different level of gait disturbance.

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