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Comparison of the Ratio of Quadriceps Muscle Activation between the MVIC and the Unloaded Knee Extension

Gun-Ho Shin[1], Da-JinJeong[1],Myeong-HyeonChae[1], Dong-Yeop Lee[1], Jae-Ho Yu[1], Jin-Seop Kim[1], Jiheon Hong*[1]

[1] *Department of Physical Therapy,Sun Moon University,Asan-si,31460 Republic of Korea*

Abstract

This study aimed to compare the ratios of quadriceps muscle activity between the maximum voluntary isometric contraction and unloaded knee extension. A total of 28 healthy men and women in their 20s who agreed to participate in the study were tested. The Ratio was calculated by measuring the muscle activity of the subject's maximum voluntary isometric contraction and unloaded knee extension of rectus femoris, vastus lateralis, and vastus medialis oblique. The data analysis used a paired t-test for the ratio comparison between the two methods. There were statistically significant differences in the ratio of the rectus femoris and vastus medialis oblique during maximum voluntary Isometric contraction and unloaded knee extension (P<.05). However, there was no statistically significant difference in the ratio of the vastus lateralis during maximum voluntary Isometric contraction and unloaded knee extension. To strengthen the vastus medialis oblique, high-intensity exercises such as maximum voluntary isometric contraction can be used, and for the rectus femoris, low-intensity exercises such as unloaded knee extension can be used.

Keywords: Muscle activity; Vastus medialis oblique; Rectus femoris; Vastus lateralis, Knee.

*Corresponding Author
Name: Jiheon Hong
Email: hgh1020@hanmail.net
Contact: +82-41-530-2732
Fax: +82-41-530-2727
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Introduction

The knee joint is one of the largest joints in the body for the weight-bearing and located in the center of a lower-body to the instability and external force of joint and the risk of damage, which means that the function of soft tissues (including the ligament, the membrane, and the muscle) becomes quite important (Lee S C *et al*., 2009). It provides

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active and passive stability to the weight-bearing in our daily lives; the stability of knee depends on soft tissues (including muscle, skin, articular capsule, tendon, and ligament) rather than the structural arrangement of bones (Choi N Y *et al*., 2015). Quadriceps femoris muscle is considered one of the most important muscles in those around the knee joint; also it is an agonist of knee extension, working for the stability of legs in a standing position or in walking (Grabiner M D *et al*., 1994). In addition, the vastus lateralis muscle of quadriceps femoris muscle works more strongly in the lower body exercise than the vastus medialis oblique, which is why there occurs the imbalance between the inner and outer sides during the exercise and then the lateral dislocation of patella (Lee S C *et al*., 2009).

Those suffering degenerative knee osteoarthritis (OA) show the cartilage degeneration and the synovium lesion (including the osteomyelitis the synovitis and the exudation) with a higher risk of joint dysfunction. Also, the muscular weakening, the decreased range of motion, and the loss of proprioception are common characteristics in those suffering degenerative knee osteoarthritis, which may lead to risking their joint health during the weight-bearing exercise (Van Ginckel A *et al*., 2019). The patellofemoral pain syndrome (PFPS) and the patella dislocation are reported to increase the instability of knee joint and become the primary cause of anterior knee joint pain (AKP) (Fulkerson J P., 2002). The PFPS often appears in those doing physical activities, which accounts for almost 10 percent of the sports rehabilitation clinic visits (Wong Y M *et al*., 2009;Callaghan M J *et al*., 2004). In common, the patellofemoral Pain should be managed under the conservative method, not the surgical method. The vastus medialis oblique of quadriceps femoris muscle works for the determination of patellofemoral joint stress and the stabilization of patella (Wilk K E *et al*., 2001). Especially, the selective contraction of vastus medialis oblique causes PFPS, which may lead to disturbing the balance of vastus lateralis and vastus medialis oblique muscle (Witvrouw E *et al*., 2000).

Applying the open kinematic chain exercise for the knee joint leads to increasing the strength of the quadriceps femoris muscle and then its shear force, as the contact between the femur and the patellae becomes smaller (Grabiner M D *et al*., 1994). On the contrary, the closed kinematic chain exercise requires the co-contraction of quadriceps femoris muscle, which leads to decreasing the opportunity of shearing force (Hungerford D S *et al*., 1979) and increasing the pressure of joint, which means it enables the functional muscular mobilization pattern of polyarticular movement (De Looze M P *et al*., 1993). Especially, the squat exercise (closed kinetic chain exercise) has the ratio of vastus medialis oblique

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and vastus lateralis muscle at 1.14 to 1 while the knee extension exercise (open kinetic chain exercise) has the ratio of both at 0.72 to 1 due to the prior activation of vastus lateralis muscle (Irish S E *et al*., 2010). The strengthening of vastus medialis oblique is recommended for those needing rehabilitation for the PFPS (Powers C M., 2000).

Earlier studies have traditionally applied open and closed kinetic chain exercises for the strengthening of vastus medialis oblique on those suffering any knee pain; however, there is few researches which compare the muscle activation ratio of quadriceps femoris muscle in the unloaded knee extension and that in the maximum voluntary isometric contraction (MVIC) for open kinetic chain exercises. Therefore, this study was designed to suggest more effective method for the selective strengthening of specific muscle based on the comparison between the muscle activation ratio of rectus femoris, vastus medialis oblique, vastus lateralis muscle in the MVIC and the unloaded knee extension.

Methods

Subjects

We studied 28 healthy adults attending Sunmoon University in Asan-si, who not experience any hospital visit or medical treatment due to knee pain. They were given a complete explanation for the purpose and method of study and voluntarily signed an informed consent for the participation in a written form. Specifically, we selected 28 healthy adults aged 20s (consisting of 14 males and 14 females) for those visiting a hospital due to the knee pain, those not receiving medical treatment, those without any pain or inconvenience due to the knee movement, those not undergoing a surgical operation on the knee and those not suffering inflammatory or degenerative arthritis and desmosis. Their body characteristics are shown as Table 1. This study progressed under the approval of Institutional Review Board in the Sunmoon University (SM-201804-020-2).

Table 1: Typical characteristics of participants (n=28)

	Men (n=14)	Women (n=14)
Age (years)	20.71±1.27	21.07±0.62
Height (cm)	174.86± 4.47	160.93± 4.6
Body mass (kg)	70.64±7.57	54.14± 7.12

Values are presented as mean ± standard deviation.

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Equipment

We used for this study the isokinetic measuring equipment (CSMI, Humax CO, USA, Italy, 2010) and the Electromyography QUS100 (Zero WIRE EMG, Italy, 2009) [Figure 1 and 2]; subjects were made to wear shorts for the electromyography before this experiment. Then, we attached electromyography on the vastus medialis oblique, vastus lateralis muscle, rectus femoris muscle of dominant limb; for the vastus medialis oblique, put them each on 2cm above the superomedial side of patella, on the vastus lateralis muscle 3-5cm above the border of patella on the line of thighbone and on the rectus femoris muscle between the patella and the anterior superior iliac spine [Figure 3]. The digitalized signal measured using the electromyography was under the bandpass filter of 20-500Hz, the full wave rectification and the smoothing using root mean square (RMS). Then, the value of muscle activation was averaged in RMS. Also, to confirm the ratio of muscles, we quantified as percentages the muscle activation of vastus medialis oblique, vastus lateralis muscle and rectus femoris muscle between the MVIC and the unloaded knee extension.

Measurement

Before this experiment, we gave a complete explanation of methodology and stability to subjects for measurement. We used the electromyography to measure the muscle activation of vastus medialis oblique, vastus lateralis muscle and rectus femoris muscle in their dominant limb. Specifically, subjects were made to wear shorts in order to clean the attachment of electromyography and minimize the skin resistance; we attached electromyography on them, so that we checked their electromyographic signal and then started this experiment. To measure the muscle activation during the MVIC, we measured the MVIC of subjects three times; specifically, the subjects were made to sit on the isokinetic dynamometer with knee flexion at 45-degree angle and extension them by the MVIC for 5 seconds with every 5 seconds recess [Figure 4]. To measure the muscle activation during the unloaded knee extension, we measured the unloaded knee extension of subjects three times at the speed of 60bpm until they were made to sit on the bed with knee flexion at 90-degree angle and knee extension finally reached knee full extension [Figure 5].

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Figure 1. Isokinetic dynamometer

Figure 2. Electromyography

Figure 3. Attachment placement

Figure 4. Maximum Voluntary Isometric Contraction

Figure 5. unloaded knee extension

Statistical analysis

This study is designed to measure and compare the ratio of muscle activation (including vastus medialis oblique, vastus lateralis muscle and rectus femoris muscle) between the MVIC and the unloaded knee extension; also, we took statistics using IBM Statistics SPSS 22.0 window program. To do so, we conducted the paired t-test and determined the p-value $<.05$ for the statistical significance level.

Results and Discussion

We measured the muscle activation of vastus medialis oblique, vastus lateralis, and rectus femoris muscle in the unloaded knee extension and in the MVIC respectively. We found a significant difference between the MVIC and unloaded knee extension on the muscle activation of rectus femoris, vastus medialis oblique, and vastus lateralis, retrospectively ($p<.05$) [Table 2]. To measure the ratio of muscles, we quantified as percentages the

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muscle activation of rectus femoris, vastus medialis oblique, and vastus lateralis muscle in the MVIC, and measured the activation ratio of rectus femoris, vastus medialis oblique, and vastus lateralis muscle in the unloaded knee extension and the MVIC. There was a significant difference between the MVIC and unloaded knee extension on the ratio of each muscle [Table 3]. On the contrary, there was no significant difference between the ratio of vastus lateralis muscle in the MVIC and that of vastus lateralis muscle in the unloaded knee extension.

Table 2.Comparison of muscle activity

Method	VMO	VL	RF
Maximum Voluntary Isometric Contraction	171.41±74.83	141.76±55.84	127.31±43.41
Unloaded Knee extension	20.96±8.35	24.74±11.38	22.23±8.3
p value	< 0.001	< 0.001	< 0.001

Values are presented as mean ± standard deviation.
VMO: vastus medialis oblique muscle, VL: vastus lateralis muscle, RF: rectus femoris muscle

Table 3.Comparison of muscle activation ratio (%)

Method	VMO	VL	RF
Maximum Voluntary Isometric Contraction	38.44±6.73	32.14 ± 7.65	29.43 ± 4.99
Unloaded Knee extension	30.35 ± 5.75	35.76 ±8.11	33.88 ± 9.44
p value	< 0.001	0.13	0.04

Values are presented as mean ± standard deviation.
VMO: vastus medialis oblique muscle, VL: vastus lateralis muscle, RF: rectus femoris muscle

Quadriceps femoris muscle consists of four muscle groups in front of thigh, including rectus femoris, vastus medialis oblique, and vastus lateralis muscle (Lieb F J *et al*., 1968). Vastus medialis oblique contributes to the stability of patella in passing the intercondylar groove of femur or sliding the femur (Irish S E *et al*., 2010). Vastus lateralis muscle works for the congener of knee joint (Luebbers P E *et al*., 2003). Rectus femoris muscle lies in front of quadriceps femoris muscle, working for the extension of knee, the formation of torque in the flex of hip joint, and then the stabilization of femur (Bordalo-Rodrigues M *et al*., 2005). Working for an agonist of knee extension, rectus femoris muscle plays an important role in walking or in a standing position (Grabiner M D *et al*., 1994). If the stability and balance of muscles supporting the knee decrease, the decrease of contact

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between muscle vastus medialis oblique and vastus lateralis muscle and the imbalance of patella occur leading to various diseases (Fitzgerald G K., 1997). This study progressed under the open kinematic chain exercise, showing that vastus medialis oblique has a higher ratio of muscle activation in the MVIC while rectus femoris muscle has a higher ratio of muscle activation in the unloaded knee extension.

Specifically, Irish et al. argued that the squat (closed kinematic chain exercise) is very effective in the selective reinforcement of vastus medialis oblique, as it has the ratio of vastus medialis oblique and vastus lateralis muscle at 1.18 to 1 (Irish S E *et al*., 2010). The previous study has suggested that the kinematic chain exercise of short arc (45-degree angle) is the best exercise for the reinforcement of the quadriceps femoris muscle (Tang S F *et al*., 2001). It has been reported that the closed kinematic chain exercise performed by adducting the hip joint increases the muscle activation of the vastus medialis oblique (Miao P *et al*., 2015). Because the hip joint flexion extends the fiber of vastus medialis oblique leading to increasing the contraction force depending on the tension characters of muscle length (Irish S E *et al*., 2010). This may contribute to the selective activation of vastus medialis oblique in the balance between vastus lateralis and vastus medialis oblique muscle (Miao P *et al*., 2015). The clinical application of closed kinematic chain exercise has significantly increased in past years especially in the rehabilitation community. This is because it can reproduce many functional movements (Witvrouw E *et al*., 2004). However, based on its results, we suggest that although the selective strengthening of vastus medialis oblique muscle is enabled in the closed kinematic chain exercise, vastus medialis oblique can be more used in the way as the MVIC, which may contribute to the selective strengthening.

Located on the most superficial quadriceps femoris muscle, rectus femoris muscle works for the hip joint flexion and knee joint extension (Mendiguchia J *et al*., 2013). Because quadriceps femoris muscle is a two-jointed muscle, rectus femoris muscle is most vulnerable to injury in a front thigh and its pathology occurs in the sprint race, jumping and kicking and is mainly related to the musculotendinous periphery (Hughes IV C *et al*., 1995; Pesquer L *et al*., 2016). Rectus femoris muscle stabilizes the pelvic bone of femur in the weight-bearing and has a higher rate of Type II fiber, which shows stronger eccentric muscle contraction and higher opportunity to cause injury (Mendiguchia J *et al*., 2013). Therefore, it is better to select the unloaded exercise rather than the maximum intensity exercise such as the MVIC for the prevention of injury and the increase of stability in the weight-bearing.

Therefore, based on the significant muscle activation rate of vastus medialis oblique in the MVIC and that of rectus femoris muscle in the unloaded knee extension, we conclude the exercise method of the MVIC for the selective strengthening of vastus medialis oblique while that of the unloaded knee extension for that of rectus femoris muscle. This study has some limitations. First, it is impossible to generalize our results on other patients and all age groups, as we selected only 28 healthy males and females. Second, this study cannot be applied to those using different muscles due to any disease. Third, the opportunity occurs that there is not the same result in the non-dominant leg, as we measured only the muscle activation of the dominant leg. Thus, we conclude that it is necessary to compare the muscle activation of the dominant and non-dominant leg. Fourth, the opportunity occurs that there is not the same result in the closed kinematic chain exercise, as we measured only the muscle activation rate of open kinematic chain exercise.

Conclusion

This study is designed to suggest more effective method for the selective strengthening of specific muscle based on the comparison between the muscle activation ratio of rectus femoris, vastus medialis oblique, and vastus lateralis muscle in the MVIC and the unloaded knee extension. There was no significant difference between the MVIC and unloaded knee extension of vastus lateralis muscle while there was any significant difference between the MVIC and unloaded knee extension of vastus medialis oblique or rectus femoris muscle. In conclusion, we suggest the exercise method of the MVIC for the selective strengthening of vastus medialis oblique and that of the unloaded knee extension for the selective strengthening of rectus femoris muscle.

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