The coordinated activities of the four heads of the quadriceps femoris muscle results in knee extension. It is still a matter of debate as to whether the different heads of the quadriceps can be activated differentially by the central nervous system at different joint angles. This study aimed to investigate the influence of different angles of knee joint on the activation level of the vastus medialis oblique (VMO), vastus lateralis (VL) and rectus femoris (RF) using electromyographic activity during maximal voluntary isometric contraction (MVIC) and occurrence of peak torque measurement. Forty healthy subjects (20 males, 20 females) participated in the study. The peak torque for the dominant leg was measured using HUR5340 leg extension/curl with simultaneous recording of MVIC of the VMO, VL and RF using surface electromyography (SEMG). Test angles were presented randomly in 30° increments from 30° to 90° of knee flexion. To get peak torque, each subject performed maximal contraction of 10 seconds at each test angle and the myoelectrical activity was recorded simultaneously. The results illustrated that peak torque occurred at 60° for the entire group, including males ($F = 39.654, p < 0.001$) and females ($F = 32, p < 0.001$). Significant difference was found in integrated electromyographic (IEMG) activity of the VMO at all the angles in males ($F = 14.665, p < 0.001$) and females ($F = 22.40, p < 0.001$), with maximum activity at 60° of knee flexion followed by 90° and then 30° of knee flexion. It was thus concluded that the myoelectrical activity of the VMO changes with change in peak torque at the different joint angles during MVIC in both sexes. 

Keywords: HUR, knee joint angle, MVIC, peak torque, SEMG

**Introduction**

The movement of daily activities requires the central nervous system to attune the force produced by the muscles across different joint angles (muscle length) according to the requirement of the body. Due to voluntary contraction, force is produced and transmitted through the tendon to the bone. As a result of that, bone can be held in position, (or) accelerated (or) decelerated across joints to bring about movement. This represents the basis of our movement. The quadriceps muscle is a prime mover in everyday life and sports; therefore, its function has been extensively studied (De Ruiter et al. 2008). Functionally, knee extension is performed with coordinated activities of the four muscle heads of the quadriceps femoris (quadriceps): the rectus femoris (RF), vastus lateralis (VL), vastus medialis oblique (VMO) and vastus intermedius (VI) muscles. Whether the different heads of the quadriceps have a different function or can be activated differentially by the central nervous system at different joint angles (muscle length) is still a matter of debate.

During maximal contraction at different knee angles, Salzman et al. (1993) reported no differences in intramuscular electromyography (EMG) between the individual quadriceps components. On the other
hand, Pincivero et al. (2004) suggested an improved VM recruitment efficiency over VL and RF across 70–90° (0° is full extension) during maximal effort and also reported that superficial quadriceps recruitment was most efficient at 90°. Moreover, De Ruiter et al. (2008) reported similar contribution of VM to total isometric knee extension torque at different knee angles, and Blazevich et al. (2006) proposed that differential activation of different quadriceps components would be expected due to the anatomical differences (e.g., fascicle angle and length), which they found among the different quadriceps components. Using surface EMG, the researcher can easily and reliably monitor the myoelectrical activity of a given muscle under different conditions like monitoring the myoelectrical activity during the peak torque of quadriceps muscle under isometric condition. The EMG signal can be used as an indicator of the intensity of each contraction under isometric condition (Basmajian et al. 1972). To study the quadriceps using EMG, establishing a normalization protocol is necessary. According to Lin et al. (2008), EMG normalization is frequently used to improve reliability by decreasing variation within and between individuals in EMG studies. The most common method of normalization is to compare the myoelectrical activity of a given contraction to the activity of maximal voluntary isometric contraction (MVIC) (Woods & Bigland-Ritchie 1983; Knight et al. 1979).

Previous studies (Pincivero et al. 2004; Onishi et al. 2002) suggest that differences in the knee joint angles are important for affecting the myoelectrical activity of muscles around the knee joint. Maximal myoelectrical activity with peak torque is always controversial. Previous studies on the relationship between strength and joint angles have demonstrated a variation in knee extensor torque between 0° and 90° of flexion (Williams & Stutzman 1959; Houtz et al. 1957; Clarke et al. 1950). The results rather uniformly indicate a minimum of extensor strength in the extended position and a maximum at 50° to 70° of flexion. Decreases in voluntary torque generation at the extremes of the functional joint range of motion (0° to 90° flexion) may be attributed to mechanical and/or muscle activation factors. Brownstein et al. (1985) found that peak torque was coincident with maximum IEMG at 50° for males and 70° in females of knee flexion. In isometric contraction against an external resistance, the external torque can easily be measured and is equal to the resisting force multiplied by the lever of this force in relation to the axis chosen. Peak torque occurs in the midrange of joint range of motion; however, the literature is unclear about the significant changes in myoelectrical activity of the quadriceps as the peak torque changes at different positions of the knee during maximal isometric contraction.

This study aimed to investigate the influence of different angles of the knee joint on the activation level of the quadriceps (VMO, VL and RF) from electromyographic activities during MVIC and occurrence of peak torque measurement.

**Methods**

**Subjects**

Forty normal healthy subjects including 20 males (age, 22.65 ± 2.45 years; height, 170.6 ± 5.8 cm; weight, 67.45 ± 10.36 kg) and 20 females (age, 21.3 ± 1.89 years; height, 162.24 ± 5.16 cm; weight, 54.72 ± 7.39 kg) were selected for the study. All were right leg dominant and were not involved in any type of resistance training. They had no history of knee, hip or lower back pathology or surgery. Before testing, informed consent was obtained from each subject. The study was approved by the ethics committee for research, GNDU Amritsar.

**Equipment**

The measuring system comprised a four-channel Myosystem 1200 electromyography (EMG) unit (Noraxon USA, Inc., Scottsdale, AZ, USA) and bipolar Ag-AgCl surface electrodes, measuring 1 cm in diameter with a center-to-center distance of 2.5 cm to record the myoelectric activity. The EMG signals were amplified by the amplifier system. DRIVER LINX with the input impedance of 10 milliohm. Gain (fixed) = 1,000 hz, Keithly A/D converter ±5 mv input range, bandwidth 10–500 Hz with no notch filter.

HUR 5340 leg extension/curl computer controlled machine is an isoinertial dynamometer which was used for evaluating isometric peak torque. This machine was the result of a research project at the University of Technology in Helsinki, Finland.

**Procedure**

Skin impedance was reduced by shaving hair around the electrode site and wiping the skin with 70% ethyl alcohol before applying the surface electrode. All the impedance levels were below 5 kohm before data collection started. Pairs of surface electrodes with diameter of 1 cm and center-to-center spacing of 2.5 cm were applied to the dominant limb. The electrodes were
covered with an electrically conducting gel and were positioned over the VMO, VL and RF of the lower limb under evaluation, and were attached using adhesive tape to avoid movement artifact. For the VMO, the electrodes were placed on the VMO muscle belly, approximately 4 cm proximal to the superomedial border of the patella. For the VL, the electrodes were applied over the VL muscle belly, approximately 8 cm proximal to the lateral joint line of the knee. For the RF, the electrodes were placed at 50% of the distance from the anterior superior iliac spine to the superior pole of the patella (Matheson et al. 2001). All electrodes were placed parallel to the corresponding muscle fiber. A ground electrode was placed on the proximal surface of the tibia. After the preparation and positioning of the electrodes, each subject warmed up on a stationary bicycle for 5 minutes. Soon afterwards, they performed sustained passive stretching of the hamstrings and quadriceps: two series of 30 seconds with an interval of 30 seconds. Then they went to the chair of the HUR leg extension/curl with hip flexed at 110° and chest, pelvis and thigh stabilized. The axis of rotation was aligned with the lateral condyle of the femur, and the moment arm fixed for every subject. Test angles were presented randomly in 30° increments from 90° to 30° of knee flexion (Figure). Each subject performed only one maximal contraction for 10 seconds in extension direction, to get the peak torque for the quadriceps at each test angle. The myoelectrical activity was also recorded while performing the same. All subjects were given consistent verbal encouragement during the maximal excursion. Two minutes of rest was allowed after each maximal contraction to avoid the effect of fatigue on performance.

Statistical analyses
The data were analyzed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). One-way ANOVA with post hoc comparison using the Scheffe test was used to test for angle-dependent differences in IEMG and torque value. Statistical significance was defined as \( p < 0.05 \).

Before analyzing the EMG recordings, the raw signals were full wave rectified and smoothed. This approach was based on the finding that the amplitude of rectified and smoothed EMG signals in a qualitatively related to the amount of force developed by the muscles. The signals during peak of contraction were analyzed. The full wave rectified and smoothed signals were analyzed with the root-mean-square (RMS) processing technique. The electromyogram obtained on performing the activity provides data in the form of motor units action potentials (MUAPs) expressed in microvolts (\( \mu V \)). Because of the variability inherent in EMG signals, it is not reasonable to compare the EMG activity of one muscle to another, or from one person to another. Therefore, some form of normalization is necessary to validate these comparisons. This is usually done by first recording the EMG of a muscle during MVIC, and then expressing all other values as a percentage of this contraction. This control value served as a standard against which activity during other exercises was compared. As this study involved analysis of only the MVICs, there was no further need for normalization.

Results
One-way ANOVA with post hoc test (Tables 1 and 2) for IEMG activity and torque at 30°, 60° and 90° of knee flexion during single maximal isometric contraction indicated that peak torque occurred at 60° for the entire group including males (\( F=59.654, p < 0.001 \)) and females (\( F=32.524, p < 0.001 \)). But between males and females, the peak torque was greater at all the angles in males. Significant difference was found in the IEMG activity of VMO at all the angles in males (\( F=14.66, p < 0.001 \)) and females (\( F=22.404, p < 0.001 \)), with maximum activity at 60° of knee flexion, followed by 90°, and then 30° of knee flexion. No significant changes were seen in the VL in males (\( F=0.232, p > 0.05 \)) and females (\( F=2.26, p > 0.05 \)).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{peak_torque_on_HUR.png}
\caption{Performance of peak torque on HUR and simultaneous recording of myoelectrical activity on the MYOSYSTEM 1200.}
\end{figure}
Discussion

In this study, we compared the influence of different knee joint angles on the activation level of the quadriceps (VMO, VL and RF) from electromyographic activities during MVIC and torque measurement. The reason for considering three different joint angles in our study was based on the contradiction of previous studies. Investigations conducted by Pincivero et al. (2003), Matheson et al. (2001), Welsch et al. (1998) and Ng et al. (1994) found that quadriceps isometric torque was maximum at 60° of knee flexion. In contrast to this, Suter and Herzog (1997) observed that the quadriceps isometric torque was maximum at 90° of knee flexion. Further, a study conducted by Brownstein et al. (1985) found that maximum peak torque and IEMG occurred in the mid range (60°), while Lieb and Perry (1971) stated that 90° was the optimal position for myoelectric activity under isometric conditions. Contradicting this, Soderberg and Cook (1983) used the 40° position as optimum. Considering the recommendations and findings of all the previous investigators as well as the fact that we wished to investigate both peak torque and IEMG, we decided to include three joint angles which cover and are representative of the inner, middle and outer joint range of motion. The primary finding of our study demonstrated that peak quadriceps torque occurred at 60° flexion (mid range) in both male and female subjects, which is similar to the findings of Lieb and Perry (1971) and Nakamura et al. (1983). These findings also appear to be similar to those of Ng et al. (1994) and Welsch et al. (1998), who found that isometric quadriceps peak torque was highest at 60° flexion. The joint angle at which peak torque occurs is called the optimal joint angle. Any change in optimal angle should reflect a change in the length–tension relationship, assuming that there is no change in the relationship between moment-arm and joint angle. It is well established that at constant levels of excitation, the amount of force generated isometrically is a function of the length of the muscle under investigation (Herzog & Ter Keurs 1988; Ismail & Ranatunga 1978; Ter Keurs et al. 1978; Rack & Westbury 1969; Gordon et al.1966). The possible reason for peak torque being in the mid range may be the length of the muscle; when the muscle was in the shortened position, less

Table 1. Peak torque (Nm) and IEMG (μV) of knee extension parameters at three different knee angles in males

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>30°</th>
<th>60°</th>
<th>90°</th>
<th>Scheffe post hoc comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak torque</td>
<td>Mean ± SD</td>
<td>98.8 ± 20.4</td>
<td>157.8 ± 24.6</td>
<td>127.2 ± 17.03</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>70–150</td>
<td>125–226</td>
<td>95–166</td>
</tr>
<tr>
<td>Vastus medialis oblique</td>
<td>Mean ± SD</td>
<td>652.4 ± 219.1</td>
<td>1,089.2 ± 277.3</td>
<td>884.7 ± 265.6</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>415.3–1,096.7</td>
<td>690.9–1,533.3</td>
<td>516.0–1,406.8</td>
</tr>
<tr>
<td>Vastus lateralis oblique</td>
<td>Mean ± SD</td>
<td>1,136.4 ± 602.1</td>
<td>1,244.0 ± 677.3</td>
<td>1,257.6 ± 579.2</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>453.0–3,163.5</td>
<td>591.7–3,293.4</td>
<td>509.8–2,829.1</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>Mean ± SD</td>
<td>873.1 ± 389.5</td>
<td>957.7 ± 455.3</td>
<td>952.7 ± 557.7</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>318.5–1,807.0</td>
<td>334.0–1,619.5</td>
<td>426.7–2,370.9</td>
</tr>
</tbody>
</table>

and the RF in males (F=0.202, p > 0.05) and females (F=1.595, p > 0.05).

Table 2. Peak torque (Nm) and IEMG (μV) of knee extension parameters at three different knee angles in females

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>30°</th>
<th>60°</th>
<th>90°</th>
<th>Scheffe post hoc comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak torque</td>
<td>Mean ± SD</td>
<td>62.75 ± 13.5</td>
<td>97.3 ± 16.7</td>
<td>74.4 ± 10.3</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>42–100</td>
<td>72–132</td>
<td>60–95</td>
</tr>
<tr>
<td>Vastus medialis oblique</td>
<td>Mean ± SD</td>
<td>367.1 ± 157.3</td>
<td>722.0 ± 166.7</td>
<td>572.8 ± 180.3</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>213.4–899.2</td>
<td>490.3–1,035.1</td>
<td>539.9–1,054.2</td>
</tr>
<tr>
<td>Vastus lateralis oblique</td>
<td>Mean ± SD</td>
<td>901.7 ± 341.3</td>
<td>1,298.1 ± 694.9</td>
<td>1,223.6 ± 760.8</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>550.4–1,663.0</td>
<td>213.3–3,021.1</td>
<td>247.1–3,305.6</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>Mean ± SD</td>
<td>540.9 ± 228.8</td>
<td>704.9 ± 349.5</td>
<td>588.3 ± 305.6</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>195.2–1,073.8</td>
<td>276.3–1,825.6</td>
<td>267.6–1,504.2</td>
</tr>
</tbody>
</table>
torque occurred as compared to the optimal position (length–tension relationship). The knee extensor torque produced by human subjects during MVIC is significantly lower when the leg is close to full extension (i.e., short muscle length). This reduction in torque could partly be due to mechanical factors such as the reduced number of attached cross bridges subsequent to sarcomere shortening beyond the optimal actin–myosin overlap. Lever arm also influences knee extension torque. However, the quadriceps lever arm, found to be maximal at around 30–50° of knee flexion and to decrease with increasing muscle length, would partly compensate for the detrimental actin–myosin overlap of shortened muscles. The present findings, however, are in contrast to those of Suter and Herzog (1997), who observed peak isometric QF torque to occur at 90° flexion, as opposed to 60°.

It was also observed that the IEMG signal of only the VMO shows similar trends as the peak torque values. The maximum myoelectrical activity was seen at 60° of knee flexion, as compared to 90° > 30° (p < 0.05). Such a finding was not seen in any previous study. As in the earlier study (Brownstein et al. 1985), results show that IEMG activity was maximum in the mid range with the peak torque as in our study. Additionally, the strength of our studies showed significant changes (p < 0.05) in myoelectrical activity with changes in the torque while moving from mid to inner or outer range (Tables 1 & 2), showing increment in the myoelectrical activity with increases in torque and showing decrement with decreases in torque. Our study overcame many of the limitations of previous studies. The reasons for the observed differences include adequate sample size, which was one of the limitations of the earlier study (Brownstein et al. 1985), duration of the contraction (10 seconds in our study compared to 3–5 seconds in other studies), and number of contractions (only one in our study compared to three or four contractions in other studies, which may have induced fatigue in the contracting muscles or maximum motor unit recruitment). When a motor unit is activated, the fibers innervated by this motor unit are stimulated and will contract. The activation of this single motor neuron will result in a weak contraction. A stronger muscle contraction is elicited when more motor units are activated that stimulate more muscle fibers. Motor units are generally recruited in order of smallest to largest (fewest fibers to most fibers) as the force of the contraction increases; this principle is known as Henneman’s Size Principle (Henneman et al. 1965). The amount of force produced by muscles depends on the motor unit activation patterns and the mechanical properties of the muscles and musculotendon unit. It is well known that altering joint position or muscle length has a significant impact on the maximum force that a muscle can produce (Linnamo et al. 2006; Hansen et al. 2003; Koo et al. 2002; Leedham & Dowling 1995). Our study shows that when the joint angles moved towards the terminal of knee extension, VMO activity is reduced as compared to the middle and inner range activity; this is similar to the previous findings of Brownstein et al. (1985), Nakamura et al. (1983), and Knight et al. (1979), and may be considered as a cause of why most patellar dislocations occur during full extension. Pincivero et al. (2004) showed that VM recruitment efficiency improved more than the VL and RF muscles across 70° to 90° flexion, and superficial quadriceps muscle recruitment was most efficient at 90°, which is contrary to our findings that showed that VMO IEMG activity followed a significant pattern of recruitment at 60° > 90° > 30° (Tables 1 and 2). Of interest is the finding that the change in VL is less sensitive to change in knee angles but their IEMG activity is almost twice as compared to the VMO in females (refer to Tables 1 & 2). However, it is not clear whether this significantly greater VL activity was elicited because it naturally contributes to greater generation of peak torque or to stabilize the patella with the increased VMO activity or because the design of the testing instrument elicited greater VL activity by providing greater contact on the lateral surface of the tibia (Figure). Recommendations for future studies should take account of possible bias in the placement of the resistance arm, which could introduce a possible source of error. The relative contribution of muscle is specific to the activity involved. VMO activity in both male and female subjects is proportional to torque output. In female subjects, contribution of VL activity is greater in the production of peak torque. We hypothesized that this may be due to the large Q angle offering a greater angle of pull. Thus, clinically, females may be more prone to strength imbalance between VMO and VL than males. This fact needs to be kept in mind for strengthening muscles to prevent injury and during rehabilitation after injury. Greatest peak torque production and VMO activity is in the mid range, i.e., 60°. This should be considered while comparing maximum peak torque production during various methods. Clinically, this fact should also be borne in mind while strengthening the quadriceps though compressive force of the patella on the femoral surface may also be maximal.
We therefore concluded that peak torque occurred in the mid range during maximal contraction of the quadriceps in both sexes. The IEMG activity of only VMO changes with changes in peak torque during maximal isometric contraction and with changes in joint angles in both sexes. Our findings indicate that VMO contributes differently to the peak torque at different knee angles.

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References


