



# Comparison of muscle activation and knee function between injured and non-injured sides post-ACL injury



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## ABSTRACT

**Background:** Decreased knee function after anterior cruciate ligament (ACL) injury is associated with decreased sports participation and even re-injury. This study aimed to assess quadriceps and hamstring activation and knee function by comparing the injured and uninjured sides following ACL injury.

**Methods:** A sample of 19 people, consisting of 15 people from the surgery group and 4 people from the non-surgery group. Knee functional assessments were performed on the injured and uninjured sides, including assessment of quadriceps and hamstring muscle activation using electromyography (EMG), and knee functional tests using single and triple hop tests. Differences in knee function between the injured and uninjured sides were identified using Paired Samples T-Tests, and non-normally distributed data were analyzed using the Wilcoxon test with a significance level of 5%. Meanwhile, a limb symmetry index (LSI) score of  $\geq 90\%$  was used to categorize adequate and symmetrical function.

**Results:** In the surgical group, there were no significant differences between the injured and uninjured sides in quadriceps ( $P=0.887$ ), hamstring ( $P=0.574$ ), single hop test ( $P=0.064$ ), except for the triple hop test ( $P=0.020$ ). In the non-surgical group, there were no significant differences between the injured and uninjured sides in quadriceps ( $P=0.715$ ), hamstring ( $P=0.225$ ), triple hop test ( $P=0.107$ ), except for the single hop test ( $P=0.008$ ). Meanwhile, LSI values showed varying results. The surgical group had LSI values for quadriceps (98.77%) and hamstring (95.31%) muscle activation, single hop test (82.58%), and triple hop test (83.29%). The non-operative group had LSI values for quadriceps muscle activation (88.62%), hamstring (85.43%), single hop test (74.07%), and triple hop test (65.13%).

**Conclusion:** ACL injury causes a dynamic decline in knee function in both operative and non-operative groups, although it shows adequate and balanced function for quadriceps and hamstring muscle activation, but only in the operative group, and for the non-operative group, quadriceps and hamstring muscle activation are not yet functionally adequate and symmetrical.

**Keywords:** anterior cruciate ligament injury, anterior cruciate ligament reconstruction, knee function, muscle activation.

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## INTRODUCTION

The anterior cruciate ligament (ACL) is one of the ligaments located in the knee joint and has the main function of preventing the tibia from moving anteriorly and maintaining the stability of the knee joint during rotation.<sup>1</sup> ACL injury has become global public health concern due to its high and increasing incidence. Reportedly, the incidence of ACL injuries in Australian hospitals has increased significantly over the past 20 years, at 5.2% per year in men and 6.2% per year in women.<sup>2</sup> In another study, the overall annual incidence of ACL injuries reached 68.6 per 100,000

people, and men had a significantly higher incidence of ACL injuries compared to women due to differences in sports participation.<sup>3</sup> Women are thought to be less involved in collision sports.<sup>4</sup> However, another study identifying the risk of ACL injury in adolescent athletes reported that 1,235 ACL injuries were identified in 17,824,251 injury events in athletes, and female athletes had a 1.5 times higher risk of ACL injury compared to male athletes across all youth sports.<sup>5</sup> Anatomical, hormonal, biomechanical, neuromuscular, and environmental factors are thought to contribute to the potential for ACL injury

occurrence in women.<sup>6</sup> Additionally, factors that differentiate the risk of ACL injury between men and women include age and level of sports participation<sup>3</sup>, type of sport participated in, and level of competition.<sup>7,8</sup>

ACL injuries are associated with a reduction in sports participation. Epidemiological data indicated that 12 months post-ACL reconstruction, 33.4% have attempted to participate in full sports competition, 33.6% have attempted modified sports training and/or competition, and 33.0% have not attempted to train or play sports.<sup>9</sup>

Meanwhile, only 55% of patients after undergoing ACL reconstruction were able to return to competitive sports levels.<sup>10</sup> Another study reported that at a follow-up of 5-8 years post-ACL reconstruction surgery, patients were less physically active compared to individuals without previous injury.<sup>11</sup> The decline in sports participation and physical inactivity post-ACL injuries is a result of various physical health problems that may arise after the injury. Research indicates that 1 to 2 years following ACL reconstruction surgery, patients often report increased knee pain and symptoms, reduced function during sports, lower quality of life, and overall poorer knee function.<sup>12</sup> These problems have long-term consequences, such as the risk of knee instability, meniscus tear, cartilage injury, and osteoarthritis.<sup>13</sup> Rehabilitation is the most important intervention to address physical function impairments and is a determining factor of successful management of ACL injury, both operatively and non-operatively.<sup>14</sup>

The hop test is a valid measure for assessing dynamic knee functional performance after ACL injury.<sup>15</sup> This is supported by other research, which shows that individuals with good hop test results after ACL injury are more likely to return to sport than those with poor hop test results.<sup>16</sup> Adequate and symmetrical function from hop test results is generally determined using the limb symmetry index (LSI) (16). An LSI value of  $\geq 90\%$  is used as a measure of adequate and balanced function, as well as an indicator of readiness to return to sport<sup>17</sup>, because it is associated with a lower risk of re-injury.<sup>18</sup> Meanwhile, to produce powerful dynamic movements, the quadriceps and hamstring muscles play a crucial role. Research reports that hamstring strength, especially in the hip flexion position, may contribute to better jumping performance 8 and 12 months after ACL reconstruction.<sup>19</sup>

Quadriceps muscle strength was associated with movement asymmetry and functional performance.<sup>20</sup> Hamstring tendon coactivation provides dynamic stability to the knee joint and prevents excessive shear forces on the ACL.<sup>21</sup> Meanwhile, decreased muscle strength and stiffness, quadriceps and hamstring activation, influence single-leg hop

performance and dynamic knee stability.<sup>22</sup> Given the similar role of the quadriceps and hamstring muscles in knee function after ACL injury, it is important to identify the strength of the quadriceps and hamstring muscles after ACL injury.

The test used to assess maximal quadriceps and hamstring muscle strength with reliable results is an isokinetic dynamometer (biodex medical systems, shirley, NY, USA).<sup>20,23-25</sup> Other qualified recommendations besides this test include a static test for knee extension strength with maximal voluntary isometric contraction (MVIC), considering the relatively high cost of purchasing an isokinetic dynamometer.<sup>26</sup> To estimate the force generated by the muscle during MVIC, electromyography (EMG) is used, which is capable of recording signals detected by a pair of electrodes placed directly on the skin surface over the target muscle.<sup>21,27-30</sup> Supported by other studies that recommend EMG, considering time and cost can be used as an alternative to the Cybex maximal isometric test to assess MVIC of the superficial quadriceps femoris muscle.<sup>31</sup> EMG is a widely used tool in the fields of Sports Science and Sports Medicine, due to its ability to measure and record muscle activity generated during contraction through electrodes attached to the skin surface.<sup>30,32</sup> Several studies have used EMG analysis to assess and evaluate motor performance, including muscle strength<sup>33</sup>, the effects of exercise movements<sup>30</sup>, neurological deficits<sup>34</sup>, muscle synergies in subacute stroke survivors<sup>35</sup>, and to identify injury risk<sup>36</sup>, including ACL injury.<sup>37,38</sup>

However, studies using EMG-based quadriceps and hamstring activation and hop test performance have not been studied simultaneously in individuals with a history of ACL injury. Previous studies have used EMG to predict muscle activity during vertical jumps that can cause anterior tibial shear forces<sup>39</sup>, examined gluteus medius and vastus medialis activation patterns during single-leg squats and single-leg drop landings<sup>29</sup>, assessed vastus lateralis and biceps femoris muscle activity during stop-jump tasks<sup>40</sup>, and assessed the greatest thigh muscle activity generated during squats, wall squats, and Spanish squats.<sup>30</sup> Hop test performance

is generally associated with thigh muscle strength testing using an isokinetic dynamometer.<sup>19,41,42</sup> Therefore, this study aimed to assess quadriceps and hamstring muscle activation and knee function through a hop test after ACL injury, comparing the injured and uninjured sides to determine the LSI value. Furthermore, the results of quadriceps and hamstring muscle activation measurements were analyzed in relation to single-leg hop performance.

## METHODS

This study used a cross-sectional survey design. The study participants were patients registered with ACL injuries at the Primary Clinic of Jakarta State University and the Yogyakarta Sports Clinic, as well as students from the Faculty of Sport Sciences at Jakarta State University who had experienced ACL injuries. Participants were contacted by telephone, and 43 responded. A selection process was then conducted to determine the eligibility of the study sample according to the study criteria.

The inclusion criteria for this study were recorded as having an ACL injury based on a doctor's diagnosis and stated clinically, having ACL injuries due to sports activities and receiving operative or non-operative treatment, and for those undergoing operative treatment (ACL reconstruction surgery), it must have been carried out 6 months ago or more from the time this study was conducted. Assessments conducted six months post ACL reconstruction surgery are widely recognized as a standard benchmark used to assess knee function post ACL reconstruction.<sup>43,44</sup> Furthermore, during this timeframe, muscle strength has been regained, the graft has matured and healed, as well as neuromuscular control and proprioceptive function are reestablished.<sup>45</sup> Participants were also required to be willing to be a research sample as indicated by signing the consent form to become a research sample. Meanwhile, the exclusion criteria in this study were participants diagnosed with other injuries, those who still showed signs of inflammation in the knee joint including pain and had a limited range of motion compared to the normal side<sup>46</sup>, as

these conditions may affect performance during strength and hop tests<sup>47</sup>, those with conditions that interfere with the participant's ability to give consent to participate in the study, and those currently experiencing health problems which may prevent examinations and tests in this study. Based on the specified criteria, the sample that met the criteria was 19 people consisting of 15 samples with operative treatment and 4 samples with non-operative treatment. The sample selection process can be seen in **Figure 1**.

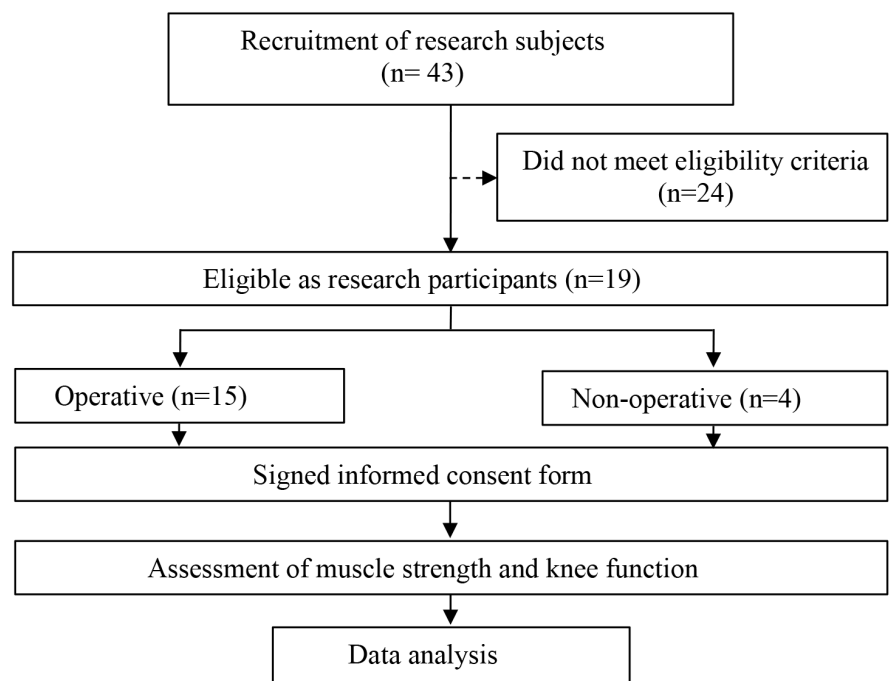
### Testing procedures

Before the assessment of muscle activation of the quadriceps and hamstrings, and knee function, the researcher will provide instructions and ensure that the participant is in good condition. Participants are asked to warm up first for 10 minutes. All assessments begin on the uninjured side first and continue with the uninjured side. The study will be stopped if during the study, participants report feeling knee pain.

### Muscle activation of the quadriceps and hamstrings assessment

Measurements were carried out by the participants performing maximum voluntary isometric contractions (MVIC) on the quadriceps and hamstring muscle groups alternately using the manual muscle testing (MMT) technique.<sup>30</sup> The MMT technique for measuring MVIC has been shown to be reliable and very valuable in terms of time and cost efficiency.<sup>31</sup> To estimate the force generated by the muscle during MVIC, EMG is used, which is capable of recording signals detected by a pair of electrodes placed directly on the skin surface over the quadriceps and hamstring muscle groups. The EMG device used was from NeuroTrac® MyoPlus4 Pro (Verity Medical Ltd, Churchtown House, Tagooat, Co. Wexford, Ireland).

Measurements of muscle activation of the quadriceps were carried out in a sitting position, and the knee was extended 45-degree from knee flexion, then the sample performed MVIC with the MMT technique.<sup>30</sup> The examiner is positioned in front of the participant in a kneeling position on the floor. The examiner holds the participant's ankles to apply resistance while maintaining the knee at 45-degree



**Figure 1.** Sample selection diagram and research flow

of flexion position, as the participant attempts to contract the quadriceps muscle through knee extension movement against the applied resistance. Meanwhile, measurements of muscle activation of the hamstrings were carried out in a prone position, knees bent (flexed) up to 75-degree, and then the sample performed MVIC with the MMT technique.<sup>30</sup> The examiner stands behind the participant and holds the participant's ankles to apply resistance while maintaining the knee at 75-degree of flexion position while the participant attempts to contract the hamstring muscles through knee flexion movement against the applied resistance. To ensure data consistency in assessments, each isometric contraction lasted 5 seconds with a 60-second rest between each trial.<sup>30</sup> Subjects were asked to do 2 trials, and the best peak torque value of the resulting muscle contraction was recorded. The peak values of maximum voluntary contractions were recorded in microvolts ( $\mu V$ ).

### Functional assessment of the knee

Objective functional assessment of the knee using the hop test. The hop test provides objective information about the asymmetry of muscle strength in reconstructive surgery.<sup>48</sup> The hop test is

also used to identify individuals who have regained dynamic knee stability after ACL injury.<sup>49</sup> The hop tests used in the study were the single-hop test and the triple-hop test. The single-hop test for distance is a significant predictor of self-reported knee function 1 year after ACL injury.<sup>50</sup> The test is performed on both sides of the leg, starting on the normal side. The single-hop test is performed by asking the participant to hop forward as far as possible using one leg and land on the same leg. The assessment is declared successful if the landing is stable on the tested leg and holds the position for 3 seconds.<sup>51</sup> The triple-hop test is performed by asking the participant to hop forward as far as possible three times in a row with one leg and land on the same leg. The opportunity to do each hop is 2 times, and the results used are the furthest hop distance and are measured in centimeters.

### Statistical analysis

Descriptive statistical analysis such as number, mean, percentage, and standard deviation were used to analyze the basic characteristics of the research sample. The normality test using Shapiro-Wilk was carried out to determine the normality of the data. Normally distributed data were then analyzed using paired sample t test

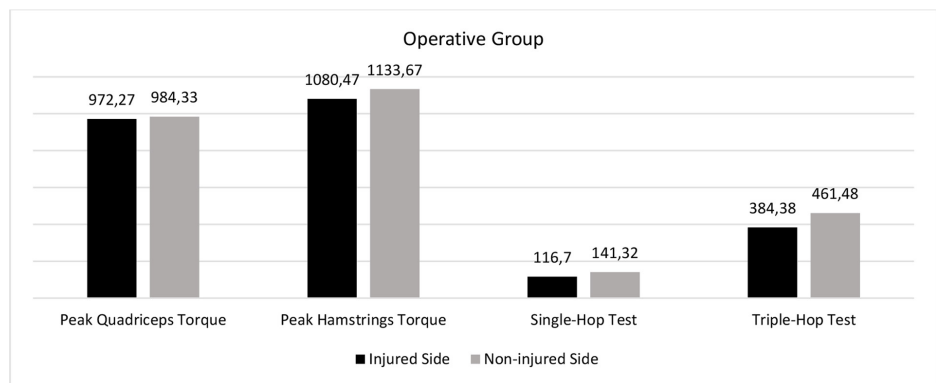
and non-normally distributed data were analyzed using Wilcoxon test analysis to determine the difference in mean values between the injured and non-injured sides. Whilst, effect size is given by Cohen's *d* and confidence interval (CI) 95%. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) Version 25.0. Meanwhile, the Limb Symmetry Index is the result of the calculation of the injured leg divided by the non-injured leg, multiplied by 100 and expressed as a percentage, used to assess limb asymmetry<sup>52</sup>, because muscle strength or function in non-injured limbs is usually used as a reference to evaluate the level of muscle function and strength. Regarding the LSI reference limit value it is generally recommended to categorize as cured or recovered, namely using an LSI value of  $\geq 90\%$ <sup>53</sup>, including a functional knee with a hop test and a maximal voluntary contraction peak value.<sup>54,55</sup>

## RESULTS

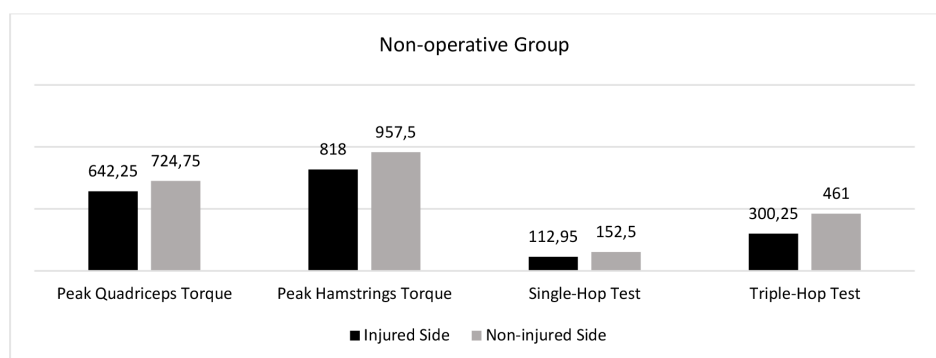
A total of 19 people met the criteria to be the sample of this study, consisting of 15 people with operative treatment and 4 people with non-operative treatment. The average age in the operative group was 22.07 years and the non-operative group was 21.25 years. The average time interval between the occurrence of ACL injury and this study in the non-operative group was 23.21 months, and the average time interval between ACL reconstruction surgery and this study in the operative group was 32.67 months. In the operative group, the most ACL injuries occurred on the right side (66.67%) followed by the left side (33.33%), while in the non-operative group, the most occurred on the right side (75%) followed by the left side (25%).

No significant differences were found between the injured and uninjured leg sides in the operative treatment group for the results of quadriceps muscle activation ( $P = 0.887$ ), hamstring muscle activation ( $P = 0.574$ ), single hop test ( $P = 0.064$ ), except for the triple hop test ( $P = 0.020$ ). The data can be seen in **Table 2** and the illustration in **Figure 2**.

No significant differences were found between the injured and uninjured leg sides in the non-operative treatment



**Figure 2.** Knee muscle and functional activation data between the injured and non-injured sides in the operative group



**Figure 3.** Knee muscle and functional activation data between the injured and non-injured sides in the non-operative group

**Table 1.** Characteristics of participants in the operative and non-operative groups

| Characteristics             | Operative (n=15)<br>Mean±SD or n(%) | Non-operative (n=4)<br>Mean±SD or n(%) |
|-----------------------------|-------------------------------------|----------------------------------------|
| Age                         | 22.07 ± 2.08                        | 21.25 ± 1.26                           |
| Sex                         |                                     |                                        |
| Male                        | 10 (66.7)                           | 4 (100.0)                              |
| Female                      | 5 (33.3)                            | 0 (0.0)                                |
| BMI                         | 24.53 ± 4.17                        | 25.72 ± 2.69                           |
| Time from operation to test | 32.67 ± 24.61                       | -                                      |
| Time from injury to test    |                                     | 23.21 ± 12.65                          |
| Injury side                 |                                     |                                        |
| Right                       | 10 (66.7)                           | 3 (75.0)                               |
| Left                        | 5 (33.3)                            | 1 (25.0)                               |

BMI, body mass index; n, number of participants; SD, standard deviation

group for the results of quadriceps muscle activation ( $P = 0.715$ ), hamstring muscle activation ( $P = 0.225$ ), triple hop test ( $P = 0.107$ ), except for the single hop test ( $P = 0.008$ ). The data can be seen in **Table 3** and the illustration in **Figure 3**.

The LSI values in the operative group for the quadriceps muscle activation assessment (98.77%), hamstring muscle

activation were 95.31%, single hop test (82.58%), and triple hop test (83.29%). Meanwhile, the LSI values in the non-operative group for the quadriceps muscle activation assessment were 88.62%, hamstring muscle activation (85.43%), single hop test (74.07%), and triple hop test (65.13%). The data is presented in **Table 4**.

**Table 2.** Results of the test of differences in average muscle activation and knee functional values between the injured side and the non-injured side of the operative group

| Variable               | Injury side<br>Mean±SD | Non-injured side<br>Mean±SD | P-value | 95% confidence interval<br>of the difference |         | Effect<br>size |
|------------------------|------------------------|-----------------------------|---------|----------------------------------------------|---------|----------------|
|                        |                        |                             |         | Lower                                        | Upper   |                |
| Peak quadriceps torque | 972.27 ± 451.45        | 984.33 ± 382.71             | 0.887   | -325.090                                     | 300.956 | -0.029         |
| Peak hamstring torque  | 1080.47 ± 310.89       | 1133.67 ± 353.84            | 0.574   | -302.319                                     | 195.919 | -0.160         |
| Single-hop test (cm)   | 116.70 ± 47.31         | 141.32 ± 47.44              | 0.064   | -60.057                                      | 10.817  | -0.520         |
| Triple-hop test (cm)   | 384.38 ± 152.06        | 461.48 ± 110.75             | 0.020   | -176.588                                     | 22.401  | -0.580         |

Cm, centimeter; SD, standard deviation.

**Table 3.** Results of the test of differences in average muscle activation and knee functional values between the injured side and the non-injured side of the non-operative group

| Variable               | Injury side<br>Mean±SD | Non-injured side<br>Mean±SD | P-value | 95% confidence interval of<br>the difference |         | Effect size |
|------------------------|------------------------|-----------------------------|---------|----------------------------------------------|---------|-------------|
|                        |                        |                             |         | Lower                                        | Upper   |             |
| Peak quadriceps torque | 642.25 ± 258.38        | 724.75 ± 361.88             | 0.715   | -554.000                                     | 755.000 | -0.250      |
| Peak hamstring torque  | 818.00 ± 387.55        | 957.50 ± 422.83             | 0.225   | -841.238                                     | 562.238 | -0.344      |
| Single-hop test (cm)   | 112.95 ± 33.77         | 152.50 ± 33.83              | 0.008   | -98.033                                      | 18.933  | -1.170      |
| Triple-hop test (cm)   | 300.25 ± 156.46        | 461.00 ± 111.70             | 0.107   | -395.947                                     | 74.447  | -1.183      |

Cm, centimeter; SD, standard deviation.

**Table 4.** Limb symmetry index values in the assessment of muscle activation and knee functional

| Variable               | Group            |                     |
|------------------------|------------------|---------------------|
|                        | Operative (n=15) | Non-operative (n=4) |
| Peak quadriceps torque | 98.77%           | 88.62%              |
| Peak hamstring torque  | 95.31%           | 85.43%              |
| Single-hop test        | 82.58%           | 74.07%              |
| Triple-hop test        | 83.29%           | 65.13%              |

n, number of participants.

## DISCUSSION

This study aimed to assess quadriceps and hamstring muscle activation and knee function through a hop test after ACL injury, comparing the injured and uninjured sides to determine the LSI value. Furthermore, the results of quadriceps and hamstring muscle activation measurements were analyzed in relation to single leg hop performance. The results of the study showed that there were no significant differences between the injured and uninjured legs except for the triple hop test results in the operative group and the single hop test for the non-operative group. Other findings from this study reported varying results for each assessment, when referring to the LSI

value  $\geq 90\%$  as a measure of adequate and balanced function, as well as an indicator of readiness to return to sport after ACL injury. In the operative and non-operative groups, the single and triple hop test results all showed functional deficits or inadequate and unbalanced function. This supports previous research that ACL injury still leaves neuromuscular deficits even though it has occurred a long time ago and which is often reported to be associated with decreased hop performance.<sup>56-58</sup> In the context of sports, post-ACL injury hop performance is one of the criteria for determining readiness to return to sport after ACL injury.<sup>54</sup> Poor ability in the single leg hop test is associated with the risk of developing osteoarthritis 5 years after injury.<sup>57</sup> This is because decreased

function is associated with a 2-4 fold increase in the risk of decreased health conditions in bone marrow lesions (BMLs) where BML is recognized as an important biomarker for OA.<sup>59,60</sup>

Hop performance is influenced by the role of the quadriceps and hamstring muscles. This is because the quadriceps muscles can affect balance during hop performance and the hamstring muscles provide knee stability during dynamic movements and prevent excessive shear forces on the ACL.<sup>20,61</sup> If both muscles are weakened, it will impact hop results.<sup>20,61</sup> However, the results of this study are only in the non-operative group, where inadequate and unbalanced quadriceps and hamstring muscle activation also resulted in deficits in the single and triple hop tests. However, in the operative group, although quadriceps and hamstring muscle activation had achieved adequate and balanced function, they did not show adequate and balanced results in the single and triple hop tests. These results suggest that other factors besides quadriceps and hamstring muscle activation influence hop results. Psychological factors such as fear of re-injury cause decreased self-confidence related to one's functional abilities, thus reducing physical activity which can potentially increase the risk of

re-injury.<sup>62</sup>

This includes when performing single hop and triple hop tests, which may be considered to have the potential to cause re-injury, resulting in movements that are not performed optimally. Meanwhile, limitations of this study include, first, it did not assess various other factors such as psychological factors, neuromuscular control, joint stability, biomechanics, and core strength, thus potentially limiting the interpretation of the deficits observed in the single-leg and triple-leg hop tests in the study sample. Second, the use of EMG devices to assess quadriceps and hamstring muscle activation. Previous research has suggested that EMG amplitude detected through electrodes attached to the skin surface during MVIC cannot be used to accurately assess absolute changes in muscle force (e.g., measured in newtons), but only relates to the magnitude of muscle activation and torque.<sup>27</sup> This is reinforced by the statement that isometric strength may not be sufficient to identify strength deficits in adolescent populations with ACL injuries.<sup>63</sup> In addition, using EMG to identify force changes during isometric contractions is important to limit the influence of crosstalk, and ensure representative activation of all muscles to provide accurate results.<sup>27</sup> Third, a limitation of this study is the use of a small sample, which means that the data cannot be fully represented in the analysis.

According to the Delaware-Oslo guidelines, the criteria for determining a successful outcome post ACL injury and reconstruction, encompass assessment across all levels of the international classification of function including effusion, giving way, muscle strength (body structure and function), PRO (activity and participation), and return to sport (participation).<sup>64</sup> Complemented by other guidelines, the assessment used to determine the decision to return to sport includes: mobility (knee flexion/extension 100% LSI), stability (balance error scoring system >90% LSI), strength (quadriceps 60, 180, 300 degrees/sec >90% LSI; hamstrings 60, 180, 300 degrees/sec >90% LSI; hamstrings/quadriceps ratio at 300 degrees/sec >55% males and >62.5% females), movement quality (landing error scoring system <5 errors), power (single-leg triple hop >90% LSI), function

(international knee documentation committee subjective knee form >90%), dan psychological readiness (ACL-return to sport after injury scale >56 points).<sup>54</sup> However, other studies have suggested the importance of thorough and careful evaluation when interpreting LSI results as a standard for return to sport after ACL injury, as it can overlook performance deficits.<sup>65</sup> Specifically, if the contralateral or comparison leg experiences a significant decline in functional performance, the injured side may appear to be more recovered even though it is not yet fully recovered.<sup>66</sup> This factor may contribute to differences in the relationship between LSI values for quadriceps and hamstring muscle activation and LSI hop test performance. Therefore, the LSI should not be used in isolation to evaluate changes in functional performance after ACLR.<sup>66</sup>

There were some limitations associated with this study, and these need to be considered. The first limitation was the relatively small sample size, which could affect the generalizability of this study. The limited functional assessments used in this study may not represent all aspects of functional factors associated with knee function and return to sports after ACL injury. The cross-sectional design of this study does not allow the long-term functional outcomes or causal effects to be assessed. Future research should be conducted using a larger sample size and adopting a multidimensional evaluation framework that encompasses all aspects that influence knee function after ACL injury and readiness to return to sport after ACL injury. Such an approach would provide a more comprehensive understanding and support more accurate decision-making regarding a safe return to sport. If functional deficits remain evident on evaluation, as observed in this study, these findings can be used as a basis for designing a structured and individualized follow-up rehabilitation program focused on addressing any remaining functional imbalances to ensure optimal knee function after ACL injury.

## CONCLUSION

ACL injury causes a dynamic decline in knee function in both operative and non-operative groups, although it

shows adequate and balanced function for quadriceps and hamstring muscle activation but only in the operative group, and for the non-operative group, quadriceps and hamstring muscle activation is not yet functionally adequate and symmetrical. Despite the limitations of this study, the results of this study provide a perspective that the importance of a continued rehabilitation program to address the remaining functional imbalance until the knee function reaches optimal recovery.

## ETHICAL CONSIDERATION

This research has obtained permission from the research ethics commission, Institut Teknologi Bandung, Indonesia with the number KEP/II/2024/X/M290524EY-PMNT.

## CONFLICT OF INTEREST

The authors declare no conflict of interest

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## AUTHOR CONTRIBUTIONS

EY drafted the original draft. DN contributed to the methodology. YS contributed to the data analysis. WK, RLA, and MIZ contributed to the conception and review of the manuscript.

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