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A MOTION ANALYSIS OF THE LOWER EXTREMITY DURING GAIT WITH SPECIAL REGARD TO THE EMG ACTIVITY OF M. ADDUCTOR LONGUS

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Rita M. Kiss[1], Zsidai Knoll[2]

[1]Academic Research Group of Structures, 1521 Budapest, Bertalan L. u. 2., Hungary
[2]Found MEDICaMENTOR 1021 Budapest, Pálos u. 3., Hungary
E-mail: kiss@vbt.bme.hu

Abstract: *This study used a comprehensive approach including kinematic and EMG data analysis to determine the electromiographical pattern of m. adductor longus. The study was performed on 105 healthy subjects. Gait analysis was performed using the zebris three-dimensional ultrasound-based system with surface electromyography (zebris). Kinematic data (spatial-temporal parameters, knee and pelvic joint kinematics) were recorded for the lower limb. The examined muscles include vastus lateralis and medialis, biceps femoris and adductor longus. The EMG traces of m. adductor longus show an adductor longus avoidance gait for a small part of subjects, which does not depend on gender and age. The results suggest that the reduced rotation of the thigh and the pelvis could result in a reduced rise in adductor longus EMG activity during pre-swing.*

Key words: *gait analysis, 3D kinematics, electromyography, m. adductor longus.*

1. INTRODUCTION

The gait patterns of healthy subjects have been assessed in a number of studies all using different techniques. The previous investigations examined muscles vastus medialis, lateralis, rectus femoris, semimembranosus, biceps femoris, tibialis anterior, and gastrocnemius. However, few studies have evaluated the changes of m. adductor longus during the gait.

Bechtol (1975) examined EMG patterns for 28 of the major muscles in the lower extremities during a gait cycle. The study was performed on 10 male and 10 female subjects. Bechtol (1975) found that the m. adductor longus was activated during the early stance, pre-swing and late swing phases.

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Ciccotti et al. (1974) analyzed EMG patterns during gait in 22 normal, healthy subjects. Muscle adductor longus was activated just at the early stance and late swing phases at six subjects out of twenty-two.

Additional studies are necessary to either support or refute the development of an adductor longus avoidance gait. The development of adductor longus avoidance gait pattern has been described as a patient's tendency to reduce or avoid contraction of adductor longus muscle during the pre-swing phase.

This study used a comprehensive approach, including kinematic and EMG data analysis to determine the electromyographical pattern of m. adductor longus

METHOD

Subjects

The study was carried out on a group of 105 healthy persons. The population consisted of sixty males and forty-five females. The data of investigated groups are summarized in Table 1.

Table 1. Mean (SD) of age, height and mass for investigated groups.

	Mass [kg]	Height [cm]	Age [years]
Male subjects (n=60)	77.89 (11.88)	178.42 (7.20)	28.17 (7.69)
Female subjects (n=45)	59.86 (6.38)	168.07 (5.70)	25.09 (4.21)

For inclusion, subjects were not to have any pathology that would affect gait and had to be unfamiliar with treadmill walking. Each subject provided informed consent before participation and signed a consent form approved by the Hungarian Human Subjects Compliance Committee.

Procedures and instrumentation

The subjects walked on a motorized treadmill (Bonte Zwolle B.V, Austria), the walking area of the treadmill belt was 330 mm $\times$ 1430 mm. Each subject was asked to perform after six minutes of familiarization time (Alton et al., 1998; Matsas et al., 2000) at least 10 minutes of walking at 3 km/h speed.

The analysis of gait features was performed using an ultrasound-based zebris CMS-HS system (ZEBRIS, Medizintechnik GmbH, Germany) consisting of the following: (a) measuring head and 5 ultrasound triplets for the recording of the kinematic data; (b) EMG system equipment with surface electrodes for the recording of neuromuscular activity. EMG signals were acquired at a sampling rate of 1000Hz, whereas the ultrasound measuring system worked at a sampling rate of 100 Hz. All the variables were further elaborated by computer.

Spatial coordinates for the determination of kinematic data were collected using the measuring head with three ultrasound transmitters and 5 ultrasound-based triplets with active markers during walking. The measuring head was positioned behind the subject (Fig. 1). Five ultrasound triplets with three active markers on each were placed on the sacrum, left and right thighs, and left and right calves (Fig.1). The data obtained from the recording of these active markers by measuring system allowed determination of the coordinates of nineteen anatomical points of the lower limbs (Fig. 2). The protocol is defined in (Kocsis, 2002) in detail.

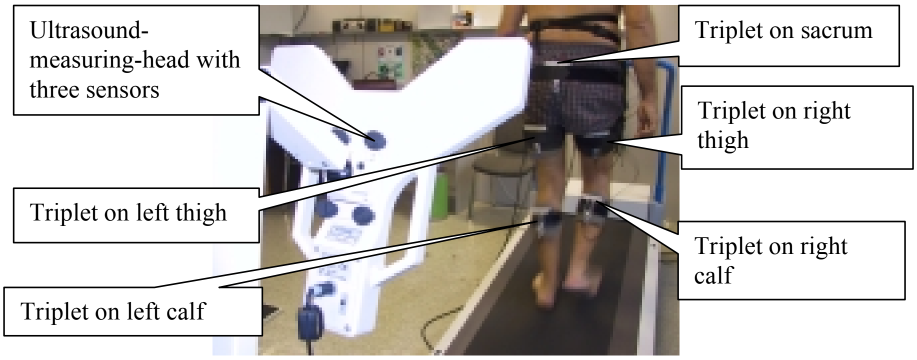

Fig.1. The arrangement of the measurement

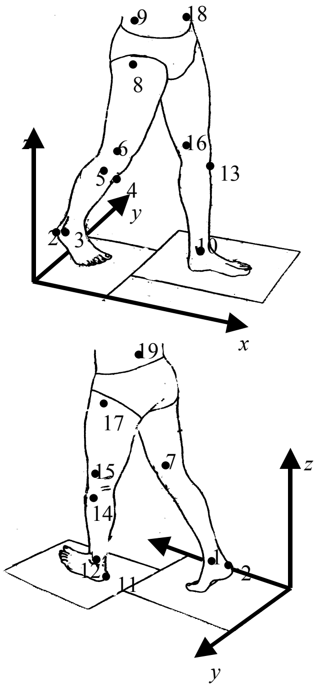

Fig. 2. Position of the anatomical points. (1) right medial malleolus, (2) right heel, (3) right lateral malleolus, (4) right tibial tubercule, (5) right fibular head, (6) right lateral femoral epicondyle, (7) right medial femoral epicondyle (8) right greater trochanter, (9) right ASIS, (10) left medial malleolus, (11) left heel, (12) left lateral malleolus, (13) left tibial tubercule, (14) left fibular head, (15) left lateral femoral epicondyle, (16) left medial femoral epicondyle (17) left greater trochanter, (18) left ASIS, (19) sacrum.

The assessed kinematic parameters are the following: (a) step-length; (b) walking base; (c) modified knee angle; (d) thigh rotation; (e) pelvic kinematics (flexion-extension, rotation, and obligation).

The anatomical joint angles are important because the range of movement is of interest to clinicians. The anatomical joint angles show how one segment is oriented relative to another. There has been some debate as to the most appropriate method of defining joint angles (Chao, 1983; Grood & Suntay, 1983). The knee angle defined as a flexion and extension, which place about the medio-lateral axis of the proximal segment. This definition evaluates frontal and transverse plane components. Our motion analysis technique reduces the effects of skin movement artifacts (Kocsis, 2002). Therefore, the definition of anatomical joint angles could be modified. The knee angle is defined as the angle between spatial vectors joining the lateral malleolus to the fibular head and joining the lateral femoral epicondyle to the greater trochanter (Fig. 3).

$$\alpha = \cos^{-1}\left[\frac{(X_8 - X_6)(X_5 - X_3) + (Y_8 - Y_6)(Y_5 - Y_3) + (Z_8 - Z_6)(Z_5 - Z_3)}{L_{35}L_{68}}\right] \qquad (1)$$

where

α is the knee angle,
X_3, Y_3, Z_3 are spatial coordinates of the malleolus lateralis,
X_5, Y_5, Z_5 are spatial coordinates of the caput fibulae,
X_6, Y_6, Z_6 are spatial coordinates of the epicondylus femoris lateralis,
X_8, Y_8, Z_8 are spatial coordinates of the trochanter major,
L_{35} is the distance joining the malleolus lateralis to the caput fibulae,
L_{68} is the distance joining the epicondylus femoris lateralis to the trochanter major.

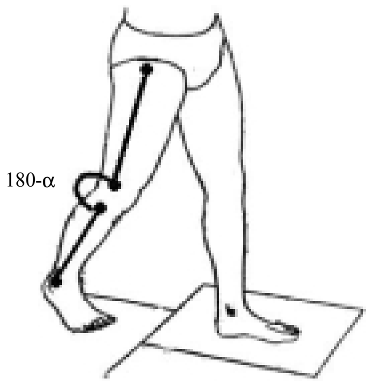

Fig. 3. Definition of the knee angle (α). The knee angle is defined as the angle between a spatial vector joining the lateral malleolus to the fibula head and a spatial vector joining the lateral femoral epicondyle to the greater trochanter.

The distance joining the malleolus lateralis to the caput fibulae can be determined by

$$L_{35} = \sqrt{(X_5 - X_3)^2 + (Y_5 - Y_3)^2 + (Z_5 - Z_3)^2} \qquad (2)$$

The distance joining the epicondylus femoris lateralis to the trochanter major can be determined by

$$L_{68} = \sqrt{(X_8 - X_6)^2 + (Y_8 - Y_6)^2 + (Z_8 - Z_6)^2} \qquad (3)$$

The above calculation method does not evaluate the frontal and the transverse plane components, but calculates the real angle between the two segments.

The motion of the pelvis could be modeled by three different angles, as pelvic flexion-extension, pelvic rotation and pelvic obligation. In our research the pelvic angles were calculated using the methods shown in literature (Chao, 1983; Grood & Suntay, 1983).

The muscle adductor longus plays a role in the rotation of the thigh; therefore the analysis of the rotation of the thigh may shed more light on the EMG pattern of muscle adductor longus. The rotational angle of the thigh was determined by calculating the angular velocity vector of the thigh as a rigid body and by the time integration of its longitudinal component about the axes of the segment as Kocsis and Beda described in (Kocsis & Beda, 2001).

The angular velocity of the body segment (Kocsis & Beda, 2001) could be determined by

$$\underline{\omega} = \frac{1}{L_{78}{}^2}\left\{\underline{r}_{78} \times (\underline{v}_7 - \underline{v}_8) + \left[\frac{\underline{r}_{68} \times \underline{r}_{78}}{L_{78}\,\sin^2\beta} \cdot \left(\frac{\underline{v}_7 - \underline{v}_8}{L_{78}} - \frac{\underline{v}_6 - \underline{v}_8}{L_{68}}\cos\beta\right)\right]\underline{r}_{78}\right\}. \tag{4}$$

where

$\underline{v}_6$ is the velocity vector of the epicondylus femoris lateralis,

$\underline{v}_7$ is the velocity vector of the epicondylus femoris medialis,

$\underline{v}_8$ is the velocity vector of the trochanter major,

$\underline{r}_{68}$ is the position vector between the epicondylus femoris lateralis and trochanter major,

$\underline{r}_{78}$ is the position vector between the epicondylus femoris medialis and trochanter major,

L_{78} is the distance between the epicondylus femoris medialis and trochanter major. The distance can be calculated from

$$L_{78} = \sqrt{(X_8 - X_7)^2 + (Y_8 - Y_7)^2 + (Z_8 - Z_7)^2} \tag{5}$$

where

X_7, Y_7, Z_7 are spatial coordinates of the epicondylus femoris medialis,

X_8, Y_8, Z_8 are spatial coordinates of the trochanter major,

L_{68} is the distance between the lateral femoral epicondyle and the great trochanter determined by Eq. (3),

β is the angle between spatial vectors joining the great trochanter to the lateral femoral epicondyle and joining the great trochanter to the medial femoral epicondyle. The angle could be determined by

$$\beta = \cos^{-1}\left[\frac{(X_8 - X_7)(X_8 - X_6) + (Y_8 - Y_7)(Y_8 - Y_6) + (Z_8 - Z_7)(Z_8 - Z_6)}{L_{78}L_{68}}\right] \tag{6}$$

The rotation of the thigh could be calculated by

$$\varphi(t) = \int \omega_t dt \tag{7}$$

where

$$\omega_t = \underline{\omega} \circ \frac{(\underline{r}_6 - \underline{r}_8)}{L_{68}} \tag{8}$$

where

$\underline{\omega}$ is the angular velocity vector determined by Eq. (4),

L_{68} is the distance joining the epicondylus femoris lateralis to the trochanter major determined by Eq. (3),

$\underline{r}_6$ is the position vector of epicondylus femoris lateralis,

$\underline{r}_8$ is the position vector of trochanter major.

EMG data were collected using bipolar surface electrodes (blue sensor P-00-S, Germany). The electrodes were placed on the skin overlying the muscle belly of the muscles vastus medialis and lateralis, biceps femoris and adductor longus of both limbs. To achieve an optimal EMG signal and low impedance, three 3 cm^2 areas of skin were sanded and cleaned. Prior to measurement, the electrode positions were tested to control for cross talk between different muscle groups. The raw data were high pass filtered to eliminate frequency components below 10 Hz, then rectified and filtered to eliminate the components of the signals over 500 Hz. The linear envelope EMG curve was determined by the root-mean square method (Vaughan, 1999) and normalized to the average of the peak EMG signal values of six gait cycles.

Treadmill walking allows the determination of the average and the standard deviation of all parameters from six gait cycles for each subject. These data were then calculated and exported for further analysis.

The different groups were defined as (a) subjects with normal gait pattern, and (b) subjects with adductor longus avoidance gait. The average trend for all variables was computed for each group. Student tests were used to determine levels of significance ($p = 0.05$) when comparing the groups.

RESULTS

Spatial-temporal parameters

Table 2 presents a summary of comparisons for subjects with normal gait pattern and subjects with adductor longus avoidance gait by selected spatial-temporal parameters (step length and walking base). No significant statistical differences were observed between the dominant and non-dominant limbs for both groups ($p>0.37$). No significant differences were observed between the group of subjects with normal gait pattern and the group of subjects with adductor longus avoidance gait pattern ($p>0.19$).

Table 2. Mean (SD) spatial-temporal parameters for subjects with normal gait pattern and for subjects with adductor longus avoidance gait pattern

	Step length [mm]		Walking base [mm]	
	dominant	non-dominant	dominant	non-dominant
Male subjects with normal gait pattern (n=46)	513.3 (26.6)	510.3 (28.8)	41.9 (8.2)	50.5 (11.5)
Female subjects with normal gait pattern (n=36)	470.7 (20.1)	466.3 (29.9)	39.0 (9.9)	46.1 (15.0)
Male subject with adductor longus avoidance gait (n=14)	515.6 (27.5)	510.0 (28.9)	40.6 (10.8)	48.9 (13.4)
Female subject with adductor longus avoidance gait (n=9)	473.2 (24.8)	468.6 (26.1)	39.4 (8.3)	45.8 (7.8)

Knee joint kinematics

Table 3 presents a summary of comparison for subjects with normal gait pattern and subjects with adductor longus avoidance gait knee joint kinematics (knee angle). No significant statistical differences were observed between the dominant and non-dominant limbs for either of the groups (p>0.39). No significant differences were observed between the group of subjects with normal gait pattern and the group of subjects with adductor longus avoidance gait pattern (p>0.31).

Table 3. Mean (SD) peak values of knee with normal gait pattern and for subjects with adductor longus avoidance gait pattern

	Peak value of extension [degree]		Peak value of flexion [degree]	
	dominant	non-dominant	dominant	non-dominant
Male subjects with normal gait pattern (n=46)	5.5 (0.98)	5.4 (1.05)	52.3 (1.32)	51.2 (1.74)
Female subjects with normal gait pattern (n=36)	7.3 (1.29)	7.7 (1.88)	57.3 (1.96)	57.6 (1.85)
Male subject with adductor longus avoidance gait (n=14)	5.3 (0.31)	5.8 (0.61)	51.4 (1.64)	53.1 (1.74)
Female subject with adductor longus avoidance gait (n=9)	7.1 (1.11)	7.2 (1.29)	55.4 (1.33)	58.4 (1.54)

Muscle EMG

Fig. 4 shows a graphical representation and comparisons for both groups. No significant differences were observed between the two groups' vastus medialis, lateralis and biceps femoris EMG activity throughout gait.

46 males and 36 females did not exhibit an adductor longus avoidance gait. This means that the adductor longus produced EMG activity during the early stance, pre-swing and late swing phases. 14 males and 9 females exhibited an adductor longus avoidance gait pattern, m. adductor longus was not activated during pre-swing phase (Fig. 4). The differences do not depend on gender and age.

Thigh kinematics

Table 4 presents a summary of comparisons for subjects without adductor longus avoidance and with adductor longus avoidance gait. Significant statistical differences in thigh rotation during pre-swing were observed between the two groups (p<0.0024).

Pelvic kinematics

Table 5 presents a summary of comparisons for subjects without adductor longus avoidance and with adductor longus avoidance gait. The significant statistical differences in pelvic rotation (p<0.0043) and in pelvic obligation (p<0.0029) during pre-swing were observed between the two groups.

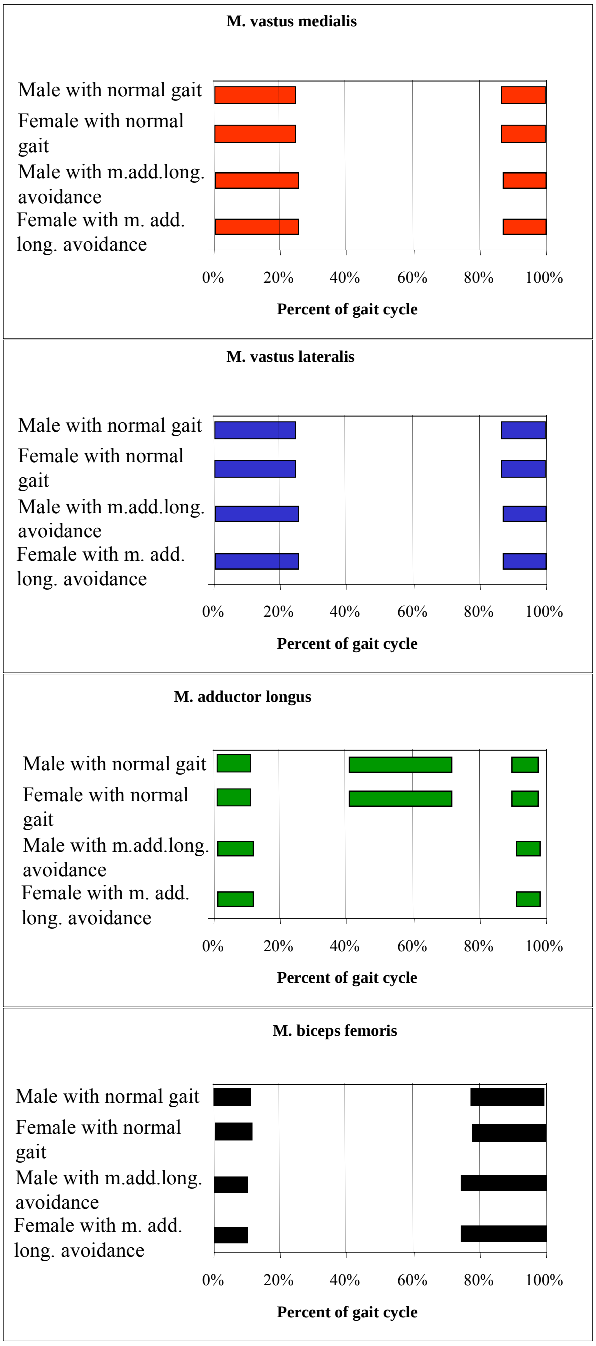

Fig. 4. EMG patterns of muscles vastus medialis, lateralis, biceps femoris and adductor longus for subjects with normal gait pattern and for subjects with adductor longus avoidance gait pattern.

Table 4. Mean (SD) thigh's rotation during preswing phase for with normal gait pattern and for subjects with adductor longus avoidance gait pattern

	Thigh's rotation	
	dominant	non-dominant
Male subjects with normal gait pattern (n=46)	4.09 (0.18)	3.87 (0.21)
Female subjects with normal gait pattern (n=36)	4.07 (0.16)	3.91 (0.17)
Male subject with adductor longus avoidance gait (n=14)	0.92 (0.17)	0.77 (0.18)
Female subject with adductor longus avoidance gait (n=9)	0.87 (0.19)	0.58 (0.29)

Table 5. Mean (SD) pelvic's rotation, obligation and flexion-extension during pre-swing phase for subjects for subjects with normal gait pattern and for subjects with adductor longus avoidance gait pattern

	Pelvic's rotation		Pelvic's obligation		Pelvic's flexion-extension	
	dominant	non-dominant	dominant	non-dominant	dominant	non-dominant
Male subjects with normal gait pattern (n=46)	3.97 (0.19)	3.77 (0.12)	5.01 (0.10)	4.87 (0.11)	11.04 (0.19)	10.87 (0.20)
Female subjects with normal gait pattern (n=36)	3.95 (0.16)	3.97 (0.15)	5.07 (0.20)	4.91 (0.27)	11.07 (0.17)	10.91 (0.18)
Male subject with adductor longus avoidance gait (n=14)	1.4 (0.21)	1.41 (0.18)	7.92 (0.37)	7.77 (0.38)	10.29 (0.17)	10.77 (0.17)
Female subject with adductor longus avoidance gait (n=9)	1.37 (0.19)	1.38 (0.27)	7.87 (0.39)	7.58 (0.39)	10.78 (0.19)	10.88 (0.20)

DISCUSSION

The adductor longus avoidance pattern is defined as a patient tendency to reduce or avoid contraction of the adductor longus muscle during the pre-swing phase. As such, significant alterations in gait mechanics may occur.

In the present investigation, evidence of an adductor longus avoidance pattern was observed in 22% of investigated subjects (Fig. 4). This finding is in contrast to Bechtol (1975) who did report any adductor longus avoidance pattern. However, the results of the present investigation are consistent with investigation of Ciccotti et al. (1974) who reported that an adductor longus avoidance phenomenon could develop in a low percent of healthy subjects. It has been suggested that inherent differences in either the number of investigated subjects or data analysis might serve to explain the variations.

CONCLUSION

No previous studies investigated the thigh's rotation to help support or refute the adductor avoidance pattern. It is possible that the reduced rotation of the thigh and the pelvis measured during pre-swing (Table 4 and 5) could be considered as the cause of adductor longus avoidance gait. The behaviour was compensated for by an increase in pelvic obligation. However, no differences could be found in other kinematic gait characteristics. The reduced rotation of thigh and pelvis could result in a reduced rise in adductor longus EMG activity during the pre-swing.

The development of adductor longus avoidance gait pattern does not depend on gender and age.

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ANALIZA POKRETA DONJIH EKSTREMITETA TOKOM ZAMAHA SA SPECIJALNIM OSVRTOM NA EMG AKTIVNOST M. ADDUCTOR LONGUS-A

Rita M. Kiss, Zsidai Knoll

U ovoj studiji korišćen je opsežan pristup koji uključuje kinematičke i EMG podatke za analizu kako bi se odredio elektromiografski obrazac m. adductor longus-a. Studija je obuhvatila 105 zdravih ispitanika. Analiza hoda je urađena korišćenjem "zebris" trodimenzionalnog ultrazvučnog sistema sa površinskom elektromiografijom ("zebris"). Kinematički podaci (spacijalno-temporalni parametri, kinematika kolena i pelvičnog dela) su beleženi za donje ekstremitete. Ispitivani mišići uključuju m. vastus lateralis i medialis, m. biceps femoris i m. adductor longus. Tragovi EMG za m. adductor longus pokazuju pad "izbegavanja" hoda za mali broj ispitanika, a koji ne zavisi od pola i uzrasta. Rezultati pokazuju da bi redukovana rotacija butina i pelvisa mogla izazvati smanjeno podizanje m. adductor longus-a i EMG aktivnost u periodu pred zamah.

Ključne reči: *analiza hoda, 3D-kinematika, elektromiografija, m.adductor longus.*