Activation patterns of quadriceps and gastrocnemius muscles during a step-up task in patients with osteoarthritis

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Abstract

Introduction: It is often seen that patients with Osteoarthritis (OA) continue to have reduced Quadriceps activity even after long term rehabilitation, suggesting that there might be overactivity of other muscles. Hence, the aim of this study was to find if there existed a difference in the muscle activity of Quadriceps and Gastrocnemius during a step up task in patients with OA as compared to normal individuals.

Aim: To assess and compare the EMG activation of Gastrocnemius and Rectus femoris in patients with OA knee and in asymptomatic individuals.

Design: Laboratory controlled exploratory design.

Material and Methods: 35 subjects with OA and 34 asymptomatic individuals were taken up for the study. Subjects were age, gender and BMI matched.Subjects underwent an isometric strength test on Isokinetic Dynamometer. The Maximum Voluntary Contraction (MVC) with an EMG machine was recorded. Subjects stepped up on a single step 10 times, during which EMG activity was recorded from Rectus Femoris, Lateral Gastrocnemius and Medial Gastrocnemius. Data was analysed from the 6th, 7th and 8th trials after normalizing raw amplitude values to MVC values.

Statistical analysis: Independent 't' test was used to compare muscle activity percentage values between groups as well as within groups.

Results: Between comparison showed a significant increase in the EMG activity of Lateral Gastrocnemius ($p<0.01$) as well as Medial Gastrocnemius ($p<0.01$) in the OA group. However, differences between Rectus Femoris activities did not reach significant levels.

Conclusion: The present study showed a significant difference between Quadriceps and Gastrocnemius muscle activities during a step up task in OA patients as compared to normal individuals.

Keywords: EMG activity, Gastrocnemius, Osteoarthritis, Quadriceps, Step up task.

Introduction

Osteoarthritis (OA) is widespread and one of the most leading causes of disability worldwide, mainly due to pain. This condition is progressive with age. It is seen commonly that the knee joint is one of the most affected. The prevalence of OA is 27% in subjects younger than 70 yrs and 44% in subjects aged 80 yrs or above.[1,2]

The hallmark impairment in knee OA is Quadriceps weakness but it is surprising that there is a shortage of information to identify the cause. The reasons behind Quadriceps weakness have been linked to factors like arthrogenous muscle inhibition, pain and effusion in the knee joint.[3-5]

Gastrocnemius is one of the key muscles performing plantarflexion. It is also capable of inducing knee extensor acceleration during the weight acceptance phase of gait but switches to being a knee flexor during the loading response to mid-stance phase in which the knee joint has to perform continuous extension. A study performed in patients who had undergone Total Knee Arthroplasty (TKA) linked Gastrocnemius over-activity to reduced knee extensor moment in stepping up as compared to normals.[6] Patients used this new learned habit as a carry-over pattern even after TKA rehabilitation. A study by Hubley-Kozey et al. found that the muscle activation patterns of lower limb alter in a systematic manner as structural severity increases in OA.[7,8] These muscle activation changes are seen to exist even after patients undergo rehabilitation after TKA. Despite better technology and improved surgical techniques, patients continue to show long term functional deficits and difficulty in Activities of Daily Living (ADL).[9,10] This gives rise to the hypothesis that the altered muscle patterns arise due to OA and continue to remain even after TKA.

It is quite well-known that OA is the leading contributor to functional limitations leading to mobility impairments which further lead to reduced quality of life.[11] A step up task is an integral part of stair climbing which in turn is an important functional requirement for mobility. The purpose of this study was to find out if there exists a difference in activation patterns between OA patients as compared to the normal population. It was hypothesized that there will be a significant difference in activation pattern between Quadriceps and Gastrocnemius of OA patients as compared to normal population. The information from this study can be used to make better rehabilitation strategies which would further improve the mobility and the quality of life of OA patients.

Material and Methods

A laboratory controlled exploratory study design was used where patients with osteoarthritis of the knee visiting the out-patient department of orthopedics and the

department of physiotherapy of Ramaiah hospital, Bangalore, were recruited using convenience sampling.

Rutherford et al (2013) conducted a study and had observed that amplitude pattern in lateral gastrocnemius among asymptomatic group was 210.2 +/- 84.4 and among the OA group with Kellgren and Lawrence grade 4 was 176.6 +/- 62.4. In the present study with step up activity, similar results were expected with 80% power at 95% confidence level. The sample size for the study was calculated as 35 subjects in each group.

Subjects: 35 volunteers (7 males, 28 females) with mean age of 53.97 ± 8.38 years were recruited for the OA study group whereas 34 volunteers (8 males, 26 females) with mean age of 52.61 ± 8.51 years were recruited for the control group. Patients were included if they were above 40 years of age, had OA severity grade of 3 or 4 according to Kellgren and Lawrence scale and were capable of doing the dynamic task independently. Exclusion criteria included those with any inflammatory joint diseases, recent fractures or surgeries, any psychological and neurological issues. An ethical clearance was obtained from the Ethics committee of Ramaiah Medical College and written informed consent forms were taken from each of the volunteers.

Preparation of sample: Surface EMG electrodes were placed on the Rectus Femoris (RF), Lateral Gastrocnemius (LG) and the Medial Gastrocnemius (MG) muscles of each subject after applying abrasive gel. The electrodes were placed according to the SENIEM (Surface EMG for a Non-Invasive Assessment of Muscles) guidelines with the recommendations of Hubley-Kozey et al (2005).

Data recording: 2 channel EMG units were used to measure the different muscle activities. A 50 Hz, low pass, 4th order Butterworth filter with a 50 Hz notch filter was used in the study. Raw signals were sampled at 2048 using the Thought Technology systems, Canada. Root mean square (RMS) was calculated at 128 Hz. EMG data were recorded using the Biograph Infinity software and were measured in microvolts and milliseconds.

Procedure for Maximum Voluntary Contraction (MVC) values: Subjects were asked to undergo an isometric strength test using the Humac Norm Isokinetic Dynamometer machine. For the strength test of the Quadriceps, subjects were seated and they had to perform continuous isometric knee extension for 10 seconds in 90 degrees of knee flexion. Three trials followed by three test contractions were performed. For the plantarflexors, the subjects had to lie down prone with knee in extension. They had to do isometric plantarflexion at 0 degree or neutral ankle for 5 seconds. Three trials followed by three test contractions were performed. EMG data were recorded from all muscles while the contractions were performed. (Fig. 1)

Step up activity: Two flights of steps were made with dimensions as 10 inches of tread length and 8 inches of tread rise according to the 2006 International Residential Codes. EMG electrodes were placed on RF, LG and MG muscles of the test leg. Subjects had to undergo 10 trials of step ups out of which the first 5 were for practice or learning experience. Data from the 6th, 7th and 8th trials of all the individual muscles were taken up for analysis. (Fig. 2)

Temporal windowing of data: All data were windowed so that only data from specific phases of the task could be analyzed. The patients were required to perform the task without any kind of support. From the recorded video, the start of the stepping up phase was identified as heel off from the ground of the test leg. The end of the step up activity was identified as relaxed double support standing on the step. This was done for all the trials of each subject. The peak amplitude activity of each muscle was identified within the start and the end of the step up activity. The raw peak amplitude values were taken up for further analysis.

Normalization procedure of EMG data: A normalization had to be done to ensure that each individual muscle come on a same relative level in order to be compared. Firstly, out of the three MVC trial values, a mean MVC value was obtained for each muscle for each individual. Then all the raw EMG peak amplitude data for each muscle of each subject during the 10 step ups were identified. A ratio value between the raw amplitude data and the mean MVC value was obtained for each muscle activity for each trial. Furthermore, the ratio values of the 6th, 7th and 8th trials were identified and the mean was calculated. This mean value was then converted into a percentage value which represented the respective muscle activity for each individual.

Fig. 1: Collection of RF MVC

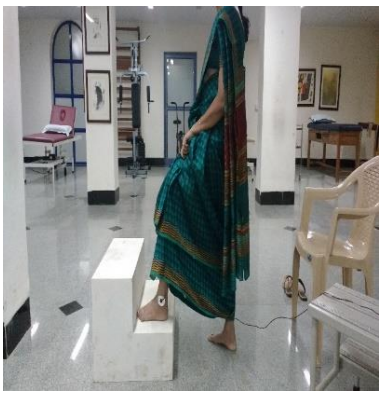

Fig. 2: Step up activity

Statistical Analysis

All data assessment and analysis were done using Microsoft Excel, where raw data was charted out and ratio and percentage values of EMG activity were calculated. Following this, mean and standard deviation were calculated for each individual muscle activity. A confidence level of 95% and a significance value of $p< 0.05$ were set for this study. Independent 't' test was used to compare muscle activity percentage values between groups as well as within groups. All statistical tests were performed in IBM SPSS 19 software.

Results

According to the objective of the study, individual muscle activity percentage values were compared between the OA group and the normal group. The lateral and the medial gastrocnemius muscle activities differed significantly between the OA and the normal group. The mean LG activity of the OA group was 99.97 ± 68.91 % as compared to the normal group where the LG activity was 51.11 ± 20.3% leading to significant level of difference with a 't' value of 4.01 and a p value of 0.0001. The mean MG activity of the OA group was found out to be 114.74 ± 79.14% as compared to the normal group where the mean MG activity was 57.02 ± 32.01%, again leading to a significant difference level with a 't' value of 3.99 and a p value of 0.0001.

Similarly, the RF activities were also compared between groups. The mean RF activity of the OA group was 75.48 ± 43.97% as compared to that of the normal group where the RF activity was 91.2 ± 55.69%. Although there was a difference seen between the two RF means, this however did not reach significant level, where the 't' value was -1.29 and the p value was 0.199. (Table 1)

Table 1: Comparison of EMG activity percentages between groups

Group	n	Muscles	Mean	SD	t-value	p-value
OA	35	RF	75.49	43.98	-1.299	0.199
Non OA	34	RF	91.21	55.69		
OA	35	LG	99.97	68.91	4.018	0.0001
Non OA	34	LG	51.12	20.30		
OA	35	MG	114.74	79.14	3.991	0.0001
Non OA	34	MG	57.03	32.01		

RF-Rectus femoris, LG –Lateral Gastrocnemius, MG-Medical Gastrocnemius

Discussion

Between group comparisons showed significant difference in the Gastrocnemius activities. This shows that the Gastrocnemius activity in the OA group was considerably higher than that of normal individuals. These results can be explained with reference to previous studies where Hubley-Kozey et al (2008) found that there was increased Gastrocnemius activity in OA patients during walking.[8] It was theorized in the study that the increased Gastrocnemius activity was a result of compensations for knee joint instability commonly found in OA patients.[12] Moreover, Winter et al (1980) in his study theorized that the total extensor support moment of the lower limbs is shared between the ankle, knee and hip joints.[13] The inferences drawn from these studies point towards the fact that the knee joint loses its optimum extensor moment in OA patients due to Quadriceps inhibition associated with bone degeneration and bone marrow lesions.[7,14] Moreover, since the knee joint loses its optimum extensor moment, the ankle and the hip joints share the total support moment to keep the lower limbs in extension. The Gastrocnemius group further compensates for the knee joint instability.

Neptune et al (2001) in his study pointed out that although the Gastrocnemius acts as a flexor at the knee joint, it also switches and helps in knee joint extension during a continuous extensor phase of the joint. This can lead to possible explanations as to why the Gastrocnemius had higher activity. Stepping up involves continuous extension of the knee joint. Since the Quadriceps loses its maximum extensor potential in OA, the Gastrocnemius group of muscles compensates as a knee joint extensor during the continuous extension phase.

There were also differences in the RF activities between the groups but this did not reach significant levels. The differences between the RF activities are due to pain in the knee joint which leads to arthrogenous muscle inhibition of the Quadriceps muscle. Because of the pain, the patient increasingly tends to avoid the use of the Quadriceps. Over a period of time the patient develops a different motor strategy of knee extension where the Quadriceps fire with a reduced potential and the action is performed by compensations from other groups of muscles such as the Gastrocnemius.[8,12] This is in agreement to the Hubley-Kozey (2008) study where it was pointed out that OA patients eventually learn a different motor strategy which gets carried over even after post TKA in patients. Andriacchi et al (1993) and Mizner et al (2005) have also reported a reduced quadriceps extensor moment and altered temporal patterns of muscle firing respectively in post TKA patients in their studies.[9,15]

Conclusion

The present study involving OA patients proved that there is a significant difference in EMG activity percentages between Quadriceps and Gastrocnemius muscles during a step up task in OA patients as compared to normal subjects. Among the limitations of the study, subjects in both the groups could not be matched exactly. Furthermore, the biomechanical changes among subjects weren't taken into account. Further studies looking in to neuromuscular alterations in OA patients might reveal more information which can be used for a better treatment strategy.

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