Change of Quadriceps Muscular Strength and Muscle Activity According to Knee Extension Angle and Body Mass Index

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ABSTRACT

The purpose of this study was to investigate the effect of body mass index (BMI) on muscle strength and activity according to the knee angle. Muscle activity of vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF) was measured for 48 healthy adults. Isokinetic equipment was used to measure the isometric strength of the knee extensors at 0°, 30°, 60°, and 90° flexion. One-way ANOVA was used to compare isometric muscle strength and activity. The maximum isometric strength of the knee extensors according to the knee angle showed a significant difference between the groups at 0°, 30°, and 90° of knee flexion (p<.05). The maximum isometric strength at 0° flexion of the knee joint was significantly different between the normal and overweight, and the underweight and overweight, respectively. In knee flexion 30°, there was a significant difference between underweight and normal, underweight and overweight. In 90° flexion, there was a significant difference between the underweight and the overweight. There was a significant difference in VM at 0° and 30° knee flexion (p < .05). Post hoc test results showed a significant difference between underweight and overweight at 0° flexion. In 30° flexion, there was a significant difference between normal and overweight, and between underweight and overweight. It is considered that selective muscle strengthening according to a specific angle is necessary according to BMI.

Keywords: Body mass index, EMG, Isometric contraction, Knee extensors, quadriceps.

Introduction

The Asian population has a body mass index (BMI) of 18.5-22.9 kg/m² for normal, over 23 kg/m² for overweight, and over 25 kg/m² for obesity.¹ These BMI are recognized as a common standard for obesity and overweight.

Knee joints provide dynamic and static stability in activities of daily living (ADL). The stability of the knee is obtained by soft tissues such as muscles, tendons, and ligaments rather than the structural arrangement.²³ The quadriceps is the main muscle of the knee extension and provides stability of the lower limb. It is an important muscle in terms of providing stability of the knee joint and is the driving force of sports and ADL.⁴ In the oriental culture, there are many flexion movements of the knee during ADL.⁵ This lifestyle causes knee joint overload and affect the high incidence of osteoarthritis.⁶⁷ Women also have a greater risk of knee soft tissue damage than men, and obesity also affects knee dysfunction and pain.⁸ Obesity, in particular, increases the stress transmitted to the joint. Previous studies have shown that a reduction in body mass index of 2 kg/m² reduces the risk of degenerative arthritis by 50%.⁹

Isometric contraction produces near-maximum muscle strength and increases muscle strength only at given joint angles.¹⁰ This contraction occurs without changes in muscle length and joints, and because the joint angle is limited, it strengthens the muscles without damage to the joint.¹¹ As the advantages of muscle strength testing using isokinetic equipment have been highlighted, studies using isokinetic equipment have been continuing.¹²¹⁴ The position of the hand, the angle of the hip and knee joint, the stability of the trunk affects the strength measurement of the hamstring or quadriceps.¹⁵ The position of joint angles as a guide to the mechanical properties of the muscles is important to reach maximum

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contraction and to assess muscle function. The maximum voluntary isometric contraction (MVIC) of vastus lateralis (VL) was significantly higher than vastus medialis (VM) and rectus femoris (RF) at knee flexion 90°. At 120°, the RF was significantly higher. At 150°, VL was higher than VM. Another EMG study reported that muscle activity was highest at 90° flexion in isometric contraction. Other researchers reported that the greatest muscle strength occurs between 60°-65° flexion. The angle is important for the maximum strength. In a comparison study of muscle strength according to BMI, the high BMI reported significantly higher fat-free mass (FFM) and absolute muscle strength than the normal. However, muscle strength per body weight was reported to be lower. In a comparison of strength according to BMI, there was a significant difference between normal, overweight, and obese, however, the muscle activity was not compared. The purpose of this study is to compare muscle strength and muscle activity according to BMI.

**Method**

**Subjects:** The forty-eight healthy adults participated in this study. Subjects with a history of surgery for knee and musculoskeletal disorders, participants in other exercise programs, knee edema or pain, and those with joint deformities were excluded. The subjects completed and participated in written consent for this study. Subjects were assigned to normal, overweight, and underweight groups. This study was conducted according to the protocol approved by the Institutional Review Board of Sun Moon University.

### Table 1: General Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Underweight (n = 13)</th>
<th>Normal (n = 20)</th>
<th>Overweight (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>20.33 ± 1.15</td>
<td>19.35 ± 1.04</td>
<td>19.8 ± 1.42</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.25 ± 7.31</td>
<td>167.30 ± 10.0</td>
<td>166.0 ± 7.15</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>49.57 ± 4.45</td>
<td>60.8 ± 17.68</td>
<td>59.11 ± 5.31</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.54 ± 0.50</td>
<td>21.2 ± 1.42</td>
<td>26.72 ± 3.7</td>
</tr>
</tbody>
</table>

Mean ± standard deviation, BMI: Body mass index

**Procedure:** The BMI was measured using a body composition analyzer (Inbody 570, Biospace, Republic of Korea, 2013). The criteria for the diagnosis of BMI were 18.5-22.9 kg/m² for normal, over 23 for overweight, and under 18.5 kg/m² [Table 1].

Muscle activity was measured by EMG analysis (QUS100 Zero WIRE EMG, Italy, 2009). Isokinetic equipment (CSMI, Humax Co, USA, 2010) was used to measure the isometric strength of the knee extensors at 0°, 30°, 60°, and 90° flexion. The subjects were prepared for 5 minutes with a comfortable walking. The subject sat on the isokinetic equipment. The trunk and the opposite leg were fixed using a strap. Hip was fixed at 90° flexion. The lever arm pad of the was fixed 2 cm above the ankle joint. The subjects performed maximum isometric contractions for 5 seconds at 0°, 30°, 60°, and 90° flexion, respectively. 5 times repeatedly, and the last 3 times were collected. A two-minute break between measurements at each angle was provided.

The electrode for VM was attached 5 cm above the superior medial border of the patella along the longitudinal axis of the femur. The electrode for VL was attached 2/3 from the greater trochanter of the femur to the patella, and the electrode for RF was attached at 1/2 from the anterior superior iliac spine to the patella [Figure 1]. The frequency of 1000 Hz was used to measurement. During the 5-second isometric contraction, EMG data for the middle three seconds were collected. The band-pass filter was set at 20-500Hz.

**Statistical Analysis:** Data were analyzed using SPSS 22.0 for windows program (SPSS INC, Chicago, IL). One-way ANOVA was used to compare isometric maximal muscle strength and muscle activity between groups. The LSD (Least Significant Difference) test was used for the post-hoc test. The statistical significance level was set at 0.05.

![Figure 1: The placement of surface electrodes](image-url)
Results

The maximum isometric strength of the knee extensors according to the knee joint angle showed a significant difference between the groups at 0°, 30°, and 90° of knee flexion (p < .05) [Table 2]. The results of the post hoc test showed that the maximum isometric strength at 0° flexion of the knee joint was significantly different between the normal and overweight, and the underweight and overweight, respectively. In knee flexion 30°, there was a significant difference between underweight and normal, underweight and overweight. In 90° flexion, there was a significant difference between the underweight and the overweight [Figure 2].

There was a significant difference in VM at 0° and 30° flexion (p < .05) [Table 3]. Post hoc test results showed a significant difference between underweight and overweight at 0° flexion. In 30° flexion, there was a significant difference between normal and overweight, and between underweight and overweight [Figure 3].

<table>
<thead>
<tr>
<th>Knee angle</th>
<th>Group</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Overweight</td>
</tr>
<tr>
<td>0°</td>
<td>18.15 ± 4.42</td>
<td>25.07 ± 10.66</td>
</tr>
<tr>
<td>30°</td>
<td>53.90 ± 11.01</td>
<td>63.73 ± 19.89</td>
</tr>
<tr>
<td>60°</td>
<td>92.35 ± 20.78</td>
<td>92.67 ± 38.81</td>
</tr>
<tr>
<td>90°</td>
<td>86.50 ± 24.47</td>
<td>94.80 ± 28.79</td>
</tr>
</tbody>
</table>

Table 2: Maximum isometric strength of knee extensors according to knee angle, (Nm)

![Figure 2: Isometric strength of the knee extensors according to body mass index in various angles](image)

![Figure 3: Muscle activation of the Vastus medialis according to body mass index](image)
Discussion

Strength is one of the important factors in health. In addition, quadriceps, which contributes most to knee extension, plays a key role in functional activity and walking by taking charge of force generation in knee extension. Obesity often has a high absolute value of strength. This was reported to be due to high FFM. It was reported that the group with high BMI had higher absolute fat mass and strength than the normal. However, muscle strength per body weight was lower. In adolescents, the peak torque was higher in obese, however, the normalized peak torque in unit weight was lower. The cause of this result is that obesity has high FFM and therefore has high muscle mass. It is also reported that sustained weight bearing results in higher muscle strength because it causes a training effect on muscle mass. Repeated loading causes higher muscle contraction activity. This process increases the cross-sectional area of the muscle and increases the number of myofilaments, resulting in a lot of cross-bridges. As a result, muscle strength increases. In the underweight, muscle strength and the fitness level was lower. It is predicted that absolute muscle strength is also lower because FFM is lower compared to overweight.

The VM and VL produce about 80% of the total extension torque of the knee joint, and the remaining 20% is produced by RF. The VM consists of two fibers with different orientations.

Table 3: Muscle activity according to knee angle between groups. (μV)

<table>
<thead>
<tr>
<th>Knee angle</th>
<th>Muscle</th>
<th>Group</th>
<th>Mean ± standard deviation</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal</td>
<td>Over weight</td>
<td>Under weight</td>
</tr>
<tr>
<td>0°</td>
<td>RF</td>
<td>8.51 ± 3.00</td>
<td>7.71 ± 3.11</td>
<td>11.9 ± 7.73</td>
</tr>
<tr>
<td></td>
<td>VM</td>
<td>7.97 ± 3.70</td>
<td>6.16 ± 2.22</td>
<td>9.91 ± 4.51</td>
</tr>
<tr>
<td></td>
<td>VL</td>
<td>9.39 ± 7.13</td>
<td>6.46 ± 3.12</td>
<td>9.51 ± 4.00</td>
</tr>
<tr>
<td>30°</td>
<td>RF</td>
<td>7.69 ± 2.20</td>
<td>6.71 ± 3.47</td>
<td>11.58 ± 10.95</td>
</tr>
<tr>
<td></td>
<td>VM</td>
<td>7.65 ± 4.32</td>
<td>4.54 ± 2.44</td>
<td>8.6 ± 5.99</td>
</tr>
<tr>
<td></td>
<td>VL</td>
<td>7.82 ± 3.10</td>
<td>5.50 ± 4.00</td>
<td>9.05 ± 5.43</td>
</tr>
<tr>
<td>60°</td>
<td>RF</td>
<td>7.2 ± 3.29</td>
<td>6.26 ± 3.44</td>
<td>7.74 ± 7.16</td>
</tr>
<tr>
<td></td>
<td>VM</td>
<td>7.65 ± 4.32</td>
<td>4.42 ± 2.46</td>
<td>6.38 ± 3.28</td>
</tr>
<tr>
<td></td>
<td>VL</td>
<td>7.74 ± 3.82</td>
<td>5.13 ± 2.98</td>
<td>8.05 ± 4.36</td>
</tr>
<tr>
<td>90°</td>
<td>RF</td>
<td>9.83 ± 3.27</td>
<td>9.78 ± 6.22</td>
<td>9.01 ± 5.10</td>
</tr>
<tr>
<td></td>
<td>VM</td>
<td>10.51 ± 3.60</td>
<td>10.10 ± 6.86</td>
<td>11.4 ± 7.70</td>
</tr>
<tr>
<td></td>
<td>VL</td>
<td>12.31 ± 5.01</td>
<td>10.64 ± 7.77</td>
<td>10.7 ± 5.65</td>
</tr>
</tbody>
</table>

Table: Mean ± standard deviation

* p < 0.05

RF: rectus femoris, VM: vastus medialis, VL: vastus lateralis.

Therefore, it plays the role of pulling the patella in the oblique direction. As a result, the patella stabilizes while passing or sliding through the intercondylar groove of the femur. The VM is mainly activated between the last 10° to 15° of the knee extension. In order to enhance the VM, muscle strengthening exercises should be performed within this angle. Damage to the VM limits the full extension of the knee joint. VM activity at the knee joint 0° flexion showed the difference between the underweight and overweight. This suggests that the VM is not working normally. Abnormal activation of the VM in the overweight and underweight may cause patellofemoral pain syndrome (PFPS). The PFPS is a disease that causes pain in the anterior portion of the knee. In patients with the PFPS, VM activation was reported to be lower than the normal. Factors that cause PFPS include excessive muscle strength of VL and weakness of VM. The VM is the weakest muscle physiologically and the muscle weakness is reported to be rapid. Muscle weakness breaks the alignment of the patella. As a result, the anterior part of the knee joint is painful and its functional role is reduced. Therefore, improper activation of VM due to obesity or underweight is a cause of diseases.
Person with obesity a high incidence of degenerative arthritis. Obesity causes degenerative arthritis in the knee joint and 1st metatarsophalangeal joint. The increase in the fat mass causes the genu varus. These deformities lead to a degenerative change as the load is concentrated on the medial of the knee joint. The weakness of VM causes genu varus. The overweight is at high risk of developing knee arthritis because of its high-fat content. The weakness of quadriceps increases pain. Pain limits activity and as a result, muscle weakness becomes worse. These results indicate that arthritis can be affected not only by repeated loading but also by muscle weakness.

The results of this study confirmed that BMI affects the isometric strength of the knee extensors and activity of VM according to the flexion angle. The overweight had the highest muscle strength because it had high FFM and high muscle mass. However, knee instability occurs due to low activity of the VM at 0° and 30°. The maximum isometric strength occurs at 60°, however, it seems that the maximum muscle strength cannot be measured due to the low muscle activity of the VM. As a result of these abnormal muscle activity, knee stability is lower, leading to an increased incidence of diseases. It is predicted that BMI may also have an impact on disease incidence. This study has some limitations. First, muscle activity was not normalized. Second, because the subjects are young adults, it is difficult to generalize them to all ages. Third, this study did not perform a gender-specific comparison. Fourth, the imbalance between the upper and lower limbs was not investigated. Finally, the position of the ankle was not considered during muscle strength measurement.

**Conclusion**

This study confirmed that the strength of the overweight was significantly higher than that of the normal and underweight. VM muscle activity in the overweight was lower at knee flexion 0° and 30°. This means that the VM is not being used properly. The VM weakness has disrupted the alignment of the knee and cause mechanical dysfunction and anterior pain of the knee joint. Muscle imbalance causes musculoskeletal disorders. Therefore, selective muscle strengthening is required according to BMI.

**Acknowledgment**

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**Ethical Clearance:** This study was conducted according to the protocol approved by the Institutional Review Board of Sun Moon University.

**Conflict of Interest:** The authors declare no conflict of interest.

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