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BEHAVIOUR OF THE KNEE AND ANKLE JOINT DURING GAIT CYCLE OF YOUNG ADULTS WITH MODERATE IDIOPATHIC SCOLIOSIS. A CONTROLLED STUDY

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ABSTRACT

Introduction: Scoliosis influences the optimal posture of the human body. The effect on the gait cycle of this entity is of major interesting. Purpose: Young adults with moderate idiopathic scoliosis (MIS) present kinematic modifications regarding the convex or concave side of the body compared to healthy people. Aim was to identify these variations. Methods: A cohort of twenty young adults (group A) having MIS and a control group (B) of fifteen healthy individuals were submitted in 3-D gait analysis with direct linear transformation method. The parameters examined were concerning the displacement of the knee and the ankle joints on x, y, and z axes. The gait cycle and the knee range of motion were examined. Results: Gait cycle in scoliosis patients showed increased duration compared to healthy people, $p < 0.05$. Regarding side to side comparison of the lower extremities in scoliosis patients the following outcomes were identified: Knee and ankle joint displacement in the ipsilateral (convex) side was increased regarding sagittal axis (x), $p < 0.05$. When compared both groups the following differences found, $p < 0.05$: The knee joint in the ipsilateral side (group A) had increased mean (z) frontal displacement. In the controlateral side (concave) of group A had decreased mean sagittal displacement and increased mean frontal and mean vertical (y) displacement. The ankle joint in the ipsilateral side had increased mean sagittal and frontal displacement. In the controlateral side had increased mean frontal displacement. The knee range of motion during the phases of gait cycle in scoliosis patients was seriously reduced compared to control group, $p < 0.05$. Discussion: Asymmetries observed amongst the lower extremities during the gait cycle of scoliosis patients. Also asymmetries observed in comparison to healthy people. Some of these asymmetries agree to other studies. A compensatory walking close to normal walking existed. These observations might prove to be helpful in treating the gait cycle of young adults with MIS.

Key words: Moderate idiopathic scoliosis, gait cycle, knee and ankle joint

INTRODUCTION

Scoliosis is defined as an appreciable lateral deviation in the normally straight vertical alignment of the spine. There is abnormal deformation between and within vertebrae, too much curvature in the frontal plane, too much vertical axis rotation in the wrong direction, and not enough curvature in the sagittal plane with i.e.a loss of normal kyphosis or with a relative lordosis (White, 1990).

The prevalence of mild to moderate scoliosis in adolescents is 3000–5000 per 100,000 population, and in adults as high as 12% (Korovessis, 1994; Weiss, 2006). Scoliosis is associated with increased pain in adults of all ages (Jackson, 1989), compared with control populations (Mayo, 1994; Weinstein, 2003). Furthermore, children and adults with mild to moderate curvatures may have reduced vital capacity and exercise capacity (Chong, 1981; DiRocco, 1988; Schwab, 2003; Szeinberg, 1988; Weinstein, 2003), and young adults with moderate scoliosis exhibit measurable changes in cardiac function (Whittle, 2002).

Scoliosis patients exhibit significantly impaired quality of life (Schwab, 2003) and young adults with moderate idiopathic scoliosis (MIS) consist a population group with increased occupational and sports activities (Weinstein, 2003) and gait cycle is of great importance. Gait analysis is used to assess, plan, and treat (Zabjek, 2001) individuals with conditions affecting their ability to walk. It is also commonly used in sports biomechanics to help athletes run more efficiently and to identify posture-related or movement-related problems in people with injuries.

The gait cycle is determine the kind, manner and way of walking amongst human beings and divided into two phases, stance and swing. Stance is the term used to designate the entire period during which the foot is on the ground. The word swing applies to the time the foot is in the air for limb advancement (Whittle, 2002).

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.

PURPOSE

In Scoliosis abnormal spinal curvatures in the frontal or sagittal plane of the thoracic and/ or lumbar spine have proven difficult to prevent or treat. These deviations of the human structures or tissues causes a significant number of deformities which are followed by an influence upon the proper distribution of forces acting in and around a joint, ligament, bone or muscle. The trunk becomes dysfunctional and the lower extremities too. The knee and ankle joint participate in a lot of roles during walking and will probably be affected from the axial misalignment of the body. The goal is to identify the degree that moderate idiopathic scoliosis influences or not the physical quantities (linear velocity, linear acceleration and linear displacement) exerted from the distal joints of the lower extremities during the gait cycle compared to those from healthy people.

The purpose of this work is: To detect the behaviour of the knee and ankle joint amongst the lower extremities of young adults with moderate idiopathic scoliosis during gait cycle and the correspondence of these joints due to an abnormal movement created always in comparison with the gait cycle of healthy people.

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 from 20 young adults with moderate idiopathic scoliosis and group B with 15 healthy people without any known spinal deformity or disease (table 1). All patients had a right thoracolumbar or left lumbar primary structural curve because these curves are closely related to pelvis and in terms with the gait cycle of human beings. The average Cobb's angle in group A was 29.4° and plumb line declination was 1.2 cm. Characteristic deformities were the functional leg length difference and the obliquity of pelvis that participated in an asynchronous gait cycle that both extremities in group A presented. Every subject signed on and participated freely in the study, approved by the local ethics board. All subjects were submitted to a clinical, radiological (Cobb, 1948), and gait assessment. The gait cycle was divided according the convexity created from the scoliosis. The term "Ipsilateral" is used for the convexity side joints and "Controlateral" for the concavity side joints in group A. In group B the distal joints of the lower extremities are presented with average values from both sides (left-right) due to minimal differences found between them.

Table 1. Demographic data.

Demographic data	***Scoliosis patients*** Group A ($n = 20$)	***Control group*** Group B ($n = 15$)
Height (cm)	1.72 (1.55–1.90)	1.70 (1.57–1.91)
Body Weight (Kg)	74 (58–92)	72 (60–90)
Age (years)	32.4 (20–40)	36.1 (23–38)
Sex	12 Females 8 Males	8 Females 7 Males

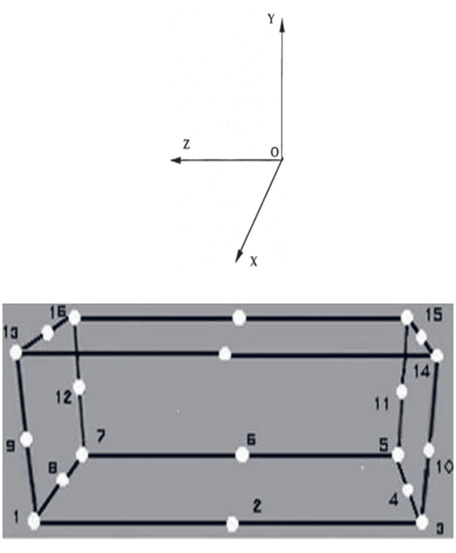
The gait assessment was succeeded with three dimensional (3D) optical analysis of walking stereotypes with "forced walking" on a mechanical treadmill.

All the motion quantification systems depend on defining the arcs and positions of the individual joints numerically and thus on the lower extremities there was installation of paper markers on the skin surface of anatomical landmarks (lateral condyle and lateral malleolus) that accurately represent the actions of specific joints (knee and ankle) necessary for movement identification. A mechanical treadmill was used and for 3D video motion analysis three digital video camera recorders where obtained. The record frequency was 50 half frames per second in each camera. From each video record were obtained coordinates of the above mentioned points and these coordinates were computed the kinematic parameters with respect to the weight and height of the patient during the locomotion on the treadmill.

A reference frame provided the reference for the description of the physical quantities of our interest (always with respect to the weight, height and the fixed anatomical points) which are: a) The linear displacement which defined as the position of a particle and its location at a given instance, b) linear velocity which defined as the rate of change in the position or the rate of displacement and c) linear acceleration which defined as the rate of change in velocity (Vaughan, 1999). Basically the reference frame displayed different perspectives in our view while the coordinate system provided different ways for the description of the physical quantities in these perspectives. This coordinate system was based upon the Cartesian 3D coordinate system (Figure 1). Finally a light bulb was used to provide the necessary light as well a treadmill on which the patient was walking during the recording period and provided the steady base for the fixed cameras that were used.

The 3D kinematic analysis of gait was succeeded with the subjects walked on a mechanical treadmill while holding supporters from the device to prevent falling and performing several times the gait cycle.

Random one of the gait cycles was selected, with respect to the steady pace of walking so as to avoid mistakes in measuring the physical quantities, and recorded by 3 cameras that were placed in a circular manner and focused in the specific points of our interest and with respect to the coordinate system. 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 so as to compare the movement stereotype between the lower extremities, and we recorded the locomotion of each leg separately. The recording took place from different angles so to be a 3D approach. Eventually the recorded data was being processed by the computer through software (Ariel Dynamics Software-APAS) and then a direct linear transformation (DLT Method) of the captured data was done so as to compute the three-dimensional image space coordinates of the subject's body joints from the relative two-dimensional digitized coordinates of each camera's view. This process involved the transformation of the relative digitized coordinates of each point in each frame to absolute image space coordinates through a computer and was possible to load all data into the computer while simultaneously displayed and evaluate multiple data sets



	X axis	Y axis	Z axis
1	0.000	0.000	0.000
2	0.500	0.000	0.000
3	1.000	0.000	0.000
4	1.000	0.000	0.250
5	1.000	0.000	0.500
6	0.500	0.000	0.500
7	0.000	0.000	0.500
8	0.000	0.000	0.250
9	0.000	0.250	0.000
10	1.000	0.250	0.000
11	1.000	0.250	0.500
12	0.000	0.250	0.500
13	0.000	0.500	0.000
14	1.000	0.500	0.000
15	1.000	0.500	0.500
16	0.000	0.500	0.500

Figure 1. A reference frame through a Cartesian 3D coordinate system and the coordinates of the control points.

for a desired sequence (Craik, 1995). These measurements (Winter, 2009) allowed computation 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 knee and ankle joint as well as the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from these joints. Also the duration of the gait cycle (sec) and the angular degrees of freedom of the knee joint (sagittal plane) were computed.

For the purpose of statistical analyses power was set at 80%. Student paired t-test was used for the purpose of statistical analysis of the behavior of the knee and ankle joints across groups and sides of the body (side to side comparison) with level of significance at 95% (Confidence interval C.I 95%) and the mean value for each quantity was used for statistical analysis. The accepted significance level was < 0.05 or lesser for all analyses.

RESULTS

Moderate idiopathic scoliosis in early adults produces a number of dysfunctional deformities that affect the postural system and produce abnormalities to the body segments that are closely related with the proper body-weight distribution and locomotion as well. The posture of the patient's bodies was asymmetrical with an inclination left or right according to the type of scoliosis. The basic movements of the trunk were affected and eventually restricted or even lost due to different types of deformity which are directly or indirectly connected with the deformity of scoliosis (Perry, 2010). The average Cobb's angle in group A was 29.4° and plumb line declination was 1.2 cm. Characteristic deformities were the functional leg length difference and the obliquity of pelvis that participated in an asynchronous gait cycle that both extremities in group A presented.

Body-weight distribution of the lower extremities was unevenly in group A and the mean difference between them was 1.495 kg (±0.205, Confidence Interval C.I 95%). which is greater compared to 0.77 kg (±0.224), $p < 0.05$, the mean difference between the extremities in control group B. Mean leg length discrepancy in group A was 1.49 cm (±0.2 cm) while in group B the difference was 0.55 cm (±0.131), $p < 0.05$. The gait cycle from both extremities in group A was asynchronous and the phases of walking were not executed in a simultaneous manner amongst them. The gait cycle in scoliosis patients was increased compared to healthy people and amongst the extremities in group A the ipsilateral side had a mean gait cycle at 1.42 sec (±0.11 sec) and the controlateral side had a mean gait cycle at 1.39 sec (±0.076 sec) while the average from both extremities (group B) had a mean gait cycle at 1.21 sec (±0.073), $p < 0.05$. Also, the mean gait cycle difference between the lower extremities from group A was 0.153 sec (±0.039 sec) and it is greater from the mean difference resulted from group B, that was 0.02 (±0.003 sec), $p < 0.05$.

The statistical differences found in scoliosis (group A) patients between ipsilateral and controlateral extremity (side to side comparison) were concerning: The knee joint in the ipsilateral side of the trunk that had 6.74 cm (± 0.89) mean sagittal displacement, higher than the mean sagittal displacement of the knee joint in the controlateral side that had 4.8 cm (±0.35), 28.8% less, $p < 0.05$ and the ankle joint at the ipsilateral side of the trunk had 6.46 cm (±0.66) mean sagittal displacement, higher than the mean sagittal displacement of the ankle joint in the controlateral side that had 4.5 cm (±0.34), 31.2% less,

$p < 0.05$. Linear 3D velocity or 3D acceleration was lesser in the ipsilateral extremity but wasn't reached the level of any significant statistical difference.

Table 2. The average Plumb line declination (cm), Cobb's angle (°) and apical rotation (grades) in scoliosis group and in healthy group.

Clinical data	Scoliosis patients Group A (*n* = 20)			Control group mean Group B (*n* = 15)			
	Average	Standard Deviation	Confi-dence Interval (±)	Average	Standard Deviation	Confi-dence Interval (±)	*P* value
	Ipsilateral side of the trunk			Trunk			
Cobb's angle (°)	29.4 (20°–34°)	2.97	1.30	0.45	0.25	0.13	**< 0.01**
Apical rotation (grades)	+1 (0/+–4)	NE	NE	NE	NE	NE	NE
Plumb line declination (cm)	1.2	0.34	0.15	0.14	0.083	0.042	**< 0.01**

Significant differences are typed in bold and are accepted for P value < 0.05.
NE not existed, Confidence interval (±C.I).

Table 3. The average body-weight distribution, Leg length discrepancy (LLD) and gait cycle in patients with moderate idiopathic scoliosis and healthy subjects.

Clinical data	Scoliosis patients Grioup (*n* = 20)						
	Average		Standard Deviation		Confidence Interval (±)		*P* value
	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	
Body weight distribution (kg)	30.1	32.51	5.6560	7.2111	3.5501	3.1603	NS
Leg lenght discrepancy (cm)	83.96	85.56	6.2387	6.4155	2.7342	2.8116	NS
Gait cycle (sec)	1.415	1.393	0.2488	0.1680	0.1091	0.0736	NS

NS not significant, i.e. P value > 0.05.

Table 4. The average body-weight distribution, LLD and gait cycle difference between ipsilateral and controlateral extremity in patients with moderate idiopathic scoliosis and healthy subjects. Control group B represented by an average value from lower extremities due to minimal differences found amongst lower extremities.

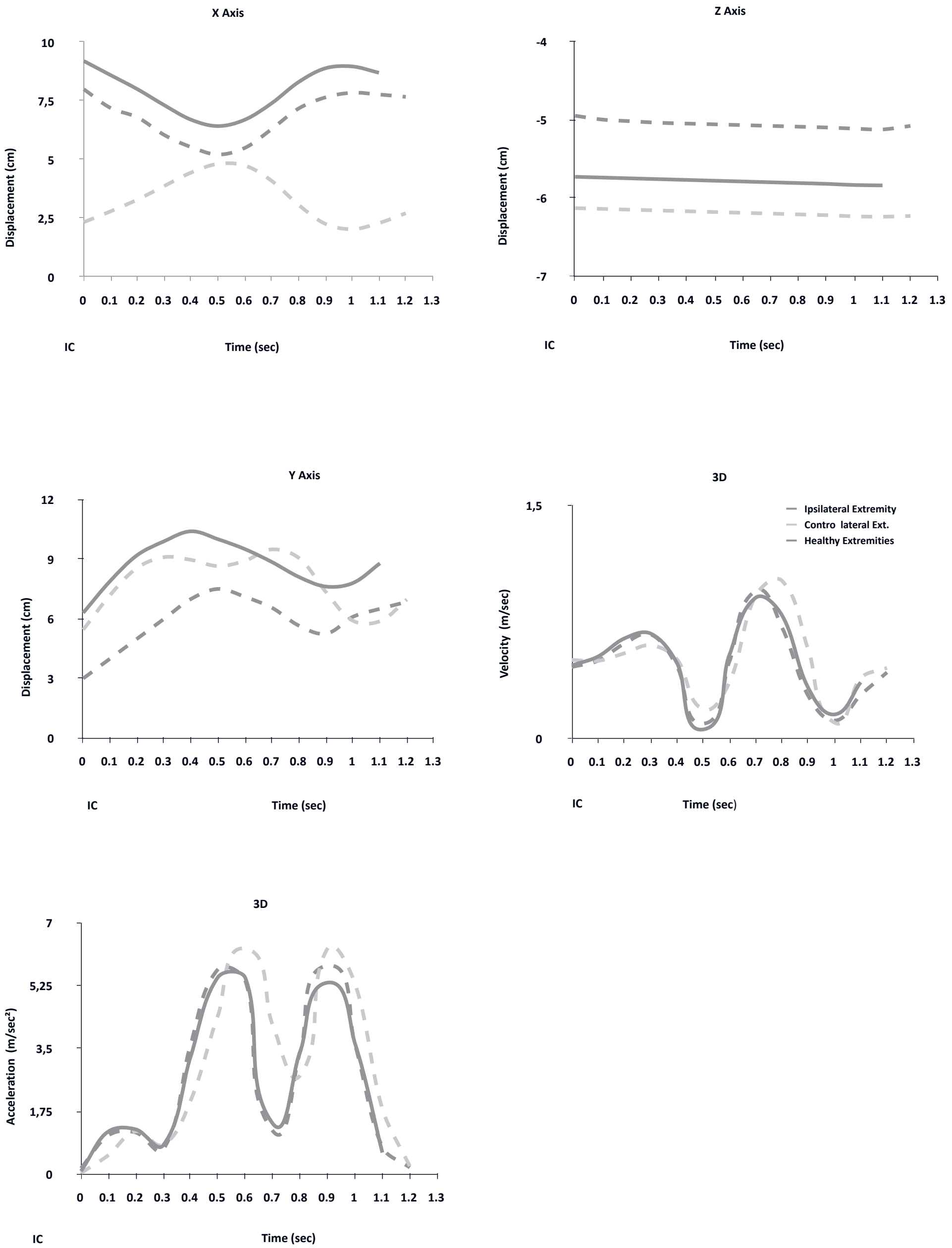
Clinical data	Scoliosis patients Group A (n = 20)			Control group mean Group B (n = 15)			
	Average	Standard Deviation	Confidence Interval (±)	Average	Standard Deviation	Confidence Interval (±)	*P* value
	Ipsilateral and controlateral extremities difference			Lower Extremities difference (mean)			
Body weight distribution (kg)	2.405	1.824937	0.799	0.22	0.443471157	0.224423246	**< 0.01**
Leg length discrepancy (cm)	1.6	0.479556	0.210	0.4866667	0.258751582	0.130943961	**< 0.01**
Gait cycle (sec)	0.022	0.084205	0.037	0.0026667	0.00507093	0.002566195	**< 0.01**

Significant differences are typed in bold and are accepted for P value < 0.05.

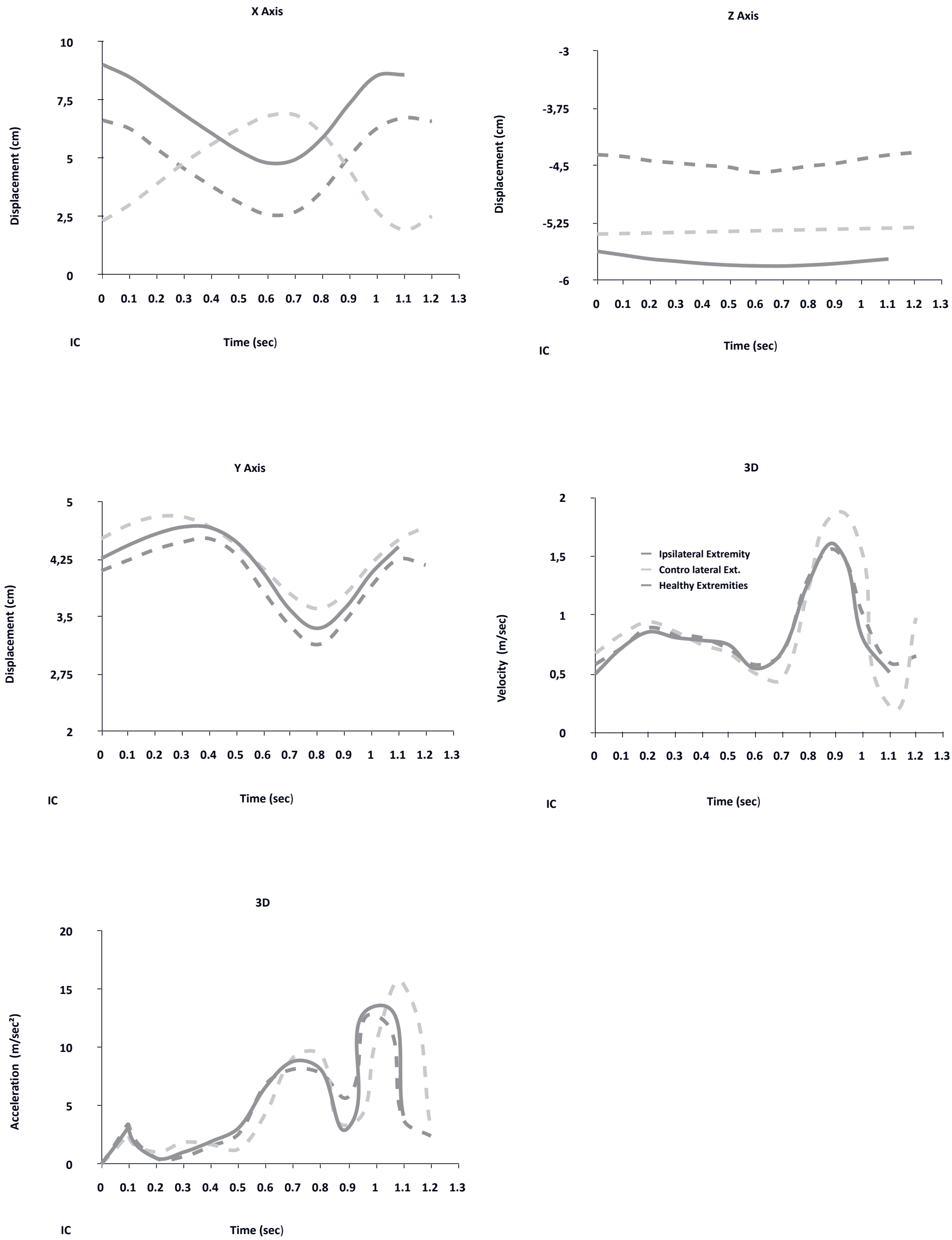
Table 5. The average body-weight distribution, LLD and gait cycle in patients with moderate idiopathic scoliosis and healthy subjects. Control group B represented by an average value from lower extremities.

Clinical data	Scoliosis patients Group A (n = 20)			Control group mean Group B (n = 15)			
	Average	Standard Deviation	Confidence Interval (±)	Average	Standard Deviation	Confidence Interval (±)	*P* value
	Ipsilateral extremity			Lower Extremities (mean)			
Body weight distribution (kg)	30.1	5.6560	3.5501	30.57	5.82	2.94	NS
Leg length discrepancy (cm)	83.96	6.2387	2.7342	85.02	6.50	3.29	NS
Gait cycle (sec)	1.42	0.2488	0.1091	1.21	0.14	0.073	**< 0.05**
	Controlateral extremity			Lower Extremities (mean)			
Body weight distribution (kg)	32.51	7.2111	3.1603	30.57	5.82	2.94	NS
Leg length discrepancy (cm)	85.56	6.4155	2.8116	85.02	6.50	3.29	NS
Gait cycle (sec)	1.39	0.1680	0.0736	1.21	0.14	0.073	**< 0.02**

Significant differences are typed in bold and are accepted for P value < 0.05.
NS not significant, i.e. P value > 0.05.



Graph 1. Typical linear displacement, velocity and acceleration of the knee joint during the gait cycle (IC stands for initial contact with the gait cycle initiated from double support phase) of young adults suffering from moderate idiopathic scoliosis (ipsilateral at the convex side) and healthy subjects (average from right and left extremity).



Graph 2. Typical linear displacement, velocity and acceleration of the ankle joint during the gait cycle (IC stands for initial contact with the gait cycle initiated from double support phase) of young adults suffering from moderate idiopathic scoliosis (ipsilateral at the convex side) and healthy subjects (average from right and left extremity).

Table 6. Kinematic data: The linear displacement (cm) in sagittal plane (x axis), gravitational plane (y axis), and frontal plane (z axis) and the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from the knee joints amongst the ipsilateral and the controlateral extremity in scoliosis patients.

Kinematic data	Scoliosis patients Group A (*n* = 20)						
	Average		Standard Deviation		Confidence Interval (±)		*P* value
Knee Joint	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	
Displacement X axis (cm)	6.7421	4.805	2.045677	0.78972	0.89654	0.346104	**< 0.01**
Displacement Y axis (cm)	7.4665	8.1705	4.714639	3.435169	2.066244	1.505501	NS
Displacement Z axis (cm)	–5.635	–5,56	0.901037	0.730825	0.39489	0.320292	NS
Velocity 3D (m/sec)	0,4398	0,45565	0,065678	0.090679	0.028784	0.039741	NS
Acceleration 3D (m/sec^2)	1.7667	1.9097	0.523855	0.857731	0.229585	0.37591	NS

Significant differences are typed in bold and are accepted for P value < 0.05.

Table 7. Kinematic data: The linear displacement (cm) in sagittal plane (x axis), gravitational plane (y axis), and frontal plane (z axis) and the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from the ankle joints amongst the ipsilateral and the controlateral extremity in scoliosis patients.

Kinematic data	Scoliosis patients Group A (*n* = 20)						
	Average		Standard Deviation		Confidence Interval (±)		*P* value
Ankle Joint	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	
Displacement X axis (cm)	6.46	4.445	1.498912	0.786381	0.656915	0.34464	**< 0.01**
Displacement Y axis (cm)	4.005	4.04	0.496806	0.456992	0.217731	0.200282	NS
Displacement Z axis (cm)	–5.32	–5.165	0.814733	0.88334	0.357066	0.387134	NS
Velocity 3D (m/sec)	0.6723	0.7176	0.124648	0.164049	0.054628	0.071896	NS
Acceleration 3D (m/sec^2)	2.7043	2.9467	1.17324	1.571771	0.514186	0.688846	NS

NS not significant, i.e. P value > 0.05.

Comparison of group A and group B showed statistical significant difference in the following parameters (C.I 95%): Relative to the knee joint, mean sagittal in the controlateral side in group A was lesser 4.48 cm (±0.35) vs. 6.53 cm (±0.43) compared to an average that both knees in group B produced. Knee's mean frontal displacement (medial-lateral) and mean vertical displacement (upward-downward) in group A was higher in controlateral side comparison to group B average value from both extremities (controlateral, y axis 8.17 cm, C.I ±1.51, z axis −5.56 cm, ±0.32/ average value from both knees, group B, y axis 4.87 cm, C.I ±0.64, z axis −4.73 cm, ±0.20). As for the knee joint in the ipsilateral side, the mean frontal displacement in scoliosis group was −5.6 cm (±0.39) and it is higher compared to −4.73 cm (±0.20) found in control group. The ankle's mean sagittal and frontal displacement in the ipsilateral side of the trunk (scoliosis patients) was higher compared to an average value resulted from both ankles in control group concerning x and z axis (ipsilateral, x axis 6.46 cm, C.I ±0.66, z axis −5.32 cm, ±0.36/healthy extremities, x axis 4.74 cm, C.I ±0.18, z axis −4.21 cm, ±0.15), while mean frontal displacement was higher in the controlateral side of group A compared to group B (controlateral −5.17 cm, (±0.39) vs. healthy extremities −4.21 cm, ±0.15), $p < 0.05$.

Table 8. Kinematic data: The linear displacement (cm) in sagittal (x axis), gravitational (y axis), and frontal planes (z axis) and the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from the knee joints amongst the ipsilateral and the mean from both extremities in healthy people.

Kinematic data	Scoliosis patients Group A (*n* = 20)			Control group mean Group B (*n* = 15)			
	Average	Standard Deviation	Confidence Interval (±)	Average	Standard Deviation	Confidence Interval (±)	*P* value
Knee Joint	Ipsilateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	6.7421	2.045677	0.89654	6.5267	0.849762	0.43003	NS
Displacement Y axis (cm)	7.4665	4.714639	2.06624	4.866	1.272705	0.64406	**NS***
Displacement Z axis (cm)	–5.635	0.901034	0.39489	–4.7333	0.400743	0.2028	**< 0.01**
Velocity 3D (m/sec)	0.4398	0.065678	0.028784	0.47	0.033434	0.01692	NS
Acceleration 3D (m/sec^2)	1.7667	0.523855	0.229585	1.938833	0.42825	0.21672	NS

Significantly different from the control group NS*

Table 9. Kinematic data: The linear displacement (cm) in sagittal plane (x axis), gravitational plane (y axis), and frontal plane (z axis) and the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from the knee joints amongst the controlateral and the mean from both extremities in healthy people.

Kinematic data	Scoliosis patients Group A (*n* = 20)			Control group mean Group B (*n* = 15)			
	Average	Standard Deviation	Confi-dence Interval (±)	Average	Standard Deviation	Confi-dence Interval (±)	*P* value
Knee Joint	Controlateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	4.805	0.78972	0.346104	6.5267	0.849762	0.43003	**< 0.01**
Displacement Y axis (cm)	8.1705	3.435169	1.505501	4.866	1.272705	0.64406	**< 0.01**
Displacement Z axis (cm)	–5.56	0.730825	0.320292	–4.7333	0.400743	0.2028	**< 0.01**
Velocity 3D (m/sec)	0.45565	0.090679	0.039741	0.47	0.033434	0.01692	NS
Acceleration 3D (m/sec^2)	1.9097	0.857731	0.37591	1.938833	0.42825	0.21672	NS

Significant differences are typed in bold and are accepted for P value < 0.05.

Table 10. Kinematic data: The linear displacement (cm) in sagittal plane (x axis), gravitational plane (y axis), and frontal plane (z axis) and the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from the ankle joints amongst the ipsilateral and the mean from both extremities in healthy people.

Kinematic data	Scoliosis patients Group A (*n* = 20)			Control group mean Group B (*n* = 15)			
	Average	Standard Deviation	Confi-dence Interval (±)	Average	Standard Deviation	Confidence Interval (±)	*P* value
Ankle Joint	Ipsilateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	6.46	1.4989119	0.656915	4.7433	0.348909	0.1765695	**< 0.01**
Displacement Y axis (cm)	4.005	0.496806	0.217731	3.84	0.350612	0.177431	NS
Displacement Z axis (cm)	–5.32	0.814733	0.357066	–4.21	0.299523	0.1515769	**< 0.01**
Velocity 3D (m/sec)	0.6723	0.124648	0.054628	0.73667	0.080504	0.04074	NS
Acceleration 3D (m/sec^2)	2.7043	1.17324	0.514186	2.95912	0.53615	0.271324	NS

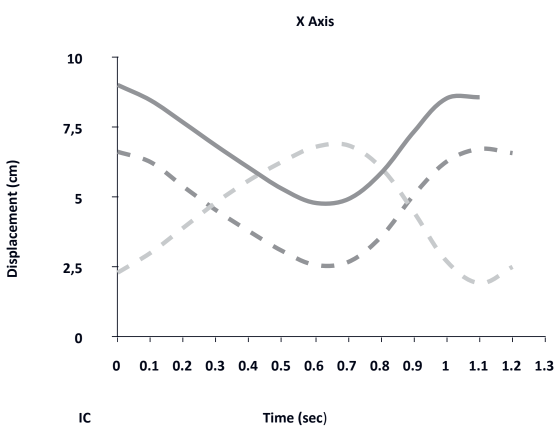
Confidence interval (±C.I).
NS not significant, i.e. P value > 0.05.

Table 11. Kinematic data: The linear displacement (cm) in sagittal plane (x axis), gravitational plane (y axis), and frontal plane (z axis) and the 3D linear velocity (m/sec) and acceleration (m/sec^2) exerted from the ankle joints amongst the controlateral and the mean from both extremities in healthy people.

Kinematic data	Scoliosis patients Group A (n = 20)			Control group mean Group B (n = 15)			
	Average	Standard Deviation	Confidence Interval(±)	Average	Standard Deviation	Confidence Interval(±)	P value
Ankle Joint	Controlateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	4.445	0.786381	0.34464	4.7433	0.348909	0.1765695	NS
Displacement Y axis (cm)	4.04	0.456992	0.200282	3.84	0.350612	0.177431	NS
Displacement Z axis (cm)	–5.165	0.88334	0.387134	–4.21	0.299523	0.1515769	**< 0.01**
Velocity 3D (m/sec)	0.7176	0.164049	0.071896	0.73667	0.080504	0.04074	NS
Acceleration 3D (m/sec^2)	2.9467	1.571771	0.688846	2.95912	0.53615	0.271324	NS

NS not significant, i.e. P value > 0.05.
Significant differences are typed in bold and are accepted for P value < 0.05.

Graph 3. Typical angles of the knee joint during the gait cycle (IC stands for initial contact with the gait cycle initiated from double support phase) of young adults suffering from moderate idiopathic scoliosis (ipsilateral at the convex side) and healthy subjects (average from right and left extremity).



During the phases of gait cycle in group A, the angles of the knee joint (in sagittal axis-x axis) amongst ipsilateral and controlateral extremities did not showed any significant difference. Regarding knee range of motion scoliosis patients had seriously reduced range of angles (degrees) during gait cycle and a number of significant statistical differences were found amongst groups and included: in scoliosis group an initial contact (from double support phase and with heel strike) of the ipsilateral knee that was extended at 30.6° (±4.91), initial and mid swing phases with 26° (±2.18) and 50.7° (±2.31) flexion on average respectively, while the controlateral knee had 34.7° (±4.91) average extension at initial contact, 26.6° (±2.54) average flexion at initial swing phase and 51.2 (±4.93) average flexion in mid swing phase. In contrast group B (non-scoliosis group) had at initial contact an average extension at 2° (±0.51) and in initial and mid swing phases an average flexion at 41.5° (±0.42) and 74.5° (±0.43), respectively, $p < 0.05$. The difference in the mean angular displacement of the knee joint, during the gait cycle, amongst the ipsilateral and the controlateral extremity in group A was not significant but it is higher (1.44°, C.I±1.07) compared to the mean angle difference exerted from the right and left knee in group B (0.87°, ±0.09), $p < 0.05$.

Table 12. Kinematic data exerted from the knee joint in the sagittal plane (x axis) amongst the ipsilateral and the controlateral extremities in scoliosis patients during the phases of the gait cycle.

Kinematic data	Scoliosis patients Group A (*n* = 20)						
	Average		Standard Deviation		Confidence Interval (±)		*P* value
Knee Joint (sagittal plane)	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	Ipsilateral extremity	Contro-lateral extremity	
Total angles of freedom	25.54	26.99	4.97	4.95	2.18	2.17	NS
Initial contact (°)	30.55	34.7	11.20	11.26	4.91	4.93	NS
Mid stance (°)	22.15	22.7	7.59	7.29	3.33	3.20	NS
Terminal stance (°)	6.45	6.71	5.42	4.90	2.38	2.15	NS
Initial swing (°)	25.9	26.6	6.08	5.80	2.66	2,54	NS
Mid swing (°)	50.65	51.2	5.26	7.19	2.31	3.15	NS
Terminal swing (°)	31.45	32.5	10.05	9.32	4.40	4.08	NS

NS not significant, i.e. P value > 0.05.

Table 13. Kinematic data exerted from the knee joint angles of freedom in the sagittal plane (x axis) amongst: a) the ipsilateral extremity of scoliosis patients and the mean from both extremities in healthy people, b) controlateral extremity of scoliosis patients and the mean from both extremities in healthy people during the phases of the gait cycle.

Kinematic data	Scoliosis patients Group A (*n* = 20)			Control group mean Group B (*n* = 15)			
	Average	Standard Deviation	Confidence Interval (±)	Average	Standard Deviation	Confidence Interval (±)	*P* value
Knee Joint (sagittal)	Ipsilateral extremity			Lower Extremities (mean)			
Total Angles of freedom	25.54	4.97	2.18	31.27	0.88	0.45	**< 0.01**
Initial contact (°)	3055	11.20	4.91	2	1	0.51	**< 0.01**
Mid stance (°)	22.15	7.59	3.33	24.5	0.80	0.41	NS
Terminal stance (°)	6.45	5.42	2.38	9.5	0.57	0.29	NS
Initial swing (°)	25.9	6.08	2.66	41.5	0.82	0.42	**< 0.01**
Mid swing (°)	50.65	5.26	2.31	74.5	0.85	0.43	**< 0.01**
Terminal swing (°)	31.45	10.05	4.40	29.5	1.15	0.58	NS
	Controlateral extremity			Lower Extremities (mean)			
Total Angles of freedom	26.99	4.95	2.17	31.27	0.88	0.45	**< 0.02**
Initial contact (°)	34.7	11.26	4.93	2	1	0.51	**< 0.01**
Mid stance (°)	22.7	7.29	3.20	24.5	0.80	0.41	NS
Terminal stance (°)	6.7	4.90	2.15	9.5	0.57	0.29	NS
Initial swing (°)	26.6	5.80	2.54	41.5	0.82	0.42	**< 0.01**
Mid swing (°)	51.2	7.19	3.15	74.5	0.85	0.43	**< 0.01**
Terminal swing (°)	32.5	9.32	4.08	29.5	1.15	0.58	NS

Significant differences are typed in bold and are accepted for P value < 0.05.
NS not significant, i.e. P value > 0.05.
Confidence interval (±C.I).

Table 14. The average differences of knee joint angles of freedom during phases of gait cycle between ipsilateral and controlateral extremities in patients with moderate idiopathic scoliosis and the lower extremities of healthy subjects.

Kinematic data	Scoliosis patients Group A (*n* = 20)			Control group Group B (*n* = 15)			
	Average	Standard Deviation	Confi-dence Interval (±)	Average	Standard Deviation	Confi-dence Interval (±)	*P* value
Knee Joint (sagittal)	Ipsilateral and controlateral extremities difference			Lower extremities difference			
Total angles of freedom	1.44	2.44	1.07	0.87	0.18	0.09	**< 0.01**
Initial contact (°)	4.15	7.17	3.14	1	0.16	0.08	**< 0.03**
Mid stance (°)	0.55	2.06	0.90	0.49	0.22	0.11	**< 0.01**
Terminal stance (°)	0.25	3.21	1.41	0.31	0.09	0.05	**< 0.01**
Initial swing (°)	0.7	2.95	1.29	0.59	0.27	0.14	**< 0.01**
Mid swing (°)	0.55	2.91	1.28	0.53	0.22	0.11	**< 0.01**
Terminal swing (°)	1.05	6.97	3.06	0.71	0.67	0.34	NS*

Significant differences are typed in bold and are accepted for P value < 0.05.
NS* different from the control group but with no significance.

DISCUSSION

Young adults suffering from scoliosis, belong to a group of population with increased demands in everyday activities. The gait cycle plays an important role in sport and occupational activities of people and can be analyzed with a simple and easy manner. The analyses could provide to us adequate information about the conservative treatment plan of individuals with conditions affecting their ability to walk since MIS is the commonest type of scoliosis. We conducted this study to detect the effects of moderate idiopathic scoliosis on gait variables, of young adults, exerted from the knee and ankle joint of the lower extremities, and the correspondence of gait cycle relative to this kind of disorder, as compared to an able-bodied population and an asymmetric scoliosis posture.

The imbalance created by scoliosis affect the postural parameters of stability (center of mass and center of pressure) (Nault, 2002), the trunk (Raso, 1998), the coronal sacropelvic morphology (Mac-Thiong, 2006) and thus an important determinant of gait that would be primarily affected (Della Croce, 2001) from this influence.

Many studies have conducted gait analysis on idiopathic scoliosis subjects with the objective of identifying differences in gait parameters between scoliosis patients and healthy subjects. Studies showed 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 (Chockalingam, 2004). 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 (Chen, 1998). Other studies, (Mahaudens, 2009) suggested that patients with adult idiopathic scoliosis present no side to side differences concerning the sagittal motion of the knee joints and the sagittal and transverse motion of the ankle joints of the lower extremities but compared to healthy individuals a sagittal knee motion restriction existed and the step length was reduced by 6 cm on average and the stance phase duration by only 2% on average. All these results indicated an almost physiological walk, even for those patients with severe scoliosis.

This study includes a major number of patients with thoraco-lumbar and lumbar primary curves because deformities at these levels are anatomically related to pelvis (Mac-Thiong, 2006). From the kinesiology examination of scoliosis people in group A, it was clearly evident that an influence upon the axial musculoskeletal system existed and similar abbreviations noted in the study of Zabjek et al., 2005. Pain is possible an important factor that influence proper posture, according to previous studies (Cordover, 1997; Weiss, 1993) and locomotion as well as the pelvic obliquity secondary to scoliosis (Perry, 2010), the resultant leg length difference (White, 1990), and the body asymmetry which produce an asymmetrical body weight distribution on stance phase (Genthon, 2005).

The mean difference in the body weight distribution amongst the lower extremities in group A, compared to this from group B was higher as well as the discrepancy too. The gait cycle that produced by the lower extremities was affected and altered, and in group A was 16.1% increased compared to the gait cycle presented in group B ($p < 0.05$) which in terms was similar to optional gait cycle (Whittle, 2002) as this shown in table 15. Also a higher mean difference existed, in the gait cycle, between ipsilateral and controlateral extremity. In contrast the mean difference amongst lower extremities in control group was minimal ($p < 0.05$).

Table 15. General gait parameters in normal male and female subjects (reprinted from Whittle, 2002).

Approximate range (95 per cent limits) for general gait parameters in free-speed walking by normal FEMALE subjects of different ages				
Age (years)	Cadence (steps/min)	Cycle time (s)	Stride length (m)	Speed (m/sec)
13–14	103–150	0.80–1.17	0.99–1.55	0.90–1.62
15–17	100–144	0.83–1.20	1.03–1.57	0.92–1.64
18–49	98–138	0.87–1.22	1.06–1.58	0.94–1.66
50–64	97–137	0.88–1.24	1.04–1.56	0.91–1.63
65–80	96–136	0.88–1.25	0.94–1.46	0.80–1.52
Approximate range (95 per cent limits) for general gait parameters in free-speed walking by normal MALE subjects of different ages				
Age (years)	Cadence (steps/min)	Cycle time (s)	Stride length (m)	Speed (m/sec)
13–14	100–149	0.81–1.20	1.06–1.64	0.95–1.67
15–17	96–142	0.85–1.25	1.15–1.75	1.03–1.75
18–49	91–135	0.89–1.32	1.25–1.85	1.10–1.82
50–64	82–126	0.95–1.46	1.22–1.82	0.96–1.68
65–80	81–125	0.96–1.48	1.11–1.71	0.81–1.61

The time difference of the gait cycle amongst ipsilateral and controlateral extremity alters the phases of gait and their time of performance. When symptoms like tightness, elongation or shortening of the soft tissues that are surrounding the bony structures and pain was present, 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 knee and ankle joints of the lower extremities as well as in their timing of performance. The phases of gait were synchronized.

From the kinematic 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 mean sagittal (forward/backward) linear displacement of the knee and ankle joints in the ipsilateral extremity (in the side of the convexity) was increased 25.7% and 33.2% respectively. In contrast, studies marked no significant sagittal motion differences amongst the same joints of the lower extremities (Mahaudens, 2009) while other studies marked asymmetries but with the compensation to occur at the controlateral extremity (Chockalingam, 2004).

Table 16. Linear displacement of the knee and ankle joints compared between subjects with MIS and healthy people (Ext/Extremity).

			Group A ($n = 20$)		Group B ($n = 20$)
Mean Linear Displacement (cm)			Ipsilateral Extremity	Controlateral Extremity	Right and Left Ext. average
	Knee Joint	X Axis	6.74	4.81	6.53
		Y Axis	7.47	8.17	4.87
		Z Axis	–5.64	–5.56	–4.73
	Ankle Joint	X Axis	6.46	4.45	4.74
		Y Axis	4.01	4.04	3.84
		Z Axis	–5.32	–5.17	–4.21

Compared scoliosis patients with control group, in our study, the analysis showed that the knee joint in the ipsilateral side (group A) had mean (z) frontal displacement (medial/lateral) increased 19.1%. The knee joint in the controlateral side showed mean sagittal (x) displacement 26.5% decreased, the mean frontal displacement and the mean vertical (y) displacement (upwards/downwards) in group A was increased 17.5% and 40.5% respectively. The ankle joint in the ipsilateral side had increased mean sagittal and frontal displacement, 36.2% and 26.4% respectively. The ankle joint in the controlateral side showed 22.8% increased mean frontal displacement.

From the above mentioned, the scoliosis group had as a part of the compensation distorted motion in all 3 axes concerning the controlateral knee joint. As for the ankle joint, distorted was the sagittal and the frontal linear displacement in the ipsilateral side. Frontal motion (medial/lateral) was affected in both knee and ankle joints from the extremities. The sagittal motion was decreased in the controlateral knee while others marked higher sagittal knee motion in control group. The sagittal motion was higher in the ipsilateral ankle while others marked no significant difference (Mahaudens, 2009). The lateral sway (medial/lateral) in the z axis was higher in both knee and ankle joints from the ipsilateral and the controlateral side of group A and confirmed with other studies (Chen, 1998). The same studies mentioned that the vertical displacement was increased but from our analyses only the controlateral knee joint showed increased gravitational displacement.

In our study, the knee joint degrees of freedom were estimated in sagittal axis. During the phases of gait cycle, performed from young adults with moderate idiopathic scoliosis, we didn't found any significant statistical differences amongst ipsilateral and controlateral extremities as well as control group too but in scoliosis patients the ipsilateral and controlateral extremity overall angular degree of freedom was lesser.

Table 17. Linear velocity and acceleration of the knee and ankle joint between subjects with MIS and control group. The gait cycle differences can be seen. (Diff/difference, Ext/extremity, Aver/average Vel/velocity and Acc/aceleration).

Linear		Group A (*n* = 20)			Group B (*n* = 20)	
		Ipsilateral Ext.	Controlateral Ext.	Diff.	Right and Left Ext. aver.	Diff.
	Gait Cycle (sec)	1.42	1.39	0.02	1.21	0.003
Knee Joint	3D Vel. (m/sec)	0.44	0.46		0.47	
	3D Acc. (m/sec^2)	1.77	1.91		1.94	
Ankle Joint	3D Vel. (m/sec)	0.67	0.72		0.74	
	3D Acc. (m/sec^2)	2.70	2.94		2.96	

Regarding the mean angular differences exerted by the ipsilateral and controlateral knee joint, during the phases of gait cycle in group A, significant statistical differences were found with the exception of the mean difference from terminal swing phase, compared to the mean angles exerted from the lower extremities in control group. This status indicated how the knee joint was affected in scoliosis group.

In group A, the ipsilateral knee had at initial contact 93% lesser extension, initial and mid swing phases with 37% and 32% lesser flexion on average compared to healthy extremities in control group, while the controlateral knee showed 94% lesser extension at initial contact, initial and mid swing phases with 36% and 31% lesser flexion on average in comparison to group B. This can be explained as a shorter stride length in conjunction to a higher sway radius of the distal parts of the lower extremities due to the fact that the gait cycle was increased in scoliosis group but with no significant statistical difference in the mean velocity and mean acceleration compared to control group. Other studies (Chen, 1998) didn't show differences in stance and stride phases amongst scoliosis patients and healthy people. With the exception of the controlateral knee joint and the ipsilateral ankle joint, especially the sagittal motion in scoliosis group is almost identical with control group. This gave to us the picture of a compensatory walking which was relatively close to normal walking.

In conclusion, this cohort of scoliosis patients with moderate scoliosis resulted in pelvic obliquity and mild leg length discrepancy showed that they accomplish the gait cycle slower in comparison to healthy people. The phases of gait cycle were asynchronous amongst ipsilateral and controlateral extremities and asymmetries exerted from ipsilateral and controlateral knee and ankle joints during gait cycle. Scoliosis patients group showed disturbances in the behavior of their distal joints in comparison to healthy people suggesting some kind of deformity and stiffness due to scoliosis. Pathologies affecting the gait cycle like inadequate extension at initial contact phase and inadequate flexion at initial and mid swing phases were present in scoliosis group. These statistical significant differences might proven to be helpful in evaluating and treating the 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, sense fatigue and pain symptoms.

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SOUHRN

Úvod: Skolióza ovlivňuje optimální držení lidského těla. Středem zájmu je její vliv na chůzi. Cíl: Mladí dospělí se střední idiopatickou skoliózou jsou porovnáváni se zdravou populací ve smyslu porovnání kinematických změn konvexity a konkavity těla. Cílem této studie bylo identifikovat tyto změny. Metody: Skupina dvaceti dospělých pacientů (skupina A) se skoliózou a kontrolní skupina (B) patnácti jedinců byla podrobena 3D analýze chůze s metodou přímé lineární transformace. Během krokového mechanismu byl sledován především rozsah pohybu kolene. Výsledky: Krokový cylus skoliotických pacientů trval déle oproti zdravým jedincům, $p < 0,05$. U skoliotiků došlo na ipsilaterální straně ke změně úhlu v kolenním kloubu vzhledem k sagitální ose, $p < 0,05$. Při porovnání obou skupin došlo k vychýlení kolenního kloubu ve frontální rovině. Na kontralaterální straně u skoliotiků pokleslo vychýlení sagitálně a vzrostlo frontálně. Vychýlení kotníku ipsilaterální strany vzrostlo v sagitální i frontální rovině, na kontralaterální straně došlo k nárůstu vychýlení frontálně. Během krokového mechanismu se rozsah pohybu v kolenním kloubu snížil. Diskuse: U skoliotických pacientů byly během krokového cyklu nalezeny na dolních končetinách asymetrie, které se shodují s daty v jiných studiích. Tyto zjištění mohou zlepšit léčbu krokového cyklu u mladých jedinců se skoliózou.

Klíčová slova: střední idiopatická skolióza, chůze, kolenní a hlezenní kloub

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