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THE BIOMECHANICAL REFLEXION OF MODERATE IDIOPATHIC SCOLIOSIS IN GAIT CYCLE OF YOUNG ADULTS.

DISSERTATION THESIS

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The biomechanical reflexion of moderate idiopathic scoliosis in gait cycle of young adults

Problem

The existence of any deviation upon the human structures or tissues through moderate idiopathic scoliosis will cause a misbalance and an influence upon the proper distribution of forces acting on and around a joint, ligament, bone or muscle. The result of such a misbalance, will be an alteration of all physical quantities exerted from different segments of the body not only in the upper trunk but in the lower trunk too and changes will occur in the upper extremities as well as in the lower extremities and their relative joints. The joints of the lower extremities, which are involved in the gait cycle, from such an influence their functions will be probably altered during the gait cycle; and movement restriction or loss is expected to be observed.

This study is relative to the three dimensional analysis of the gait cycle of young adults suffering from moderate idiopathic scoliosis (MIS), in the lumbar or thoraco-lumbar part of the vertebra column. It is based upon the presentation of cases suffering from scoliosis, patients that went under an elaborate thorough of kinesiologic, anthropometric and kinematic analysis so as someone to be capable to extract useful information of how the locomotion and the posture corresponds to this kind of disorder. Scoliosis patients exhibit significantly impaired quality of life (Schwab et al, 2003) and young adults with MIS consist a population group with increased occupational and sports activities (Weinstein et al, 2003) and gait cycle is of great importance. Gait analysis is used to identify and treat (Lewit , 2000, Zabjeket al,2005) individuals with conditions affecting their posture and in terms their ability to walk.

The Kinematic analysis is trying to seek how the gait cycle of the lower extremities correspond to moderate idiopathic scoliosis and what kind of alteration will be exerted upon the physical quantities (linear displacement, linear velocity and linear acceleration) that the major 3 joints (hip, knee and ankle) of the lower extremities produce during locomotion. Expectable asymmetries, for our interest, during locomotion may either concern the function (kinematic point of view) of the center of gravity or may concern the creation of abnormal locomotion from the lower limbs, or both.

The general hypothesis: the scoliotic shape of the trunk will result in dynamical characteristics of whole body locomotion movement.

Aims

To detect the biomechanical reflexion of moderate idiopathic scoliosis upon the major joints of the lower extremities and the center of gravity during gait cycle of young adults as well as the correspondence of these anatomical points 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 of 20 young adults with moderate idiopathic scoliosis and group B of 15 healthy people without any known spinal deformity or disease (table1).

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^o to 40^o (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 0,5 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 (Harris and Stanley, 2002), radiological (Cobb, 1948), (for group A) 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. 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. The equation used for DLT Method was:

$$u = \frac{L_1 x + L_2 y + L_3 z + L_4}{L_9 x + L_{10} y + L_{11} z + 1}$$
$$v = \frac{L_5 x + L_6 y + L_7 z + L_8}{L_9 x + L_{10} y + L_{11} z + 1},$$

where two reference frames are defined: the **object-space reference frame** (the *XYZ*-system) and **image-plane reference frame** (the *UV*-system). The optical system of the camera/projector maps point *O* in the object space to image *I* in the image plane. [*x*, *y*, *z*] is the object-space coordinates of point *O* while [*u*, *v*] is the image-plane coordinates of the image point *I*. Points *I*, *N* & *O* thus are collinear (Figure 1). This is the so-called **collinearity condition**, the basis of the DLT method. Coefficients L_1 to L_{11} in equation are the **DLT parameters** that reflect the relationships between the object-space reference frame and the image-plane reference frame and note that *u* and v are the image plane coordinates in the real-life length unit, such as ***cm***.

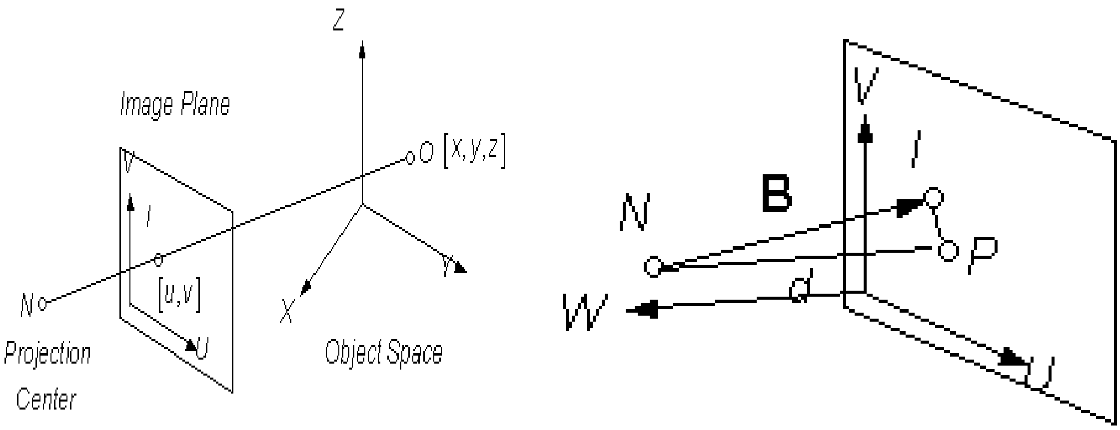


Figure 1 The DLT Method of the captured data was done so as to compute the three-dimensional image space coordinates of the subject's body joints from the relative two-dimensional digitized coordinates of each camera's view. Add axis *W* to the image plane reference frame as the third axis to make the image-plane reference frame 3-dimensional. The *W*-coordinates of the points on the image plane are always 0, and the 3-dimensional position of point *I* becomes [*u*, *v*, 0]. A new point *P*, the **principal point**, was introduced and the line drawn from the projection center *N* to the image plane, parallel to axis *W* and perpendicular to the image plane, is called the **principal axis** and the principal point is the intersection of the principal axis with the image plane.

These measurements (Winter, 2009) 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 as the angles of the knee joint (sagittal plane) during the phases of gait cycle.

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

	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 (^{0})	29,4^0 (22-34)	±1,30	NA	
Apical rotation (grades)	+1 (0/+-4)		NA	
Plumb line declination (cm)	1,6	±0,15	0,14	±0,04

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

Results

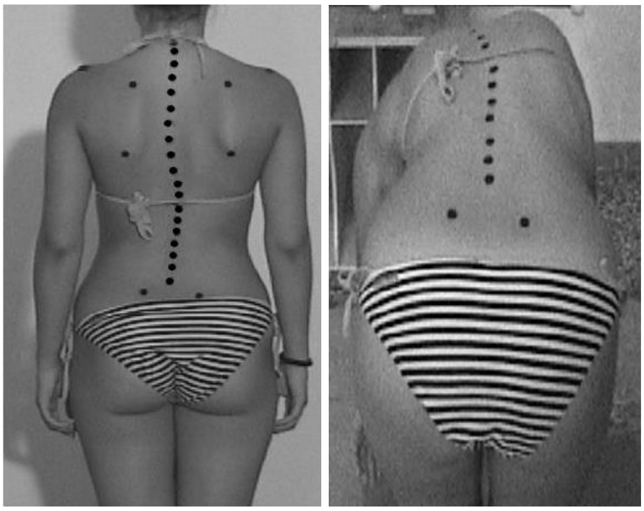
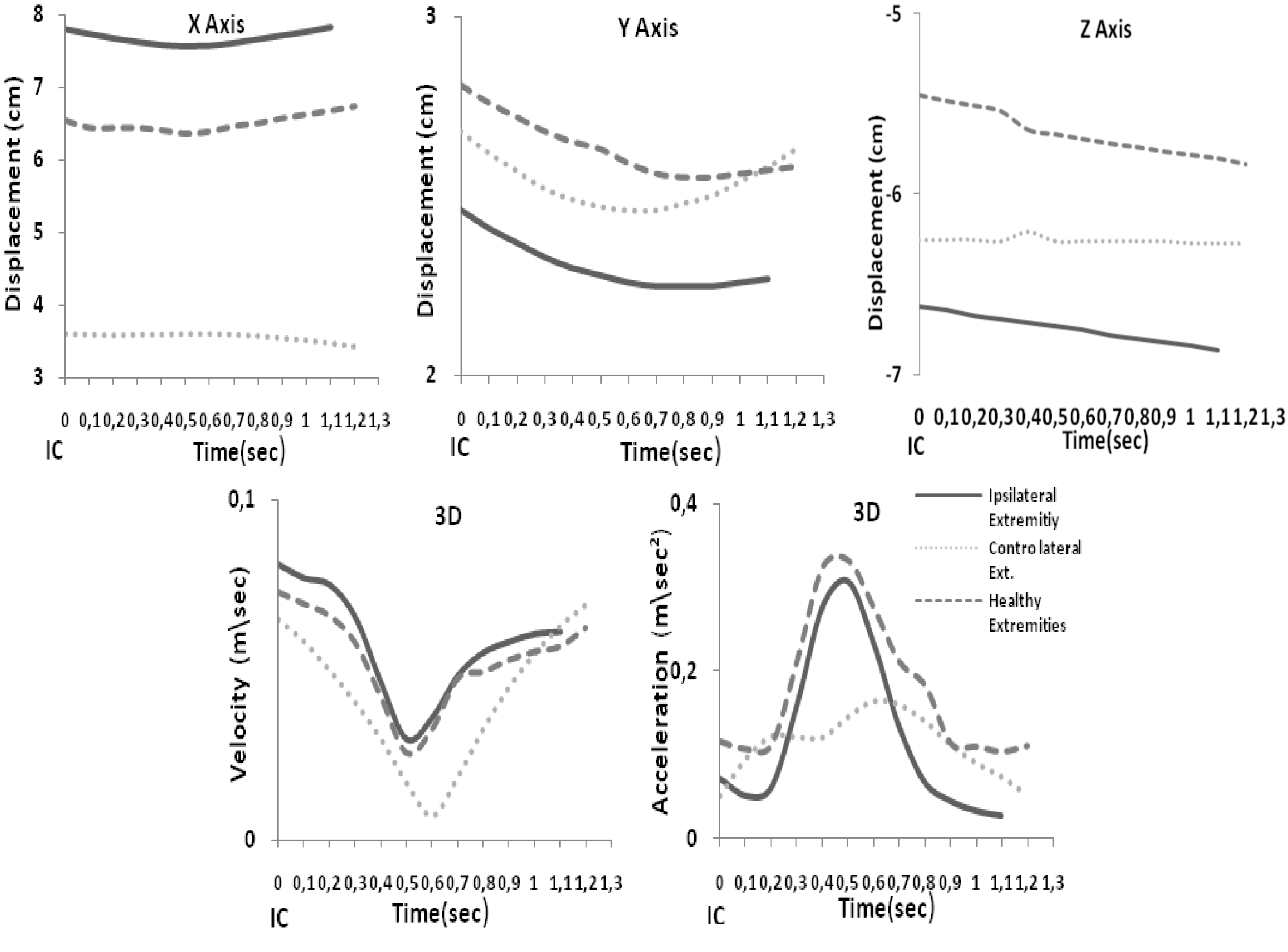
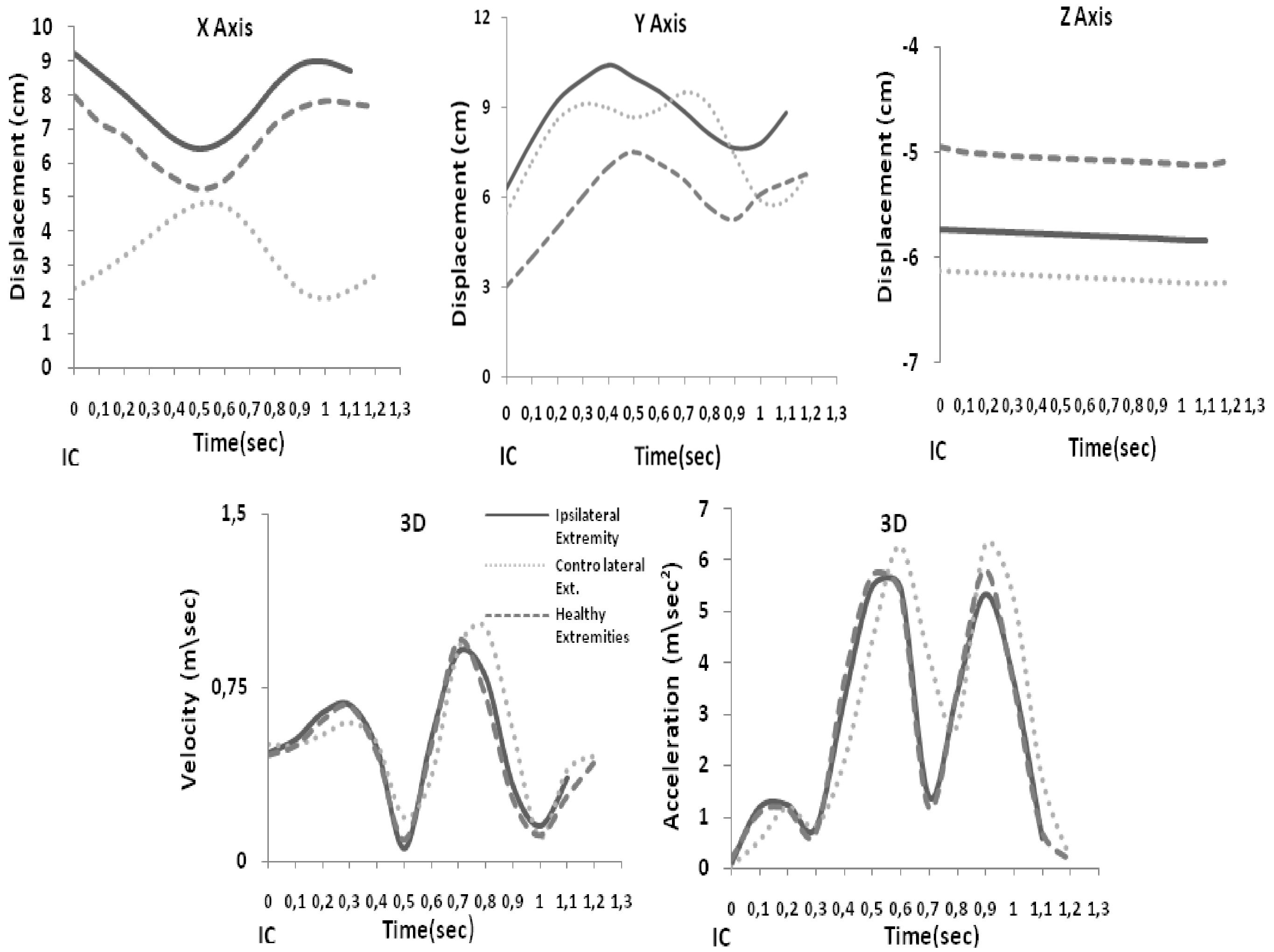


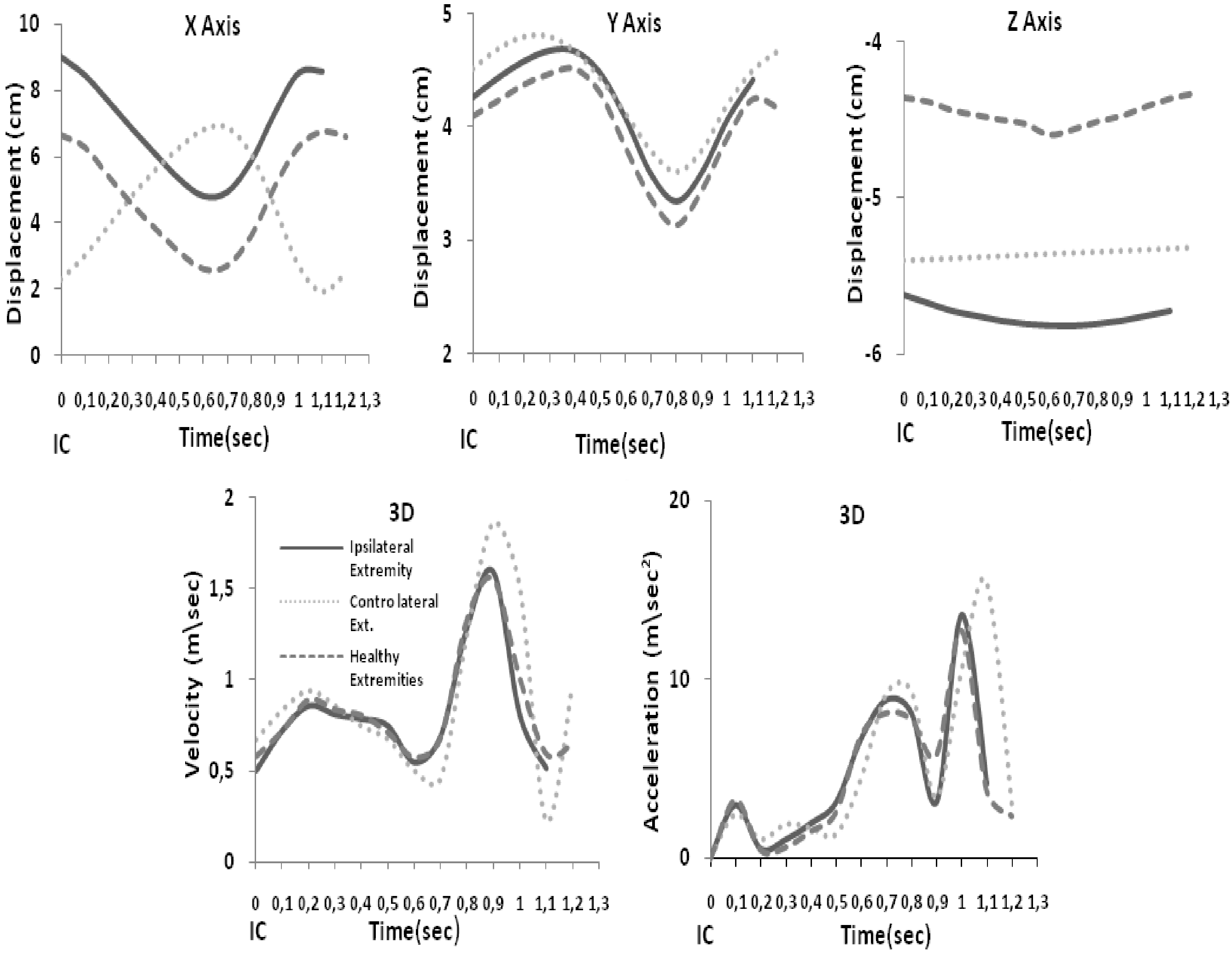
Photo 1 Typical moderate thoracolumbar scoliosis.



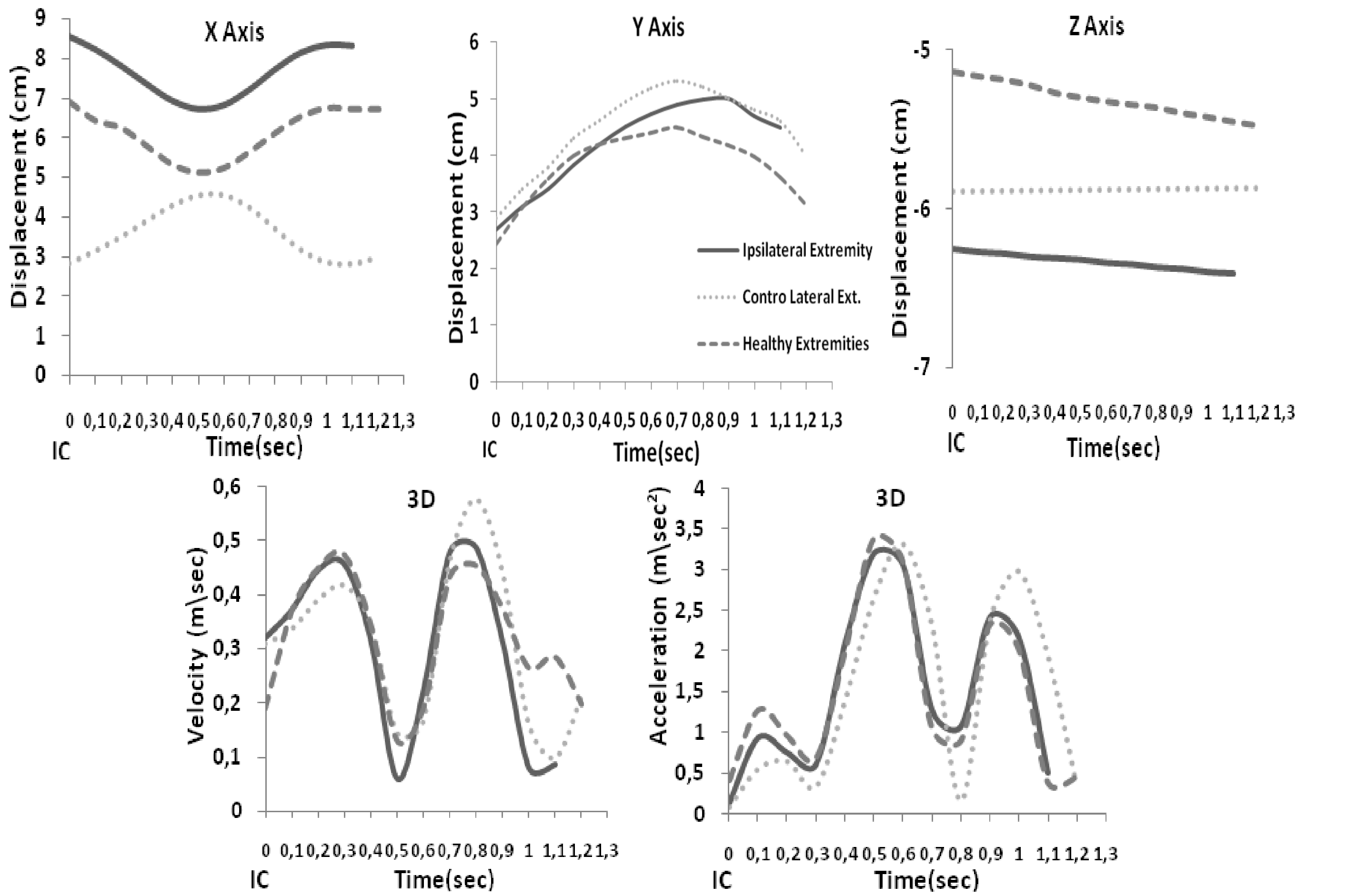
Graph 1 Thoracolumbar scoliosis: Typical linear displacement, velocity and acceleration of the hip joint during the gait cycle (IC stands for initial contact with the gait cycle initiated from double support phase) of young adults suffering from moderate idiopathic scoliosis (ipsilateral at the convex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



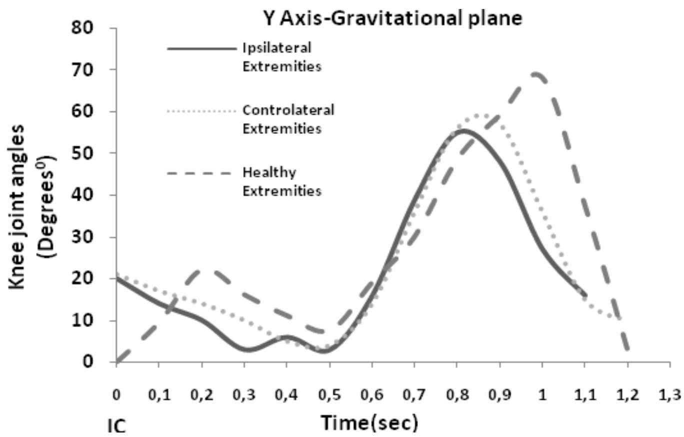
Graph 2 Thoracolumbar scoliosis: Typical linear displacement, velocity and acceleration of the knee joint during the gait cycle (IC stands for initial contact with the gait cycle initiated from double support phase) of young adults suffering from moderate idiopathic scoliosis (ipsilateral at the convex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



Graph 3 Thoracolumbar scoliosis: 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).



Graph 4 Thoracolumbar scoliosis: Typical linear displacement, velocity and acceleration of the center of gravity 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 5 Thoracolumbar scoliosis: 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).

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 $29{,}4^0$and plumb line declination was 1,2cm. Mean leg length discrepancy in group A was 1,2cm (±0,2cm, C.I 95%) while in group B the difference was 0,3cm (±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.

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

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

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

Body-weight distribution of the lower extremities was unevenly in group A (Table 4) 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 (±0,2cm) 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 1,42sec (±0,11sec) and the controlateral side had a mean gait cycle at 1,39sec (±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 0,153sec (±0,039sec) and it is greater from the mean difference resulted from group B, that was 0,02 (±0,003sec), $p<0{,}05$. The statistical differences found in scoliosis (group A) patients between ipsilateral and controlateral extremity (side to side comparison) were concerning: The hip joint in the ipsilateral side of the trunk that had 6,4cm (±0,99) mean sagittal displacement (x axis), higher than the mean sagittal displacement (forward / backward) of the hip joint in the controlateral side that had 4,48cm (±0,53), $p<0{,}05$. The knee joint in the ipsilateral side of the trunk that had 6,74cm (±0,89) mean sagittal displacement, higher than the mean sagittal displacement of the knee joint in the controlateral side that had 4,8cm (±0,35), p<0,05 and the ankle joint at the ipsilateral side of the trunk had 6,46cm (±0,66) mean sagittal displacement, higher than the mean sagittal displacement of the ankle joint in the controlateral side that had 4,5cm (±0,34), p<0,05. The center of gravity (midway between hips, few cm ahead S_2) in the ipsilateral side of the trunk that had 6,47cm (±0,88) mean sagittal displacement, higher than the mean sagittal displacement of the center of gravity in the controlateral side that had 4,35cm (±0,47), p<0,05.

Linear 3D velocity and 3D acceleration was lesser in the ipsilateral extremity but wasn't reached the level of any significant statistical difference.

Clinical data	Scoliosis patients Group A (*n* =20)						
	Average		Standard Deviation		Confidence Interval(±)		*P* value
	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	
Body weight distribution (Kg)	30,1	32,51	5,6560	7,2111	3,5501	3,1603	NS
Leg length 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

Table 4 The average body-weight distribution, Leg length discrepancy (LLD) and gait cycle in patients with moderate idiopathic scoliosis and healthy subjects. NS not significant, i.e. P value >0.05

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	0,486666	0,258751582	0,130943961	**<0,01**
Gait cycle (sec)	0,022	0,0842052	0,037	0,002666	0,00507093	0,002566195	**<0,01**

Table 5 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. Significant differences are typed in bold and are accepted for P value <0.05

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**

Table 6 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

Kinematic data	Scoliosis patients Group A (n=20)						
	Average		Standard Deviation		Confidence Interval(±)		*P* value
Hip Joint	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	
Displacement X axis (cm)	6,365	4,48	2,257916	1,210307	0,989557	0,530431	**<0,03**
Displacement Y axis (cm)	2,915	2,94	0,856108	0,852489	0,375199	0,373613	NS
Displacement Z axis (cm)	-6,11	-5,835	1,185394	0,927518	0,519512	0,406495	NS
Displacement 3D (cm)	2,455	2,14	0,778308	0,871417	0,341102	0,381909	NS
Velocity 3D (m/sec)	0,0566	0,0576	0,017733	0,024095	0,007772	0,01056	NS
Acceleration 3D (m/sec^2)	0,185	0,21945	0,073339	0,135828	0,032142	0,059528	NS
Knee Joint	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral 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
Ankle Joint	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral 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/sec2)	2,7043	2,9467	1,17324	1,571771	0,514186	0,688846	NS
Center of gravity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	
Displacement X axis (cm)	6,465	4,33	1,9982295	1,075615	0,875747	0,4714	<0,01
Displacement Y axis (cm)	5,5355	5,5245	4,574625	4,47451	2,004881	1,961004	NS
Displacement Z axis (cm)	-5,84	-5,595	0,919038	0,7598303	0,402779	0,3330042	NS
Displacement 3D (cm)	11,56	10,945	3,493814	1,531245	1,531203	0,671085	NS
Velocity 3D (m/sec)	0,2959	0,3122	0,081886	0,074586	0,035888	0,032688	NS
Acceleration 3D (m/sec2)	1,047	1,1728	0,371145	0,591763	0,162659	0,259347	NS

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 hip, knee and ankle joints and the center of gravity amongst the ipsilateral and the controlateral extremity in scoliosis patients. Significant differences are typed in bold and are accepted for P value <0.05, NS not significant, i.e. P value >0.05, Significant differences are typed in bold and are accepted for P value <0.05

Comparison of group A and group B showed statistical significant difference in the following parameters (C.I 95%):

Hip measurements showed that ipsilateral side (group A) had -6,11cm (±0,52) increased mean frontal displacement (medial / lateral) compared to an average from both hips (group B) that had -5,10 cm (±0,23) mean frontal displacement (z axis), p<0,05. Also, group A had reduced mean sagittal (x axis-forward / backward direction), and increased frontal displacement in the hip joint of the controlateral side compared to an average value that both hips in group B produced (x axis, controlateral side, 4,48 cm, C.I ±0,53 vs. healthy extremities 6,41 cm, ±0.52 / z axis, controlateral side, -5,8 cm, ±0,41 vs. healthy ext. -5,10 cm, ±0,23), p<0,05. Relative to the knee joint, mean sagittal in the controlateral side in group A was lesser 4,48cm (±0,35) vs. 6,53cm (±0,43) compared to an average that both knees in group B produced . Knee's mean frontal displacement and mean vertical displacement in group A was increased in controlateral side comparison to group B average value from both extremities (controlateral, y axis 8,17cm, C.I ±1,51, z axis -5,56cm, ±0,32/ average value from both knees, group B, y axis 4,87cm,C.I ±0,64, z axis -4,73cm, ±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 6,46cm, C.I ±0,66, z axis -5,32cm, ±0,36/ healthy extremities, x axis 4,74cm,C.I ±0,18, z axis -4,21cm, ±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), $p<0,05$. The center of gravity had significantly reduced mean sagittal displacement in scoliosis patient's controlateral side, being 4,33cm (±0,47) for group A and 6,07cm (±0,52) for group B, $p<0,05$.

Linear 3D velocity and acceleration was lesser in Group A but wasn't reached the level of any significant statistical difference.

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
Hip Joint	Ipsilateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	6,365	2,257916	0,989557	6,40666	1,031099	0,52180	NS
Displacement Y axis (cm)	2,915	0,856108	0,375199	2,69667	0,553388	0,280048	NS
Displacement Z axis (cm)	-6,11	1,185394	0,519512	-5,10333	0,451769	0,228622	**<0,02**
Displacement 3D (cm)	2,455	0,778308	0,341102	2,02	0,324478	0,164205	NS
Velocity 3D (m/sec)	0,0566	0,017733	0,007772	0,0646	0,004521	0,002288	NS
Acceleration 3D (m/sec^2)	0,185	0,073339	0,032142	0,233633	0,032479	0,016436	NS
Hip Joint	Controlateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	4,48	1,210307	0,530431	6,40666	1,031099	0,52180	**<0,01**
Displacement Y axis (cm)	2,94	0,852489	0,373613	2,69667	0,553388	0,280048	NS
Displacement Z axis (cm)	-5,835	0,927518	0,406495	-5,10333	0,451769	0,228622	**<0,05**
Displacement 3D (cm)	2,14	0,871417	0,381909	2,02	0,324478	0,164205	NS
Velocity 3D (m/sec)	0,0576	0,024095	0,01056	0,0646	0,004521	0,002288	NS
Acceleration 3D (m/sec^2)	0,21945	0,135828	0,059528	0,233633	0,032479	0,016436	NS

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 hip joints: a) amongst the ipsilateral extremity and the mean from both extremities in healthy people and b) amongst the controlateral extremity and the mean from both extremities in healthy people. Significant differences are typed in bold and are accepted for P value <0.05, NS not significant, i.e. P value >0.05

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
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

Table 9 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: a) amongst the ipsilateral extremity and the mean from both extremities in healthy people and b) amongst the controlateral extremity and the mean from both extremities in healthy people. Significantly different from the control group NS*, Significant differences are typed in bold and are accepted for P value <0.05

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	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
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

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: a) amongst the ipsilateral extremity and the mean from both extremities in healthy people and b) amongst the controlateral extremity and the mean from both extremities in healthy people. Confidence interval (±C.I), NS not significant, i.e. P value >0.05

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
Center of gravity	Ipsilateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	6,465	1,9982295	0,875747	6,07	1,0326457	0,52258123	NS
Displacement Y axis (cm)	5,5355	4,574625	2,004881	3,562	1,948334	0,985975	NS
Displacement Z axis (cm)	-5,84	0,919038	0,402779	-5,24333	0,4174184	0,21123896	NS*
Displacement 3D (cm)	11,56	3,493814	1,531203	10,37	1,307233	0,661539	NS
Velocity 3D (m/sec)	0,2959	0,081886	0,035888	0,348467	0,072243	0,036559	NS
Acceleration 3D (m/sec^2)	1,047	0,371145	0,162659	1,203533	0,379745	0,192174	NS
Center of gravity	Controlateral extremity			Lower extremities (mean)			
Displacement X axis (cm)	4,33	1,075615	0,4714	6,07	1,0326457	0,52258123	**<0,01**
Displacement Y axis (cm)	5,5245	4,47451	1,961004	3,562	1,948334	0,985975	NS
Displacement Z axis (cm)	-5,595	0,7598303	0,3330042	-5,24333	0,4174184	0,21123896	NS
Displacement 3D (cm)	10,945	1,531245	0,671085	10,37	1,307233	0,661539	NS
Velocity 3D (m/sec)	0,3122	0,074586	0,032688	0,348467	0,072243	0,036559	NS
Acceleration 3D (m/sec^2)	1,1728	0,591763	0,259347	1,203533	0,379745	0,192174	NS

Table 11 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 center of gravity: a) amongst the ipsilateral extremity and the mean from both extremities in healthy people and b) amongst the controlateral extremity and the mean from both extremities in healthy people. Significant differences are typed in bold and are accepted for P value <0.05, NS not significant, i.e. P value >0.05

Kinematic data	Scoliosis patients Group A (*n* =20)						
	Average		Standard Deviation		Confidence Interval(±)		*P* value
Knee Joint (sagittal plane)	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	Ipsilateral extremity	Controlateral extremity	
Total angles of freedom	25,54	26,99	4,97	4,95	2,18	2,17	NS
Initial contact(^{0})	30,55	34,7	11,20	11,26	4,91	4,93	NS
Mid stance(^{0})	22,15	22,7	7,59	7,29	3,33	3,20	NS
Terminal stance(^{0})	6,45	6,71	5,42	4,90	2,38	2,15	NS
Initial swing(^{0})	25,9	26,6	6,08	5,80	2,66	2,54	NS
Mid swing(^{0})	50,65	51,2	5,26	7,19	2,31	3,15	NS
Terminal swing(^{0})	31,45	32,5	10,05	9,32	4,40	4,08	NS

Table 12 Kinematic data exerted from the knee joint in the sagittal plane (y axis) amongst the ipsilateral and the controlateral extremities in scoliosis patients during the phases of the gait cycle. NS not significant, i.e. P value >0.05

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 30,6^0 (±4,91), initial and mid swing phases with 26^0 (±2,18) and 50,7^0 (±2,31) flexion on average respectively, while the controlateral knee had 34,7^0 (±4,91) average extension at initial contact, 26,6^0 (±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 (±0,51) and in initial and mid swing phases an average flexion at 41,5^0 (±0,42) and 74,5^0 (±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 ($1,44^0$,C.I ±1,07) compared to the mean angle difference exerted from the right and left knee in group B ($0,87^0$, ±0,09), p<0,05.

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(^{0})	30,55	11,20	4,91	2	1	0,51	**<0,01**
Mid stance(^{0})	22,15	7,59	3,33	24,5	0,80	0,41	NS
Terminal stance(^{0})	6,45	5,42	2,38	9,5	0,57	0,29	NS
Initial swing(^{0})	25,9	6,08	2,66	41,5	0,82	0,42	**<0,01**
Mid swing(^{0})	50,65	5,26	2,31	74,5	0,85	0,43	**<0,01**
Terminal swing(^{0})	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(^{0})	34,7	11,26	4,93	2	1	0,51	**<0,01**
Mid stance(^{0})	22,7	7,29	3,20	24,5	0,80	0,41	NS
Terminal stance(^{0})	6,7	4,90	2,15	9,5	0,57	0,29	NS
Initial swing(^{0})	26,6	5,80	2,54	41,5	0,82	0,42	**<0,01**
Mid swing(^{0})	51,2	7,19	3,15	74,5	0,85	0,43	**<0,01**
Terminal swing(^{0})	32,5	9,32	4,08	29,5	1,15	0,58	NS
	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(^{0})	4,15	7,17	3,14	1	0,16	0,08	**<0,03**
Mid stance(^{0})	0,55	2,06	0,90	0,49	0,22	0,11	**<0,01**
Terminal stance(^{0})	0,25	3,21	1,41	0,31	0,09	0,05	**<0,01**
Initial swing(^{0})	0,7	2,95	1,29	0,59	0,27	0,14	**<0,01**
Mid swing(^{0})	0,55	2,91	1,28	0,53	0,22	0,11	**<0,01**
Terminal swing(^{0})	1,05	6,97	3,06	0,71	0,67	0,34	**NS***

Table 13 Kinematic data exerted from the knee joint angles of freedom in the vertical plane (y 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 and c) 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. 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), 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 important role in sport and occupational activities of people and can be analysed with a simple and easy manner. The analyses could provide to us adequate information about the 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 hip the knee and ankle joint of the lower extremities as well as the center of gravity, 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 et al, 2002), the trunk (Raso et al, 1998), the coronal sacropelvic morphology (Mac

Thiong et al, 2006) and thus an important determinant of gait that would be primarily affected (Della Croce et al, 2001) from this influence.

Studies showed that adolescent idiopathic scoliosis was not affecting the 3D displacement of pelvis during normal walking, resulted as a prolonged duration of activation of par vertebral muscles and equilibrium was maintained (Mahaudens et al, 2005) while other studies (Syczewska et al, 2006) showed that orientation of the pelvis during walking altered and this induces changes in gait stereotype.

Other 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 et al, 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 et al, 1998). Other studies, (Mahaudens et al, 2009) 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 and sagittal knee motion restriction existed, the sagittal angular speed of the knee and ankle joint was decreased 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 et al, 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 et al, 1997, Weiss, 1993) and locomotion as well as the pelvic obliquity secondary to scoliosis (Perry and Burnfield, 2010), the resultant leg length difference (White and Panjabi, 1990), and the body asymmetry which produce an asymmetrical body weight distribution on stance phase (Genthon et al, 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 14,8 % increased compared to the gait cycle presented in group B ($p<0,05$) which in terms was similar to optional gait cycle (Whittle et al, 2002) as this shown in table 14. 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 ($p<0,05$).

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

Table 14 General gait parameters in normal male and female subjects (reprinted from Whittle, 2002).

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 major joints of the lower extremities and the center of gravity 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 hip, knee and ankle joints in the ipsilateral extremity (in the side of the convexity) was increased 29,6%, 25,7% and 33,2% respectively. The mean sagittal linear displacement concerning the center of gravity was increased 32,8% in the ipsilateral extremity. In contrast, studies marked no significant sagittal motion differences amongst the same joints of the lower extremities (Mahaudens et al, 2009) while other studies marked asymmetries but with the compensation to occur at the controlateral extremity (Chockalingam et al, 2004).

Compared scoliosis patients with control group, in our study, the analysis showed that: the hip joint in the ipsilateral side (group A) had mean (z) frontal displacement (medial/lateral) increased 16,6%, while the hip joint in the controlateral side (group A) had mean (z) frontal displacement increased 12,6% and mean sagittal displacement decreased 30,1%. The knee joint in the ipsilateral side (group A) had mean (z) frontal displacement 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. The center of gravity in the controlateral side (group A) had mean (z) sagittal displacement decreased 28,6%.

Linear 3D velocity and acceleration was lesser in Group A but wasn't reached the level of any significant statistical difference.

From the above mentioned, scoliosis group had an increased sagittal displacement existed as for the 3 major joints of the ipsilateral extremity (shorter extremity) and the transmission of the center of gravity compared to the controlateral extremity. When compared both groups, the controlateral hip joint and the center of gravity had lesser sagittal displacement. Scoliosis group had as a part of the compensation or the imbalance distorted motion in all 3 axes concerning the controlateral knee joint compared to healthy people. 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 and increased in the ipsilateral ankle while Mahaudens et al, 2009 marked higher sagittal knee motion in scoliosis people but regarding the sagittal motion of the ipsilateral ankle did not observe any significant difference. 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 et al, 1998). The same studies mentioned that the vertical displacement was increased but from our analyses only the controlateral knee joint showed increased gravitational displacement (upwards / downwards).

Other researchers (Kramers et al, 2004) 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

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.

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 period of time in scoliosis group but with no significant statistical difference in the mean velocity and mean acceleration compared to control group. Other studies (Chen et al, 1998) didn't show differences in stance and stride phases amongst scoliosis patients and healthy people. With the exception of the controlateral hip joint, knee joint, center of gravity 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.

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.

Conclusion

Scoliosis patients exhibit significantly impaired quality of life and young adults with MIS consist a population group with increased occupational and sports activities and gait cycle is of great importance. Gait analysis is used to identify and treat 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 exerted from the lower extremities and the transition of the CoG during the gait cycle of young adults in comparison to the gait cycle of healthy people.

Regarding this topic there are a lot of studies to our knowledge, but this study focuses on direct linear transformation method for analyses of gait cycle and transmission of the centre of gravity during walking.

Scoliosis patients (MIS) with moderate scoliosis resulted in pelvic obliquity and mild leg length discrepancy showed that abnormal posture of the body is capable to induce changes in locomotion during gait cycle and alter their gait manner. Despite that state, a compensatory walking existed and it was relatively close to normal walking. Scoliosis patients had their body-weight distribution unevenly distibuted amongst the lower extremities and they accomplish the gait cycle slower in comparison to healthy people. The phases of gait cycle were asynchronous between ipsilateral and controlateral extremities in scoliosis people and asymmetries can be found concerning a reduced sagittal displacement of the ipsilateral hip, knee and ankle joints as well as the transition of the center of gravity related to the same controlateral anatomical points during gait cycle. Scoliosis patients group showed disturbances in the behaviour of the major joints of the lower extremities and the center of gravity 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 as well as excessive abduction or valgus / varus. These statistical significant differences might proven to be helpful in evaluating and treating the gait cycle of young adults with moderate idiopathic scoliosis. 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. The observations provided important information about posture and the corresponding locomotion in such patients and create a basis for expansion of knowledge of treatment of the gait cycle.

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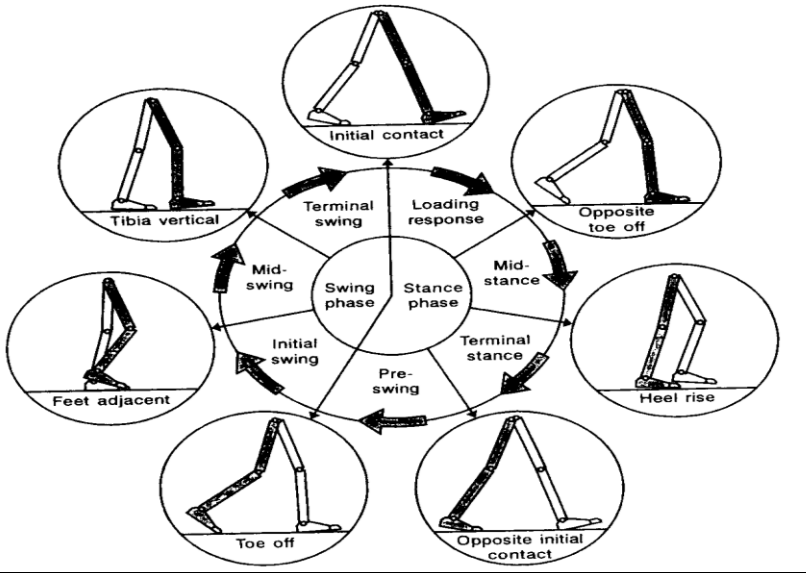
ABBREVIATIONS



Initial contact-IC
Opposite toe off-OTO
Heel rise-HR
Opposite initial contact-OIC
Toe off-TO
Feet adjacent-FA
Tibia vertical-TV
Loading response-LR
Mid-stance-MS
Terminal stance-TSt
Pre-swing-PSw
Initial swing-ISw
Mid-swing-MSw
Terminal swing-TSw
Base of support-BOS

(Adapted Whittle,2002)