

Comparative Study on Muscle Activity and Torque Value of Quadriceps of Healthy Adults

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Purpose: The current study seeks to identify the relationship between torque values of the quadriceps and muscle activity during isometric and isokinetic exercises.

Methods: The subjects of the study included 29 healthy individuals (17 men and 12 women) who took part in isometric and isokinetic exercises that utilized the quadriceps. The isometric exercises were performed three times each at 4 different angles (0, 30, 60, and 90 degrees). For the isokinetic exercises, concentric contraction and eccentric contraction were undertaken three times each at two angular velocities (30 and 60 degrees).

Results: The muscle activity of the quadriceps during the isometric exercises showed significant differences at the 30, 60, and 90 degree angles. During the concentric contractions and eccentric contractions, muscle activity at the peak torque of the quadriceps indicated significant differences in vastus medialis, vastus lateralis, and rectus femoris at angular velocities of 30 and 60 degrees.

Conclusion: When applied clinically based on the biomechanical analysis of the current study, it is possible to anticipate and selectively strengthen muscles with isometric and isokinetic exercises for not only healthy adults and professional athletes, but also for those who experience limited knee movement for long periods following knee surgeries.

Keywords: Electromyography, Isometric contraction, Isokinetic contraction

INTRODUCTION

Knee joints are some of the joints that are regularly used in physical activity, and they also help provide overall balance for the body.¹ By performing flexion frequently, knee joints help carry out a great deal of activities and undergo substantial stress, which often leads to damage and wear and tear to the joints and causes pain and functional restrictions when walking, climbing stairs, and sitting/standing up.² Successful rehabilitation of the knee joints requires restoring muscular strength and thus stabilizing knee joints' functionality.³ Also critical are exercises that stabilize and strengthen the quadriceps and restore their functions.⁴

Weakened quadriceps often cause difficulties in the extension of knee joints when sitting, which also happens when external loads are limited to the weight of the calf.⁵ Of the quadriceps, if muscular

imbalance of vastus medialis and vastus lateralis occurs, patellofemoral pain syndrome can develop and weaken the functions of the knee joints. There have studied the muscle activity of vastus medialis and vastus lateralis in patellofemoral pain syndrome patients, and other research has found that as the quadriceps constitute the tendon in the knee joints, they can affect dislocation of the knee bones.⁷⁻¹⁰ Out of all the quadriceps, the vastus medialis is the weakest physiologically is the first to atrophy, and is slow to recover; therefore, it can cause imbalance of the quadriceps.¹¹

While studies on the quadriceps have primarily focused on rehabilitation and preventive interventions, some studies have examined how damage to the quadriceps can change the mechanical stress environment of the knees and cause adjustments to the nerve roots. In particular, some studies have looked into the causes that undermine the ability of the quadriceps to produce muscular strength by

Received Jun 2, 2016 Revised Jun 22, 2016

Accepted Jun 22, 2016

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analyzing electromyograms and walking. These studies have provided basic information related to mechanical stress on the knees caused by injuries.^{12,13}

For the purpose of strengthening and assessing the muscular strength of the quadriceps, isokinetic devices, such as the Biodex System, are used.¹⁴ Such devices are considered gold standard tools as they enable not only quantitative evaluation of muscular functions, but also assessment of various factors such as torque values, strength, and endurance.¹⁵ In addition, torque values are critical indicators for quantitative evaluation of muscles, and they are regarded as the overall result of tension caused by muscular contractions.¹⁶ Previous studies on torque values include comparisons of peak torque values of the quadriceps and hamstrings with isokinetic exercises,¹⁷ and of the effects of maximum grip strength and wrist torque values during isokinetic exercises with different wrist positions.¹⁸ In addition, there have been several studies on the correlation between muscle activity caused by the movement of joints and torque values, which have proven the existence of a correlation between muscle activity and torque values.¹⁹ While there have been studies on muscle activity and torque values utilizing electromyograms and isokinetic devices, no study has examined the activity of different muscles at different angles in the relationship between the muscle activity of the quadriceps and torque values. Therefore, the current study seeks to identify the relationship between torque values and the muscle activity of the quadriceps with isometric exercises conducted at four angles (0, 30, 60, and 90 degrees) and isokinetic exercises performed at the angle of 30 and 60 degrees.

METHODS

1. Subjects

The subjects of the current study were comprised of 29 healthy individuals (17 men and 12 women). Before beginning the experiments, the subjects were briefed on the purpose and methods of the study, and the experiments proceeded with those who voluntarily agreed to participate. The subjects were asked to fill out and submit a statement of consent in accordance with the ethical principles for medical research involving human subjects of the Declaration of Helsinki. In terms of protocol, the current study obtained approval from the Ethics Committee of Catholic University of Daegu to conduct the experiment.

The average age of the subjects was 23.55, the average height was 171.2 cm, the average weight was 64.9 kg and the average BMI (Korean Dietetic Association, 2008) was 22.0 kg/m². The inclusion criteria were; 1. Subject without orthopedic or neurologic problems within 1 year, 2. Subject without functional limitations or pain on the knee joints, 3. Subject without diseases causing autonomic nerve system problem, 4. Subject without cognitive limitation causing difficulties to participate in the study, 5. Subject with the distance between ankles or knees no more than 4 cm.¹⁴

2. Experimental methods

1) Measurement

(1) Biodex system IV

An isokinetic muscular strength measurement device (Biodex System IV, Biodex Medical Systems, USA) was used for the study. Isokinetic muscular strength measurement devices are characterized by their ability to measure the quantitative values of muscular strength during isokinetic and isometric exercises. The Biodex device was used to activate the quadriceps as they were the subject of the experiment. Subject performed stretching exercises to prevent muscle spasm and to improve joint mobility and muscle flexibility prior to measurements (standing hamstring stretching 10 times each leg and sit to stand 10 times). For minimizing muscle fatigue, subject rested as long as needed between isometric and isokinetic movements. Measurements at each joint angles were performed randomly.^{20,21} Isometric exercises were performed three times each at 0, 30, 60, and 90 degree angles, with the maximum extension of the knees (0 degrees) as the standard. In addition, for the isokinetic exercises, after the joint range of motion was measured for each subject concentric and eccentric contractions were conducted three times each at 30 degrees per second and 60 degrees per second within the measured range of motion.

(2) Surface EMG

In order to measure the muscle activity of the quadriceps, an 8-channel wireless surface electromyogram device (WEMG-8 [LXM5308], LAXTHA, Korea) was used. To begin with, the hairs on the quadriceps of the participants were shaved away, and the skin was swept gently with sand paper and wiped with an alcohol-smear swab to minimize friction between the electrodes and the skin before placing electrodes on the vastus medialis, vastus latera-

lis, and rectus femoris of the left and right legs. The electrodes were placed on the vastus medialis at 55 degrees of the long axis of the thigh above the knee bones 3 to 4 cm inwards. For the rectus femoris, the electrodes were placed on the midpoint between anterior inferior iliac spine and knee bones, 9 to 16 cm above the knee bones. For the vastus lateralis, the electrodes were placed at 15 degrees of the long axis of the thigh, 6 to 8 cm outwards above the knee bones. Ground electrodes were placed on the surface of the knee bone of the opposite leg, and the spaces between the electrodes for each channel were kept at 2.2 cm.²² The sampling rate collected through electromyographic signals was set at 1,024 Hz, and 10-450 Hz band-pass filters and 60 Hz notch filters were used. EMG data were rectified and smoothed using a Root Mean Square (RMS) algorithm. %MVIC was used for normalization of the EMG data and %MVIC were measured prior to data collection in manual muscle testing positions.²³

2) Statistical analysis

SPSS version 18.0 was used for computing statistics. To compare differences in muscle activity during the isometric exercises at four different angles, a repeated one-way ANOVA was used, while a one-way ANOVA was used to compare differences in muscle activity during isokinetic exercises at two different angle. For the post-hoc test, Bonferroni was used. The level of statistical significance was set at 0.05.

RESULTS

The muscle activity of the quadriceps measured at different angles of isometric exercises showed significantly higher across the three different angles ($p < 0.05$). The result of post-hoc analysis indicated significantly higher at the isometric exercises of 30 and 60 degrees in the vastus medialis and rectus femoris and in the vastus medialis and vastus lateralis and at 90 degrees in the rectus femoris and vastus lateralis (Table 1). During the concentric contraction, the level of muscle activity at the maximum torque value of the quadriceps showed significantly higher in all three different muscles at the isokinetic exercises of 30 degrees ($p < 0.05$). The result of the post-hoc analysis indicated significantly higher in the vastus medialis and vastus lateralis and in the rectus femoris and vastus lateralis. During an eccentric contraction, the level of muscle activity at the maximum torque value of the quadriceps showed significantly higher in all the three different muscles at the isokinetic exercises of 30 degrees ($p < 0.05$). The results of the post-hoc analysis indicated significantly higher in the vastus medialis and vastus lateralis and in the rectus femoris and vastus lateralis (Table 2).

DISCUSSION

The current study aims to explore and compare the relationship between torque values and muscle activity of the quadriceps by having healthy men and women in their twenties conduct isometric exer-

Table 1. Comparison of quadriceps muscles EMG according to isometric exercise (Unit: %MVIC)

	0°	30°	60°	90°	F
VM	248.89±127.82	153.81±96.17	176.17±148.71	192.96±112.59	12.95*
RF	282.51±159.73	232.18±159.11	256.02±157.01	256.90±150.06	3.54*
VL	295.98±131.11	219.46±142.93	265.96±208.33	260.47±148.42	9.09*
F	2.052	9.324*	7.669*	6.898*	

VM: Vastus medialis, RF: Rectus femoris, VL: Vastus lateralis.
* $p < 0.05$.

Table 2. Comparison of quadriceps muscles peak torque according to 30°, 60° isokinetic exercise during concentric and eccentric contraction (Unit: N/m)

	VM (a)	RF (b)	VL (c)	F	post-hoc
Concentric contraction 30°	0.27±0.09	0.31±0.09	0.41±0.11	15.98*	a, b>c
60°	0.29±0.08	0.32±0.07	0.39±0.07	14.73*	a, b>c
Eccentric contraction 30°	0.28±0.10	0.30±0.08	0.42±0.11	19.32*	a, b>c
60°	0.30±0.08	0.30±0.06	0.40±0.08	18.80*	a, b>c

VM: Vastus medialis, RF: Rectus femoris, VL: Vastus lateralis.
* $p < 0.05$.

cises at different angles of knee joints and isokinetic exercises at different angle.

The quadriceps is a very important muscle that provides stability for the knee joints when standing or walking. However, frequent use of the quadriceps can lead to various illnesses that cause knee pain, such as degenerative arthritis and patellofemoral pain syndrome.^{2,24,25} In the case of patellofemoral pain syndrome, the strengthening of vastus medialis of the quadriceps is suggested among various rehabilitation strategies. In addition, resistance exercises for increasing muscular strength include isometric, isotonic, and isokinetic exercises, out of which isokinetic exercises are widely used for rehabilitation including those conducted within an individual's range of motion.²⁶

In this study, muscle activities of rectus femoris, vastus medialis, and vastus lateralis during isometric contractions at 0, 30, 60, and 90 degrees were measured. The muscle activities of vastus medialis showed significant differences among 4 different angles, especially, between 0 and 30, 0 and 60, 30 and 90, and 60 and 90 degrees ($p < 0.05$). Also, vastus lateralis demonstrated significantly different muscle activities among 4 angles, especially between 0 and 30, 30 and 60, 30 and 90, and 60 and 90 degrees ($p < 0.05$). In case of rectus femoris, there was significant difference of muscle activities among at 4 angles, but showed no significance with post-hoc test. At the comparisons among muscles, there were differences of muscle activities at 30, 60, and 90 degrees. In post-hoc test, the differences between vastus medialis and rectus femoris at 30 and 60 degrees were significant ($p < 0.05$). The differences between vastus medialis and vastus lateralis were also significant ($p < 0.05$) at 30 and 60 degrees. However, the difference between rectus femoris and vastus lateralis only at 90 degree was significant ($p < 0.05$). These results showed the level of muscle activity was changed based on joint angles, which meant muscle playing a main role during a certain movement was also changed depending on angles. For example, vastus medialis showed increased activities at 0 and 90 degrees, but not at 30 and 60 degrees. Rectus femoris and vastus lateralis demonstrated increased activities so did angles.

This study measured the maximum torque values of concentric contractions and eccentric contractions during isokinetic exercises performed at angle of 30 and 60 degrees in percentiles. The results of the study indicate significant differences in all three muscles (the vastus medialis, vastus lateralis, and rectus femoris) during the con-

centric and eccentric contractions. Also, it was shown that the more the angle increased in all muscles except for the vastus lateralis, the more the muscle activity increased during both concentric and eccentric contractions. This is in line with the results of past study, which contend that the lower the angular velocity fell during isokinetic exercises, the lower the muscle activity dropped.²⁷ An overall assessment of muscle activity values during isometric exercises and torque values during isokinetic exercises indicates that increases in angle during concentric contraction leads to higher torque values of the vastus medialis and lower torque values of the vastus lateralis. The same was observed during eccentric contraction. It means that greater angle results in greater muscle contractions of the vastus medialis and lower muscle contractions of the vastus lateralis at the same time.

It means vastus medialis is contributing more in torque generation during movement with fast angular velocity, while vastus lateralis contributes less. These results were consistent with the study by Na et al.²⁸ in which vastus medialis showed increased muscle activities with increased angle like 60°/sec, 120°/sec, and 180°/sec during eccentric contractions, while the muscle activities of vastus lateralis was decreased. In their study, it was also found that the activity of vastus lateralis was increased mostly during eccentric contraction at 60°/sec and decreased as angular velocity slowed. A review of the analysis of isometric and isokinetic exercises shows that muscle activity and the ratios of different muscles that contribute to torque values are more or less in proportion. It indicates that muscle activity and torque values are related, which means that information on the value of one of the two could help estimate the value of the other during rehabilitation exercises.

The results of this study showed the correlation between muscle activity levels and the ability of torque generation, in which higher muscle activities is, more torque is generated. Therefore, if the patient activated muscles more after rehabilitation, it is inferred that the muscle generates more torque. Clinical application of the biomechanical analysis of the current study could help selectively anticipate and strengthen muscles through isometric and isokinetic exercises for adults, professional athletes, and people who experience limited knee movement for long periods following knee surgery. Moreover, for those who are in need of knee rehabilitation exercises, the measurement of torque values alone could provide a basis for anticipating the muscle activity of the quadriceps. It can en-

able faster and more accurate rehabilitation by promptly identifying which muscle has high or low levels of activity. It is recommended that future studies increase the number of subjects and samples to include those suffering from knee pain and conduct an in-depth examination of the possibility of selectively strengthening and rehabilitating weakened muscles.

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