Static and dynamic factors related to pelvic retraction during gait in cerebral palsy hemiplegia

Yoon Hae Kwak

Department of Medicine

The Graduate School, Yonsei University

연세대학교
YONSEI UNIVERSITY

Static and dynamic factors related to pelvic retraction during gait in cerebral palsy hemiplegia

Directed by Professor Hyun Woo Kim

The Doctoral Dissertation
submitted to the Department of Medicine,
the Graduate School of Yonsei University
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

Yoon Hae Kwak

December 2016

연세대학교
YONSEI UNIVERSITY

This certifies that the Doctoral Dissertation of Yoon Hae Kwak is approved.

Thesis Supervisor : Hyun Woo Kim

Thesis Committee Member #1 : Myung-Joon Kim

Thesis Committee Member #2 : Deog Young Kim

Thesis Committee Member #3: Hae-Dong Lee

Thesis Committee Member #4: Kun Bo Park

The Graduate School
Yonsei University

December 2016

ACKNOWLEDGEMENTS

I would like to express the deepest appreciation to my thesis supervisor, Professor Hyun Woo Kim. Without his guidance and persistent help this dissertation would not have been possible.

I am also indebted to my committee members, Professor Myung-Joon Kim, Deog Young Kim, Hae-Dong Lee and Kun Bo Park, whose work demonstrated to me the concern for searching question and provide a quest for the study. In addition, a thank you to Professor Chung Mo Nam and Hye Jin Jee, who give a helping hand as an excellent statistical analysis.

Finally, I truly thank to my mom in heaven, father and sisters who always support me through happy and difficult times alike.

<TABLE OF CONTENTS>

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Static and dynamic factors related to pelvic retraction
during gait in cerebral palsy hemiplegia

Yoon Hae Kwak

Department of Medicine
The Graduate School, Yonsei University

(Directed by Professor Hyun Woo Kim)

Pelvic retraction is commonly encountered as a characteristic gait pattern of patients with hemiplegic cerebral palsy but until now previous reports have focused on specific gait parameters or limited clinical factors. The purpose of this study was to compare the static and dynamic variables between pelvic retraction and normal pelvic motion, and to determine the causes of pelvic retraction in patients with hemiplegic cerebral palsy. In total, 212 patients were divided into two groups: group I consisted of 113 patients who had excessive pelvic retraction, and group II comprised 99 patients with normal pelvic rotation. Clinical static variables and dynamic gait variables were compared between the two groups, and 27 dynamic gait variables were selected for multivariate factor analysis. In logistic regression analysis, sagittal plane motion of the ankle and pelvis, hip transverse motion, Winter classification, and upper extremity asymmetry significantly affected pelvic retraction. Pelvic retraction in spastic hemiplegic cerebral palsy is affected not only by the increased ankle equinus but also by dynamic variables such as sagittal pelvic motion and transverse hip rotation, and clinical variables such as Winter classification and upper extremity asymmetry, which quantify the severity of neurological impairment.

Key words : pelvic retraction, cerebral palsy hemiplegia, gait analysis

Static and dynamic factors related to pelvic retraction during gait in cerebral palsy hemiplegia

Yoon Hae Kwak

Department of Medicine
The Graduate School, Yonsei University

(Directed by Professor Hyun Woo Kim)

I. INTRODUCTION

During normal gait, the ipsilateral pelvis is slightly rotated internally, owing to the forward position of the foot at initial contact. There is a gradual external rotation to a value below 5° by the time of contralateral limb contact, and pelvic motion is quite subtle[1]. However, pelvic motion can be greatly amplified in pathologic gait as a primary or compensatory effect of skeletal or neuromuscular impairment. Pelvic retraction is commonly seen as a characteristic gait pattern in patients with cerebral palsy. Excessive pelvic rotation during gait can lead to functional problems as well as cosmetic concerns due to an asymmetric gait pattern, but the cause of excessive pelvic rotation in patients with cerebral palsy is not yet fully understood[2].

Because pelvic retraction has been considered to be a primary neurological deficit related to a lesion of the central nervous system, orthopedic surgeons have not addressed this as a surgical problem, and have focused mainly on ankle equinus or foot deformity[3,4]. In addition, several studies suggest that pelvic retraction may be secondary to muscle spasticity or may be a coping response to bony torsional deformities, as pelvic retraction has been shown to improve with various surgical procedures[5,6]. Although previous studies reported that the causes of pelvic retraction are multifactorial in origin, they did not discriminate hemiplegia from diplegia, and did not identify the important factors that cause excessive pelvic retraction[1,2].

Recently, there were many studies that showed improvement of pelvic retraction after surgical treatment of lower extremities of cerebral palsy. This means that pelvic retraction is derived from the other gait problems or underlying pathologic clinical factors that can be improved. To our knowledge, no prior study has reported in detail the clinical and gait factors affecting pelvic retraction in relatively large numbers of children only with hemiplegic cerebral palsy and its clinical importance in this condition. The purposes of this study were to identify which factors cause excessive pelvic retraction in patients with hemiplegic cerebral palsy in terms of clinical static and dynamic gait variables, and to predict the patient's outcome in each condition with these factors.

II. MATERIALS AND METHODS

1. Subjects

The present study was a retrospective review, and was approved by our hospital's institutional review board (IRB No. 4-2007-0070 and 4-2009-0035).

In total, 312 patients with spastic hemiplegic cerebral palsy who underwent gait analysis in our institute between July 2002 and June 2009 were included. Of these, 59 patients were excluded for various reasons, including history of previous operation, absence of complete data, and difficulty in managing data obtained with different versions of the gait analysis system. Thus, 253 patients who were able to ambulate independently without any assistance, GMFCS I and II, were selected.

Transverse pelvic rotation in gait analysis was reviewed and compared with our normative database. Average pelvic rotation was calculated by averaging the maximum and minimum values of pelvic rotation over the stance phase, and pelvic retraction was defined when an average pelvic rotation was more than -2 standard deviations (SDs) from the normal control (<-4.75°). Average pelvic rotation with >-1 SDs (>-2.24°) was considered within normal range. Patients who displayed pelvic retraction between -2 and -1 SDs from the normal mean were excluded. In addition to gait analysis numeric data, video recordings and the graph pattern of gait were analyzed, as some patients had a sinusoidal or reverse pattern rather than an entire pelvic retraction pattern. From this initial analysis, 41 patients were excluded, leaving a final total of 212 patients remaining in the study (Fig. 1). These 212 patients comprised 84 (39.6%) female and 128 (60.4%) male patients.

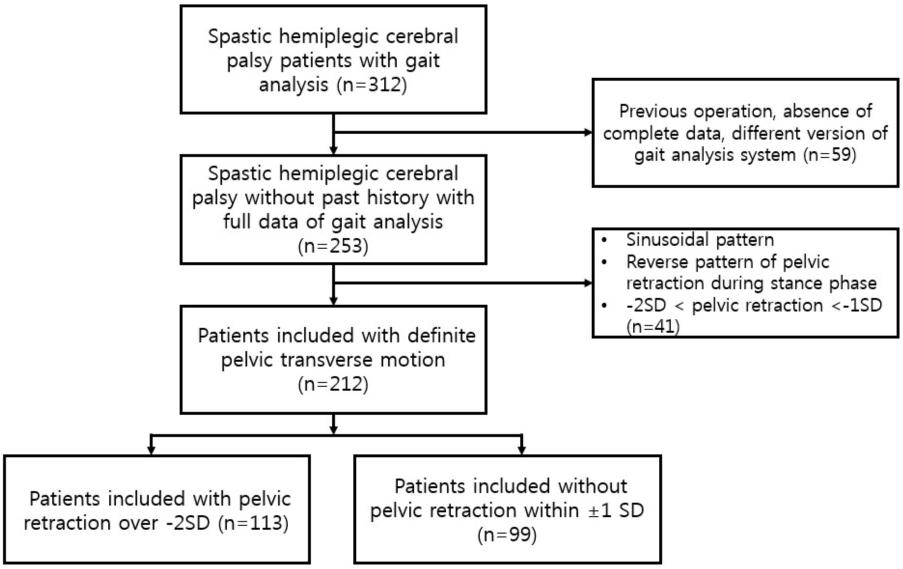

Figure 1. Patients search strategy

Mean age at time of gait analysis was 8 years and 8 months (range 38 months to 29 years). There were 127 patients (59.9%) with right hemiplegia and 85 (40.1%) with left hemiplegia. Subjects were divided into two groups: group I consisted of 113 patients (44.7%, 113/253) who had a pelvic retraction gait pattern, and group II comprised 99 patients (39.1%, 99/253) who had pelvic rotation within the normal range.

2. Measurement of clinical static and dynamic gait variables

We reviewed the imaging study, medical records, gait analysis, video analysis, and dynamic foot-pressure measurement of all patients. Scannogram and computed tomography (CT) were also evaluated prior to the gait analysis. Clinical physical examinations were recorded as part of the clinical evaluation prior to gait analysis, and we reviewed these variables from the medical records.

Gait analysis was performed using a VICON 370 Motion Analysis System

(Oxford Metrics, Oxford, England) with six infrared cameras, and data on ground-reaction forces were gathered from multiple force platforms (Advanced Mechanical Technology, Watertown, MA, USA). All subjects were asked to walk barefoot at a self-selected speed along a 15-m walkway with the markers in place. Force plates under the walkway recorded ground-reaction forces during walking trials, and joint moments were expressed as internal moments to counter the ground-reaction force. Video and dynamic foot-pressure measurement (Tekscan, South Boston, MA, USA) were recorded simultaneously.

Scannogram results for 175 (82.5%) patients (93 patients in group I and 82 in group II) and of the 212 patients, 172 (81.1%) had undergone commuted tomography (CT) to allow accurate measurement of torsion at the time of gait evaluation. The physical examination comprised a passive range of motion of joint and a Duncan-Ely test for rectus tightness, popliteal angle for hamstring tightness, Silverskiöld test for gastrocnemius and soleus muscles tightness. Pes equinovarus, one of the static variables, was defined as an inversion and plantar flexion of the hindfoot with or without forefoot supination, detected by physical examination, video analysis, and dynamic foot-pressure measurement. Recurvatum gait pattern and the gait pattern based on Winter classification[7] were determined using the gait and video analysis. Recurvatum gait was defined as a clinical static variable because it is a type of qualitative classification that is descriptive, does not require statistical techniques, and relies only on sagittal kinematic data. We modified the Winter classification because many patients do not belong to any group. Some patients in our study showed ankle equinus with knee hyperflexion and a good range of motion during the stance phase, and we considered this gait pattern as type III. The other two patterns (III and IV) were applied to our study as IV and V. Upper extremity involvement was defined as a clinical static variable, and was based on observation of the video records. It was classified into two types: ‘more involved’ upper extremity involvement had approximately 30° or more of elbow flexion during ambulation, and ‘less involved’ upper extremity involvement had minimal or no elbow flexion.

In gait analysis, conventional gait model was used for analysis in this study.

The conventional gait model divides the body into seven segments (the pelvis and two femurs, tibias and feet). These segments are linked by joints that are all assumed to be ball and socket joints (three degrees of freedom). The position of each joint is defined within its proximal segment and used to define its distal segment. The segments are defined from the measured positions of markers. This conventional model derives the pelvic segment from markers placed upon a pelvic frame aligned with the anterior superior iliac spines(ASISs) and posterior superior iliac spines and the anthrometric measure of the inter-ASIS distance. Thigh and shank wands are aligned perpendicular to the knee joint flexion-extension axis and transmalleolar axis, respectively, and the frontal plane of the thigh and shank segments is defined perpendicular to these wands. Markers were also positioned on the lateral aspect of the knee flexion/extension axis, antero-inferior to the tip of the lateral malleoli, the head of the fifth metatarsals and the lateral heels. Gait variables over the stance phase were measured and 21 parameters were selected for the multifactorial analysis, because gait parameters are not independent factors, and are interrelated between joints and planes [8–11]. With 6 temporospatial parameters, a total of 27 clinically relevant kinematic parameters for the lower limb were chosen for multifactorial analysis as dynamic gait variables [1,6,12].

3. Statistical analysis

An inter-group comparison was made between groups for both clinical static and dynamic gait variables, using a two-tailed t-test. The level of significance was set at $p < 0.05$. Based on previous studies[1,6,13] and considering the comparison in our study, 5 clinical static variables and 27 dynamic gait variables were selected. Multivariate factor analysis was performed, with age and dynamic gait variables used to define dynamic factors, considering the difference according to patient age and the correlation between the gait parameters. Logistic regression analysis was performed with dynamic factors and selected relevant clinical static variables to evaluate their effect on pelvic retraction. Receiver operating characteristic (ROC) curves were used to identify which dynamic factors or clinical static variables were contributing to the pelvic retraction.

III. RESULTS

1. Comparison between groups

The average age of group I was lower than that of group II. Only eight (4.6%) patients had leg length equalization and there was no statistical difference in the leg length discrepancy between the two groups. One 11-year-old patient had a discrepancy in leg length of 41 mm, but the discrepancy in all the other patients was less than 25 mm. There was no statistical difference in femoral anteversion and tibial torsion between the two groups. Gastrocnemius tightness and soleus tightness were significantly lower in group I compared with group II. Other findings from the physical examination were not statistically different between the two groups (Table I).

Table 1. Comparison of clinical static variables between the two groups.

Parameter	Group I			Group II			*p* Value
Age, year	7.94	±	4.49	9.49	±	5.06	0.0189*
Leg length discrepancy, mm	6.61	±	4.67	7.16	±	6.30	0.5209
Femoral anteversion, degrees	29.25	±	11.88	26.22	±	12.43	0.1047
Tibial torsion, degrees	29.09	±	10.54	27.51	±	10.00	0.3708
Popliteal angle, degrees	21.49	±	13.85	21.55	±	12.33	0.9767
Gastrocnemius tightness, degrees	83.87	±	17.15	90.64	±	8.34	0.0005*
Soleus tightness, degrees	91.03	±	17.30	98.35	±	9.29	0.0003*
Hip flexion, degrees	120.78	±	5.55	120.43	±	2.41	0.5649
External rotation, degrees	45.37	±	9.96	48.12	±	13.32	0.1597
Internal rotation, degrees	42.26	±	9.79	42.39	±	12.88	0.9431

(*p<0.05)

Group I had significantly more severely involved pes equinovarus than group II, but there was no statistical difference in recurvatum gait between the two groups. Group I had significantly higher Winter classification and significantly more severe upper extremity asymmetry. Using our modified Winter classification, type II was more common in group I (46 of 113 patients; 40.7%) and type I was more common in group II (34 of 99 patients 34.3%). Types IV and V were seen in smaller numbers of the total study population, affecting 36 (17.0%) and 6 (2.8%) of the patients, respectively (Table II). Regarding the temporospatial data, the opposite foot off time, stride length, step length, and walking speed were decreased in group I compared with group II (Table III).

Table 2. Comparison of clinical static variables between the two groups.

	Group I		**Group II**		**Chi-square**
	O	X	O	X	***p* Value**
Recurvatum gait	50	63	35	64	0.187
Pes equinovarus	44	68	23	76	0.028*
Upper extremity asymmetry	34	61	7	81	<0.001*

	Group I					**Group II**					**Chi-square**
	I	II	III	IV	V	I	II	III	IV	V	***p* Value**
Modified Winter classification	17	46	22	24	4	34	29	22	12	2	0.010*
	0	1	2	3		0	1	2	3		
Rectus tightness	32	24	3	0		43	16	2	1		0.153

(*k^2<0.05.)

Table 3. Temporospatial parameters in groups I and II.

Parameter	Group I			Group II			*p* Value
Cadence, steps/min	123.81	±	26.33	123.86	±	19.64	0.9874
Opposite foot off, s	14.98	±	3.84	14.04	±	2.89	<.0001*
Stride length, m	0.79	±	0.22	0.88	±	0.22	0.0054*
Step length, m	0.39	±	0.11	0.45	±	0.09	0.0003*
Walking speed, m/s	0.8	±	0.25	0.89	±	0.23	0.0081*

(Values are given as mean ± standard deviation. *$p < 0.05$.)

In the sagittal plane, average anterior pelvic tilt was increased in group I compared with group II. Average pelvic rotation and pelvic rotation at initial contact were significantly more retracted in group I than group II rightly. In the coronal plane, there was a difference in average pelvic obliquity between the two groups, and group I had downward pelvic obliquity during the stance phase. Maximum hip extension was reduced in group I compared with group II. Maximum abduction and adduction of the hip joint was not statistically different in spite of pelvic motion in the coronal plane. Average hip rotation also showed the statistical difference between the groups. Maximum knee flexion and maximum ankle dorsiflexion were decreased in group I compared with group II. At initial contact, ankle equinus was more severe in group I than in group II. Average ankle transverse angle was also significantly different, but mean foot progression angle was not statistically different between groups (Table IV).

Table 4. Dynamic gait variables in group I and II

Parameter	Group I			Group II			*p* Value
Average anterior pelvic tilt	19.20	±	6.04	15.76	±	5.67	<0.0001*
Average pelvic rotation	-13.17	±	5.75	-0.81	±	3.77	<0.0001*
Pelvic rotation at initial contact	-8.45	±	7.29	1.84	±	5.47	<0.0001*
Average pelvic obliquity	-1.97	±	4.50	-0.51	±	2.68	0.0042*
Maximum hip extension	6.70	±	11.32	-0.59	±	7.98	<0.0001*
Average hip rotation	1.37	±	9.86	-1.57	±	8.04	0.0177*
Maximum hip abduction	6.81	±	5.54	6.14	±	4.85	0.3519
Maximum hip adduction	-5.32	±	5.84	-5.90	±	4.68	0.4271
Maximum knee extension	9.32	±	11.77	9.62	±	9.25	0.8376
Maximum knee flexion	41.55	±	10.00	45.78	±	9.20	0.0016*
Maximum ankle dorsiflexion	3.39	±	13.48	10.46	±	7.64	< 0.0001*
Ankle dorsiflexion at initial contact	-11.16	±	10.07	-6.90	±	7.44	0.0005*
Average ankle rotation	5.95	±	14.10	-0.63	±	10.43	0.0001*
Average foot progression angle	0.17	±	19.31	-3.30	±	12.47	0.1238
Range of ankle motion	22.43	±	7.43	24.87	±	7.48	0.0183*

(Values are given as mean ± standard deviation, $*p < 0.05$.)

2. Multivariate factor analysis and logistic regression analysis

The first eight factors accounted for 79.96% of the total variability between the two groups. Factor 1 mainly indicated the ankle equinus pattern, which was one of the important variables (19.28%). Factor 2 was a function of step/stride length and walking speed, while factor 3 consisted of cadence, step, and stride time. Factor 4 corresponded to a transverse angle of ankle and foot progression, and factor 5 was the knee sagittal angle, which reflected the flexion and extension of the knee joint. Factor 6 was the coronal plane motion of the pelvis and hip joint, factor 7 was the pelvic anterior tilt in the sagittal plane, and factor 8 was the transverse motion of the hip joint (Table V).

Table 5. Multivariate factor analysis

Parameter	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
Age	0.0580	0.5734	0.3450	0.0071	0.2599	0.0116	0.0739	-0.0516
Cadence	-0.0545	-0.0829	**-0.9619†**	0.0049	0.0405	-0.0394	0.0085	0.0021
Stride time	-0.0003	-0.0044	**0.9925†**	0.0188	-0.0211	0.0107	-0.0279	-0.0039
Step time	0.0133	-0.0081	**0.9624†**	0.0304	-0.0428	0.0033	-0.0141	0.0253
Stride length	-0.0174	**0.9220†**	0.1635	-0.0160	-0.0523	0.0451	-0.0410	-0.0013
Step length	-0.0780	**0.9235†**	0.0442	0.0034	-0.0417	-0.0105	-0.0621	-0.0205
Walking speed	0.0064	**0.8578†**	-0.3231	-0.0198	-0.0659	0.0452	0.0000	0.0172
Range of motion of pelvic sagittal motion	-0.2601	-0.0758	0.1436	0.0610	-0.1807	0.0126	0.3718	0.1680
Average pelvic anterior tilt	0.0318	-0.0735	-0.0932	0.0024	0.0166	0.0106	**0.9022†**	-0.0320
Range of motion of pelvic coronal motion	0.0030	0.2318	-0.0340	-0.0430	-0.3606	0.1658	0.5165	0.0684
Average pelvic obliquity	-0.0130	-0.1302	0.0393	0.1818	0.2054	**0.7360†**	-0.3500	-0.1974
Minimum hip sagittal angle	-0.0480	-0.1037	0.1361	-0.0196	0.4636	-0.0378	0.6406	-0.0388
Average hip sagittal angle	0.0123	0.0271	-0.0145	0.0515	0.5384	-0.0339	0.6781	-0.0821
Maximum hip coronal angle	-0.0311	0.0996	0.0340	-0.0345	-0.0910	**0.8790†**	0.1735	0.0682
Average hip coronal angle	0.0212	0.0335	0.0121	-0.0559	0.0560	**0.9438†**	0.0893	0.0177
Maximum hip transverse angle	0.0342	-0.0009	-0.0678	0.0698	0.0315	-0.0567	0.0051	**0.9404†**
Average hip transverse angle	0.0139	-0.0722	0.0837	0.0536	0.0905	0.0318	-0.0089	**0.9293†**

Minimum knee sagittal angle	-0.0282	0.1853	-0.0817	-0.0769	**0.9538†**	0.0411	-0.1195	0.0456
Range of motion of knee sagittal motion	0.1480	0.1783	-0.1292	0.1751	-0.6728	-0.0067	0.0390	-0.1729
Knee sagittal angle at initial contact	0.1369	-0.0698	-0.2025	0.2871	0.5249	0.1001	0.1709	-0.0367
Average knee transverse angle	0.0335	0.5276	0.0674	0.1399	0.1300	-0.4179	0.0458	-0.1089
Maximum ankle sagittal angle	**0.9347†**	-0.0016	0.0160	-0.0163	-0.0287	-0.0029	-0.0485	-0.0131
Minimum ankle sagittal angle	**0.8981†**	-0.0591	0.1255	-0.0685	-0.0666	-0.0473	0.0334	0.0100
Average ankle sagittal angle	**0.9624†**	0.0013	0.0312	-0.0379	-0.0290	-0.0084	0.0098	0.0082
Ankle sagittal angle at initial contact	**0.9496†**	-0.0115	-0.0667	0.0460	0.0160	0.0378	-0.0168	0.0541
Average ankle transverse angle	-0.0950	-0.1563	0.0888	**0.8463†**	-0.2326	-0.0175	0.0794	-0.2171
Maximum foot progression angle	-0.0473	0.0898	-0.0078	**0.9208†**	0.0523	-0.0062	-0.0257	0.1729
Average foot progression angle	0.0237	0.0741	-0.0038	**0.9470†**	0.0614	0.0107	-0.0430	0.1617

(†Factor > 0.7000.)

Logistic regression analysis with eight dynamic factors and five clinical static variables suggested that factor 1 (ankle equinus) and factors 7 and 8 (pelvic anterior tilt and transverse motion of the hip joint) had an influence on pelvic retraction. Among the clinical static variables, Winter classification and upper extremity asymmetry had a causal interaction on transverse pelvic motion. Gastrocnemius and soleus tightness, which were significantly different in the comparison between the groups, showed no difference statistically, in spite of factor 1 having an influence on pelvic retraction (Table VI). The ROC curve with clinical static variables and dynamic factors showed the power of the influence on pelvic retraction, and the gastrocnemius and soleus tightness curves showed a very similar pattern (Fig. 2).

Table 6. Logistic regression analysis with dynamic factors and clinical variables

Parameter		Estimate	Standard Error	95% Wald Confidence	Limits	Pr > k^2
Factor 1		0.382	0.350	0.192	0.757	0.0059‡
Factor 2		0.689	0.236	0.434	1.094	0.1139
Factor 3		1.013	0.219	0.660	1.555	0.9525
Factor 4		0.935	0.236	0.589	1.484	0.7760
Factor 5		1.411	0.332	0.736	2.706	0.2996
Factor 6		1.037	0.257	0.627	1.715	0.8885
Factor 7		2.305	0.263	1.376	3.861	0.0015‡
Factor 8		1.540	0.217	1.006	2.358	0.0470‡
Winter class	5 vs 1	0.015	1.590	<0.001	0.841	0.0208‡
Winter class	4 vs 1	0.844	0.584	0.190	3.754	0.5478
Winter class	3 vs 1	1.540	0.552	0.452	5.253	0.0842
Winter class	2 vs 1	3.785	0.658	1.202	11.921	0.0049‡
Gastrocnemius tightness		1.001	0.034	0.936	1.070	0.9860
Soleus tightness		0.998	0.033	0.935	1.065	0.9465
Pes equinovarus		2.381	0.266	0.838	6.763	0.1033
Upper extremity asymmetry		3.440	0.295	1.081	10.941	0.0364‡

(‡k^2<0.05)

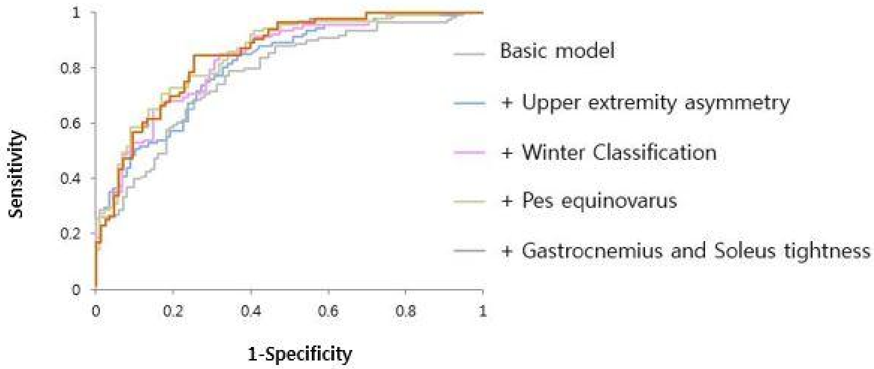

Figure 2. Receiver operating characteristic (ROC) curve consisting of basic dynamic factors and 5 clinical static variables. The closer the ROC plot is to the upper left corner, the higher the overall accuracy of the parameters. Compared with using dynamic factors alone (basic model), including the clinical static variables improved the sensitivity. Among the clinical static variables, soleus tightness and gastrocnemius tightness showed almost the same pattern, and in fact, the two graphs overlapped.

IV. DISCUSSION

The patients with cerebral palsy hemiplegia have different clinical and gait characteristics from the patients with cerebral palsy diplegia. Pelvic retraction gait pattern is one of the common characteristic gait patterns in patients with cerebral palsy, but it has been considered based on different underlying condition. In addition, if the cause of the pelvic retraction could be clarified, the surgical results could be predicted more clearly.

Limb length discrepancy is common in patients with hemiplegic cerebral palsy, but rarely requires any treatment. In previous studies about pelvic retraction, limb length discrepancy was not considered, even though patients having limb length discrepancy demonstrated an altered gait pattern or a limp[12,14,15]. Thus, we suspect that leg length discrepancy is one of the causes of pelvic retraction, but there was no statistical importance between groups. Unlike previous reports[16,17], we found no statistical difference in both of radiologic and clinical torsion between our two groups. The relation between gait parameters and radiological evaluation is a separate entity to be addressed, and should be considered in a separate study[4,18]. Physical examination of the hip joint in the current study found no difference, and only the physical examination of the ankle joint found differences between the groups, such as gastrocnemius and soleus tightness. This was also observed in previous studies[19,20] that normal forward progression of the tibia over the supporting foot during the stance phase of gait is prevented by tight calf musculature, and pelvic retraction might occur as a consequence of this interruption to the body’s forward progression during stance. Pes equinovarus and recurvatum gait can be differentiated easily by clinicians in office-based examinations, and they are closely related due to the same mechanism of gastrocnemius tightness. Also, these factors are affected by other muscles around the knee and ankle and these factors are related to the tightness of gastrocnemius and soleus, but are not factors directly related to pelvic retraction. Winter classification is widely used for patients with hemiplegic cerebral palsy, but it has some limitations because it is based solely on gait analysis and most of all, some of patients cannot be involved in any group. Various authors have reported new systems or modifications of existing systems[21-24]. We used a modified Winter classification because we had patients with knee hyperflexion and good range of motion during the stance phase. Rodda and Graham[23] categorized as Type 2A and 2B but authors used hierarchical expression for statistics. Logistic regression analysis showed that Winter types IV and V had a negative effect on pelvic retraction, whereas type V made no contribution. There were few patients with type IV and V, and this may have affected the reverse results in the logistic regression analysis. The severity of gait pattern in terms of Winter classification being the cause of pelvic retraction, and the correlation between the degree of severity and pelvic retraction could not be explained clearly in our study. Upper extremity asymmetry which is one of the characteristics in hemiplegia that is different from diplegia represents a severity of neurologic involvement[25], there was no previous study mentioned an association upper extremity asymmetry and pelvic motion. Upper limb asymmetry was significantly different between our two groups, and was also found to be a causative factor of pelvic retraction in multivariate analysis. Winter classification and upper extremity asymmetry that are representative of neurological severity in patients with hemiplegic cerebral palsy could be factors involved in pelvic retraction, and this was confirmed by the logistic regression analysis.

Opposite foot off time, stride length, step length, and walking speed were worse in group I than in group II. Temporospatial parameters are related to leg length, so inequality of limb length could be a factor in these differences, but in our study, there was no statistical difference in the leg length discrepancy between groups. Thus, the temporospatial parameters appear to be a relevant factor contributing to pelvic retraction. Previous studies mainly discussed specific gait parameters, and our results correlate with those[1,5]. Average hip rotation, average ankle rotation, maximum hip extension, maximum knee flexion, and maximum ankle dorsiflexion were statistically different between the two groups. Although there was no difference in rectus femoris muscle tightness between the groups, patients in group I had a lower degree of hip extension compared with group II. Pelvic retraction leads to increased pelvic anterior tilt and downward pelvic obliquity in the coronal plane, and this may be the cause of the lack of hip extension. Group I also showed decreased maximum knee flexion compared with group II, and this is also the result of the pelvic retraction compensated for by the decreased hip extension. There was no difference in the popliteal angle and tightness of the rectus femoris muscle between the groups. The decreased ankle dorsiflexion in group I is a result of the fixed tightness of the gastrocnemius and soleus muscles, and this difference was confirmed by the physical examination. In our logistic regression analysis, ankle sagittal motion, pelvic sagittal motion, and hip transverse angle were also causative factors for the pelvic retraction.

However, in the logistic regression analysis, gastrocnemius and soleus muscle tightness was not the causative factor of pelvic retraction. This problem could be due to a separate physical examination of the gastrocnemius and soleus. The ROC curve showed that both clinical variables and dynamic factors produced the pelvic retraction pattern with higher overall accuracy, but there was no difference between the gastrocnemius and soleus muscles in the degree of tightness. The individual effects of the gastrocnemius and soleus muscles should be assessed in a future study.

Our study has several limitations. Variable clinical factors could have influence on pelvic retraction, but in our study, we used only five factors for logistic regression analysis. Because other factors that appeared to have little importance in univariate comparison can give a reverse effect on statistics, we chose specific factors that seemed to have clinical importance for pelvic retraction, but the selection bias could be a problem of final results. We assessed only the hemiplegic side and did not compare it with the unaffected side, but a side-to-side evaluation could be an important tool to assess the pattern of pelvic retraction [5,20,26,27].

However, our study did deal with both the clinical and dynamic factors that are characteristic of patients with hemiplegic cerebral palsy. To our knowledge, this study is the first study to include important clinical factors that are easily assessed in office-based clinics. We found that the severity of ankle and pelvic motion in the sagittal plane and hip motion in the transverse plane were the causes for excessive pelvic retraction and clinical severity based on Winter classification, and that upper extremity asymmetry could also be contributing to pelvic retraction.

V. CONCLUSION

Pelvic retraction during gait in cerebral palsy hemiplegia is not only due to secondary cause as ankle equinus but also affected by other dynamic gait factors as sagittal pelvic motion and transverse hip rotation and clinical factors as Winter classification and upper extremity asymmetry which mean neurologic severity as primary causes. We can consider these static and dynamic factors for the treatment and prognosis.

REFERENCES

1. O'Sullivan R, Walsh M, Jenkinson A, O'Brien T. Factors associated with pelvic retraction during gait in cerebral palsy. Gait Posture 2007;25(3):425-31.
2. Fonseca ST, Holt KG, Fetters L, Saltzman E. Dynamic resources used in ambulation by children with spastic hemiplegic cerebral palsy: relationship to kinematics, energetics, and asymmetries. Phys Ther 2004;84(4): 344-58.
3. DeLuca PA, Davis RB 3rd, Ounpuu S, Sirkin R. Alterations in surgical decision making in patients with cerebral palsy based on three-dimensional gait analysis. J Pediatr Orthop 1997;17(5):608-14.
4. Aktas S, Aiona MD, Orendurff M. Evaluation of rotational gait abnormality in the patients cerebral palsy. J Pediatr Orthop 2000;20(2):217-20.
5. de Morais Filho MC, Kawamura CM, Andrade PH, Dos Santos MB, Pickel MR, Neto RB. Factors associated with pelvic asymmetry in transverse plane during gait in patients with cerebral palsy. J Pediatr Orthop B 2009;18(6):320-4.
6. Kay RM, Rethlefsen S, Reed M, Do KP, Skaggs DL, Wren TA. Changes in pelvic rotation after soft tissue and bony surgery in ambulatory children with cerebral palsy. J Pediatr Orthop 2004;24(3):278-82.
7. Winters TF Jr, Gage JR, Hicks R. Gait patterns in spastic hemiplegia in children and young adults. J Bone Joint Surg Am 1987;69(3):437-41.
8. Carriero A, Zavatsky A, Stebbins J, Theologis T, Shefelbine SJ. Determination of gait patterns in children with spastic diplegic cerebral palsy using principal components. Gait Posture 2009;29(1):71-5.
9. Carriero A, Zavatsky A, Stebbins J, Theologis T, Shefelbine SJ. Correlation between lower limb bone morphology and gait characteristics in children with spastic diplegic cerebral palsy. J Pediatr Orthop 2009;29(1):73-9.
10. Russell SD, Bennett BC, Kerrigan DC, Abel MF. Determinants of gait as applied to children with cerebral palsy. Gait Posture 2007;26(2):295-300.
11. Schutte LM, Narayanan U, Stout JL, Selber P, Gage JR, Schwartz MH. An index for quantifying deviations from normal gait. Gait Posture 2000;11(1):25-31.

12. Saraph V, Zwick EB, Steinwender G, Auner C, Schneider F, Linhart W. Leg lengthening as part of gait improvement surgery in cerebral palsy: an evaluation using gait analysis. Gait Posture 2006;23(1):83-90.
13. Ounpuu S, DeLuca P Davis R, Romness M. Long-term effects of femoral derotation osteotomies: an evaluation using three-dimensional gait analysis. J Pediatr Orthop 2002;22(2):139-45.
14. Gurney B. Leg length discrepancy. Gait Posture 2002;15(2):195-206.
15. Perttunen JR, Anttila E, Sodergard J, Merikanto J, Komi PV. Gait asymmetry in patients with limb length discrepancy. Scand J Med Sci Sports 2004;14(1):49-56.
16. Saraph V, Zwick EB, Zwick G, Dreier M, Steinwender G, Linhart W. Effect of derotation osteotomy of the femur on hip and pelvis rotations in hemiplegic and diplegic children. J Pediatr Orthop B 2002;11(2):159-66.
17. Graham HK, Baker R, Dobson F, Morris ME. Multilevel orthopaedic surgery in group IV spastic hemiplegia. J Bone Joint Surg Br 2005;87(4):548-55.
18. Carty CP, Walsh HP, Gillett JG, Phillips T, Edwards JM, deLacy M, et al. The effect of femoral derotation osteotomy on transverse plane hip and pelvic kinematics in children with cerebral palsy: a systematic review and meta-analysis. Gait Posture 2014;40(3):333-40.
19. Park CI, Park ES, Kim HW, Rha DW. Soft tissue surgery for equinus deformity in spastic hemiplegic cerebral palsy: effects on kinematic and kinetic parameters. Yonsei Med J 2006;47(5):657-66.
20. Brunner R, Dreher T, Romkes J, Frigo C. Effects of plantarflexion on pelvis and lower limb kinematics. Gait Posture 2008;28(1):150-6.
21. Wren TA, Rethlefsen S, Kay RM. Prevalence of specific gait abnormalities in children with cerebral palsy: influence of cerebral palsy subtype, age, and previous surgery. J Pediatr Orthop 2005;25(1):79-83.
22. Hullin MG, Robb JE, Loudon IR. Gait patterns in children with hemiplegic spastic cerebral palsy. J Pediatr Orthop B 1996 ;5(4):247-51.
23. Rodda J, Graham HK. Classification of gait patterns in spastic hemiplegia and spastic diplegia: a basis for a management algorithm. Eur J Neurol 2001;8 Suppl

5:98-108.

24. Riad J, Haglund-Akerlind Y, Miller F. Classification of spastic hemiplegic cerebral palsy in children. J Pediatr Orthop 2007;27(7):758-64.
25. Riad J, Coleman S, Miller F. Arm posturing during walking in children with spastic hemiplegic cerebral palsy. J Pediatr Orthop 2007;27(2):137-41.
26. Bohm H, Stief F, Dussa CU, Doderlein L. Predictors of pelvic retraction in children with cerebral palsy derived from gait pattern and clinical testing. Gait Posture 2012;35(2):250-4.
27. Cimolin V, Galli M, Tenore N, Albertini G, Crivellini M. Gait strategy of uninvolved limb in children with spastic hemiplegia. Eura Medicophys 2007;43(3):303-10.

ABSTRACT(IN KOREAN)

뇌성마비 편마비 환아에서 골반 외회전 보행에 관여하는 임상적 요인 및 동작분석학적 요인 분석

<지도교수 김 현 우>

연세대학교 대학원 의학과

곽 윤 해

일반적인 보행에서 초기 입각기에 발의 진행을 위해 동측의 골반은 약간 내회전을 하는 양상을 보인다. 그 이후에 반대쪽 발의 진행을 위해서 동측의 골반은 외회전을 하게 되는데 이러한 골반의 움직임은 약 5도 정도로 알려져 있어 외관상 뚜렷이 관찰되지 않는다. 그러나 뇌성마비 환아와 같은 병적 보행을 하는 경우에는 신경, 근골격계의 손상에 의해 특정 보행 양상이 증폭되어 관찰되거나 특징적인 보행 소견을 보이게 된다. 그 중 뇌성마비 편마비 환아에서 나타나는 특징적인 골반 외회전 보행은 임상적으로 비교적 흔하게 관찰되나 그 원인이 명확히 밝혀져 있지 않으며 현재까지 보고된 연구에서는 연구 설계상 특정한 동작 분석 인자 혹은 특정 임상 요인에 국한되어 있는 한계가 있다. 이러한 병적 양상의 원인이 초기에는 신경학적 손상에 의한 일차적인 원인에 의한 것으로 생각되어 치료를 통해 교정할 수 없는 병변이라고 생각하였기 때문에 연구가 진행되지 않았으나 이후에 골변형이나 연부조직의 변형에 대한 수술적 치료를 시행하고 골반 수술을 시행하지 않은 경우에도 골반 외회전 보행이 호전되는 임상적인 경험을 함으로써 이러한 보행의 양상이 다른 부위의 변형 혹은 증상에 의한 이차적인 혹은 삼차적인 원인에 의한 특징적 보행 소견으로 생각되어 이후에는 골변형이나 연부조직 변형에 의한 골반 외회전 변형의 발생을 관찰하는 연구들이 시행되었다. 기존의 연구들은 주로 뇌성마비 양하지 마비와 편마비 환아를 구분하지 않고 분석하였고 비교적 적은 환자군을 대상으로 하였으며 특정 치료의 유, 무에 따른 변화를 확인하거나 보행 분석의 결과에 따른 양적 평가만을 시행함으로써 원인적인 평가가 어려운 한계가 있다. 이에

본 연구에서는 뇌성마비 편마비 환아 중 특징적인 골반 외회전 보행을 보이는 환아군과 골반의 움직임이 평균 이내의 보행을 보이는 군으로 구분하여 두 군간에 임상적인 요인과 동적인 동작분석 요인을 비교 분석하고자 하였다.

전체 312명의 뇌성마비 편마비 환자들을 대상으로 하였으며 59명의 환자들이 과거 수술력, 분석 자료의 미비 등의 이유로 제외되었으며 또한 균일한 골반 외회전 양상을 보이지 않는 환자 등 41명의 환자들이 제외되었다. 총 212명의 뇌성마비 편마비 환아 중 첫번째 군은 113명의 환자들로 구성이 되었으며 이는 평균 13.17도, 표준편차 5.75도의 골반 외회전 보행을 보였다. 두번째 군은 99명의 환자들로 구성이 되었으며 골반 보행이 정상 보행 환자의 평균을 넘는 외회전 양상을 보이지 않았으며 평균 0.81도, 표준편차 3.77도의 외회전 양상을 보였다. 두 군간 임상적인 요인과 동작분석학적 요인을 우선 단순 비교 분석하였다.

임상 요인 중 하지 부동, 대퇴 염전 및 경골 염전과 고관절 운동 범위에 통계적으로 의미 있는 차이를 보이지 않았다. 그러나 비복근 및 가자미근의 구축에는 양 군에서 통계적으로 의미 있는 차이를 보였다. 족부 변형의 측정을 위해서 동작 분석 검사 결과뿐만 아니라 족저압 검사 자료와 비디오 촬영 자료를 이용하였으며 뇌성마비 편마비에서 주로 특징적으로 나타나는 상지의 비대칭적인 구축과 보행의 관계를 확인하기 위해 비디오 촬영 자료를 확인하였고 이에 두 가지 임상 요인 모두 통계적으로 의미 있는 차이를 보였다. 한편 뇌성마비 편마비 환자의 분류 기준으로 많이 사용되고 있는 Winter 분류법을 분석에 적용하였는데 이 분류법은 1987년 발표되어 현재까지 많이 사용되고 있고 쉽게 적용할 수 있는 장점이 있으나 많은 환자들이 미분류로 적용되는 한계가 있어 본 연구에서는 변형된 Winter 분류법을 적용하였고 이에 두 군간 통계적으로 의미 있는 차이가 나타났다. 동적 인자로서 보행 분석의 시공간 변수들 중 분속수를 제외한 인자들로서 보행 속도, 활보장 값 등이 양 군간 의미 있는 차이를 보였다. 동작 분석 변수들의 단순 비교 분석에서는 평균 골반 전방 경사, 초기 접지시 평균 골반 회전, 최대 고관절 신전, 최대 슬관절 굴곡, 최대 족근관절 족배굴곡, 초기 접지 시 족근관절 족배굴곡, 평균 족근관절 회전 등의 값이 양 군간 통계적으로 의미

있는 차이를 보였다. 기존의 문헌의 결과를 토대로 27개의 의미 있는 동작 분석 변수를 선정하여 추가적인 다변량 요인 분석을 시행하였다. 이는 동작 분석 결과의 특성 상 같은 관절을 시상면, 관상면 그리고 횡단면의 세가지 측면에서 평가하기 때문에 값들이 서로 영향을 주며 또한 각 관절 간에도 유기적으로 연결되어 있기 때문에 요인으로 묶어 결과에 통계적인 오류를 줄이기 위함이다. 이를 위해 동작 분석 변수를 대상으로 요인 분석을 시행하여 8개의 요인으로 구분하였고 여기에 통계적으로 의미 있는 결과를 보여준 임상 변수를 추가하여 인과 관계를 분석하기 위한 로지스틱 회귀 분석을 시행하였다. 그 결과 족근 관절과 골반의 시상면에서의 움직임과 고관절의 횡단면 움직임, Winter 분류법 그리고 상지의 비대칭적 움직임이 골반의 외회전에 영향을 주는 인자로 나타났다. 따라서 뇌성마비 편마비 환아에서 골반의 외회전 보행은 증가된 족근관절의 첨족 보행 양상의 영향을 받을 뿐만 아니라 시상면 상의 골반의 움직임과 같은 동적인 변수의 영향과 신경 손상 정도를 반영하는 Winter 분류법과 상지의 이환 정도에 따른 비대칭적 움직임과 같은 임상적인 요인의 영향을 받은 것으로 보인다.

뇌성 마비 환자에서 나타나는 병적 보행 중 하나인 골반의 외회전 보행은 양하지 마비 환자보다 편마비 환자에서 더 빈도가 잦은 것으로 알려져 있다. 뇌성마비 편마비 환자는 뇌성마비 양하지 마비 환자에 비하여 보행 능력이 좋으며 대부분의 환자에서 독립 보행이 가능하지만 특징적으로 몸의 환측에만 상지의 변형이 발생하고 하지 부동이 있으며 족부 변형의 양상 등이 다르기 때문에 이러한 요인들이 두 질환군에 차이를 유발할 것으로 사료되어 특징적인 임상 소견을 반영하고자 하였다. 또한 기존의 논문들이 보행 분석 결과의 양적인 평가를 통해 분석을 하였다면 본 연구에서는 양적인 평가뿐만 아니라 이 과정에서 누락될 수 있는 질적인 평가를 위해 각 환자의 보행 분석 영상을 확인하여 분석의 정확도를 높이고자 하였다. 또한 뇌성마비 편마비 환자 중 특정 병변을 갖고 있는 환자만을 대상으로 하는 기존의 연구와 달리 선택 오류를 최소화하기 위하여 수술력이 없는 내원한 모든 편마비 환자를 대상으로 하였고 양하지 마비 환자를 배제함으로써 단일 환자군을 대상으로 하여 결과에 미치는 오류를 줄이고자 하였다. 본 연구에서는 상지의 동작 분석 자료를

통한 평가를 시행하지 않았으며 편마비 환자의 건측의 영향을 고려하지 않은 한계가 있다. 그럼에도 불구하고 본 연구는 뇌성마비 편마비 환자 단일군에서 임상적인 요인과 보행 분석의 동적 요인을 모두 반영하여 회귀 분석 방법으로 원인을 평가하고자 하였으며 그 결과 기존 연구에서 보여진 바와 같이 족근 관절의 시상면 상의 움직임과 고관절의 횡단면상의 움직임의 영향을 받으며 또한 Winter 분류법과 상지 이환 정도의 차이의 영향을 받는 것으로 나타났으며 이러한 연구 결과를 토대로 임상적으로 치료의 결과를 예측하고 반영할 수 있는 의의가 있을 것으로 사료된다.

핵심되는 말 : 골반 외회전, 뇌성마비 편마비, 동작분석