Research Paper: The Effect of Stump Level on Activity and Fatigability of Knee Extensor Muscles

Gholamreza Olyaei[1], Mohammad Reza Hadian[1], Saeed Talebian[1], Shohreh Jalaie[1], Seyed Asadullah Arslan[1], Masood Abdullah Hussein[1*]

1. Department of Physiotherapy, School of Rehabilitation, Tehran University of Medical Sciences, International Campus, Tehran, Iran.

Use your device to scan and read the article online

Citation: Olyaei Gh, Hadian MR, Talebian S, Jalaie Sh, Arslan SA, Abdullah Hussein M. The Effect of Stump Level on Activity and Fatigability of Knee Extensor Muscles. Journal of Modern Rehabilitation. 2017; 11(4):231-236.

doi:

Article info:
Received: 17 May 2017
Accepted: 24 Aug 2017

ABSTRACT

Introduction: Muscle fatigue is tiredness, in other words, loss of productive capacity of power in response to the activity. The development of fatigue during prolonged exercise may be evaluated by repeated assessments of maximal voluntary force. This study aimed to determine the effect of muscle fatigue on trans-tibial stump level in knee extensor muscles (vastus lateralis, vastus medialis, and rectus femoris) at 30 and 45 degree knee flexions by using surface electromyography.

Materials and Methods: Forty male amputees with trans-tibial amputation, aged between 18-50 years were assigned randomly in three groups; performed three isometric contractions with extended knee at 80% of the maximal voluntary contraction. Median Frequency (MDF) and Root Mean Square (RMS) values were obtained by surface electromyography from the knee extensor muscles at 30 and 45 degree knee flexions. Force values in stump and sound sides during knee flexion at 30 and 45 degree were also compared.

Results: Median frequency on sound side showed more fatigue and MDF-RMS between stump levels was short, medium, and long for knee extensor muscles at 30 and 45 degree, before and after the fatigue. No significant effect between stump and sound side was found. Vastus lateralis muscle showed more power than vastus medialis and rectus femoris muscles before fatigue. But after fatigue, rectus femoris muscle showed more power than vastus medialis and vastus lateralis.

Conclusion: Results have confirmed that trans-tibial amputees with good functional ability showed more fatigability on the sound side while stump side showed more power. Vastus lateralis muscle had maximum power on both sides. Vastus medialis and rectus femoris of long stump levels and vastus lateralis muscle of short levels were more powerful.

Keywords:
Muscle fatigue, Electromyography, Amputation

1. Introduction

Fatigue is failure to maintain the required or expected force or an inability to continue working at a given exercise intensity [1].

The muscle fatigue or weariness is tiredness and the loss of productive capacity of power in response to the activity. Numerous physiological and psychological experiments have addressed the causes of fatigue. Physiological investigations have focused mainly on the relationship between

* Corresponding Author:
Masood Abdullah Hussein, MSc. Student
Address: Department of Physiotherapy, School of Rehabilitation, Tehran University of Medical Sciences, International Campus, Tehran, Iran.
Tel: +98 (990) 4663543
E-mail: ma.zedawan@yahoo.com

exercise, endurance, circulatory, metabolic, muscular, nutritional, and thermoregulatory factors and showed that many parameters affect the capacity for prolonged exercise. The development of fatigue during prolonged exercise may be evaluated by repeated assessments of maximal voluntary force or power output [2].

Reliable assessment of muscle fatigue is highly dependent upon measurement of the force generating capacity. In humans, what is often used is Maximal Voluntary Isometric Contraction (MVIC). Several authors have pointed out that voluntarily generated force can be limited by lack of motivation and inhibitory effects at various levels in the central nervous system and at the muscle level. Maximal Voluntary Contraction (MVC) force or power output has been set as a sort of 'gold standard' to identify whether fatigue occurs or not [3]. Fatigue during exercise with the knee-extensors is easily quantified because there is only one direction of force generation (or movement), and the leg can be kept in a standard testing position. With practice and vocal encouragement by the staff, a low variability of unfatigued MVCs of upper and lower limb joints is reported [4]. In order to investigate the fatigue processes in more detail, one approach is to compare the effect on maximal power output with the effect on maximal force generating capacity. Newham et al. (1991) examined the isokinetic torque and the isometric force generating capacity before and 4 minutes after maximum knee extension. The MVC force and the maximal torque measured during fast isokinetic contractions drops to about 80%, whereas a slightly larger fall was observed for slow isokinetic contractions. Hence, the overall fatigue was thus comparable as judged by the different test contractions [5].

Amputation is the resection of a part of the lower or upper extremity of the body because of trauma, medical illness, or surgery. As a surgical measure, it is used to control pain or disease process in the affected limb such as malignancy or gangrene. In some cases, it is carried out on individual as a preventative surgery for such problems. Amputation had also been used as a tactic in war. It is classified on the basis of anatomical levels and site at which the amputation took place. For example, an amputation between the wrist and elbow is termed Trans-Radial (T.R), also known as below-elbow amputation. It can be an amputation of above and below knee, partial foot, hip disarticulation, and knee disarticulation (Through Knee) for the lower limb [6]. There are two basic techniques commonly used for Below Knee (BK) amputation. The long posterior flap technique was introduced by Burgess and Romano in 1967 which is the most commonly used method [7]. The skew flap technique was described by Robinson in 1982 [8]. During pre-prosthetic and post-prosthetic the end stump is important to relieve pain because movement becomes difficult with pain.

The importance of the topic and shortage of data were the my main reasons and motivation to perform this research. Surface EMG (sEMG) is often used to measure the muscle force production [9]. The rationale of this study was to find out the effect of muscle fatigue on Trans-Tibial (T.T) amputation. Muscle fatigue can be helpful to determine the duration and the type of exercise at rehabilitation centers.

2. Materials and Methods

After the approval from the Ethics Committee of Tehran University of Medical Sciences (TUMS), this study was conducted at the physical rehabilitation center of International Committee of the Red Cross (ICRC) in Iraq. Forty male amputees with T.T amputation, aged between 18-50 years were assigned randomly in three groups; Group (A) amputees with short T.T amputation, Group (B) with medium T.T amputation, and group (C) with long T.T amputation. Raw data were collected by using sEMG device (NTS-2000-SEMG-4) [10]. Each amputee was assessed in both stump and sound sides for any redness or injury. MVIC of knee extensor muscles was measured by using digital Lutron force gauge (LT FG-5020) before and after fatigue. The subjects comfortably maintained their knees at 30 and 45 degree knee flexion for both knees [11] and the force was measured in Newtons (N). Every patient executed three valid repetitions with 80% of MVC for 10 seconds to find the mean of maximum fatigue [12]. A resting time of 20 seconds was given between repetitions.

An amputee with T.T (BK) amputation contracted his muscles to reach muscle fatigue point which was measured by dynamometer. Electrodes were placed according to the guidelines of surface EMG for non-invasive assessment of muscles. Position of dynamometer was set at the resistant of knee flexion at 30 and 45 degree and placed on the 80% of length in stump and sound legs. First test was for selecting MVC, amputee performed 80% of MVC with knee flexion at 30 and 45 degree [13]. Mean force of 80% MVC for 3 trials was measured to select the extent of muscle fatigue. The next tests were performed before and after muscle fatigue by asking amputee to contract his muscle at 30 and 45 degree knee flexion by maintaining same position and it was monitored by dynamometer to reach at fix point which was selected previously from 3 trials of MVC to get fatigue point.

Fatigue of the knee extensors, Vastus Medialis (VM), Rectus Femoris (RF) and Vastus Lateralis (VL) quadriceps muscles was measured in both stump and sound sides using force transducer (N) after taking 80% of MVC. Maximum muscle activity during 5 seconds of early (before) and late (after fatigue occurred) was selected for comparison. Median frequency at above mentioned durations (5 seconds before and 5 seconds after fatigue) was considered for the analyses of fatigability. Maximum and minimum amplitude with duration were selected to measure muscle fatigue. Root mean square (RMS) was also measured for muscle fatigue process [14-17].

3. Results

The Median Frequencies (MDF) and RMS are presented in Table 1, by illustrating all study variables and conven-

Table 1. Differences of MDF and RMS for stump and sound sides with 30 and 45 degree flexion

Runs Test												
Statistics	Difference of Median Frequency RMS Stump Side											
	30 Degree Flexion			45 Degree Flexion			30 Degree Flexion			45 Degree Flexion		
	VM	RF	VL	VM	RF	VL	VM	RF	VL	VM	RF	VL
Test value	0.27	0.4	0.335	0.235	0.25	0.14	0.105	0.15	0.11	0.175	0.305	0.265
Cases<Test value	19	17	20	20	20	19	20	20	20	20	20	20
Cases>Test value	21	23	20	20	20	21	20	20	20	20	20	20
Total cases	40	40	40	40	40	40	40	40	40	40	40	40
Number of runs	18	20	26	19	26	20	18	15	20	19	22	21
Z	-0.787	-0.02	1.44	-0.48	1.44	-0.15	-0.80	-1.76	-0.16	-0.481	0.16	0.00
Asymp. Sig. (2-tailed)	0.431	0.987	0.149	0.63	0.15	0.89	0.42	0.08	0.87	0.63	0.87	1.00
C.S.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

JMR

Table 2. Indirect speeds to sEMG signal resulted by a fatigue status for stump side and sound side with 30 degree flexion of VM, RF, and VL muscles by Huber's Estimator test

Indirect Speed to EMG Signal					
Stump Side/Sound Side	Periods	Huber's μ Estimator	S^2	μ/S^2	Decay % (Order)
RMS of stump side 30 degree flexion of VM	Before fatigue	398.264	21.3525	18.6519	19.05 (5)
	After fatigue	352.0809	23.3186	15.0987	
RMS of stump side 30 degree flexion of RF	Before fatigue	472.2296	20.3768	23.1749	19.42 (4)
	After fatigue	368.0204	19.7078	18.6738	
RMS of stump side 30 degree flexion of VI	Before fatigue	486.8129	24.5393	19.8381	12.63 (6)
	After fatigue	349.3903	20.1592	17.3316	
RMS of sound side 30 degree flexion of VM	Before fatigue	84.4783	15.2265	5.5481	37.66 (2)
	After fatigue	62.367	18.0316	3.4588	
RMS of sound side 30 degree flexion of RF	Before fatigue	441.7827	19.2443	22.9565	21.79 (3)
	After fatigue	346.2258	19.2833	17.9547	
RMS of sound side 30 degree flexion of VI	Before fatigue	475.0918	17.488	27.1667	37.92 (1)
	After fatigue	323.2446	19.1656	16.8659	

JMR

Table 3. Indirect speeds to EMG signals resulted by fatigue status of stump and sound sides at 45 degree flexion of VM, RF, and VL muscles by using Huber's Estimator test

Indirect Speed to sEMG Signal					
Stump Side/Sound Side	Periods	Huber's µ Estimator	S^2	μ/S^2	Decay %
RMS of stump side 45 degree flexion of VM	Before fatigue	435.7318	23.8261	18.2880	13.87 (5)
	After fatigue	373.3348	23.7007	15.7521	
RMS of stump side 45 degree flexion of RF	Before fatigue	82.2507	5.2963	15.5298	20.33 (4)
	After fatigue	76.0119	6.1436	12.3725	
RMS of stump side 45 degree flexion of VL	Before fatigue	475.4936	22.684	20.9616	10.83 (6)
	After fatigue	369.2583	19.7551	18.6918	
RMS of sound side 45 degree flexion of VM	Before fatigue	418.1973	14.8683	28.1268	25.94 (3)
	After fatigue	336.5194	16.1547	20.8311	
RMS of sound side 45 degree flexion of RF	Before fatigue	425.1867	19.0393	22.3321	34.00 (1)
	After fatigue	360.0421	24.4269	14.7396	
RMS of sound side 45 degree flexion of VL	Before fatigue	494.9488	19.0284	26.0111	33.74 (2)
	After fatigue	369.1821	21.4193	17.2360	

JMR

tional effects resulted from fatigue. Since no significant differences at P>0.05 were accounted for MDF, it could be concluded that a meaningful constraint had occurred due to fatigue. In other words, with no significant difference throughout the applied tests, fatigue changes indicated that the sample was not random.

Degenerative effects of fatigue were estimated from sound side muscles (VM, RF and VL) by indirect speed of sEMG signals and were reported in Table 2. Fatigue was higher in sound side than stump side at 30 degree knee flexion. Results showed that vast majority of fatigue was experienced in RMS of sound side at 30 degree flexion of VL, and were accounted as 37.92%, while RMS of stump side at 30 degree flexion of VL had reported the low result (12.63%). Both muscles, VM and RF were recorded as 37.66%, 21.79%, respectively in sound side at 30 degree knee flexion while in stump side these were 19.05% and 19.42%, respectively which showed the muscle fatigue in sound side.

Table 4. Differences in median frequency of VM, RF and VL muscles between stump levels (short, medium, and long) by repeated measured test

Level of Stump	VM Muscle			RF Muscle			VL Muscle		
	Mean Difference (I-J)	SD Error	Sig.	Mean Difference (I-J)	SD Error	Sig.	Mean Difference (I-J)	SD Error	Sig.
Short	26.0967	60.43822	0.668	42.6467	37.27301	0.260	26.8282	37.85764	0.483
Medium	06.1873	63.84951	0.923	27.3515	39.37680	0.492	12.0170	39.99443	0.766
Long	32.2802	61.77234	0.604	69.9982	38.09591	0.074	14.8113	38.69345	0.704

JMR

The results in Table 3 present the decays percentage of sEMG signals, indirect speed was due to fatigue of sound side at 45° knee flexion, followed by RF, VL and VM which were recorded as 34.00%, 33.74%, and 25.94%, respectively. The decay percentages of muscle fatigue in stump side were 20.33% for RF, 13.87% for VM, and 10.83% for VL. Results also clarified the muscle fatigue in sound side with 45 degree flexion.

There was no significant difference between stump levels; short, medium and long, for knee extensor muscles (VM, RF & VL) as shown in Table 4. The mean value of VL muscle increased in short stump than its mean in medium and long stump levels. The mean values of RF and VM muscle also increased in long stump level compared to their mean values in short and medium stump levels.

4. Discussion

Previous researchers had also discussed the effect of knee extensor fatigue on the muscle force and one such study proved significant decrease in the peak force of fatigued limb which is similar to present study but no significant changes in the non-fatigued limb's muscle force were noted [18]. Active and independent ambulation with less expenditure of energy is the main objective during rehabilitation [6]. The rehabilitation program for pre- and post-prosthetic must include strengthening, maintenance of joint range of motion, best movement coordination of the remaining muscles and adequate development of proprioception. Patients with trans-tibial amputation have energy expenditure around 9% to 42% higher than people without amputations [19]. According to the findings of present research (Table 2), fatigue in the sound side extensor muscles was more than the stump side. One study previously evaluated the strength and endurance of the quadriceps and hamstring muscles in T.T amputees and showed that the fatigue index for extension was not significantly different in the sound limb from the amputated limb but fatigue index for flexion was significantly higher in the sound limb which also indicates the proper functioning of stump side muscles. Therefore, a significant and good reaction from the muscles of the amputated limb could be expected if a correct strengthening and endurance training program is selected properly [20].

Results of the present study showed an increase in muscle fatigues, sEMG, RMS for all three extensor muscles (VM, RF and VL) of the knee on the sound side at 30 and 45 degree knee flexion with 80% of MVC. Results confirmed more muscle fatigue on sound side compared to the stump side [21] in case of pressure on both sides at 30 and 45 degree knee flexion. Time and repetition of exercise for stump side must be taken into consideration because of difference in muscle fatigue, tightness, weakness; impaired balance due to gait asymmetries between two sides before and after performing prosthesis [22].

Results have also confirmed that T.T amputees with good functional ability at 30 and 45 degree knee flexion showed more fatigability on the sound side compared to the stump side. The stump side has also shown more power parameters in knee extensor muscles than the sound side. The VL muscle on stump and sound sides at both knees flexions (30 and 45 degree) had more power than RF and VM muscles. RF muscle of stump side with 30 degree knee flexion showed more power than 45 degree flexion. The long stump level had more power than medium and short stump levels for VM and RF muscles, while the short stump levels had more power than long and medium stump levels for VL muscle.

Ethical Considerations

Compliance with ethical guideline

This research was approved by the Ethics Committee of Tehran University of Medical Sciences.

Funding

The present article was extracted from the MSc. thesis of Masood Abdullah Hussein at Department of Physiotherapy, Tehran University of Medical Sciences. The research was conducted at Physical Rehabilitation Center for Proshesis & Orthosis (ICRC) in Erbil / Iraq.

Conflict of interest

We confirm that this work has not been published elsewhere and is original. We also confirm that there is no conflict of interest to disclose and all the authors approved the manuscript for submission.

Acknowledgements

We appreciate all the relevant authorities at TUMS and the participants for helping us to accomplish this research.

References

[1] Booth FW, Thomason DB. Molecular and cellular adaptation of muscle in response to exercise: perspectives of various models. Physiological Reviews. 1991; 71(2):541-85. [DOI:10.1152/physsrev.1991.71.2.541]

[2] Nybo L, Secher NH. Cerebral perturbations provoked by prolonged exercise. Progress in Neurobiology. 2004; 72(4):223-61. [DOI:10.1016/j.pneurobio.2004.03.005]

[3] Vøllestad NK. Measurement of human muscle fatigue. Journal of Neuroscience Methods. 1997; 74(2):219-27. [DOI:10.1016/S0165-0270(97)02251-6]

[4] Gandevia SC, Enoka RM, McComas AJ, Stuart DG, Thomas CK. Neurobiology of muscle fatigue. Fatigue. 1995; 384:515–25. [DOI:10.1007/978-1-4899-1016-5_39]

[5] Newham D, McCarthy T, Turner J. Voluntary activation of human quadriceps during and after isokinetic exercise. Journal of Applied Physiology. 1991; 71(6):2122-6. [DOI:10.1152/japapl.1991.71.6.2122]

[6] Engstrom B, Van de Ven C. Physiotherapy for amputees: the Roehampton approach. London: Churchill Livingstone; 1985.

[7] Ruckley CV, Stonebridge PA, Prescott RJ. Skewflap versus long posterior flap in below-knee amputations: multicenter trial. Journal of Vascular Surgery. 1991; 13(3):423-7. [DOI:10.1067/mva.1991.25644]

[8] Rosenman LD. Syme amputation for ischemic disease in the foot. The American Journal of Surgery. 1969; 118(2):194-9. [DOI:10.1016/0002-9610(69)90120-2]

[9] Wang L, Buchanan TS. Prediction of joint moments using a neural network model of muscle activations from EMG signals. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 2002; 10(1):30-7. [DOI:10.1109/TNSRE.2002.1021584]

[10] Seibt R, Shnieder J. A new method for quantification of muscular force and fatigue by using surface electromyographical measurements. BioMedical Engineering OnLine. 2012; 11:55.

[11] Saito A, Akima H. Knee joint angle affects EMG–force relationship in the vastus intermedius muscle. Journal of Electromyography and Kinesiology. 2013; 23(6):1406-12. [DOI:10.1016/j.jelekin.2013.08.009]

[12] Talebian S, Bagheri H, Hosseini M, Olyaei GR. The investigation of median frequency changes in paraspinal muscles following fatigue. Iranian Rehabilitation Journal. 2009; 7(2):31-35.

[13] Bilodeau M, Schindler-Ivens S, Williams D, Chandran R, Sharma S. EMG frequency content changes with increasing force and during fatigue in the quadriceps femoris muscle of men and women. Journal of Electromyography and Kinesiology. 2003; 13(1):83-92. [DOI:10.1016/S1050-6411(02)00050-0]

[14] Wojtys EM, Wylie BB, Huston LJ. The effects of muscle fatigue on neuromuscular function and anterior tibial translation in healthy knees. The American Journal of Sports Medicine. 1996; 24(5):615-21. [DOI:10.1177/036354659602400509]

[15] Roebroeck ME, Harlaar J, Lankhorst GJ. Reliability assessment of isometric knee extension measurements with a computer-assisted hand-held dynamometer. Archives of Physical Medicine and Rehabilitation. 1998; 79(4):442-8. [DOI:10.1016/S0003-9993(98)90147-2]

[16] Rainoldi A, Melchiorri G, Caruso I. A method for positioning electrodes during surface EMG recordings in lower limb muscles. Journal of Neuroscience Methods. 2004; 134(1):37-43. [DOI:10.1016/j.jneumeth.2003.10.014]

[17] Surakka J, Virtanen A, Aunola S, Maentaka K, Pekkarinen H. Reliability of knee muscle strength and fatigue measurements. Biology of Sport. 2005; 22(4):301.

[18] Arora S, Budden S, Byrne JM, Behm DG. Effect of unilateral knee extensor fatigue on force and balance of the contralateral limb. European Journal of Applied Physiology. 2015; 115(10):2177-87. [DOI:10.1007/s00421-015-3198-5]

[19] Pedrinelli A, Saito M, Coelho RF, Fontes RB, Guarniero R. Comparative study of the strength of the flexor and extensor muscles of the knee through isokinetic evaluation in normal subjects and patients subjected to trans-tibial amputation. Prosthetics and Orthotics International. 2002; 26(3):195-205. [DOI:10.1080/03093640208726648]

[20] Moirenfeld I, Ayalon M, Ben Sira D, Isakov E. Isokinetic strength and endurance of the knee extensors and flexors in transtibial amputees. Prosthetics and Orthotics International. 2000; 24(3):221-5. [DOI:10.1080/03093640008726551]

[21] Isakov E, Burger H, Gregoric M, Marincek C. Stump length as related to atrophy and strength of the thigh muscles in transtibial amputees. Prosthetics and Orthotics International. 1996; 20(2):96-100. [DOI:10.3109/03093649609164425]

[22] Kapp S. Visual analysis of prosthetic gait. In: Douglas G, Smith, MD editors. Atlas of amputation and limb deficiencies: Surgical, prosthetic, and rehabilitation principles 3rd edition. Rosemont: American Academy of Orthopedic Surgeons; 2004.