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The postural stability control and gait pattern of idiopathic scoliosis adolescents

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Abstract

Objective. The static postural equilibrium and gait patterns between idiopathic scoliotic (IS) patients and normal subjects were studied to verify the best method to identify the functional disability in IS patients.
Design. The static stability in six postures and gait patterns among normal subjects and IS patients were compared.
Background. Postural stability control and gait analysis are non-invasive methods to identify many diseases. However, the dysfunction of IS patients in postural stability control and gait pattern is not clear. The results of this research may lead to further understanding of the etiology of idiopathic scoliosis in the postural equilibrium influencing aspects.
Methods. Thirty IS patients and fifteen normal subjects were recruited for postural stability control test and gait analysis using the force plate and 3-D motion analysis system.
Results. 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.
Conclusions. The IS patients are poor in postural stability control, but their gait pattern is similar to that of normal subjects. Standing with trunk at full flexion is the most effective position to identify the postural stability control of IS patient.

Relevance

The outcome of surgery in IS patients may be able evaluated by performing a postural stability control test.

Key words: Scoliosis, biomechanics, static postural stability, gait, range of motion

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Introduction

Idiopathic scoliotic (IS) patients have postural equilibrium problems[1–3]. Yamada et al.[4] first found equilibrium dysfunction in 57 out of 70 of IS patients and 1 out of 20 normal subjects when investigating the drift reactions and optokinetic nystagmus. Later, Okada and Yamamoto[5] found the deformity rate increased in IS children who were retarded in equilibrium function. Diener et al.[2] quantified the postural sway in normal subjects and patients with cerebellar disease, and found the sway pattern is distinct for different cerebellar diseases such as spinal ataxia, vestibulocerebellar lesions, etc. The sitting imbalance with the presence of lumbar spinal deformity was also reported by Smith and Emans[6].

Byl and Gray[7] found that the balance behaviors between normal subjects and IS patients were similar in stable, and static balance positions. However, in visual and somatosensory challenged positions, the IS patients produced higher body sway, especially for cases of spinal curvature greater than 40°, patients with spinal surgery and those with rapid progression in spine deformity. Chen et al.[8] found that the lateral sway of body center of mass was abnormal in the IS patients, and visual correction contributes to the maintenance of postural stability in IS patients.

Gait analysis has been shown to provide an objective and quantifiable assessment of function in patients with chronic low back pain (LBP). Khoda-

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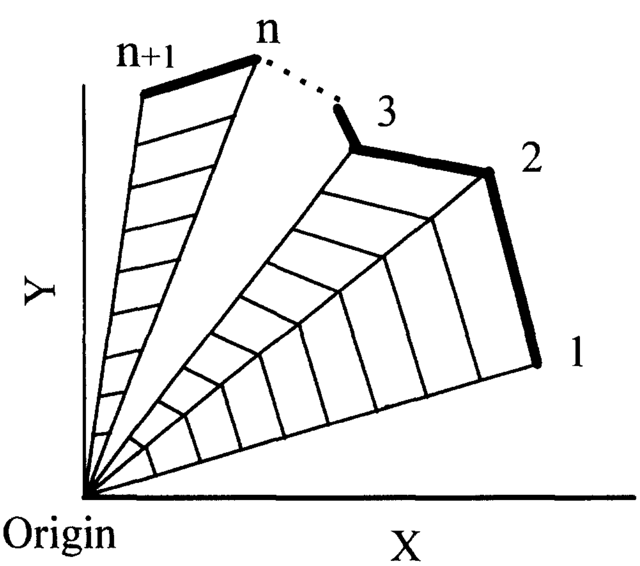

Figure 1. The sway area is the integrated area within two continuous instantaneous center of pressure (COP) and origin during the span of the task.

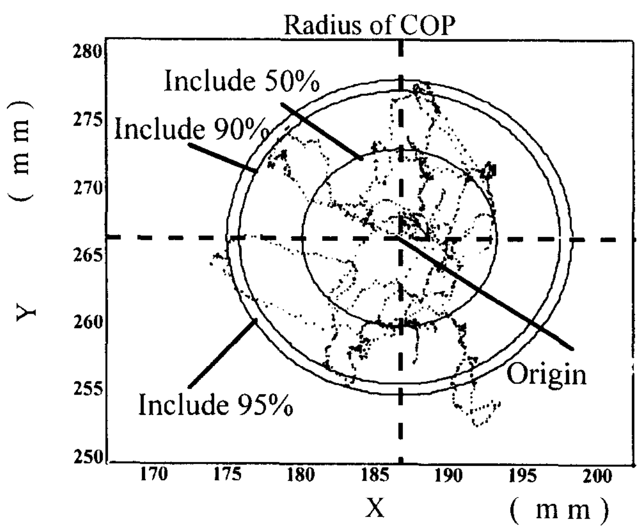

Figure 2. The sway radius is defined as the radius which includes 90% of COP points.

dadeh et al.[9] demonstrated that the duration of stance and swing was much longer in LBP patients. Khodadadeh and Eisenstein[10] evaluated the gait of LBP patients before and after surgery. In their study, 67% patients confirmed the perception of pain with the dysfunction showed in gait analysis. Gainey et al.[11] showed that the velocity and cadence decreased, and the stride time and double-limb support time increased in patients with Paget disease.

The postural stability control test represents the static response, and the gait assessment represents the dynamic response of the subjects. It is hypothesized that the movement of body center of mass during gait may reflect the deformity of spinal curve. The purpose of this research is to analyze static equilibrium in several postures and to assess the gait patterns between IS patients and normal subjects; this will enable us to determine a more effective method to identify the functional disability in IS patients.

Methods

Subjects

Thirty IS patients and fifteen normal persons were included in this study (Table 1). All the patients were untreated and recruited from the out-patient clinic of Department of Orthopaedic, National Taiwan University Hospital. Eight of IS patients were classified to King I and eleven were classified to King II[12]. These two types (19 patients) were evaluated for both postural and gait analysis. Others were tested for static analysis only (Table 2). Lateral curvature of the thoracolumbar spine ranged from 22° to 67° Cobb angle. All fifteen normal subjects were without neurological or musculoskeletal abnormalities.

Static stability

The subjects were asked to stand barefoot on the force plate (Kistler Instrument Corp.) with eyes opened and closed for the following postures: (1)

Table 1. Number, age and gender of subjects

	Scoliotic patients	Normal subjects
Number	30	15
Age range	11–21	14–20
Mean	16.6 ± 3.8	16.8 ± 3.1
Sex (male/female)	2/28	2/13

Table 2. Number of idiopathic scoliotic patients used in postural stability control test and gait analysis

King type	I	II	III	IV	V
Number of subjects	8	11	4	3	4
Static control test	x	x	x	x	x
Gait analysis	x	x			

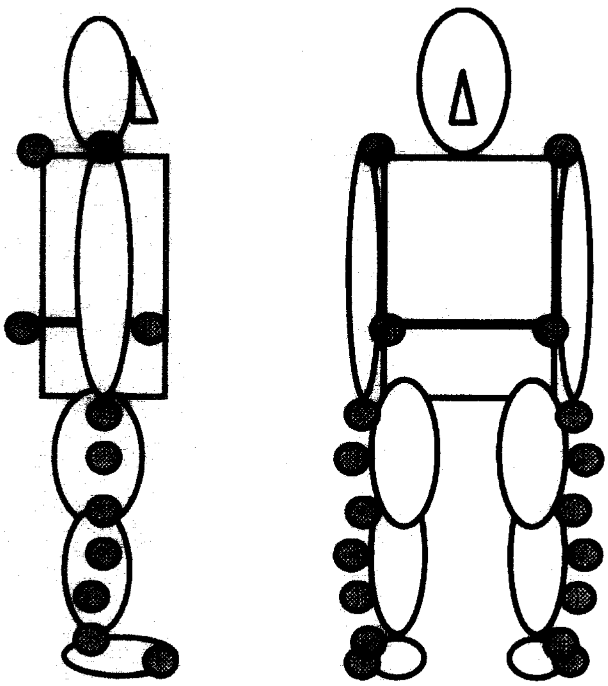

Figure 3. The placement of the body markers for gait analysis.

heels together and toes out 30°, (2) feet parallel and 8 cm apart, (3) flex trunk to maximum, (4) extend trunk to maximum, (5) holding a mass of 2 kg with both hands close to trunk, and (6) holding a mass of 2 kg with both hands lifted forward. The first four tasks lasted for 30 s, whereas the last two lasted for 10 s.

The center of pressure (COP) was recorded using the force plate at a sampling rate of 50 Hz and transmitted to a personal computer to calculate the four parameters, i.e. sway area, lateral sway, sagittal sway and sway radius. In total, 1500 and 500 instantaneous COP points were collected in 30 and 10 s tasks, respectively. The original measurement is the geometric center of all instantaneous COP points. The above four parameters are defined as follows: (1) sway area is the integration of area within two continuous instantaneous COP and the original points (Figure 1); (2) lateral sway is the accumulation of lateral distance of COP points; (3) sagittal sway is the accumulation of sagittal distance of COP points during the span of task; and (4) sway radius is the radius that includes 90% instantaneous COP points (Figure 2). The sway area and sway radius represent different physiologic responses. The sway area represents the instantaneous postural stability control, and the sway radius represents the overall equilibrium domain without the information of instantaneous response (Table 2).

Gait analysis

Twenty markers were placed on upper body and lower extremities. Seven markers were attached to each leg. Two markers were placed at the anterior superior iliac spine (ASIS) and one was at the sacrum. The shoulder markers and cervical marker were placed on the subject so that the line passes through the sternoclavicular joint and the seventh cervical vertebra. Each marker on the shoulder was placed mid-distance between the neck and lateral aspect of the shoulder (Figure 3). The stance phase, cadence and stride length of each leg was calculated from heel stride of first step to the second step.

All the subjects were asked to walk with their natural speed for six trials. The apparatus consisted of two Kistler force plates and the Elite 3-D motion analysis system. Four video cameras were set up to detect infra-red light reflected from the markers at sampling rate of 100 Hz. Six range of motions (ROM) were calculated, i.e., shoulder at transverse plane (SH_t) and coronal plane (SH_t), pelvis at transverse plane (PL_t) and coronal plane (PL_c), and spine at sagittal plane (SP_s) and coronal plane (SP_c). The angular motion of the ankle, knee and hip joints between right and left legs were also compared among the IS patients and normal subjects. The difference between normal subjects and IS patients in both postural stability control test and gait analysis was compared.

Results

The IS patients produced higher values for all four sway variables especially in cases of standing without loading. The sagittal sway (except for posture 3: standing with full flexion) was not significantly different between normal subjects and IS patients for both eyes opened and closed. However, the difference in lateral sway was significant in most of the free standing cases. Posture 3 is the most effective posture in identifying differences for all variables between normal subjects and IS patients, whereas the posture 6, i.e., holding loads with hand straight forward, is the least effective one among all six postures (Table 3).

Cadence is significantly slower in the IS patients. There is no significant difference in stance phase, cadence and stride length between left and right legs in all groups (Table 4). The only exception is that the cadence of right leg is significantly higher in normal subjects than IS patients. The ROM of PL_t and SP_c were larger in normal subjects than IS patients, whereas the ROM of SH_t, SH_c, PL_c and SP_s were about the same between groups. The ROM between right and left leg were also not significantly different among groups, except that the ROM of PL_t of King type I patients was higher in left leg cycle (Figure 4). The ROM of SP_c is larger in normal subjects than King type I and type II patients. The sagittal angular motion of the ankle, knee and hip during gait were similar between normal subjects, King type I and type II IS patients (Figure 5).

Discussion

The postural stability control of IS patients was worse than normal subjects in general. The lateral sway was significantly larger in the IS patients than in normal subjects, but no significant difference was found in sagittal sway except at flexion posture. This may be due to the imbalance moment induced by shifting of body mass center caused by scoliotic spine, especially in the lateral direction. The postural stability control in sagittal direction of IS patients decreased especially in flexion posture. The flexion posture was also proved to be the best posture among all six to identify the outcome between normal subjects and IS patients. The extra loading of spine increased the postural stability for both the IS patients and normal subjects. This may be due to the increased muscle strength induced by the external loading.

The posture effect on sway area and sway radius is consistent in many cases. However, an exception was noticed, i.e., the IS patients produced significantly higher sway area but not sway radius at extension posture with eyes opened and standing with feet parallel. The physiologic meaning of sway area and sway radius is not clearly distinguished. However, the authors believe that the sway area represents the capability of the instantaneous control of muscular system due to the integration of the instantaneous

Table 3. The mean (standard deviation) of sway area, lateral sway, sagittal sway, and sway radius between the normal subjects and the idiopathic scoliotic patients in six postures with eyes opened and closed

Eyes position	Sway area (cm^2)					
	opened			closed		
	Nml	Sco	*p*	Nml	Sco	*p*
1	720(163)	1059(446)	0.004*	1080(539)	2867(8389)	0.386
2	447(98)	765(419)	0.004*	558(215)	791(425)	0.036*
3	1095(465)	1645(1091)	0.050*	1299(526)	2224(1184)	0.004*
4	1299(578)	2062(1279)	0.026*	2043(1174)	3538(5027)	0.232
5	227(77)	288(166)	0.153	276(108)	483(567)	0.141
6	275(160)	430(336)	0.074	379(209)	519(390)	0.167
Eyes position	**Lateral sway (cm)**					
	opened			closed		
	Nml	Sco	*p*	Nml	Sco	*p*
1	18.6(5.0)	25.9(8.1)	0.001*	22.6(7.3)	41.7(86.2)	0.368
2	13.4(5.1)	17.0(6.8)	0.050*	12.2(3.8)	18.0(7.4)	0.003*
3	24.9(6.2)	28.9(9.7)	0.117	27.3(8.4)	35.1(12.3)	0.027*
4	25.2(6.7)	31.5(10.4)	0.029*	28.8(10.3)	38.8(13.3)	0.007*
5	15.0(4.4)	16.9(7.6)	0.336	16.1(5.1)	21.1(9.2)	0.042*
6	15.6(5.9)	18.9(7.1)	0.097	18.0(6.1)	21.1(9.0)	0.195
Eyes position	**Sagittal sway (cm)**					
	opened			closed		
	Nml	Sco	*p*	Nml	Sco	*p*
1	21.1(5.5)	25.4(12.6)	0.181	26.0(8.7)	42.6(54.0)	0.216
2	20.4(4.2)	25.9(13.2)	0.110	23.2(7.1)	26.3(15.7)	0.435
3	25.3(7.9)	33.8(15.3)	0.031*	25.5(9.6)	39.0(23.3)	0.029*
4	31.7(12.5)	38.6(19.0)	0.179	39.8(18.1)	40.3(17.5)	0.921
5	14.5(3.8)	19.6(13.1)	0.117	18.0(4.8)	22.2(14.5)	0.247
6	18.0(6.3)	20.8(12.5)	0.394	22.6(9.9)	25.1(15.1)	0.536
Eyes position	**Sway radius (cm)**					
	opened			closed		
	Nml	Sco	*p*	Nml	Sco	*p*
1	7.8(2.4)	10.8(4.4)	0.012*	10.3(4.3)	19.9(53.5)	0.431
2	7.3(2.7)	9.3(3.9)	0.050*	8.1(3.1)	8.9(2.7)	0.307
3	9.9(3.1)	13.2(4.6)	0.007*	11.6(3.5)	15.0(5.3)	0.023*
4	12.0(3.6)	13.3(4.9)	0.337	13.4(5.2)	16.2(5.5)	0.082
5	8.6(1.8)	10.1(4.0)	0.151	9.9(2.7)	11.9(5.1)	0.138
6	9.4(3.3)	11.0(4.2)	0.172	11.7(4.6)	12.6(5.8)	0.573

Nml: normal subjects, Sco: Scoliotic patients, *p*: *p* value, *, $p < 0.05$.

Table 4. The stance phase, cadence and stride length of normal subjects, King type I and King type II patients

		Normal	Type I	Type II
Stance phase	Right	58 (SD 2.7)	58 (SD 2.8)	59 (SD 2.6)
(% of gait cycle)	Left	59 (SD 2.1)	59 (SD 2.0)	59 (SD 2.3)
Cadence	Right	114 (SD 6.5)	103 (SD 7.0)	105 (SD 9.0)
(step min^{-1})	Left	113 (SD 10)	106 (SD 9.1)	107 (SD 8.4)
Stride length	Right	127 (SD 7.7)	126 (SD 10.9)	120 (SD 9.9)
(cm)	Left	123 (SD 6.6)	124 (SD 9.8)	120 (SD 13.2)

p value among normal, King type I and King type II patients

		Normal-I	Normal-II	Type I-II
Stance phase	Right	0.471	0.233	0.567
	Left	0.472	0.222	0.536
Cadence	Right	0.0001*	0.002*	0.188
	Left	0.054	0.062	0.797
Stride length	Right	0.806	0.195	0.175
	Left	0.768	0.297	0.248

*$p < 0.05$

areas, whereas the sway radius represents the overall performance of muscular system due to the average of the longer period of time. The results of this study may reflect that the spinae muscle of IS patient is poor in instantaneous control of extension when eyes opened, but the overall performance is about the same. This outcome may be used in identifying the neuromuscular function of spinae muscles for the postural stability control in IS patients.

The stance phase, cadence, stride length and the angular motion of lower limbs of normal subject in our study are consistent with previous studies[13–16]. All the above variables except cadence were not significantly different between IS patients and normal

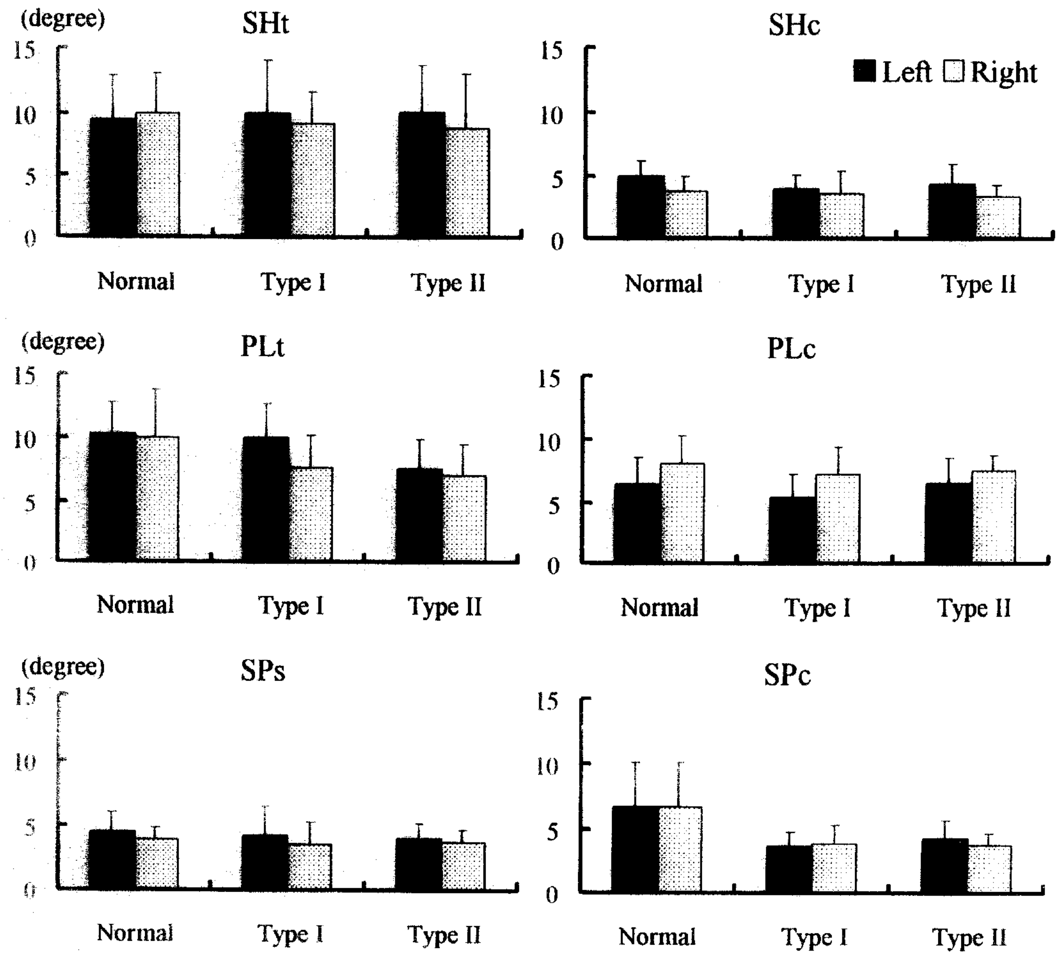

Figure 4. The range of motion (ROM) of shoulder and pelvis on transverse and coronal plane, and spine on sagittal and coronal plane. The *p* values which are smaller than 0.05 can be found in PL_t: $N_r–II_r = 0.020$, $I_r–I_l = 0.050$, $I_l–II_l = 0.020$; SP_c: $N_l–I_l = 0.003$, $N_l–II_l = 0.019$, $N_r–I_r = 0.007$, $N_r–II_r = 0.003$ using two tailed *t*-test, where N: normal, I: King type I, II: King type II, $_l$: left leg, $_r$: right leg.

subjects. Therefore, we may conclude that the scoliotic spine does not affect the mechanics of the lower limbs. The slower cadence of IS patients may be due to the less postural stability control of body center for IS patients.

The ROM of shoulder on transverse and coronal planes, pelvis on coronal plane and spine on sagittal plane was not significantly different. The ROM of pelvis on transverse plane and spine on coronal plane was smaller in the IS patients. The plausible reason for this phenomenon may be that the IS patients need to restrict their pelvic and spinal movement in order to keep the upper body balance because of geometric asymmetry like the spinal deformity in lateral direction and the mal-alignment of spinae muscles. One interesting aspect is that the IS patients obtain smaller ROM of spine in coronal plane, but higher lateral sway. This may imply that the IS patients produced higher stability control in walking than in standing.

The spinal curve shape does not affect the ROM in most cases, except for the pelvis at the transverse plane, which is larger at the left leg cycle of King type I, but smaller at King type II patients. This result may be due to the complex outcome of deformity of spinal curve and mal-alignment of muscle, and may provide a validation for the modeling of scoliotic musculoskeletal system.

In future studies, factors such as spine curve shapes (King type III, IV, V), gender and age[17,18] should be included to compare performance of postural stability control and gait patterns. A neuromusculoskeletal model for scoliosis is expected to be built based on the observed data in this research. The outcome of pre-operation and post-operation can also be evaluated not only from the radiograph but also from the performance of postural stability control.

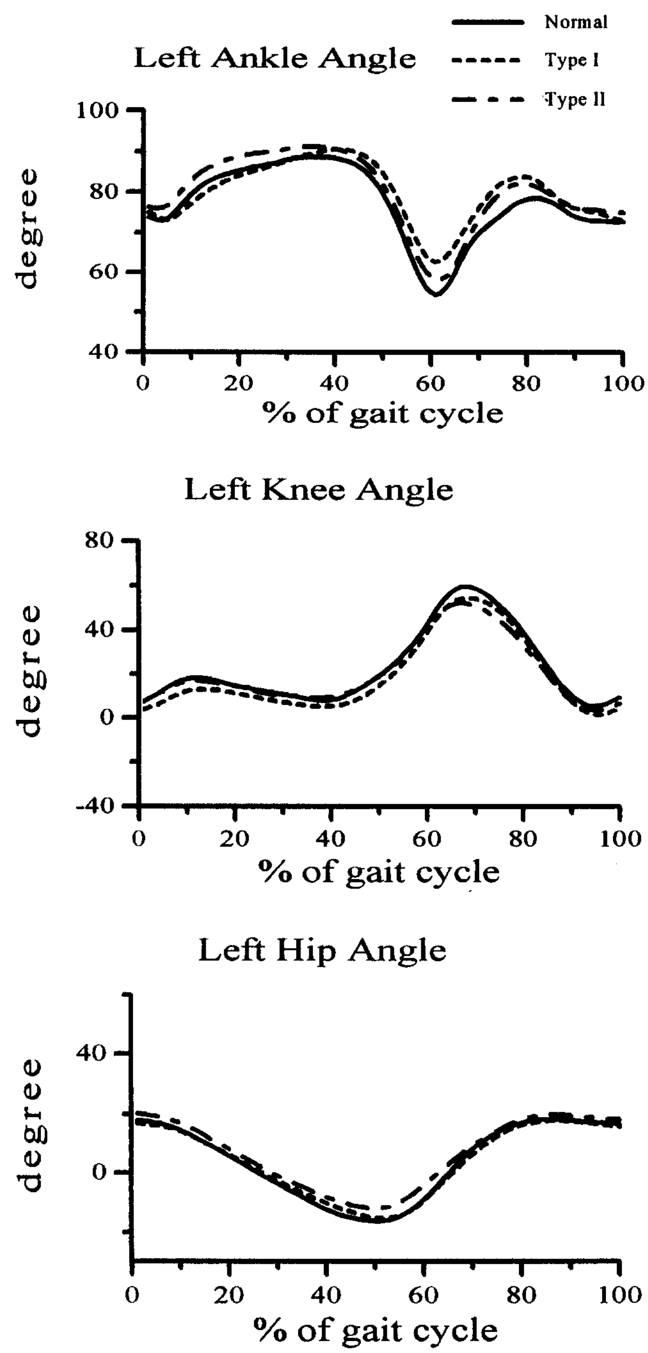

Figure 5. The angular displacement of left lower limb joints. The patterns of the left leg and right leg were similar. The differences between normal subjects, King type I and King type II patients are not significant.

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