Analysis of quadriceps muscle activation at different squat angles using maximum voluntary isometric contraction (MVIC): a pilot study

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Abstract. The quadriceps muscles play a crucial role in active knee joint stabilization, particularly during functional activities such as squatting. Squat angle variations may influence muscle activation levels. This study aimed to analyze differences in activation of the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) during squat variations using the Maximum Voluntary Isometric Contraction (MVIC) parameter. This pilot study used an Experimental Single Group design involving 12 male futsal athletes from Universitas Muhammadiyah Surakarta (aged 19–22 years, normal BMI, normal Q-angle). Muscle activation was measured with surface electromyography (sEMG) at squat angles of 120°, 90°, and 60°, each repeated three times. Data analysis included the Shapiro-Wilk test for normality and Repeated Measures ANOVA for inter-angle differences. Result showed that the highest activation at 120° was observed in VL (98.73 μV), at 90° in VM (133.42 μV), and at 60° also in VM (176.80 μV). Repeated Measures ANOVA revealed significant differences across all squat angles ($p<0.05$). Squat angle variation influences quadriceps muscle activation. VM showed dominant activation at 90° and 60°, whereas VL was dominant at 120°. These findings may guide the design of targeted quadriceps strengthening programs based on knee joint angle.

1 Introduction

Of all daily activities involving the body, the lower extremities are the most important limbs in the mobilization of each individual. This is related to the knee. The knee is a complex biomechanical and anatomical joint that functionally bears the weight of the body when walking, running, and other activities. In addition, the knee joint is surrounded by many ligaments and muscles that can have the potential for secondary injury. Of the 517 reported cases of quadriceps strain, the injury rate was 1.07/10,000 in athletes[1].

The muscles that play an important role in the knee joint are the quadriceps muscle group, which consists of the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius muscles. The quadriceps muscle group functions as active stabilization of the knee joint and

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also plays a role in joint movement, especially flexion. To perform movements, the knee joint requires good flexibility. Flexibility is the ability to move a single joint or a series of joints smoothly and easily through a pain-free Range of Motion (ROM) that is not limited, which is influenced by the distensibility of the joint capsule, muscle viscosity, and the tightness of ligaments and tendons [2]. Additionally, to maintain muscle performance, maximum strength is required to prevent injuries during activities.

Exercises to increase quadriceps muscle strength include isometric exercises on the leg press or squats. Isometric quadriceps exercises are static exercises that involve muscle contraction without changing the length of the muscle. According to research by [3], squats can increase leg, hip, and back strength and are also a key exercise in sports performance and knee rehabilitation programs. Squats are a functional exercise in the form of a closed kinetic chain for the quadriceps muscles. To do this, stand with your feet apart (32 cm). Then, lower your body weight until your knees are flexed at about 20-30º. The eccentric work of the quadriceps muscle can also cause a rapid deceleration in knee joint flexion and continue to contract against gravity during squats. When working effectively on the lower back, hips, and legs, there are slight variations in technique and muscle involvement.

Several studies have described the kinematic, kinetic, and muscle activity patterns of the knee and hip during squats. Research conducted by[4] to compare the kinematics, dynamics, strength, and energy in joint differences during the cycle of various squat variations showed that during maximum squats, all related muscles must be fully activated to achieve the maneuver and will form normalization in terms of muscle activation. There is an increase in minimum hip angle during squats followed by intradiscal pressure, compression on the vertebrae, tibiofemoral, and patellofemoral joints.

Electromyography (EMG) has been widely used for studies analyzing movement to determine function through electromyography (EMG) signals via human motor signal analysis data [5]. To determine the activation of the quadriceps muscle group during squats at angles of 120°, 90°, and 60° using the Maximum Voluntary Isometric Contraction (MVIC) parameter. The MVIC method is used to measure muscle strength and provides more objective interval data compared to Manual Muscle Testing (MMT). It is also a safe and simple method for assessing muscle strength [6].

According to research conducted based on gender, women have a larger Q-angle than men. The Q-angle in women is less than 22° with knee extension and less than 9° with 90° knee flexion. In men, the Q-angle is less than 18° in the extended position and less than 8° with the knee in a 90° flexed position. The typical Q-angle is 12° for men and 17° for women [7].

A Body Mass Index (BMI) exceeding the normal range can increase the risk of musculoskeletal issues [8]. Before performing EMG placement, the Body Mass Index (BMI) must be considered. This is because one factor that interferes with sEMG signals is thick fat tissue, which can reduce muscle output signals and contribute to geographical changes in the surface where the electrodes are placed [9].

2 Research Methods

The research design was a pilot study, which is a small feasibility study designed to test various aspects of a method planned for a larger, more rigorous, or confirmatory investigation. The research method used was an experimental single group design, in which the researcher involved only one group that met the inclusion criteria. Furthermore, each respondent was given the same intervention. The data analysis technique used in this study was the Repeated Anova Effectiveness Test. The data was obtained from measurements using an electromyograph (EMG) performed on 12 subjects with three measurements at each squat angle and presented in the form of a graph with mean values showing RF, VM, and VL activation when squatting at angles of 120º, 90º, and 60º. Meanwhile, the Shapiro Wilk test was used to test the normality of the data.

Data collection began on November 26, 2022. The population in this study were students of Muhammadiyah University Surakarta who participated in the Futsal University Team and met the inclusion criteria, namely: (a) male respondents, (b) participated in a futsal club, (c) aged 19-22 years, (d) normal BMI, (e) normal knee alignment using inspection, (f) normal Q-angle. The exclusion criteria were: (a) history of lower extremity fracture (femur), (b) valgus posture in the lower extremities, (c) bone and muscle abnormalities in the lower extremities.

Twelve subjects who met the inclusion criteria passed the research screening. The research location was the Gymnasium Laboratory of Muhammadiyah University Surakarta. This study was conducted based on EC number: 087/EC/XII/2022, dated November 21, 2022, issued by the Ethics Committee of the Dr. Soedjono Type II 04.05.01 Hospital.

3 Result and Discussion

3.1 Result

3.1.1 Respondent Characteristics Test

The criteria for this study are based on the inclusion criteria outlined in the following table:

Table 1. Respondent Characteristics

Criteria	Frequency	(%)
Age (years)		
19-20	4	40
21-22	8	60
Gender		
Male	12	100
Female	0	0
BMI		
Normal (19-25)	12	100
***Q-Angle* (Male)**		
<18º	12	100

Screening results conducted prior to data collection using sEMG, which was done to select respondents who met the inclusion criteria for this study.

Table 2. Electromyograph activity refers to the Maximal Voluntary Isometric Contraction (MVIC) for squats at angles of 120^0, 90^0, and 60^0

No	Muscle	Average value		
		120º	**90º**	**60º**
1.	**VL**	98.73	126.68	138.30
2.	**RF**	81.83	108.01	156.08
3.	**VM**	97.78	133.42	176.80

*VL muscle = Vastus Lateralis, RF = Rectus Femoris, VM = Vastus Medialis

* NT = Maximum Value

Table 2 above shows the *mean* values *of Maximum Voluntary Isometric Contraction* during *squats* at angles of 120°, 90°, and 60°. During a 120° *squat*, the muscle with the highest activation high activation is *the Vastus Lateralis muscle*. Meanwhile, during *squats* at angles of 90° and 60°, the muscle with the highest activation is *the Vastus Medialis muscle*.

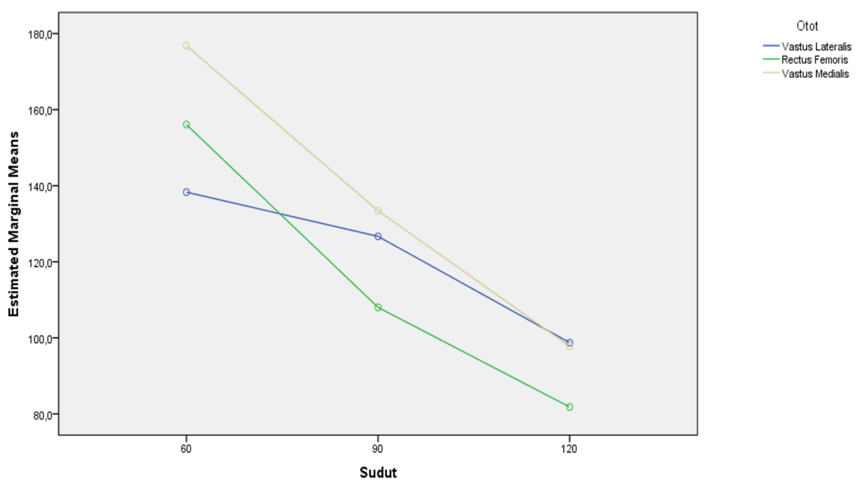

Fig.1 SPSS results of muscle activation during *squats* at angles of 120°, 90°, and 60°

3.1.2 Normality Test

Using the *Shapiro Wilk* test, the sample size was <50 people. *Shapiro Wilk* can be seen from the *p-value* >0.05, which is normally distributed, whereas if *the p-value* is <0.05, the data is not normally distributed.

Table 3. *Shapiro Wilk* Normality Test

Variable	p-value	α= 0.05	Description
120º angle	0.055	>0.05	Normal
90º angle	0.055	>0.05	Normal
60° angle	0.000	<0.05	Not Normal

Based on SPSS calculations, it is known that *the p-value* is >0.05 for the 120º *squat* angle, which has a score of 0.055. Because 0.055 > 0.05, the data is normally distributed. Meanwhile, the 90º *squat* angle has a score of 0.055. Because 0.055 > 0.05, the data is normally distributed, and for the 60º *squat* angle, the score is 0.000. Because 0.000 < 0.05, the data is not normally distributed.

3.1.3 Repeated ANOVA Test

To examine significant differences at each *squat* angle *(using Surface Electromyograph parameters)*. The interpretation of the values is as follows: If the value is <0.05, then the angle has a significant effect; if the significance value is >0.5, then it does not have a significant effect.

Table 4. Repeated ANOVA Test Results

Variable	p-value	α = 0.05	Description
120º angle	0.000	<0.05	Has a significant effect
90º angle	0.000	<0.05	Has a significant effect
60° angle	0.000	<0.05	Has a significant feel

At an angle of 120º, the score is 0.000, so the data result for an angle of 120º is 0.000 >0.05, which means that there is a correlation. At an angle of 90º with a score of 0.000, the data result for an angle of 90º is 0.000>0.05 correlated. At an angle of 60º with a score of 0.000, the data result for an angle of 60º is 0.000 & gt;0.05 correlated.

3.2 Discussion

3.2.1 Respondent Characteristics

The respondents in this study were members of a futsal club. In terms of the average age of the research subjects, which ranged from 18 to 24 years, the most frequent age was 21 years, with 6 respondents. In this age range, based on [10] reviewed using *electromyography*, there is an increase in mass and metabolic efficiency of the *quadriceps* muscle, which is related to daily activities.

In males, the knees tend to be valgus, as *the Q-angle* in males is smaller than in females, increasing the risk of falls or injuries. Therefore, the role of *the quadriceps* muscle group is crucial in maintaining *hip* and *knee* stability (Singh & Yadav, 2020).

3.2.2 Muscle Activation During Squat

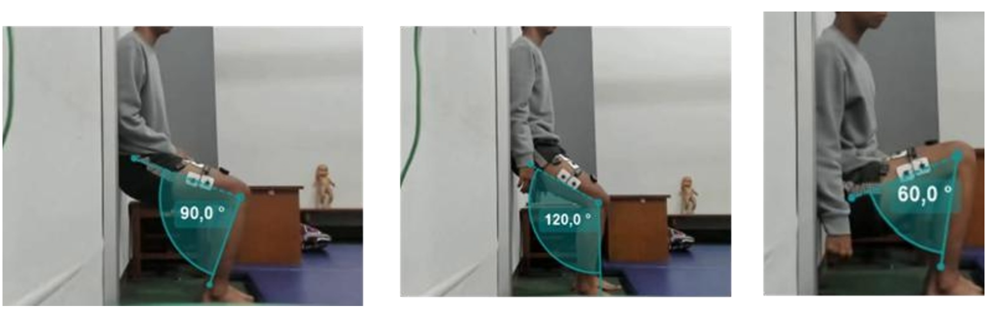

Fig 2. ROM measurement during squats

The RF activation graph during *squats* at 120º and 90º is the lowest compared to VL and VM. Then, at a squat angle of 60º, there is a significant increase compared to VL. This occurs because the *quadriceps* muscle group is the primary mover, especially VL and VM, which have much higher activation compared to RM. Therefore, RM plays a role in *hip* flexion and *knee* extension *(two-joint muscle)*[11] .

During the 120º squat, the activation of the VL did not differ significantly from that of the VM because both muscles are involved in *plantar flexion* of *the ankle*, which is the *instep kick* movement when kicking a ball. VL activation during a 90° *squat* showed lower activation compared to VM. This is because VM plays a larger role than VL during *squats* in stabilizing *the ankle joint* [12]. The peak activation of the *quadriceps* muscle group occurs during an 80-90° squat, with no further increase with greater knee flexion (Singh & Yadav, 2020).

VM activation shows a significant increase compared to RF and VL during squats at angles of 120º, 90º, and 60º. This may occur because VM activation during *squats* plays a role in reducing tibialis internal rotation and patellofemoral compression during *squats*, thus requiring more activation[13]. The squat movement utilizes muscles with different morphologies (monoarticular and biarticular). Muscle strength also varies depending on joint position, whether the muscle acts as a primary mover or stabilizer, or whether the muscle functions dynamically or statically. Position and function drive muscle performance during squats. Muscle activation patterns change in monoarticular and biarticular knee and hip extensors during squats. Different knee angles enhance understanding of maximizing muscle activation and the optimal position in squats for specific evaluation and assessment using sEMG [14] .

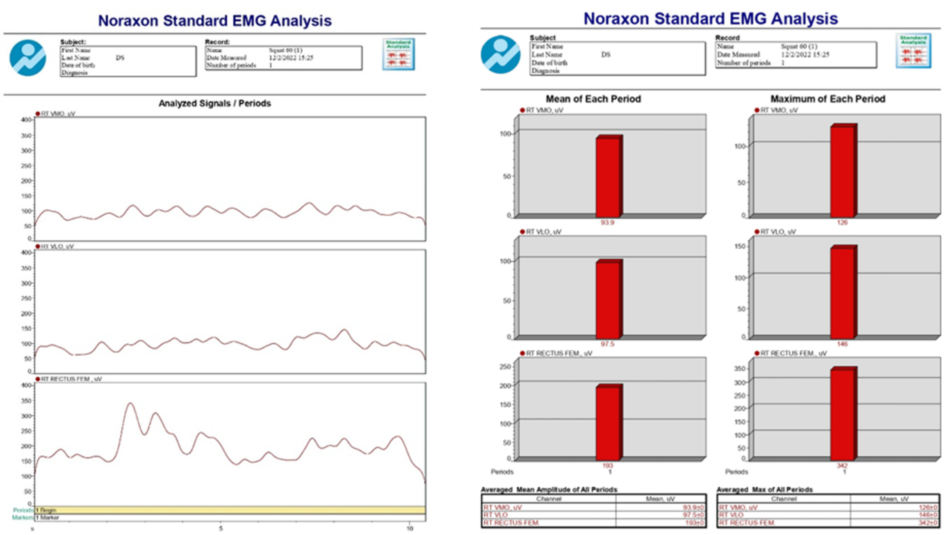

Fig 3. Noracon S-EMG Results

Exercise frequency involves a series of sustained muscle contractions, either of long or short duration, depending on the nature of the physical activity [15]. The effects of exercise on muscles can be considered short-term or immediate, both during and immediately after exercise, as well as long-term and lasting effects [16] . The heavier the intensity of an activity, the greater the muscle movement. This results in a higher energy expenditure required to perform the activity. A large or excessive expenditure of energy will cause fatigue.

4 Conclusion

Based on the analysis of the graphs from the examination of quadriceps muscle group activation at various squat angles using the MVIC parameter, there are differences in muscle activation at each squat angle. At a 120° squat angle, the muscle with the highest activation was the m.Vastus Lateralis. At a 90° squat angle, the muscle with the highest activation was the m.Vastus Medialis, and at a 60° squat angle, the m.Vastus Medialis was the muscle with the highest activation.

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