

## The Effect of Femoral Anteversion on Composite Hip and Thigh Muscle EMG Amplitude Ratio During Stair Ascent

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### Abstract

The purpose of this study was to compare the differences of hip and thigh muscle activities between subjects with increased and decreased femoral anteversion during stair ascent. Twelve healthy female volunteers participated in this study. The subjects were divided into two groups (group 1 with increased anteversion of the hip, group 2 with decreased anteversion of the hip). This study analyzed differences in each mean peak gluteus maximus (GM), gluteus medius (GD) and tensor fascia lata (TFL) EMG amplitude: composite mean peak hip muscles (GM, GD, TFL) EMG amplitude ratios and in each mean peak vastus medialis oblique (VMO), vastus lateralis (VL), biceps femoris (HM) and semitendinosus (HL) EMG amplitude: composite thigh muscles (VMO, VL, HM, HL) EMG amplitude ratios among subjects with decreased or increased relative femoral anteversion. EMG ratios were compared in the stance and swing phase of stair ascent. Group 1 showed an increased standardized mean GM and GD EMG amplitude and decreased standardized mean TFL to composite mean hip muscles EMG amplitude ratios in stair ascent during both stance and swing phase. Also, group 1 showed an increased standardized mean HL EMG amplitude and decreased standardized mean VL and HM to composite mean thigh muscles EMG amplitude ratios in stair ascent during both stance and swing phases. There was no statistically significant difference in vastus medialis oblique between subjects with increased or decreased relative femoral anteversion. In order to provide rehabilitation professionals with a clearer picture of the specific requirements of the stair climbing task, further research must be expanded to include a wider range of age groups that represent the general public, such as including middle-aged healthy persons.

**Key Words:** Femoral anteversion; Hip and thigh; Stair ascent.

### Introduction

The ability to climb stairs with relative ease is important to one's quality of life (Heller et al, 2001). Stairs are frequently encountered during the course of daily activities. To enhance gait

rehabilitation and aid in the design of optimal work in public environments at which stairs are often used, a better understanding of the biomechanics of normal stair ascent and descent is necessary. As well, the addition of data base on yet another mode of walking will provide val-

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uable aid to our total understanding of the diverse and complicated processes involved within human locomotion (McFadyen and Winter, 1988). Stair climbing is of a particular interest because stairs are frequently encountered obstacles in daily living, and require greater knee moments and ranges of motion than those required in level walking (Andriacchi et al., 1982). Stair climbing increases mean cycle duration and decreases stance time than level walking and shows different patterns between stair and level walking (knee flexor/extensor, hip abductors and ankle dorsiflexor during swing phase) (Nadeau et al., 2003). The most striking difference between stair ascent and level walking was that the peak patellofemoral contact force was 8 times higher during stair ascent (Costigan et al., 2002). Individuals with patellofemoral pain (PFP) reduce the amount of the knee flexion used during stair ascent and descent (Crossley et al., 2004). PFP demonstrated lower peak knee extensor moments during stair ambulation (Salsich et al., 2001). Abduction-adduction moments at the knee cannot be ignored when trying to understand the demands placed on the knee during stair climbing (Kowalk et al., 1996). The hip and knee posterior-anterior shear forces and the knee flexion moment were higher during stair climbing than during level walking (Costigan et al., 2002)

In normal stair ascent and descent, the greatest variability was seen at the hip, while stereotypic kinematic patterns were emerged at the ankle and knee for all subjects across the 24 trials. Stair climbing is more critical than walking in pre-clinical assessment of primary stability in cementless total hip arthroplasty (THA) in vitro (Kassi et al., 2004). Femoral anteversion may lead to an increased risk of THA implant loosening (Kleemann et al., 2003). Femoral anteversion is a parameter that the surgeon is able to determine anteversion angle during total hip arthroplasty. Thus, the outcome of anteversion af-

ter surgery may lead to increased loading, which would be most prominent during repetitive daily activities, such as walking and stair climbing, and therefore trigger implant loosening.

Femoral anteversion influences vastus medialis (-27%) and gluteus medius (-34%) electromyography amplitude in isometric hip external rotation (Nyland et al., 2004). Increasing the anteversion to an angle 30 leads to hip contact forces and bending moments up to 28% (Heller et al., 2001). The anteversion is considered a possible factors for the onset of joint degeneration (Halpern et al., 1979; Reikeras et al., 1982). Ruwe et al. (1992) described a femoral anteversion measurement method with subjects positioned in prone with the test side knee flexed 90°. In this position, the passive medial hip rotation angle at the point of maximum greater trochanter prominence was measured using a handheld goniometer. Ruwe et al. (1992) reported stronger correlations between this method of femoral anteversion measurement and intra-operative measurements taken with surgical pins placed in the femoral neck center than with two differing radiographic methods. Kozic et al. (1997), using a similar method but without greater trochanter palpation, reported a good correlation between medial femoral rotation and femoral anteversion ( $r=.80$ ). Femoral anteversion is the primary contributor to medial hip rotation displacement of non-impaired subjects when they are measured in a prone position. Femoral anteversion is known to have a direct influence on patellar alignment or tracking. Both clinical evaluations and biomechanical testing have confirmed that increased patellofemoral contact pressure occurs with increased femoral anteversion. Excessive in-toeing or out-toeing has been shown to relate with many different compensatory problems of the lower extremity, including tibial torsion, genu valgum, pes planus, pes equinus, and metatarsus varus.

Yet, the analysis which compares to differences of hip and thigh muscles EMG activities according to the level of femoral anteversion during stair ascent has not been studied. Thus, the goal of the present study was to compare the differences of hip and thigh muscle activities between subjects with increased and decreased femoral anteversion during stair ascent.

## Methods

### Subjects

Twelve non-impaired female college student (mean age=20.2 years, SD=1.0, mean height=160.3 cm, SD=2.6, mean weight=52.9 kg, SD=2.7) volunteers participated in this study. All subjects had no history of low back, or lower extremity injury. The age, height, weight and anteversion angle characteristics of the subjects are summarized in Table 1.

**Table 1.** Age, height, weight and anteversion angle characteristics of the subjects

Variable	group 1 (n1=5)	group 2 (n2=7)
Age (yrs)	20.2±1.6 <sup>a</sup>	20.1±.4
Height (cm)	159.4±2.7	160.8±2.6
Weight (kg)	51.2±2.9	54.1±1.7
Anteversion angle (°)	67.0±6.7	32.8±2.2

<sup>a</sup>Mean±SD

### Instruments

The experimental staircase was consisted of three steps constructed from two box modules, and one rectangular module was used as the top platform. The step dimensions were 16 (riser) × 30 cm (tread). The handheld goniometer was used to measure the range of passive medial hip rotation motion in prone position. The muscle activity was recored by electromyography<sup>1)</sup> and low-impedance bipolar silver/silver chloride adhe-

sive surface EMG electrodes<sup>2)</sup>. Foot switches were placed on the heel to determine the beginning and ending of stance phase.

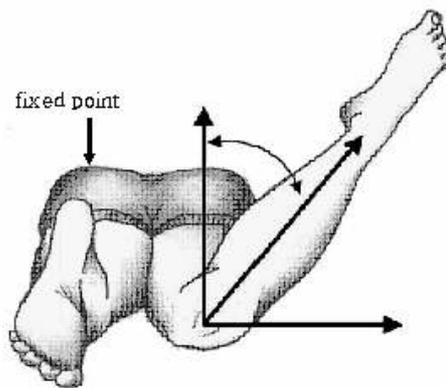
### Test Procedures

All subjects were warmed up for 3 minutes using squatting to standing. The warm-up was performed to increase subject comfort during stair ascent. Following warm-up, passive medial hip rotation of the lower extremity that subjects preferred to use when performing a single leg hop was measured with a handheld goniometer using the method described by Kozic et al. (1997) with subjects positioned prone on a plinth. The moving arm of the goniometer was aligned with the tibial shaft, and the stationary arm was aligned with the top of the plinth. Femoral anteversion was estimated from the angle formed between vertical and maximal passive medial hip rotation (Figure 1). We chose to use the non-palpation method of medial hip rotation measurement to eliminate the subjectivity of attempting to determine the medial hip rotation angle of exact greater trochanter prominence.

Following skin preparation with rubbing alcohol swabbing, the test lower extremity was instrumented with low-impedance bipolar silver/silver chloride adhesive surface EMG electrodes. Electrodes were placed over gluteus maximus (GX, 35% from the second sacral vertebra to the greater trochanter, starting the second sacral vertebra), gluteus medius (GD, 35% from the iliac crest to the greater trochanter, starting from the greater trochanter), tensor fascia lata (TFL, 75 mm from the anterior superior iliac spine, along a line oriented of 30° with respect to the line joining the anterior superior iliac spine and the greater trochanter), vastus medialis oblique (VMO, 50 mm from the superior medial side of the patella along a line medially oriented at an angle of 50° with

<sup>1)</sup> EMG MP100WSW, BIOPAC System Inc., CA., U.S.A.

<sup>2)</sup> Myotronics-Noromed, INC, USA.



**Figure 1.** Femoral anteversion estimation method

respect to the anterior superior iliac spine), vastus lateralis (VL, 95 mm along a line from the superior lateral side of the patella to the anterior superior iliac spine, starting from the patella), biceps femoris (HM, 35% from the ischial tuberosity to the lateral side of popliteus cavity, starting from the ischial tuberosity) and semitendinosus muscles (HL, 35% from the ischial tuberosity to the medial side of the popliteus cavity, starting from the ischial tuberosity) (Rainoldi et al., 2004). Electrodes were aligned parallel to the known muscle fiber orientations at each site. A ground electrode was placed over the anterior superior iliac spine of the opposite lower extremity.

Electromyographic data were sampled at 1000 Hz using a MP100WSW and a notebook computer. The following EMG signal conditioning parameters were used, amplifier gain=1000 dB, 60 Hz bandstop filter.

Seven trials of ascent with comfortable speed (natural speed) were performed by each subject, and the highest and lowest data were excluded.

### Statistical Analysis

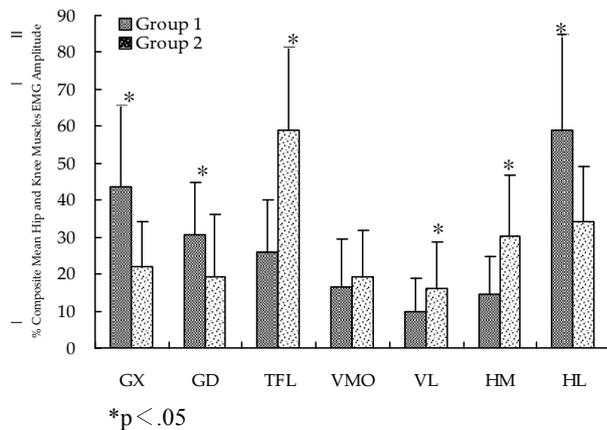
Group differences for each mean peak gluteus maximus, gluteus medius and tensor fascia lata EMG amplitude to composite mean peak hip muscles (GX, GD, TFL) EMG ratios and each mean peak vastus medialis oblique, vastus later-

alis, biceps femoris and semitendinosus EMG amplitude to composite mean peak thigh muscles (peak VMOL, VL, HM and HL) EMG ratios were compared using Mann-Whitney U tests in stance and swing phase of stair ascent (SPSS version 12.0 software). Because the small group sizes did not allow for parametric assumptions of normality, Mann-Whitney U tests were selected for group comparisons. Statistical significance was set at an alpha level of  $p < .05$ .

### Results

There were statistically significant differences in all muscles composite EMG amplitude between group 1 (anteverted hip) and 2 (retroverted hip) in stair ascent during stance phase (Table 2), except VL. Figure 2 shows the differences of all muscles composite EMG amplitude between group 1 and 2 in stair ascent during stance phase.

Subjects with anteverted hip (group 1) showed an increased standardized mean GX ( $43.4 \pm 22.1$  vs.  $21.9 \pm 12.2$ , Mann-Whitney  $U=198$ ,  $p=.000$ ) and GD ( $30.8 \pm 14.0$  vs.  $19.3 \pm 16.7$ , Mann-Whitney  $U=217$ ,  $p=.001$ ) EMG amplitude and that a decreased standardized mean TFL ( $25.8 \pm 14.3$  vs.  $58.5 \pm 22.4$ , Mann-Whitney  $U=113$ ,  $p=.000$ ) to composite mean hip muscles (GX, GD, TFL) EMG amplitude ratios compared to subjects in group 2 during stance phase. Also, group 1 showed an increased standardized mean HL ( $59.1 \pm 25.7$  vs.  $34.1 \pm 15.0$ , Mann-Whitney  $U=207$ ,  $p=.001$ ) EMG amplitude and a decreased standardized mean VL ( $9.7 \pm 9.2$  vs.  $16.3 \pm 12.6$ , Mann-Whitney  $U=244$ ,  $p=.004$ ) and HM ( $14.7 \pm 10.1$  vs.  $30.3 \pm 16.4$ , Mann-Whitney  $U=182$ ,  $p=.000$ ) to composite mean thigh muscles (VMO, VL, HM, HL) EMG amplitude ratios compared to subjects in group 2 during stance phase. There was no statistically significant difference in VMO between group 1 and 2 in stair ascent



\*p < .05  
**Figure 2.** Group comparison of composite EMG amplitude during stance phase

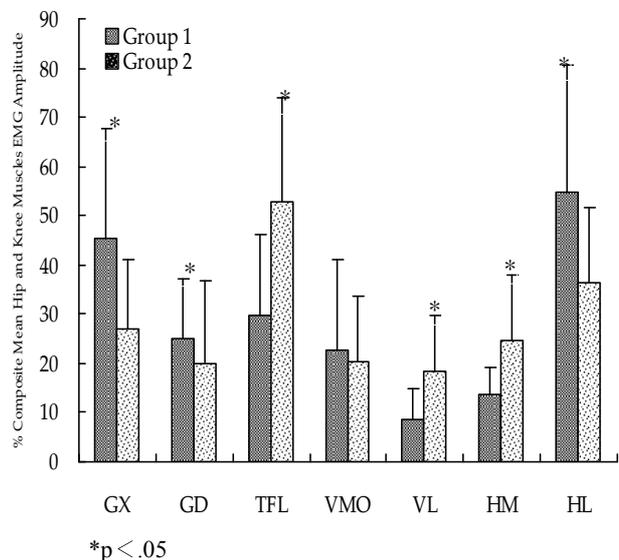
during stance phase.

There were statistically significant differences in all muscles composite EMG amplitude between group 1 and 2 in stair ascent during stance phase, except VL in stair ascent during swing phase (Table 3). Figure 3 shows the differences of all muscles composite EMG amplitude between group 1 and 2 in stair ascent during swing phase. Group 1 showed increased standardized mean GX (45.4±22.3 vs. 27.1±14.1, Mann-Whitney U=218, p=.001) and GD (25.1±12.1 vs. 19.9±16.7, Mann-Whitney U =294, p=.031) EMG amplitude and a decreased standardized mean TFL (29.6±16.5 vs. 53.0±21.1, Mann-Whitney U=171, p=.000) to composite mean hip muscles (GX, GD, TFL) EMG amplitude ratios compared in group 2 during swing phase. Also, group 1 showed an increased stand-

amplitude during swing phase

	group 2 (n2=7)	Mann-Whitney U	p
	27.1±14.1	218	.001*
	19.9±16.7	294	.031
	53.0±21.1	171	.000
	20.5±13.1	429	.899
	18.4±11.1	196	.000
	24.8±13.0	217	.001
	36.2±15.3	265	.010

ardized mean HL (54.9±25.7 vs. 36.2±15.3,



\*p < .05  
**Figure 3.** Group comparison of composite EMG amplitude during swing phase

Mann-Whitney U=265, p=.010) EMG amplitude

**Table 2.** Group comparison of composite EMG amplitude during stance phase

Muscles	group 1 (n1=5)	group 2 (n2=7)	Mann-Whitney U	p
Gluteus maximus (GX)	43.4±22.1 <sup>†</sup>	21.9±12.2	198	.000*
Gluteus medius (GD)	30.8±14.0	19.3±16.7	217	.001
Tensor fascia lata (TFL)	25.8±14.3	58.5±22.4	113	.000
Vastus medialis oblique (VMO)	16.5±13.2	19.3±12.5	352	.200
Vastus lateralis (VL)	9.7±9.2	16.3±12.6	244	.004
Biceps femoris (HM)	14.7±10.1	30.3±16.4	182	.000
Semitendinosus (HL)	59.1±25.7	34.1±15.0	207	.001

<sup>†</sup>%, \*p < .05

and decreased standardized mean VL ( $8.7 \pm 6.3$  vs.  $18.4 \pm 11.1$ , Mann-Whitney  $U=196$ ,  $p=.000$ ) and HM ( $13.6 \pm 5.5$  vs.  $24.8 \pm 13.0$ , Mann-Whitney  $U=217$ ,  $p=.001$ ) to composite mean thigh muscles (VMO, VL, HM, HL) EMG amplitude ratios compared to subjects in group 2 during swing phase. There was no statistically significant differences in VMO between group 1 and 2 in stair ascent during swing phase.

### Discussion

This study has explored the effect of anteversion on hip and thigh muscles EMG activities in both stance and swing phase during stair ascent. Specifically, group differences for each mean peak GX, GD and TFL EMG amplitude to composite mean peak hip muscles (GX, GD, TFL) EMG ratios and each mean peak VMO, VL, HM and HL EMG amplitude to composite mean peak thigh muscles (peak VMO, VL, HM and HL) EMG ratios were compared in stance and swing phase of stair ascent.

The study of stair walking, by comparison, has received less attention. Fitch et al. (1974) have provided qualitative analysis, while most works offering quantitative analysis of stair gait have mainly emphasized electromyographic data only. Other researchers have shown similar muscular timing patterns for the soleus, tibialis anterior and rectus femoris during ascent and the tibialis anterior and gastrocnemius (Townsend et al., 1978) while walking down stairs. Shinno (1971) discussed, although qualitatively, the magnitudes of knee muscular activity during stair walking and pointed out the importance of the quadriceps, in particular the VL, in providing the greatest activity beginning from single leg support in ascent. He also reported greater activity in the quadriceps during ascent than during de-

scend and comparably smaller hamstrings activity for both modes.

A few studies have employed kinetic analyses for stair walking. Andriacchi et al. (1980) differentiated the transition period during the initiation and termination of ascent and descent from those of steady state stair walking. However, with only a three step staircase, the top of the staircase in ascent and the floor in descent were incorporated as one of the steps during the stair walking stride. As this would affect both stride length and velocity, their torque and even joint angle data must be questioned as being representative at fully established stairway patterns.

Morrison (1969) has provided kinetic data for the knee joint for both modes of stair gait. The data agree with Shinno (1971) that the quadriceps are the predominant force producers during the early part of stance while ascending stairs, and in late stance during descent. However, Morrison (1969) gave greater emphasis to the quadriceps femoris.

Anteversion is considered a possible factor for the onset of joint degeneration. It has been suggested that femoral anteversion plays an important role in the load transfer from implant to bone and hence may alter the outcome of a total hip arthroplasty. The recent models suggest that larger anteversion may lead to increase proximal femoral bending moments and thereby influence bone remodelling and the long-term performance of implants. Based on current mechanical analysis, large modifications of anteversion, compared to the pre-operative situation, appear to be detrimental and should be avoided.

Recent studies have suggested that femoral anteversion plays an important role in the load transfer from implant to bone and hence influences the outcome of anteversion during surgery. This may lead to increased loading, which would be most prominent during repetitive daily activities, such as walking and stair climbing, and

therefore trigger implant loosening. In the studies of Heller et al. (2001), a simulated increase of anteversion to an angle of 30° led to increased hip contact forces and increased moments in the frontal plane. In subjects with anteversion hip, considerably increased hip contact forces were found during walking and stair climbing.

Stair climbing activities induced the highest mechanical instability at the bone prosthesis interface which may compromise the necessary osseointegration process. Active simulation of muscle forces considerably affects the primary stability of cementless hip endoprostheses. Preclinical in vitro tests should simulate stair climbing and include the active role of muscles in the assessment of initial implant stability. Otherwise micro-movements may be underestimated and the primary stability overestimated. In vitro testing of other cementless prostheses using similar loading conditions as presented in this study could help discriminate potentially poor stem designs with respect to initial stability.

Kinetic and electromyography (EMG) analyses have further specified the muscle groups recruited in stair tasks and level walking. Previous analyses measuring the kinetics of the lower limbs have shown that greater knee moments were required in the stair climbing tasks than in level walking and that the largest increase in the sagittal moment in stair climbing occurs at the knee joint (Andriacchi et al., 1980; McFadyen and Winter, 1988). Comparison of the percentage of maximal activation level of some lower limb muscles also reveals significantly higher activation of the knee extensor muscles (VL and medialis) and medial hamstring muscles during walking up stairs than level walking

The knee flexors in stair climbing have received little attention. Results of the present study revealed an important role of the knee flexors during stair climbing that has not been discussed related to the energy to avoid the in-

termediate step of the stairs. In addition to the hip adductor assistance for step avoidance mentioned above, the present work also confirms that stair climbing, like going over obstacles, requires a reorganisation of lower limb to a knee flexor strategy. From the work of McFadyen and Winter (1988), it was clearly demonstrated that obstructed walking results in less absorption by the knee extensors followed by a novel burst of energy generation by the knee flexors at the transition from stance to swing.

Therefore there were major differences in patterns between level and stair walking concerning the knee flexors and extensors, hip abductors, and the magnitude of dorsiflexion at the ankle during the swing phase. These findings should particularly be considered in the rehabilitation of stair and level walking. Additional studies on stair climbing including comparisons of the joint kinematic and kinetic patterns across different speeds of stair walking and between young, middle aged and elderly adults will further allow a better understanding of stair walking patterns in healthy individuals.

In order to provide rehabilitation professionals with a clearer picture of the specific requirements of the stair climbing task, further research must be expanded to include a wider range of age groups that represent the general public, such as including middle-aged healthy persons.

## Conclusion

Among subjects with increased relative femoral anteversion, there were increased standardized mean GX and GD EMG amplitude and a decreased standardized mean TFL to composite mean hip muscles (GX, GD, TFL) EMG amplitude ratios compared to subjects with decreased relative femoral anteversion during both stance and swing phase in stair ascent. Also, subjects

with increased relative femoral anteversion had increased standardized mean HL EMG amplitude and decreased standardized mean VL and HM to composite mean thigh muscles (VMO, VL, HM, semitendiosus) EMG amplitude ratios compared to subjects with decreased relative femoral anteversion during both stance and swing phase in stair ascent. There was no statistically significant difference in VMO between subjects with increased relative femoral anteversion and decreased relative femoral anteversion in stair ascent during both stance and swing phase.

These data can be used as baseline measures in therapeutic exercise studies such as preventive hip and knee osteoarthritis exercise development in patients with increased and decreased femoral anteversion relatively.

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