May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

Kinematic Analysis of Hip Retrotorsion during Stair Descent in Adults

Dong-Sik Oh
Dept. of Physical Therapy, Division of Health Science, Hanseo University, Republic of Korea
dongsiko@hanseo.ac.kr

Article Info
Volume 83
Page Number: 7015 - 7025
Publication Issue:
May - June 2020

Article History
***Article Received**: 19 November 2019*
***Revised**: 27 January 2020*
***Accepted**: 24 February 2020*
***Publication**: 18 May 2020*

Abstract:
Background: Gait patterns resulting from femoral torsion can lead to gait disorders or early degenerative arthritis.The purpose of this study was to conduct a kinematic analysis of adults with hip retrotorsion when walking down stairs.Methods: Ten students with hip retrotorsion were selected from 230 healthy men and women, and 30 were selected as the normal group by random sampling, excluding those with hip antetorsion and hip retrotorsion. The Wilcoxon code rank test was used to compare the left and right hip joints of the affected and non-affected sides in both the hip retrotorsion and normal groups.Results: Significant differences were seen in the joints at several studied angles due to varying increases and decreases between the affected and non-affected sides in the hip retrotorsiongroup($p < .05$).However,the hip and ankle-joint ranges of motion and the maximum and minimum angles in the sagittal, frontal, and transverse planes showed no significant differences between the left and right sides of the hip joint in the normal group ($p > .05$).Conclusions: Young adults with hip retrotorsion showed more flexion than extension of the hip joint in the sagittal plane during stair descent. In the frontal and transverse planes, the affected side of the hip retrotorsion group showed lower hip internal rotation and higher hip abduction, ankle eversion than those on the non-affected side.

Keywords: Femur, Gait Analysis, Joint, Kinematic, Retrotorsion

I. INTRODUCTION

Stair walking is a common motion in everyday life and requires more physical load and range of motion in the lower limb joints than walking on flat ground, resulting in higher energy consumption than ordinary walking. Stair descent has also been reported to have a higher fall risk than stair ascent.

The transverse axis of the femoral neck and femoral condyle is tilted forward from the frontal plane by more than 30 degrees at birth, and the angle gradually decreases inwardly until 6 years of age to around 15 degrees in adults, on average. Cases in which the angle of inclination is higher than the normal 15 degrees are called hip antetorsion, and cases in which the angle is reduced to below 8 degrees and tilted backward against the femoral shaft are called hip retrotorsion[4].

Gait patterns resulting from excessive antetorsion or retrotorsion of the femur can lead to gait disorders or early degenerative arthritis, including hip osteoarthritis, hip labral tearing, and patellofemoral pain [5]–[7], and have been reported to affect not only knee stability, but also the waist [8].

Until now, examination of the femoral torsion for hip rotation has been mainly conducted using radiotherapy, but this static evaluation method does not fully reflect the dynamic elements of gait; hence, 3D analysis is now recommended [9], [10]. The walking of normal people is symmetrical, but subtle kinematic or kinetic asymmetry can occur [11]. Studying the functional asymmetry of gait may help to explain gait disorder in neurologically impaired patients or in normal people at risk of falling [12], and gait analysis to assess normal gait function may be critical in clinical or rehabilitation processes [13].

Thus, even though many studies of femoral torsion and kinetic studies of stair walking have been conducted, kinematic walking research into hip retrotorsion is insufficient [14]. This study therefore aims to analyze the kinematic factors of hip joints during stair descent in young adults with hip retrotorsion, to help prevent future disease and to gather basic data on walking.

II. Materials and Methods

1) SUBJECTS

A total of 230 healthy men and women attending H University in Chungcheongnam-do were surveyed, and cross-sectional research was conducted on 10 students with hip retrotorsion. A total of 30 men and women were randomly sampled as the normal group, excluding those who had hip antetorsion or hip retrotorsion. The subjects of the study were told the purpose, process, and evaluation methods of this study and voluntarily agreed to participate.

The exclusion criteria were experience of surgery in the lower extremities; difficulty in walking due to pain; congenital malformations; visual, auditory, or neurological disorders; a body mass index (BMI) of 23 or higher in the lower body; a 0.5 cm or greater difference in the lengths of the legs; and scoliosis, knee varus, or valgus.

2) MEASURING TOOLSAND EQUIPMENT

i. HIP-JOINT RANGE OF MOTION: The range of motion of the hip joint was measured using a Level Angle Finder (Kraft, USA).

ii. GAIT ANALYSIS: The rotational motion of the hip joint was measured using a NoraxonMyoMotion (Scottsdale, AZ, USA) three-dimensional motion analyzer.

3) EXPERIMENTAL METHODS

All subjects flexed their knees 90 degrees, with the pelvis fixed in the supine position, and their hip-joint range of motion was measured using Craig's Test [4]. After the test, only the subjects with hip retrotorsion were selected, and they performed a stair descent. All subjects were instructed to wear comfortable trousers and sneakers, but not slippers. After the sensor was attached while subjects wore the clothes and shoes they had selected for the experiment, they were instructed to use their usual, natural stair-walking motion and were provided an adaptation period of one descent and ascent of 10 stairs. The pelvic sensor was attached above the sacrum, and the femoral sensor was attached to a site above the patella and a quarter below the quadriceps, where the sensor does not change in position due to the contraction of muscles during walking. The subjects were analyzed using a 3D motion analyzer for the motion pattern of the hip joint at the early stage of the stance phase, when the right foot touches the ground, and during stair descent from the first step to the last step. The height and width of each step were 8cm and 190cm, respectively; the total length of the stairs was 300cm, and the slope was 35 degrees.

4) ANALYSIS METHOD

All data were analyzed using SPSS version 12.0 (SPSS Inc., Chicago, IL, USA). The Wilcoxon code rank test was used to compare the left and right hip joints of the affected and non-affected sides in both the hip retrotorsion and the normal groups. The statistical significance level was set to $\alpha=0.05$.

Fig. 1 Hip retrotorsion

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

Fig.2 Sensor attachment

III. RESULTS

1) A Comparison of the Range of Motion and the maximum And Minimum Hip-Joint Angles in The Sagittal, Frontal, and Transverse Planes Between the Affected And Non-Affected Sides in The Hip Retrotorsion Group Found the Following

The joint ranges of motion in the transverse plane showed a significant difference because the range of motion of the affected side decreased more than it did on the non-affected side ($p < .05$) (Table 2).The maximum hip-joint angles in the frontal plane showed a significant difference because the abduction on the affected side increased more than it did on the non-affected side ($p < .05$) (Table 3). The minimum hip-joint angles in the frontal plane showed a significant difference because the adduction on the affected side decreased more than it did on the non-affected side ($p < .05$). The minimum hip-joint angles in the transverse plane showed a significant difference because the internal rotation on the affected side decreased more than it did on the non-affected side ($p < .05$) (Table 4).

2) A Comparison of The Range of Motion And the Maximum and Minimum Knee-Joint Angles in the Sagittal Plane Between the Affected and Non-Affected Sides in the Hip Retrotorsion Group Found the Following

The knee-joint ranges of motion and the maximum and minimum angles in the sagittal plane showed no significant differences between the two sides ($p > .05$) (Table 5).

3) A Comparison of the Range of Motion and the Maximum and Minimum Ankle-Joint Angles in the Sagittal, Frontal, and Transverse Planes Between the Affected and Non-Affected Sides in the Hip Retrotorsion Group Found the Following

The ankle-joint ranges of motion and maximum angles in the sagittal, frontal, and transverse planes showed no significant differences between the two sides ($p > .05$) (Tables 6 and 7). The minimum ankle-joint angles in the frontal plane showed a significant difference because the eversion on the affected side increased more than it did on the non-affected side ($p < .05$) (Table 8).

4) A Comparison of the Range of Motion and the Maximum and Minimum Hip and Ankle-Joint Angles in the Sagittal, Frontal, and Transverse Planes Between the Left And Right Sides of the Hip Joint in the Normal Group Found the Following

The hip and ankle-joint ranges of motion and the maximum and minimum angles in the sagittal, frontal, and transverse planes showed no significant differences between the two sides ($p > .05$) (Tables 2–8).

5) A Comparison of the Range of Motion and the Maximum and Minimum Knee-Joint Angles in The Sagittal Plane Between the Left and Right Sides of the Knee Joint in the Normal Group Found the Following

The knee-joint ranges of motion and the maximum and minimum angles in the sagittal plane showed no significant differences between the two sides ($p > .05$) (Table 5).

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

Table 1. General characteristics of the subjects

Variables	Normal (n=30)	Retrotorsion (n=10)
Age (year)	23.93±1.51[a]	22.60±1.52
Sex(Male/Female)	12/18	7/3
Side(left/right)	0/30	6/4
BMI(kg/m^2)	20.83±0.76	20.95±1.02
Leg length discrepancy	83.91±3.47	83.7±4.05
External Hip Rotation(°)	43.13±5.71	64.25±5.37
Internal Hip Rotation(°)	32.52±6.45	16.75±2.06

[a] Mean ± Standard deviation
BMI: Body Mass Index

Table 2. Comparison of the range of motion of the hip-joint angles inthe sagittal, frontal,and transverse planes

		Range of motion		p
		Affect/Lt	Non-affect/Rt	
Sagittal Plane (Fl/Ex)	Retrotorsion	24.22±5.06 [a]	25.49±2.24	0.57
	Normal	27.98±5.45	29.47±4.79	0.20
Frontal Plane (Ab/Ad)	Retrotorsion	15.87±6.48	15.91±6.19	0.87
	Normal	17.00±4.43	15.55±4.31	0.09
Transverse Plane (In R/Ex R)	Retrotorsion	11.55±7.77	15.38±8.25	0.03*
	Normal	21.55±6.68	20.29±5.11	0.41

[a] Mean ± Standard deviation
Fl:Flexion,Ex:Extension,Ab:Abduction,Ad:Abduction,InR:InternalRotation,
ExR:ExternalRotation
* $p<.05$

Table 3. Comparison of themaximum hip-jointangles in the sagittal, frontal, andtransverse planes

		Maximum Angle		p
		Affect/Lt	Non-affect/Rt	
Sagittal Plane (Fl/Ex)	Retrotorsion	36.02±4.40[a]	36.40±4.34	0.87
	Normal	35.38±10.11	37.35±7.60	0.11
Frontal Plane (Ab/Ad)	Retrotorsion	11.02±6.88	8.27±6.05	0.04*
	Normal	4.54±2.69	4.86±3.60	0.60
Transverse Plane (In R/Ex R)	Retrotorsion	15.11±7.04	13.84±4.82	0.07
	Normal	16.10±10.60	17.75±8.36	0.94

[a] Mean ± Standard deviation
Fl:Flexion,Ex:Extension,Ab:Abduction,Ad:Abduction,InR:InternalRotation,
ExR:ExternalRotation
* $p<.05$

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

Table 4. Comparison of the minimum hip-joint angles in the sagittal, frontal, and transverse planes

		Minimum Angle		p
		Affect/Lt	Non-affect/Rt	
Sagittal Plane (Fl/Ex)	Retrotorsion	11.80±4.76[a]	10.91±3.88	0.57
	Normal	7.40±7.92	7.87±6.46	0.52
Frontal Plane (Ab/Ad)	Retrotorsion	-4.85±2.10	-7.64±2.06	0.01*
	Normal	-12.46±4.43	-10.69±3.56	0.14
Transverse Plane (In R/Ex R)	Retrotorsion	3.56±8.41	-1.54±7.30	0.00*
	Normal	-5.45±6.02	-2.54±7.73	0.41

[a] Mean ± Standard deviation
Fl:Flexion, Ex: Extension, Ab: Abduction, Ad: Abduction, In R: Internal Rotation,
Ex R: External Rotation
* p<.05

Table 5. Comparison of therange of motion, maximum,andminimumKnee-jointangles in theSagittal Plane

		Sagittal Plane(Fl/Ex)		p
		Affect/Lt	Non-affect/Rt	
Range of Motion	Retrotorsion	90.51±7.92 [a]	92.25±8.56	0.44
	Normal	88.29±5.31	92.42±10.08	0.06
Maximum	Retrotorsion	98.71±11.88	98.83±11.35	0.87
	Normal	98.59±7.80	100.94±11.56	0.07
Minimum	Retrotorsion	8.19±7.70	6.57±6.96	0.57
	Normal	10.29±6.66	8.52±5.80	0.21

[a] Mean ± Standard deviation
Fl:Flexion, Ex: Extension

Table 6. Comparison of the range of motion of the ankle-joint angles in the sagittal, frontal,and transverse planes

		Range of motion		p
		Affect/Lt	Non-affect/Rt	
Sagittal Plane (PF/DF)	Retrotorsion	80.41±23.58[a]	76.93±24.36	0.09
	Normal	71.05±5.81	70.73±7.38	0.65
Frontal Plane (In/E)	Retrotorsion	29.01±9.76	26.43±6.09	0.33
	Normal	23.78±7.62	21.96±5.85	0.06
Transverse Plane (Ab/Ad)	Retrotorsion	22.21±10.29	21.79±7.94	0.87
	Normal	19.16±3.28	19.11±4.96	0.35

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

[a] Mean ± Standard deviation

PF:Plantar Flexion, DF: DorsiFlexion, In: Inversion, E: Eversion,Ab: Abduction,
Ad: Abduction

Table 7. Comparison of the maximum ankle-joint angles in the sagittal, frontal, and transverse planes

		Maximum Angle		p
		Affect/Lt	Non-affect/Rt	
Sagittal Plane(PF/DF)	Retrotorsion	25.57±13.65[a]	20.80±16.24	0.06
	Normal	19.63±5.87	17.69±6.90	0.10
Frontal Plane (In/E)	Retrotorsion	17.03±7.22	18.34±6.10	0.64
	Normal	16.69±6.00	14.86±5.24	0.13
Transverse Plane (Ab/Ad)	Retrotorsion	7.02±6.29	8.69±8.54	0.57
	Normal	7.63±4.60	9.41±6.80	0.55

[a] Mean ± Standard deviation
PF: Plantar Flexion, DF: DorsiFlexion, In: Inversion, E: Eversion, Ab: Abduction,
Ad: Abduction

Table 8. Comparison of the minimum ankle-joint angles in the sagittal, frontal, and transverse planes

		Minimum Angle		p
		Affect/Lt	Non-affect/Rt	
Sagittal Plane (PF/DF)	Retrotorsion	-34.83±11.52 [a]	-36.12±9.70	0.50
	Normal	-31.42±4.81	-33.04±6.29	0.16
Frontal Plane (In/E)	Retrotorsion	-11.97±11.52	-8.09±7.56	0.04*
	Normal	-7.09±4.81	-8.19±4.65	0.29
Transverse Plane (Ab/Ad)	Retrotorsion	-15.18±9.78	-13.09±12.38	0.50
	Normal	-11.52±5.09	-9.70±5.21	0.16

[a] Mean ± Standard deviation.
PF: Plantar Flexion, DF: DorsiFlexion, In: Inversion, E: Eversion, Ab: Abduction,
Ad: Abduction
* $p<.05$

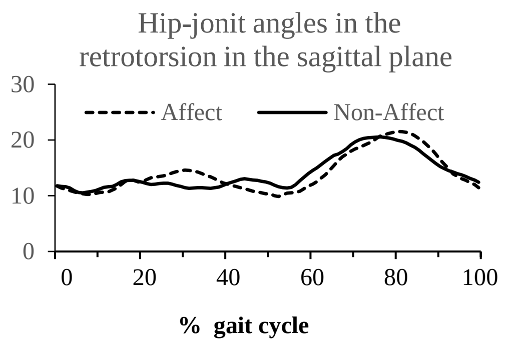

Fig. 3 Hip-joint angles in the sagittal plane [flexion(+) and extension(-)] in the hip retrotorsion group during stair

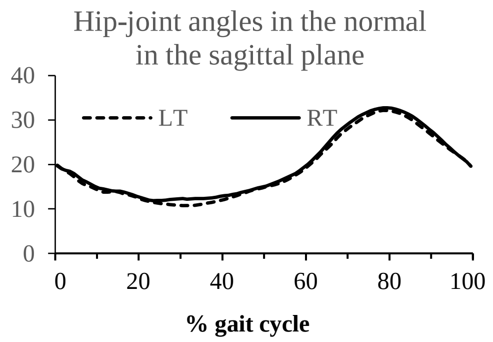

Fig. 4Hip-joint angles in the sagittal plane [flexion(+) and extension(-)] in the normal group during stair descent

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

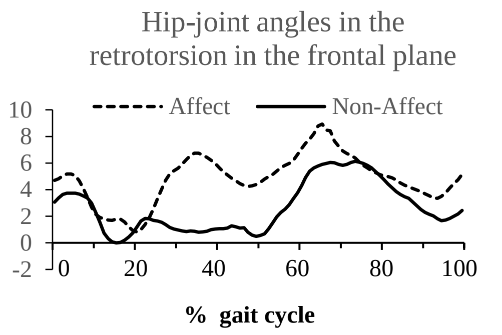

Fig. 5Hip-joint angles in the frontal plane [abduction(+) and adduction(-)]in the hip retrotorsion group during stair

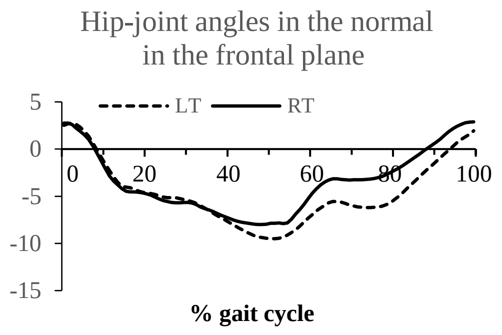

Fig. 6 Hip-joint angles in the frontal plane [abduction(+) and adduction(-)]in the normal group during stair descent

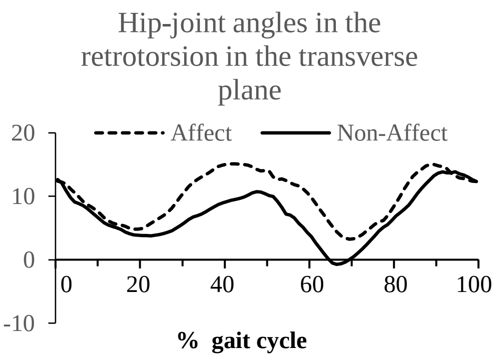

Fig. 7Hip-joint angles in the transverse plane [external rotation(+) and internal rotation(-)] in the hip retrotorsion group during stair descent

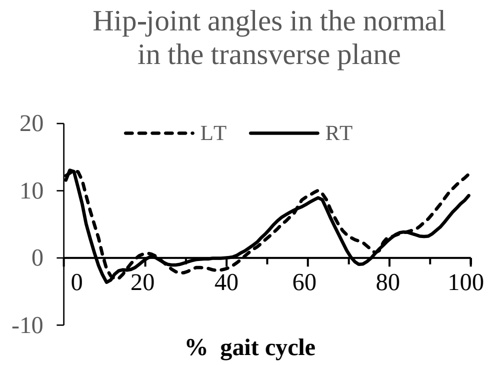

Fig. 8Hip-joint angles in the transverse plane [external rotation(+) and internal rotation(-)] in the normal group during stair descent

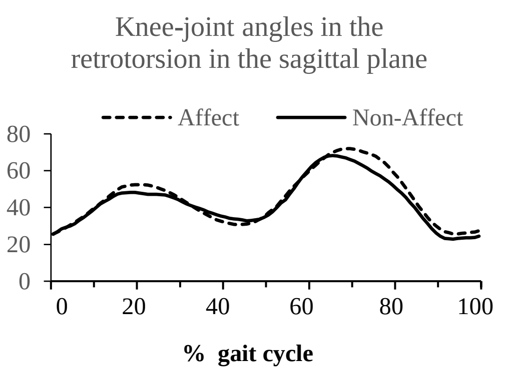

Fig.9 Knee-joint angles in the sagittal plane [flexion(+)andextension(-)]in the hip retrotorsion group during stair descent

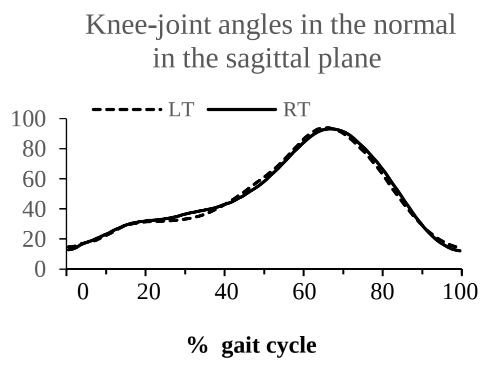

Fig.10 Knee-joint angles in the sagittal plane [flexion(+) and extension(-)] in the normal group during stair descent

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

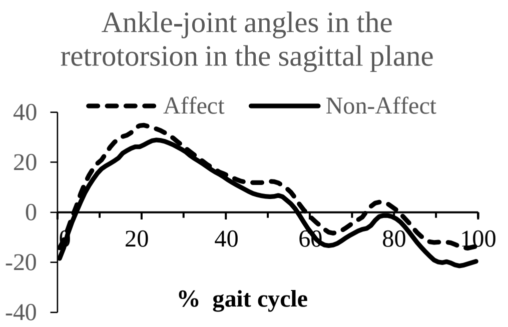

Fig. 11 Ankle-joint angles in the sagittal plane [dorsiflexion(+) and plantar flexion(-)] in the hip retrotorsion group during stair descent

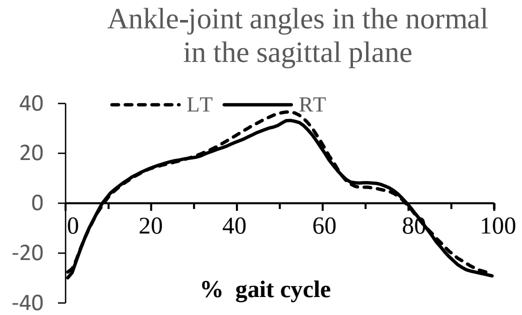

Fig. 12 Ankle-joint angles in the sagittal plane [dorsiflexion(+) and plantar flexion(-)] in the normal group during stair descent

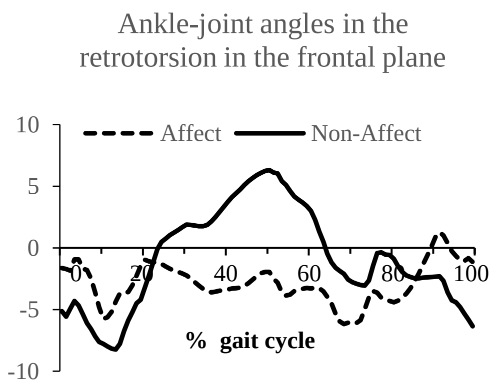

Fig. 13 Ankle-joint angles in the frontal plane [inversion(+) and eversion(-)] in the hip retrotorsion group during stair descent

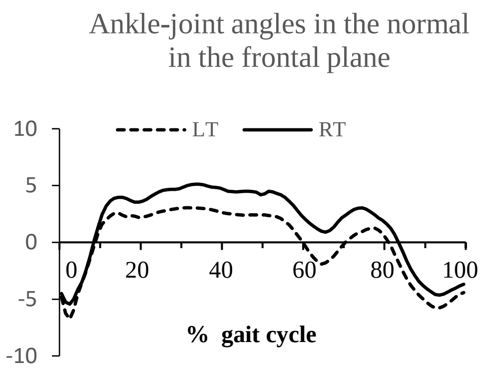

Fig. 14 Ankle-joint angles in the frontal plane [inversion(+) and eversion(-)] in the normal group during stair descent

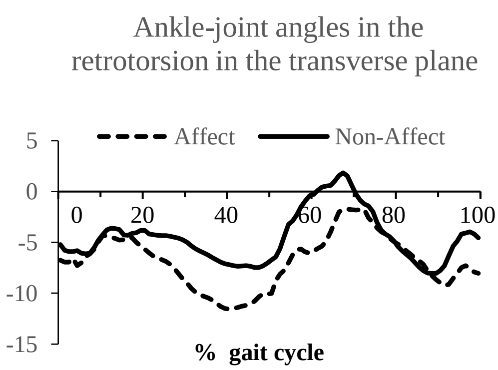

Fig. 15 Ankle-joint angles in the transverse plane[abduction(+) and adduction(-)] in the hip retrotorsion group during stair descent

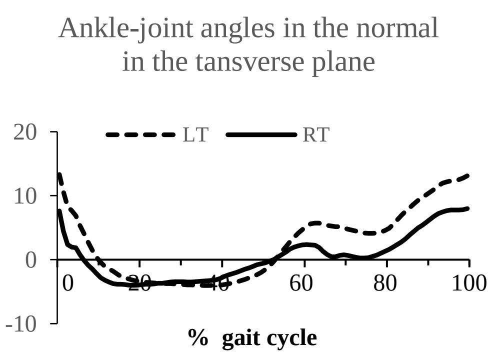

Fig. 16 Ankle-joint angles in the transverse plane[abduction(+) and adduction(-)] in the normal group during stair descent

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 7015 - 7025

IV. Discussion

This study investigated the motion pattern of the hip joint during stair descent in young adults with hip retrotorsion. Kwon et al. [15] reported that hip motion on flat ground occurs mainly in the sagittal plane, and that the greatest flexion occurs at the beginning of the stance phase and at complete extension during the rest of the stance phase. Furthermore, in the frontal and transverse planes, the width of motion is small and the femur and pelvis rotate simultaneously. However, according to Kim et al. [16], unlike walking on flat ground, the hip joint is more flexed on both the left and right sides than in the sagittal plane during the entire stance phase. Protopapadaki et al. [17] reported that the hip and knee joints flex in the sagittal plane during the entire stance phase during stair descent in young adults, which is consistent with the results of this study. The hip-joint maximum and minimum angles in the sagittal plane did not differ between the affected and non-affected sides of the hip retrotorsion group nor between the left and right sides of the normal group. However, the minimum and maximum angles of the hip joints were flexed during the stair descents of both the hip retrotorsion group and the normal group, suggesting that they flexed the hip joints rather than extending them during their gait.

Per the results of this study, the maximum hip-joint angle in the frontal plane of the hip retrotorsion group increased abduction more on the affected side than it did on the non-affected side during the stance phase, and the minimum hip-joint angle decreased adduction more on the affected side than it did on the non-affected side during the stance phase. However, there was no difference in the angle between the left and right sides in the frontal plane of the normal group, and both sides showed mostly adduction during the entire gait cycle.

Bruderer-Hofstetter et al. [10] reported that hip adduction moment increased during walking on flat ground in a hip antetorsion group but that further research would be required to determine whether adduction is increased by hip antetorsion or whether abduction is increased by hip retrotorsion. The minimum ankle-joint angle in the frontal plane of the hip retrotorsion group increased eversion more on the affected side than it did on the non-affected side during the stance phase, and the affected side also showed mainly eversion compared to the non-affected side’s inversion during the entire gait cycle.

In the transverse plane, there is a slight anatomical external rotation of the hip joint, but internal rotation occurs during the stair descent motion, and most of the internal rotations occur during the stance phase [15], [16]. However, the hip retrotorsion group showed a difference from the normal group in this study. The minimum hip-joint angle in the transverse plane of the hip retrotorsion group had greater increased external rotation on the affected side than it did on the non-affected side during the swing phase,and thehip-joint ranges of motion decreased more on the affected side than they did on the non-affected side.The normal and hip retrotorsion groups showed clearly different walking patterns during the entire gait cycle. In the normal group, the hip internal rotation increased in the left and right sides during the initial stance phase, but in the hip retrotorsion group, external, rather than internal, rotation occurred. These results are consistent with previous studies that found that external rotation increased due to the restriction of internal rotation on the affected side of the hip retrotorsion group compared to the normal group [18], [19]. However, during the swing phase, the normal and hip retrotorsion groups showed similar walking patterns on both sides, and the hip retrotorsion group walked with more hip internal rotation of the non-affected side than the affected side.

As discussed above, the normal and hip retrotorsion groups showed different walking patterns; the rotation pattern of the hip joint should therefore be examined and evaluated carefully, because it can seriously damage the function of the musculoskeletal system by causing hip and knee deviations as well as waist deviations.

The limitations of this study are as follows:

It is difficult to generalize the results of this study because of the small number of subjects with hip retrotorsion. Results may also vary depending on the data collection methods and differences in the subjects, staircases, and motion analysis devices. Furthermore, there may be differences in the strides and walking methods of Asians and Westerners [20]–[22]. Therefore, to compensate for these limitations, follow-up studies should conduct kinematic and kinetic analyses of various joints for subjects with hip antetorsion as well as those with hip retrotorsion.

V. Conclusion

Young adults with hip retrotorsion showed more flexion than extension of the hip joint in the sagittal plane during stair descent. In the frontal and transverse planes, the affected side of the hip retrotorsion group showed lower hip internal rotation and higher hip abduction and ankle eversion than did those on the non-affected side. The findings of this study are expected to be used as basic data for the prevention of musculoskeletal diseases that can be caused by femoral torsion in daily life as well as for research on walking.

I. References

[1] Bennett, Hunter J., Zhang, Songning., Shen, Guangping., Weinhandl, Joshua T., Paquette, Max R., Reinbolt, Jeffrey and Coe, Dawn P. "Effects of Toe-in and Wider Step Width in Stair Ascent with Different Knee Alignments." Med Sci Sports Exerc 49.3 (2017): 563-572.

[2] Startzell, J. K., Owens, D. A., Mulfinger, L. M. and Cavanagh, P. R. "Stair Negotiation in Older People: A Review." J Am Geriatr Soc 48.5 (2000): 567-580.

[3] Singhal, Kunal., Kim, Jemin., Casebolt, Jeffrey., Lee, Sangwoo., Han, Ki Hoon and Kwon, Young-Hoo. "Kinetic Comparison of Older Men and Women during Walk-to-Stair Descent Transition." Gait Posture 40.4 (2014): 600-604.

[4] Souza, Richard B. and Powers, Christopher M. "Concurrent Criterion-Related Validity and Reliability of a Clinical Test to Measure Femoral Anteversion." J Orthop Sports Phys Ther 39.8 (2009): 586-592.

[5] Tönnis, D. and Heinecke, A. "Acetabular and Femoral Anteversion: Relationship with Osteoarthritis of the Hip." J Bone Joint Surg Am 81.12 (1999): 1747-1770.

[6] Worlicek, Michael C., Wörner, Michael L., Craiovan, Benjamin S., Zeman, Florian., Grifka, Joachim., Renkawitz, Tobias F. and Weber, Markus. "Lesser Trochanter Size on Plain Anteroposterior Radiographs Correlates with Native Femoral Anteversion." The Journal of Arthroplasty (2017):

[7] Bell-Jenje, T., Olivier, B., Wood, W., Rogers, S., Green, A. and McKinon, W. "The Association between Loss of Ankle Dorsiflexion Range of Movement, and Hip Adduction and Internal Rotation during a Step Down Test." Man Ther 21. (2016): 256-261.

[8] Cibulka, Michael T., Strube, Michael J., Meier, Damon., Selsor, Michelle., Wheatley, Christopher., Wilson, Nathan G. and Irrgang, James J. "Symmetrical and Asymmetrical Hip Rotation and its Relationship to Hip Rotator Muscle Strength." Clin Biomech 25.1 (2010): 56-62.

[9] Radler, Christof., Kranzl, Andreas., Manner, Hans Michael., Höglinger, Michaela., Ganger, Rudolf and Grill, Franz. "Torsional Profile Versus Gait Analysis: Consistency between the Anatomic Torsion and the Resulting Gait Pattern in Patients with Rotational Malalignment of the Lower Extremity." Gait Posture 32.3 (2010): 405-410.

[10] Bruderer-Hofstetter, Marina., Fenner, Verena., Payne, Erika., Zdenek, Katja., Klima, Harry and Wegener, Regina. "Gait Deviations and Compensations in Pediatric Patients with Increased Femoral Torsion." J Orthop Res 33.2 (2015): 155-162.

[11] Shorter, K. Alex., Polk, John D., Rosengren, Karl S. and Hsiao-Wecksler, Elizabeth T. "A New Approach to Detecting Asymmetries in Gait." Clin Biomech 23.4 (2008): 459-467.

[12] Polk, John D., Stumpf, Rebecca M. and Rosengren, Karl S. "Limb Dominance, Foot Orientation and Functional Asymmetry during Walking Gait." Gait Posture 52. (2017): 140-146.

[13] Worsley, Peter R., Whatling, Gemma., Barrett, David., Holt, Cathy., Stokes, Maria and Taylor, Mark. "Assessing Changes in Subjective and Objective Function from Pre-to Post-Knee Arthroplasty using the Cardiff Dempster-Shafer Theory Classifier." Comput Methods Biomech Biomed Engin 19.4 (2016): 418-427.

[14] Oh, DongSik. "Gait Analysis in Adult People with Hip Retrotorsion." Asia-pacific Society of Convergent Research Interchange, Daejeon, Republic of Korea, 2November 2019.Vol. 6, No.2, International Journal of IT-based Public Health Management,2019,pp. 27-34. http://dx.doi.org/10.21742/ijiphm.

[15] Kwon, O. W., Won, J. H., Oh, J. S., Lee, L. W. and Kim, S. J. "Effects of the Hip Internal Rotation Gait on Gluteal and Erector Spinae Muscle Activity." Phys Ther Korea 13.1 (2006): 24-31.

[16] Kim, Y. S., Kim, E. J. and Seo, C. J. "The Comparative Analysis of EMG and Gait Patterns of Lower Extremities

during Going Up Stairs and Down." Kor J Phys Edu 45. (2006): 535-545.

[17] Protopapadaki, Anastasia., Drechsler, Wendy I., Cramp, Mary C., Coutts, Fiona J. and Scott, Oona M. "Hip, Knee, Ankle Kinematics and Kinetics during Stair Ascent and Descent in Healthy Young Individuals." Clin Biomech 22.2 (2007): 203-210.

[18] Uding, Alexandria., Bloom, Nancy J., Commean, Paul K., Hillen, Travis J., Patterson, Jacqueline D., Clohisy, John C. and Harris-Hayes, Marcie. "Clinical Tests to Determine Femoral Version Category in People with Chronic Hip Joint Pain and Asymptomatic Controls." Musculoskelet Sci Pract 39. (2019): 115-122.

[19] Accadbled, Franck and Cahuzac, Jean-Philippe. "["In-Toeing and Out-Toeing"]." Rev Prat 56.2 (2006): 165-171.

[20] Samuel, Dinesh., Rowe, Philip., Hood, Victoria and Nicol, Alexander. "The Biomechanical Functional Demand Placed on Knee and Hip Muscles of Older Adults during Stair Ascent and Descent." Gait posture 34.2 (2011): 239-244.

[21] Mian, Omar S., Thom, Jeanette M., Narici, Marco V. and Baltzopoulos, Vasilios. "Kinematics of Stair Descent in Young and Older Adults and the Impact of Exercise Training." Gait posture 25.1 (2007): 9-17.

[22] Ryu, Taebeum., Soon Choi, Hwa., Choi, Hoonwoo and Chung, Min K. "A Comparison of Gait Characteristics between Korean and Western People for Establishing Korean Gait Reference Data." Int J Ind Ergon 36.12 (2006): 1023-1030.