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Immediate effect of stair exercise on stiffness, tone, and pressure pain threshold of thoracolumbar fascia in individuals with lower limb amputation: a preliminary report

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Abstract

Background: Adaptations to the use of prosthesis in individuals with a lower limb amputation may cause changes in lumbopelvic region structures during daily life activities.

Objective: To investigate the effect of stair exercise on the stiffness, tone, and pressure pain threshold (PPT) of the thoracolumbar fascia (TLF) in individuals with unilateral lower limb amputation.

Design: This is a prospective preliminary study.

Methods: The study was conducted in Prosthetic Orthotic Centers in Istanbul. Syrian individuals with unilateral transtibial (n = 17) and transfemoral (n = 15) amputation who received prosthesis and rehabilitation services at the centers between February 2020 and December 2020 were included in the study. The subjects were instructed to ascend and descend a nine-step stair one at a time at their maximum possible speed. Measurements were made before and immediately after the stair exercise. Tone and stiffness of TLF was measured using myometer. PPT was measured using algometer. Low back pain was evaluated using numerical pain rating scale.

Results: In the transfemoral amputation group, PPT measurements taken immediately after stair exercise were significantly decreased in both the amputated ($P = 0.001$) and intact ($P = 0.021$) sides, whereas significant reduction in stiffness when compared with the prestair levels was observed only at the intact side ($P = 0.019$). The change in PPT values on the amputated side was significantly higher in individuals with transfemoral amputation than those in individuals with transtibial amputation ($P = 0.011$).

Conclusion: The decrease in PPT values of TLF in the transfemoral amputation group was considered as a precursor sign for low back pain development. Thus, exercises and preventive rehabilitation programs targeting TLF may be needed, especially in this group.

Keywords

amputation, pressure pain threshold, stiffness, thoracolumbar fascia, tone

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Introduction

Thoracolumbar fascia (TLF) is the largest aponeurosis found in humans.[1] It creates an exoskeleton for the lumbar region muscles and reduces friction between muscles during movement.[2] In addition, it plays an important role in load transfer between muscles of the trunk-spine[3] and spine-pelvis lower extremities.[4] Furthermore, it is richly innervated and is an important source of nociceptive stimulation.[2] In individuals with low back pain (LBP), its thickness increases, and the organization of its layers is disrupted.[5] In addition, some changes occur in the center of coordination areas (located on TLF) of the muscle groups (paravertebral muscles and quadratus lumborum) closely related to LBP.[6,7] Center of coordination designates the fascial areas, which are approximately 2 cm^2 in size for each muscle group, wherein force exerted during contraction of the related muscle is reflected on the surface of deep fascia through the endomysium, perimysium, and epimysium. According to the Fascial Manipulation Theory, therapies targeting these areas of TLF should be administered for eliminating LBP.[6,7] Pressure pain threshold (PPT) (hyperalgesia) has been reported to be lower in the lumbar region (peripheral sensitization) in individuals with LBP compared with those without LBP, but low PPT has been reported to be maintained even in other body parts that are not related to this area (central sensitization).[8,9] Based on these studies, it may be predicted that the changes occurring in PPT of TLF, which is a rich neural network region, may be associated with the risk of developing LBP and should be investigated.

When an individual starts using a prosthesis after lower limb amputation, the body exhibits biomechanical changes according to the amputation level and consequently develops adaptation mechanisms on both the intact and amputated sides.[10] When the adaptation mechanisms occurring in individuals with unilateral transtibial and transfemoral amputation were examined, it was observed that similar compensation mechanisms are activated in the lumbopelvic region to ensure equilibrium,[11] compensate for

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the loss of plantar flexion, compensate for the loss sensory-motor input, and stimulate forward movement of the trunk.[12,13] These mechanisms seem to be more pronounced in the transfemoral amputation group. Asymmetric movement patterns and abnormal tissue loading develop in the lumbopelvic region because of these adaptations. These adaptations consequently cause deformations in the musculoskeletal system[13] and may ultimately result in secondary musculoskeletal diseases such as LBP, muscle strength imbalances, osteoarthritis, and scoliosis.[10]

In individuals with transtibial and transfemoral amputations, the mechanisms that develop during ambulation causing asymmetric muscle recruitment in paravertebral muscles[14] and reflexively increased activation[13] have been suggested as factors in LBP development. In addition, it has been reported that adaptations in the musculoskeletal system cause an imbalance in the contribution of both contractile and passive structures (fascia, capsule, ligament, etc.) to stability of the trunk.[15] Although asymmetric muscle recruitment developing simultaneously with asymmetric lumbopelvic motion is believed to be the main factor triggering pain of myofascial origin, the relationship between the two is not completely elucidated.[16]

During stair activity, adaptation mechanisms of individuals with amputation are revealed in a more exaggerated manner, putting more strain on the musculoskeletal system compared with walking on level ground. This strain increases the risk of developing musculoskeletal problems and additional disability.[17,18] Therefore, it is necessary to investigate the effects of adaptation mechanisms developed during stair gait in individuals with amputation on passive and contractile structures. To the best of our knowledge, the effects of stair gait on the tone and stiffness characteristics of TLF in individuals with amputation have not yet been studied in the literature.

This primary aim of this study was to investigate the immediate effect of stair exercise on tone and stiffness of TLF in individuals with transtibial and transfemoral amputation. In addition, the second aim was to investigate the effect of stair gait on PPT values of TLF. Our hypotheses were that stair activity results in 1) an increase in tone and stiffness of TLF and 2) a decrease in PPT values.

Methods

Subjects

This study was conducted at Prosthetic Orthotic Center managed by the Alliance of International Doctors, between February 2020 and December 2020. Inactive Syrian male individuals with unilateral transtibial (n = 17; 36.41 ± 11.68 years) and transfemoral (n = 15; 30.13 ± 9.15 years) amputation who received prosthesis and rehabilitation services at the center were included in the study. Approval for the study was obtained from the Ethics Committee of Noninterventional Clinical Research of Faculty of Medicine, Marmara University (09.2019.969). The study group was informed about the purpose and content of the study, and written informed consent was obtained from all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki. Clinical Trial record was obtained (NCT04324788).

Individuals with a transtibial and transfemoral amputation who had been using prosthesis for at least 6 months before the study, wearing the prosthetics for at least 3 hours a day, with no history of falling causing pain or injury in the low back region in the previous 6 months, and with a good prosthesis comfort (determined by subjective report stated by subjects) were included in the study. Individuals with LBP history before amputation and with LBP history due to specific pathology (disc herniation, spinal stenosis, etc.), with additional orthopedic or neurological disorders that may cause functional impairment, with a disease that would affect their myofascial properties, and those using antidepressant medications were excluded from the study.

Study design

Before the measurements, each case was informed about the content and measurement methods of the study. First, the demographic (age, height, weight, exercise habits), amputation (level/cause of amputation), and prosthesis-related (duration of prosthesis using/daily use) data were collected through face-to-face interviews.

Subjects were evaluated at baseline (prestair) and immediately postexercise (poststair). Passive tone (Hz), stiffness (N/m), and PPT (lb) values of the TLF were measured in both the amputated and the intact sides. LBP scores were recorded. All measurements were conducted at normal room temperature (22°C–24°C) between 9:00 and 11:00 AM by the same physiotherapist.

Stair gait patterns of subjects were determined according to the Stair Assessment Index (SAI, Spearman Rho between 0.89 and 1.00 for both comparisons within raters for validity).[19] Although SAI is a unique and useful tool for evaluating stair gait patterns in individuals with a transfemoral amputation, it was also used for determining stair gait pattern for individuals with a transtibial amputation in this study. According to SAI, stair gait pattern comprises 13 levels, ranging from 0 (cannot do/refuses to do) to 13 (without rail and assistive device, step-over-step pattern). Subjects were instructed to ascend and descend stairs as in their daily life, and their corresponding SAI scores were recorded.[19]

Stair exercise

Stair climb test (SCT) was used as a stair exercise.[20] SCT (intraclass correlation coefficient = 0.79; 95% confidence interval, 0.57–0.90) was performed in accordance with the stair ascending and descending pattern determined by SAI for each subject. Subjects were instructed to ascend and descend a 9-step stair (each step with 20 cm height) at their maximum possible speed, and the time required to complete the test was recorded.

Measurement of tone and stiffness

The tone (intrinsic tension of the tissue at passive or resting state without any voluntary contraction) and stiffness (the resistance of tissue to deformation caused by applied force) of TLF were measured using a myometer (MyotonPro, Myoton AS, Tallinn, Estonia).[21] Measurements were performed in the prone position from the center of coordination region (3 cm lateral to the processus spinosus of L1 vertebra) located on the TLF for the paravertebral muscles.[6,7,21] To avoid the effects of changes in intra-abdominal pressure on oscillations, the patients were instructed to hold their breath for 5s after inspiration during measurements.

Tone and stiffness were calculated by averaging the tissue-generated oscillator responses against three repetitive mechanical stimuli (0.40 N, 15 ms).[7]

Measurement of LBP

The existence and severity of LBP was investigated with numerical pain rating score. The subjects were asked to mark the level of their current pain status on a scale between 0 (no pain) and 10 (the most severe pain).[7]

Measurement of PPT

PPT evaluation was conducted at the center of coordination area of paravertebral muscles with the digital algometer device (Algometer Commander, Jtech Medical, MM036_K, 2016). Initially, all subjects received training to familiarize themselves with the procedure; the measurements obtained during training were not used for data analysis. Subjects were instructed to inform the examiner as soon as the perception of compression became painful (pain threshold). During constant velocity and gradual pressure application (perpendicular to the site of the evaluation and approximately 1 kg/s), the pressure level at which the patient felt pain was recorded as the PPT value. The average of three measurements taken with 10-second pause between them and from the same point was used in the analyses.[8]

Sample size and statistical analysis

In the determination of the sample size, a similar study[18] was used and the number of participants was determined as 15 for each group (power = 0.856). Eighteen individuals with transtibial amputations and 16 individuals with transfemoral amputations were evaluated against the possibility of dropout rate. One participant who received painkillers during the study and another who felt unrest during the measurement were excluded from the study, and the study was completed with 17 individuals with a transtibial amputation and 15 individuals with a transfemoral amputation.

In this study, the significance level was set at $P \leq 0.05$ for all evaluations, and statistical procedures were performed using SPSS 21.0 (SPSS Inc., Chicago, IL) for Windows. Descriptive statistical techniques (mean and SD) were used to describe the groups. The compliance of the data with the normal distribution was evaluated with the Shapiro–Wilk test. Paired sample t test was used to evaluate intragroup comparisons. Evaluations were made in consideration of intersubject factor and time (before and after), using 2×2 mixed model analysis of variance.

Results

The demographic, amputation-related, and prosthetic characteristics of the subjects are shown in Table 1. Both groups were similar for body mass index (BMI), prosthesis use duration, and daily prosthesis wearing time ($P > 0.05$). However, SCT completion time was significantly lower in the transtibial amputation group when compared with the transfemoral amputation group ($P = 0.001$) (Table 1).

Subjects in both groups had similar averages for tone values on the amputated and intact sides at both measurement times ($P > 0.05$) (Table 2).

In the transtibial amputation group, there was no difference in both amputated and intact side stiffness values between measurement times ($P > 0.05$) (Table 2). However, for individuals with a transfemoral amputation, the stiffness values were significantly decreased in the intact side after the stair exercise (poststair) compared with the prestair exercise level ($P = 0.019$) (Table 2).

Regarding stiffness and tone differences values at measurement times (prestair/poststair), intergroup comparison found no statistical significance between the groups on both the intact and amputated sides ($P > 0.05$) (Table 2).

Intragroup and intergroup comparisons of pain values showed no significant difference ($P > 0.05$) (Table 3). In the transfemoral amputation group, PPT values decreased significantly on the

Table 1. Demographic, amputation, and prosthesis-related characteristics of the participants.

Characteristics	TT n = 17 (mean ± SD)	TF n = 15 (mean ± SD)	*P*
Age	36.41 ± 11.68	30.13 ± 9.15	0.104
BMI (kg/cm^2)	25.11 ± 3.08	22.61 ± 4.78	0.085
SCT (s)	17.73 ± 4.14	28.25 ± 9.37	**0.001**
Duration of prosthesis use (mo)	87.12 ± 87.47	58.13 ± 76.17	0.329
	Subgroups	TT n (%)	TF n (%)
SAI score	3	1 (5.9)	14 (93.3)
	4	—	4 (6.7)
	11	8 (47.1)	—
	13	8 (47.1)	—
Cause of amputation	Accident	3 (17.6)	2 (13.3)
	War	12 (70.6)	13 (86.7)
	Chronic disease (DM)	2 (11.8)	—
Duration of daily prosthesis use (h)	3–5	2 (11.8)	2 (13.3)
	5–8	—	3 (20)
	>8	15 (88.2)	10 (66.7)

Abbreviations: BMI, body mass index; DM, diabetes mellitus; SAI, Stair Assessment Index; SCT, stair climb test; TF, transfemoral, TT, transtibial.
Bold values indicate statistically significance differences.

Table 2. Intragroup and intergroup comparison of tone and stiffness values of thoracolumbal fascia.

Groups	Parameters	Side	Prestair exercise (mean ± SD)	Poststair exercise (mean ± SD)	*P*	TT vs. TF *P*[a]
TT (n = 17)	Stiffness (N/m)	Intact	297 ± 64.01	287 ± 64.15	0.216	0.287
		Amputated	282 ± 64.34	278 ± 58.19	0.422	0.454
		P[b]	0.292	0.474		
	Tone (Hz)	Intact	15.85 ± 1.65	15.80 ± 1.80	0.851	0.107
		Amputated	15.45 ± 1.88	15.70 ± 1.99	0.208	0.600
		P[b]	0.301	0.783		
TF (n = 15)	Stiffness (N/m)	Intact	302 ± 70.44	279 ± 64.13	**0.019**	
		Amputated	292 ± 68.54	284 ± 46.51	0.505	
		P[b]	0.297	0.542		
	Tone (Hz)	Intact	15.62 ± 1.48	15.30 ± 1.27	0.158	
		Amputated	15.26 ± 1.63	15.34 ± 1.26	0.794	
		P[b]	0.769	0.468		

Abbreviations: TF, transfemoral; TT, transtibial.
[b]Paired sample *t* test.
[a]Analysis of variance.
Bold values indicate statistically significance differences.

amputated ($P = 0.001$) and intact sides ($P = 0.021$) after the stair exercise. However, in the transtibial amputation group, there was no difference in PPT values (Table 3).

Regarding PPT differences values at measurements times (prestair/poststair), a significant difference was found between transtibial amputation (0.42 ± 1.33) and transfemoral amputation (2.03 ± 1.99) groups on the amputated side ($P = 0.011$) (Table 3).

Discussion

This study investigated the immediate effect of stair exercise on tone, stiffness, and PPT values of TLF in individuals with transtibial and transfemoral amputations. The study findings revealed that in the transfemoral amputation group, stiffness values were significantly lower only on the intact side at poststair compared with prestair levels. Furthermore, it was observed that PPT values decreased significantly after the stair exercise on both the intact and amputated sides after the stair exercise. In the transfemoral amputation group, the difference in PPT values between measurement times on the amputated side was found to be significantly higher than that of the transtibial amputation group.

When SCT times of transtibial and transfemoral amputation groups were compared, they were significantly lower in favor of the transtibial group. Given the similarity of demographic characteristics between the groups, the decisive factor in SCT time was believed to be the amputation level.

Increased muscle tone causes increased stiffness,[22] which consequently increases energy consumption due to increased tissue resistance to deformation and may cause injury to the antagonist muscle.[23] Walking downstairs is an eccentric type of exercise. It is reported that muscle pain and stiffness, especially after a strenuous eccentric exercise (especially an exercise protocol of repeated stair descents), is defined as delayed onset muscle soreness.[24] Therefore, it is especially important that an eccentric exercise does not increase stiffness. In this study, muscle tone values did not have statistically significant changes on the intact and amputated sides

Table 3. Intragroup and intergroup comparison of participants in view of PPT and pain scores.

Parameters	Groups	Side	Prestair exercise (mean ± SD)	Poststair exercise (mean ± SD)	*P*	TT vs.TF *P*[a]
PPT (lb)	TT (n = 17)	Intact	9.19 ± 3.32	8.53 ± 3.31	0.146	0.295
		Amputated	8.68 ± 3.08	8.25 ± 3.15	0.206	0.011
		P[b]	0.191	0.108		
	TF (n = 15)	Intact	10.09 ± 2.28	8.70 ± 3.10	**0.021**	
		Amputated	10.37 ± 2.87	8.34 ± 3.23	**0.001**	
		P[b]	0.468	0.249		
Pain	TT (n = 17)	Low back	2.61 ± 2.59	2.80 ± 3.15	0.518	0.792
	TF (n = 15)		3.48 ± 2.86	3.76 ± 3.25	0.134	

Abbreviations: PPT, pressure pain threshold; TF, transfemoral; TT, transtibial.
[b]Paired sample *t* test.
[a]Analysis of variance for PPT differences values between prestair and poststair exercise.
Bold values indicate statistically significance differences.

in either group immediately after the stair exercise. However, the stiffness values decreased (although not significantly) immediately after the stair exercise. In the transfemoral amputation group, the decrease in stiffness on the intact side was significant at poststair when compared with that of the prestair levels. Because stiffness has been reported to increase with rest periods[25,26] and decrease with low-level light exercises, the stair exercise seems to be mobilizing and beneficial for stiffness on the intact side in the transfemoral amputation group, which is similar to the views of Lakie and Robson.[26] Low mean age and BMI values of the groups in addition to long daily prosthesis-wearing periods are believed to contribute toward the mobilizing effect of stair exercises.

Pain values were similar across the transtibial and transfemoral amputation groups for both sides at all measurement times. Although 34.37% of the subjects did not report any pain between prestair and poststair measurements and the intensity of pain did not change in 40.62% of the subjects, a slight acute increase in pain was observed after the stair exercise in only 18.75% of the subjects. Given the studies linking LBP with asymmetrical movement patterns and associated increased muscle activation in individuals with amputation,[10,27] pain values obtained in the study were consistent with low muscle tone.

Although the incidence of LBP has been reported to be higher in individuals with transfemoral amputation,[28] the relatively young age and low BMI of the individuals with a transfemoral amputation evaluated in this study may have played roles in negating the effects of factors that could cause LBP development.[27]

Studies have reported that TLF has a dense nociceptive receptor content (three times that of the spinal muscles).[29] Furthermore, dorsal horn neurons respond to mechanical, chemical, and electrical stimuli with strong and long-term sensitization.[30] Hence, TLF tissue has been reported to contribute significantly to LBP.[2,30] In the able-bodied population, PPT values have been reported to be lower in individuals with LBP when compared with healthy individuals[31,32]; such low levels are observed not only in the low back region but also in other body parts unrelated to the low back. Neurobiological and biopsychosocial factors are believed to be involved in the origin of this common pain, defined as central sensitization.[33] In this study, PPT measurements were performed by application of blunt pressure from the center of coordination belonging to paravertebral muscles and located on TLF. It has been stated that pain elicited by blunt pressure is not a result of central sensitization but that of peripheral sensitization, which occurs when the nociceptor stimulation threshold is lowered and silent neurons are activated because of local stimulus.[33] In addition, it has been reported that during the release of pain against blunt pressure, nociceptors of deep tissue are mainly activated, whereas cutaneous afferents play a minimal role.[34] In this study, PPT values for both sides in the transtibial amputation group decreased after the stair exercise when compared with the prestair levels, although not significantly. On the contrary, PPT values in the transfemoral group decreased significantly after the stair exercise for both the intact and amputated sides. Furthermore, the change in PPT values after stair exercise in the transfemoral amputation group was found to be significantly higher than that of the transtibial amputation group. Gradually increasing pain sensitivity on application of pressure after the stair exercise, an activity that does not increase tone and stiffness, suggests that the discharges of pain receptors in this area increase with activity, and this increase is longer in duration for individuals with a transfemoral amputation. Given that gait asymmetry observed in individuals with amputation can trigger myofascial pain,[28] the decrease in PPT may be attributed to asymmetric patterns revealed in the stair exercise. It is believed that PPT values that decrease in a nontiring stair exercise would further decrease in heavy activity or may be a sign of imminent LBP. Contrary to our opinion, there is also a study suggesting that pain causes PPT values to decrease in patients with LPB, but low PPT cannot be a risk factor of LBP.[11] Therefore, the effect of stair exercise on tone, stiffness, and PPT values of TLF and the relationship between these values and LBP need to be investigated further. Furthermore, the change in PPT values after stair exercise in the transfemoral amputation group was found to be significantly higher than that of the transtibial amputation group.

Lack of a control group is one of the limitations of our study. Further studies involving a control group comprising able-bodied individuals are needed. SCT was used as a stair exercise, and only the immediate effect was investigated. Studies using a more challenging stair exercise are required, and studies with longer follow-up periods are needed. The lack of a blind assessor may have created a bias. This situation constitutes other limitations of our study. In addition, we believe that examining the relationship between tissue properties and PPT values with back pain in future studies will provide important data on low back problems seen in amputation groups.

In conclusion, there was a significant decrease in the stiffness of TLF after stair exercise compared with the prestair levels on the intact side in the transfemoral amputation group. Similarly, in this group, PPT values of both sides showed a significant decrease immediately after the exercise. The decrease in PPT values being more significant in individuals with a transfemoral amputation can be considered as a precursor sign of LBP development in this group, which may be caused by stair exercise requiring the use of knee joint, making it a more challenging activity for individuals with a transfemoral amputation when climbing stairs. Therefore, it can be assumed that the addition of TLF-targeted therapies to rehabilitation programs may be beneficial for preventing LBP.

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Supplemental material

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