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HIP JOINT AND CENTER OF GRAVITY KINEMATICS IN GAIT CYCLE OF YOUNG ADULTS WITH MODERATE IDIOPATHIC SCOLIOSIS. A CONTROLLED STUDY

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SUMMARY

Introduction: Scoliosis influences the body and the pelvic region, a major determinant of gait. The effect on pelvic locomotion throughout the gait cycle of this entity is of major interesting. **Purpose:** To study the hip joint and center of gravity (CoG) locomotion in young adults with Moderate Idiopathic Scoliosis (MIS) compared to healthy population during the gait cycle. Aim of the study was also the differences in-between lower extremities of scoliosis patients. **Methods:** A cohort of twenty young adults (group A) having MIS and a control group (B) of fifteen healthy individuals were submitted in 3D gait analysis with direct linear transformation method. The parameters examined were concerning the displacement of the hip joint (greater trochanter) and the CoG on x, y and z axes. Additionally, the gait cycle duration was examined. **Results:** Mid leg length discrepancy (1.2 cm ± 0.2, C.I 95%) was evident in scoliosis patients. Regarding side to side comparison of the lower extremities in group A the following outcomes were identified: Hip and CoG had increased sagittal (forward/backward) displacement on the ipsilateral side (to scoliosis curve) compared to the controlateral side, $p < 0.05$. When comparing group A to group B the following differences were found ($p < 0.05$): (a) gait cycle in group A had increased duration compared to group B (an average from both extremities), (b) the hip in the ipsilateral side demonstrated increased frontal displacement (medial/lateral), (c) the hip in the controlateral side had increased frontal displacement and decreased sagittal displacement and (d) the CoG in the controlateral side had decreased sagittal displacement. **Discussion:** Scoliosis patients presented asymmetries in-between sides of the body regarding hip and CoG displacement at the sagittal axis. Produced higher lateral sway area and controlateral reduced sagittal motion than normal subjects. The gait cycle had increased duration compared to healthy people. The kinematic analysis combined to the clinical examination can create a basis for conservative intervention as well as further studies on biomechanics of MIS.

Key words: adult idiopathic scoliosis, gait cycle, hip, pelvis, centre of gravity

INTRODUCTION

Scoliosis presented with an appreciable lateral deviation and rotation in the otherwise normally straight vertical alignment of the spine [25]. Idiopathic scoliosis, taking into account curves above 10°, is present in 2–3% of the general population [11, 20]. It is most common during late childhood, in particular in girls [15] but the prevalence of small curves, less than 20°, is about equal in males and females. From the total population of patients suffering from this condition, 3% will need some kind of conservative treatment [10]. It has been estimated that approximately 65% of scoliosis cases are idiopathic [5]. Scoliosis is associated with increased pain in adults of all ages, compared with control populations [16, 23]. Furthermore, children and adults with mild to moderate curvatures may have reduced exercise capacity [21, 23].

PURPOSE

Moderate idiopathic scoliosis (MIS) produces a number of dysfunctional deformities that affect the postural system and the body segments that are closely related with locomotion. The basic movements of the trunk are influenced due to different types of deformity like, tightness, elongation, or shortening of the soft tissues. Pain is also one factor that plays an important role in the restriction or loss of locomotion [18].

Pelvis is directly connected with the vertebra column and as a result is imbalanced [12]. Pelvic locomotion has a major role in walking and in this article is represented by the actions of the hip joints and the transmission of the center of gravity (midway between hips, few cm ahead S_2) during gait cycle. The center of gravity and the hip joint participate in a lot of roles during walking and will probably be affected from the axial misalignment of the body.

Scoliosis patients exhibit significantly impaired quality of life [21] and young adults with MIS consist a population group with increased occupational and sports activities [23] and gait cycle is of great importance. Gait analysis is used to identify and treat [9, 28] individuals with conditions affecting their posture and in terms their ability to walk.

We conducted this study in an effort to identify the degree that MIS influences the physical quantities of the pelvis during the gait cycle of young adults in comparison to the gait cycle of healthy people.

There are no many published studies regarding this topic and ours is the first; to our knowledge, that focuses on direct linear transformation method for analyses of gait cycle and transmission of the centre of gravity during walking.

METHODS

For the purpose of this study thirty-five young adults (with similar anthropometric characteristics) of both sexes were selected and divided in two groups: Group A consisted of 20 young adults with moderate idiopathic scoliosis and group B of 15 healthy people without any known spinal deformity or disease (table 1).

Inclusion criteria for group A were: age more than eighteen years and less than fifty (as we wanted to study established deformities in people with no degenerative spine so we arbitrarily set as limit fifty years of age), lumbar and thoraco-lumbar curves (as these will probably have greater impact on pelvic locomotion), scoliosis curves between 20° to 40° (smaller curves might not influence gait and bigger are not so commonly met). Inclusion criteria for group B were same age variation to group A, no clinically examined spine deformity, no limb length discrepancy more than 1.8 cm (as this could influence gait cycle pattern).

Every subject signed on and participated freely in the study, approved by the local ethics board. All subjects were submitted to a clinical [7], radiological (for group A) [3] and gait assessment.

In group A the gait cycle is characterized according to the convexity of the spine. The term "Ipsilateral" is used for the convexity side joints and "Controlateral" for the concavity side joints in group A. In group B, the average values from both sides of the body were used due to close similarities found amongst them.

The 3D kinematic analysis of gait was succeeded with the subjects walked on a mechanical treadmill, with self selected speed. A typical one of the gait cycles was selected after achieving a steady pace of walking so as to avoid mistakes in measuring the physical quantities. Gait cycle in each extremity was initiated with initial contact (IC-heel contact) from double support position at 0 seconds and ended at the next initial contact. Paper markers were installed on the skin surface of anatomical landmarks (major trochanter, lateral condyle and lateral malleolus) that accurately represent the movement identification of the hip, knee and ankle joints. The markers on the knee and ankle were necessary to provide information of the gait cycle. For 3D video motion analysis three digital video camera recorders where obtained. The physical quantities of our interest are: (a) The linear displacement measured in cm, (b) linear velocity in m/sec and (c) linear acceleration in m/sec^2.

The software used for direct linear transformation (DLT Method) was APAS from Ariel Dynamics. These measurements [27] allowed calculation of the sagittal plane (x axis – forward/backward direction), vertical plane (y axis – gravitational-upward/ downward direction), and frontal plane (z axis – left/right-medial/lateral direction) of the physical quantities. The duration of the gait cycle and the center of gravity displacement were calculated as well.

Power was set at 80%. Student t-test was used for the purpose of statistical analysis with level of significance at 95%.

Table 1. Demographical, clinical and radiological data (NA: not available)

	Group A	C.I 95%	Group B	C.I 95%
Height (m)	1.72 (1.55–1.90)	± 0.52	1.70 (1.57–1.91)	± 0.65
Body Weight (Kg)	74 (58–92)	± 3.10	72 (60–90)	± 2.90
Age (years)	32.4 (20–40)	± 1.82	36.1 (23–38)	± 1.38
Sex	12 Females, 8 Males		8 Females, 7 Males	
Cobb's angle (°)	29.4° (22–34)	± 1.30	NA	
Apical rotation (grades)	+1 (0/±4)		NA	
Plumb line declination (cm)	1.6	± 0.15	0.14	± 0.04

RESULTS

All patients of group A had a right thoraco-lumbar or left lumbar primary structural curve. The average Cobb's angle in group A was 29.4° and plumb line declination was 1.2 cm. Mean leg length discrepancy in group A was 1.2 cm (± 0.2 cm, C.I 95%) while in group B the difference was 0.3 cm (± 0.13).

Scoliosis patients showed typical deformities regarding lumbar region, scapula and pelvis (table 2). When examining range of motion, an obvious hip joint flexion restriction was noted as well as reduced lateral flexion of the spine ipsilateral to the curve. Restriction in rotation and extension of the spine was less, but worth noticing. More detailed clinical examination is shown in table 3.

Table 2. Effect of scoliosis upon the musculoskeletal system (NE: not existed).

Clinical data	Type of scoliosis	Lumbar Lordosis	Pelvic tilt	Head & neck posture	Shoulder & scapula position	Iliac crest & PSIS
Scoliosis patients Group A (*n* = 20)	Thoraco-lumbar (16) Lumbar (4)	Hyper-lordosis in 60% of all cases. Flattening in 30% of all cases.	Existed in 100% of all cases.	Protruded in 100% of all cases.	Elevation in 100% of all cases.	Elevation in 100% of all cases.
Control group Group B (*n* = 15)	NE	Hyper-lordosis in 15% of all cases. Flattening in 5% of all cases.	Existed in 5% of all cases.	NE	NE	NE

Table 3. Human locomotion restriction or loss (NE: not existed, SLR: straight leg raise).

Clinical data	Trunk and spine			Lumbar extension	Hip joint left & right extremity		SLR left & right extremity	Pain presence
	Flexion	Lateral flexion	Rotation	Range of movement	External rotation	Internal rotation	Hip flexion / knee extension	During movement
Scoliosis patients Group A (*n* = 20)	Limited in 30% of all cases.	Limited in one side in 100% of all cases.	Limited in one side in 70% of all cases.	Hypo-mobile in 80% of all cases.	Difference in 100% of all cases.	Difference in 100% of all cases.	Difference in 85% of all cases.	90% of all cases during lateral-flexion & rotation.
Control group Group B (*n* = 15)	NE	NE	NE	NE	NE	NE	Difference in 5% of all cases.	NE

Regarding the gait cycle duration results were as follows: In group A, the ipsilateral side had a mean gait cycle of 1.42 sec (± 0.11 sec) and the controlateral side had a mean gait cycle of 1.39 sec (± 0.08 sec), 95% C.I (table 4). The gait cycle of group B had duration of 1.21 sec (± 0.073, average from both extremities, 95% C.I). Totally, the gait cycle duration was found 14.8% longer in group A (scoliosis patients) compared to group B, $p < 0.05$ (table 5).

Regarding displacement, the statistical differences found in scoliosis (group A) patients between ipsilateral and controlateral extremity (side to side comparison) were as follows: The hip joint sagittal displacement (forward–backward) in the ipsilateral side was 29.6 % higher than the controlateral, $p < 0.05$, (table 6). Center of gravity sagittal displacement on the ipsilateral side was found 32.8% higher than that of the controlateral side, $p < 0.05$ (table 6).

Table 4. Gait cycle duration in lower extremities of group A. Comparison between them.

	Ipsilateral extremity	**Controlateral extremity**	***p*-value**
Gait cycle duration (sec)	1.41 (± 0.11)	1.39 (± 0.08)	NS

NS: not significant.

Table 5. Gait cycle duration of both groups. Scoliosis group completed the gait cycle in a slower rate. Group B represented by an average value from lower extremities.

	Group A *(n = 20)*	**Group B *(n = 15)***	***p-value***
	Ipsilateral extremity	Lower Extremities	
Gait cycle (sec)	1.42 (± 0.10)	1.21 (± 0.07)	**< 0.05**
	Controlateral extremity	Lower Extremities	
Gait cycle (sec)	1.39 (± 0.07)	1.21 (± 0.07)	**< 0.02**

Significant differences are typed in bold, C.I 95%.

Table 6. Hip (greater trochanter) and Center of Gravity linear displacement in scoliosis patients (group A) (C.I 95%). Comparison between extremities.

Kinematic data	**Hip joint**			**Center of Gravity**		
	Ipsilateral extremity	**Controlateral extremity**	***p*-value**	**Ipsilateral extremity**	**Controlateral extremity**	***p*-value**
Displacement X axis (cm)	6.36 (± 0.98)	4.48 (± 0.53)	**< 0.03**	6.46 (± 0.87)	4.33 (± 0.47)	**< 0.01**
Displacement Y axis (cm)	2.91 (± 0.37)	2.94 (± 0.37)	NS	5.53 (± 0.20)	5.52 (± 0.19)	NS
Displacement Z axis (cm)	–6.11 (± 0.51)	–5.83 (± 0.40)	NS	–5.84 (± 0.4)	–5.59 (± 0.33)	NS
Velocity 3D (m/sec)	0.05 (± 0.00)	0.05 (± 0.01)	NS	0.29 (± 0.03)	0.31 (± 0.03)	NS
Acceleration 3D (m/sec^2)	0.18 (± 0.03)	0.21 (± 0.05)	NS	1.04 (± 0.160	1.17 (± 0.25)	NS

NS: not significant. Significant differences are typed in bold. The symbol minus of Z axis is indicative of lateral displacement.

Comparison of group A and group B showed statistical significant difference in the following parameters:

Ipsilateral side hip in group A had 16.6% greater mean frontal displacement (medial–lateral) compared to an average from both hips of group B, $p < 0.05$. On the controlateral hip (group A) a reduced 30.1% mean sagittal and an increased 12.6% frontal displacement compared to group B was found ($p < 0.05$) (table 7). The center of gravity had significantly reduced mean sagittal displacement by 28.6% in scoliosis patient's controlateral side, $p < 0.05$ (table 8).

Table 7. Ipsilateral (to scoliosis curve) and Controlateral (to the scoliosis curve) hip joint linear displacement (C.I 95%). Comparison to an average value of both extremities of the control group B.

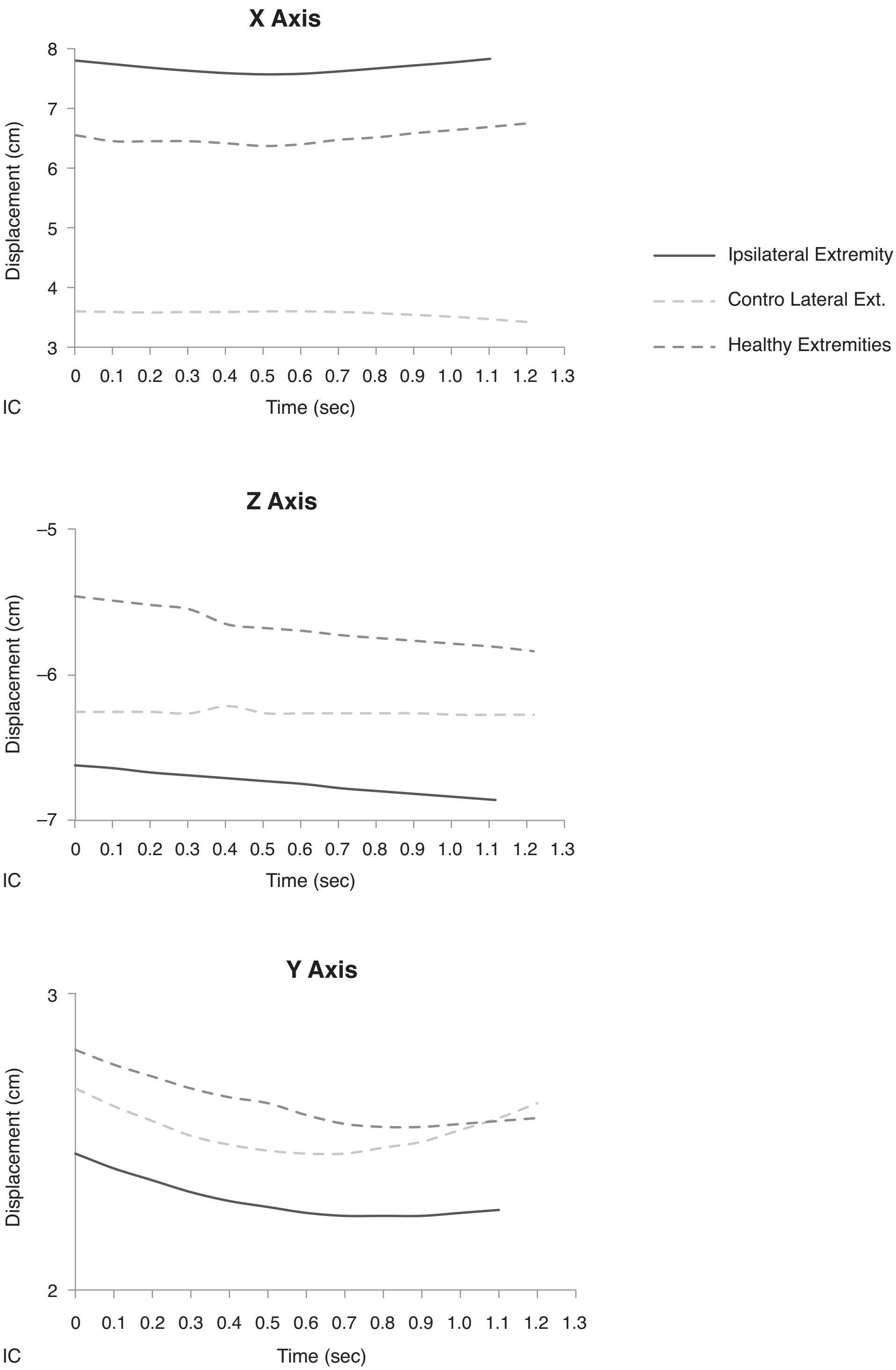
Hip joint	**Group B (*n* = 15)**	**Group A (*n* = 20) ipsilateral extremity**	***p*-value**	**Group A (*n* = 20) Controlateral extremity**	***p*-value**
Displacement X axis (cm)	6.40 (± 0.52)	6.36 (± 0.98)	NS	4.48 (± 0.53)	**< 0.01**
Displacement Y axis (cm)	2.69 (± 0.28)	2.91 (± 0.37)	NS	2.94 (± 0.37)	NS
Displacement Z axis (cm)	–5.10 (± 0.22)	–6.11 (± 0.51)	**< 0.02**	–5.83 (± 0.40)	**< 0.05**
Velocity 3D (m/sec)	0.06 (± 0.00)	0.05 (± 0.00)	NS	0.05 (± 0.01)	NS
Acceleration 3D (m/sec^2)	0.23 (± 0.01)	0.18 (± 0.03)	NS	0.21 (± 0.05)	NS

Significant differences are typed in bold. NS: not significant. The symbol minus of Z axis is indicative of lateral displacement.

Table 8. Ipsilateral (to scoliosis curve) and Controlateral (to scoliosis curve) center of gravity linear displacement (C.I 95%). Comparison to an average value of both extremities of the control group B.

Center of gravity (CoG)	**Group B (*n* = 15)**	**Group A (*n* = 20) Ipsilateral extremity**	***p*-value**	**Group A (*n* = 20) Controlateral extremity**	***p*-value**
Displacement X axis (cm)	6.07 (± 0.52)	6.46 (± 0.87)	NS	4.33 (± 0.47)	**< 0.01**
Displacement Y axis (cm)	3.56 (± 0.98)	5.53 (± 0.20)	NS	5.52 (± 1.96)	NS
Displacement Z axis (cm)	–5.24 (± 0.21)	–5.84 (± 0.40)	NS	–5.59 (± 0.33)	NS
Velocity 3D (m/sec)	0.34 (± 0.03)	0.29 (± 0.03)	NS	0.31 (± 0.03)	NS
Acceleration 3D (m/sec^2)	1.20 (± 0.19)	1.04 (± 0.16)	NS	1.17 (± 0.25)	NS

Significant differences are typed in bold. NS: not significant. The symbol minus of Z axis is indicative of lateral displacement.


X Axis
Displacement (cm)
8
7
6
5
4
3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
IC
Time (sec)
Ipsilateral Extremity
Contro Lateral Ext.
Healthy Extremities
Z Axis
Displacement (cm)
–5
–6
–7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
IC
Time (sec)
Y Axis
Displacement (cm)
3
2
0
0.1
0.2
0.3
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1.0
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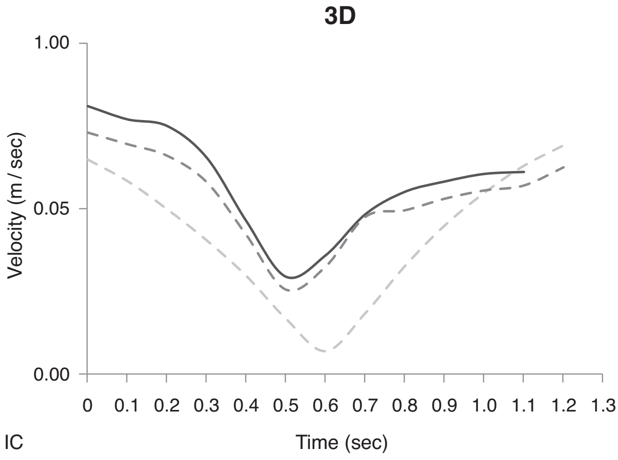
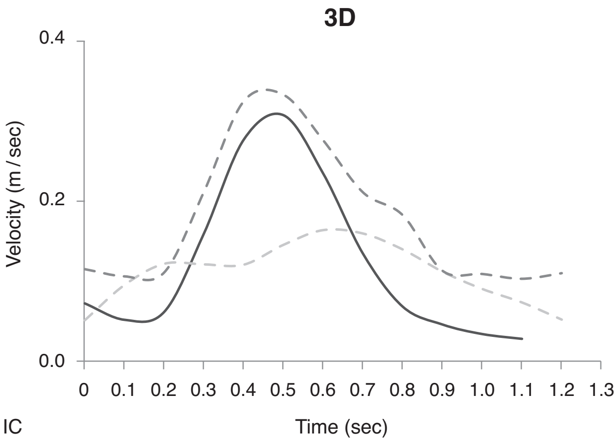
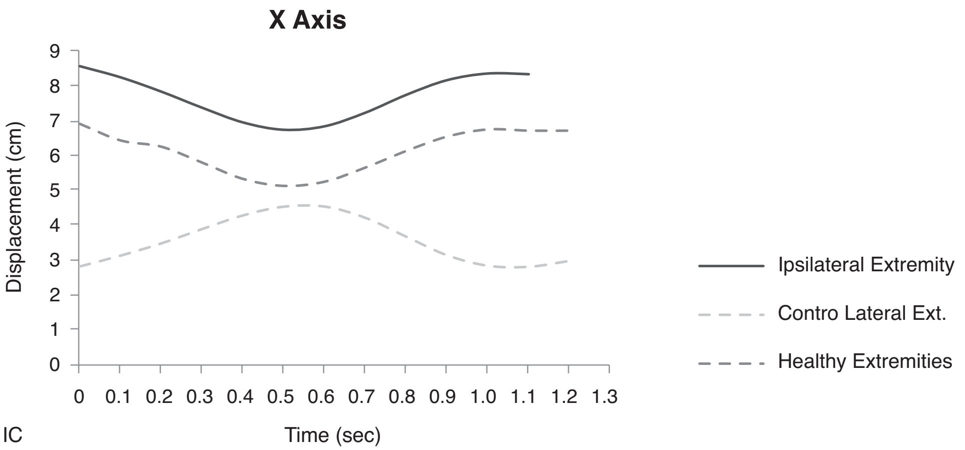
1.2
1.3
IC
Time (sec)





Graph 1. Hip joint. Typical linear displacement in X (sagittal), Y (gravitational) and Z (frontal) axes as well as velocity and acceleration during the gait cycle (IC stands for initial contact). Group B/ healthy, Ipsilateral hip /group A/ same side to the scoliosis curve, Controlateral /group A/ opposite side to the scoliosis curve)


X Axis
Displacement (cm)
9
8
7
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5
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2
1
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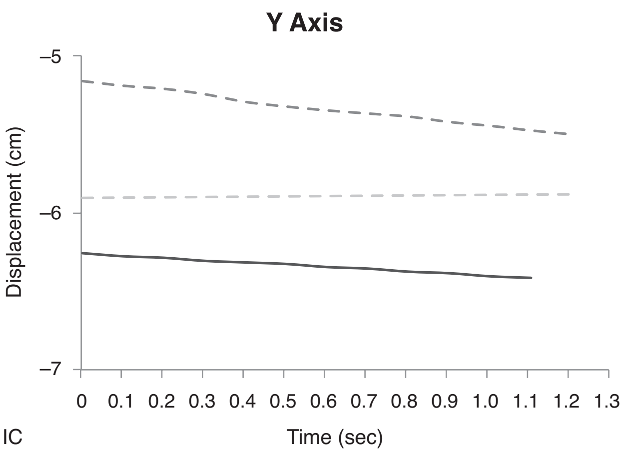
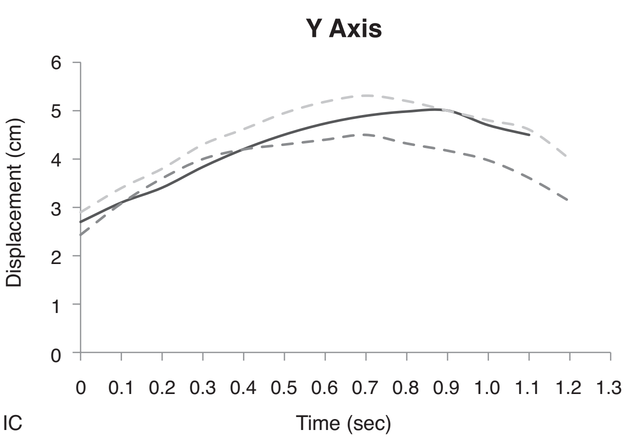
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
IC
Time (sec)
Ipsilateral Extremity
Contro Lateral Ext.
Healthy Extremities


Y Axis
Displacement (cm)
–5
–6
–7
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
IC
Time (sec)


Y Axis
Displacement (cm)
6
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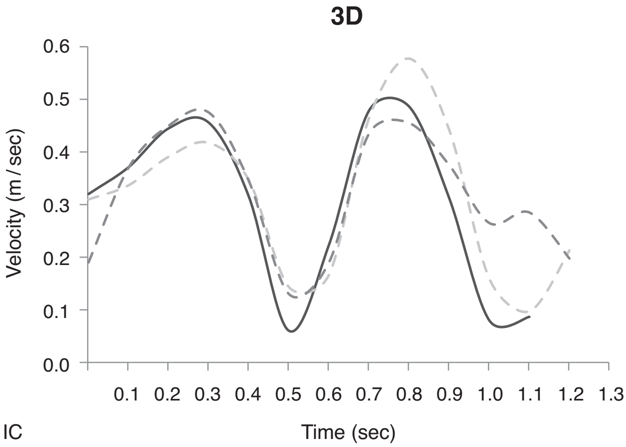
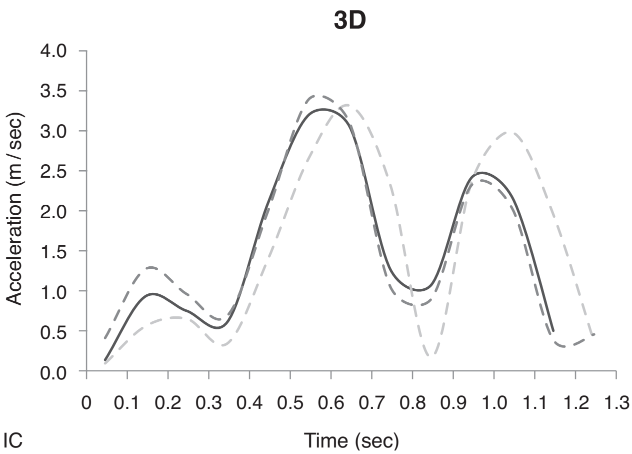
IC
Time (sec)





Graph 2. Centre of gravity. Typical linear displacement in X (sagittal), Y (gravitational) and Z (frontal) axes as well as velocity and acceleration during the gait cycle (IC stands for initial contact). Group B/ healthy, Ipsilateral hip /group A/ same side to the scoliosis curve, Controlateral /group A/ opposite side to the scoliosis curve.

DISCUSSION

Young adults have increased demands in everyday activities. The gait cycle plays important role in sport and occupational activities. We conducted this study to detect the effects of moderate idiopathic scoliosis (commonest type of scoliosis) on gait variables exerted from the hip joint and the center of gravity as compared to an able-bodied population. We combined the results to the findings of clinical examination (mainly motion restriction). We tried to offer a basis of better understanding.

The imbalance created by scoliosis affects the postural parameters of stability of the trunk [17, 19]. It also affects the coronal sacropelvic morphology [12]. As a result, important determinants of gait can be primarily affected [6]. The study of Mahaudens et al. [14] showed that idiopathic scoliosis in adolescents (not adults) does not affect the 3D displacement of pelvis during normal walking and equilibrium was maintained. On the contrary the study from Syczeswska et al. [22] showed that orientation of the pelvis during walking altered and this induces changes in gait stereotype. Chen et al. [1] mentioned that the IS patients generally produced higher sway area, lateral sway, sagittal sway and sway radius than normal subjects. The cadence is smaller in the IS patients, but the stance phase and stride phase are similar to normal subjects. Chockalingam et al. [2] noted that asymmetries in the gait pattern were detected in scoliosis patients and possible gait compensation is occurring, so that the subjects compensate on the controlateral pelvis/lower limb to that of the curve. Mahaudens et al. [13] suggested that patients with adult idiopathic scoliosis present no side to side differences but compared to healthy individuals a frontal pelvis, hip, and a transversal hip motion restriction existed. All these results indicated an almost physiological walk, even for those patients with severe scoliosis. Other researchers noted that sagittal plane hip motion followed a physiological pattern during gait cycle and the most significant and marked asymmetry was seen in the transverse plane, denoted as a torsional offset of the upper trunk in relation to the symmetrically rotating pelvis [8].

This study focused on patients with moderate thoraco-lumbar and lumbar primary curves because deformities at these levels are anatomically related to pelvis [12] and contribute to gait pathology. In scoliosis group, an influence upon the axial musculoskeletal system existed and similar abbreviations noted in the study of Zabjek et al. [29]. Although none of the group A patients had pain, this parameter (when present) is an important factor that influences proper posture and locomotion [4, 24].

There was mild leg length discrepancy found in scoliosis patients. It might play its role in the walking pattern but we considered it as an integral component of the examined pathology (lumbar and thoraco-lumbar scoliosis). This is the reason why we preferred not to exclude scoliosis patients when discrepancy was found. It is useful to report that the shorter extremity was on the ipsilateral side and the longer on the controlateral.

We chose the subjects to walk in their normal, self-selected speed because the gait cycle pattern will approximate more closely their daily walking manner [22]. Other studies preferred to explore the gait pathology by dividing the gait cycle into phases. Instead we preferred seconds as a unit of measuring time so as to emphasize the difference in the gait cycle duration.

The gait cycle from the lower extremities in group A was affected and altered and had increased duration compared to group B, in which in terms was similar to optional gait cycle [26].

The time difference of the gait cycle amongst ipsilateral and controlateral extremity in group A alters the phases of gait and their time of performance. Symptoms like tightness, elongation or shortening of the soft tissues were present as shown from clinical examination. They were connected with both general gait attributes (unisommetry and unisochrony) in group A while the gait analysis in control group, with almost identical anthropometric characteristics, presented minimal differences in the physical quantities exerted from the hip joints of the lower extremities and the centre of gravity as well as in their timing of performance.

From the kinetic point of view, the motion restriction found in our study during the gait cycle and in a side-to-side comparison in group A, the sagittal (forward/backward) linear displacement of the hip joint in the ipsilateral extremity (in the side of the convexity) was greatly increased. The sagittal linear displacement of the center of gravity, in the same joint, was increased too.

When comparing scoliosis patients with the control group, in our study, the analysis showed that: The hip joint in the ipsilateral side had increased frontal displacement (medial/lateral), while the hip joint in the controlateral side had increased frontal and decreased sagittal (forwards/backwards) displacement. The center of gravity in the controlateral side had mean sagittal displacement decreased. Linear 3D velocity and acceleration was lesser in scoliosis group but did not reach the level of significant statistical difference.

There is a contradiction in the results found in the literature about the gait pathology of scoliosis patients. From the above mentioned, scoliosis group had an increased frontal displacement in the hip joint of the ipsilateral and controlateral extremities like other studies observed too [1] while others observed motion restriction [14] in this axis (a fact which cannot be adequately explained). In our study, the ipsilateral hip joint and the centre of gravity had a similar sagittal displacement relative to the displacement of healthy people. The sagittal displacement of the same anatomical points in the controlateral extremity, the longer side, was lesser in comparison to group B, a condition that certificates compensation in the controlateral pelvis/limb like others mentioned [2]. We must add that despite pelvis obliquity in scoliosis people, the linear displacement in gravitational axis (upwards/downwards) was not altered compared with control group.

In conclusion this cohort of patients, with established but not degenerative scoliosis, showed that abnormal posture of the body is capable to induce changes in hip and CoG locomotion during gait cycle. Scoliosis patients, compared to healthy people, accomplish the gait cycle slower and an influence on their gait manner existed. This state derived from their postural misalignment possibly due to deformity and stiffness. Pathologies affecting the gait cycle like inadequate flexion/extension of the hip at initial contact or terminal stance phase respectively or excessive abduction of the hip at weight bearing phase were obvious in scoliosis group.

These statistical significant differences might prove to be helpful in evaluating the pelvic region and the correspondent gait cycle of young adults with moderate idiopathic scoliosis. The observations provided important information about posture and the corresponding locomotion in such patients and create a basis for further studies on biomechanics and clinical entities like athletic and occupational performance, fatigue and pain symptoms. Further studies focusing on improving range of motion, where found restricted, and/or leg length correction by orthotics and investigate their impact on gait and performance would be of great value.

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KINEMATIKA TĚŽIŠTĚ KYČELNÍHO KOUBU PŘI CHŮZI MLADÝCH DOSPĚLÝCH SE STŘEDNÍ IDIOPATICKOU SKOLIÓZOU. ŘÍZENÁ STUDIE

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SOUHRN

Skolióza ovlivňuje tělo a pánevní oblast. Tato studie zkoumá pohyb kyčelního kloubu a těžiště (CoG) subjektů se střední idiopatické skoliózou (MIS) ve srovnání se zdravou populací během cyklu chůze. Cílem této studie bylo také popsat rozdíly mezi dolními končetinami skoliotických pacientů. 20 mladých dospělých S (sk. A) s MIS a 15 členná kontrolní skupina (B) podstoupila 3D analýzu chůze s metodou přímé lineární transformace. Sledovanými parametry byly: změna umístění kyčelního kloubu (trochanter maj.) a těžiště na osách x, y a z; délka cyklu chůze. U pacientů se skoliózou byl patrný rozdíl délky DK (1.2 cm ± 0.2, C.I. 95 %). Při stranovém porovnání DK sk. A byl zjištěn rozdíl vychýlení kyčle a CoG v sagitální rovině na straně skoliózy (ipsilaterální) a na straně protější (kontralaterální). Při porovnání skupin A a B byly zjištěny následující rozdíly ($p < 0.05$): (a) cyklus chůze trval ve sk. A déle než ve sk. B, (b) kyčel na kontralaterální straně měla vyšší vychýlení v rovině frontální a nižší v rovině sagitální, (c) těžiště na kontralaterální mělo nižší sagitální vychýlení.

Klíčová slova: idiopatická skolióza u dospělých, cyklus chůze, kyčel, pánev, těžiště

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