THE EFFECT OF MUSCLE STRENGTH NORMALIZATION PROCEEDURES ON DECISIONS TO RETURN TO SPORT

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The objective of this study was to evaluate different methods of normalizing and reporting muscle strength for making decisions about return to sport following an anterior cruciate ligament injury. 42 participants performed 5 isometric knee extensions on an isokinetic dynamometer. The peak force as well as the rate of torque development were determined and expressed either as the average of 4 trials or the peak value. In addition, the limb symmetry index was determined for each condition and compared. Using the peak method resulted in significantly higher values ($p<0.000$) peak strength average strength (145.1±60.5 Nm) as compared to the average value (136.0±57.0 Nm) with both methods yielding similar limb symmetry indexes. There was also a strong relationship between these the between peak and average strength values ($r=0.99$, $p<0.000$), rate of torque development ($r=0.95$, $p<0.000$) and limb symmetry index ($r=0.98$, $p<0.000$). The differences between methods suggests an inability to give a consistent effort likely due to impairments in muscle endurance or neuronuclear control of the quadriceps. The choice of whether to choose the peak or average value should be considered carefully in light of these results and reflect whether the clinician or coach are most interested in the absolute ability or the overall ability of the quadriceps to generate force when assessing recovery from a knee injury.

KEYWORDS: Rate of torque development, muscle strength, isometric, rehabilitation, return to sport

INTRODUCTION: Over 200,000 anterior cruciate ligament reconstructions (ACL) occur annually in the United States(Majewski et al., 2006). The injury commonly occurs in a wide range of sports from skiing to rugby, basketball and soccer(Majewski et al., 2006). Following an ACL tear there is a protracted period of time of rehabilitation before the athlete is able to return to sport (Lepley et al., 2020). Unfortunately return to sport rates remain low, with up to 50% of athletes unable to return to sport or to their prior level of sport (Ardern et al., 2011). While the reasons for not returning to sport are multifactorial, reductions in muscle strength are thought to be important contributors. In particular, quadriceps muscle weakness is thought to be an important factor(Noehren & Snyder-Mackler, 2020).

Quadriceps muscle weakness after an ACL tear is pervasive. Emerging work shows that these strength deficits may persist for up to 2-8 years following the injury (Lepley, 2015; Lepley et al., 2020). Given the chronicity of the loss of strength, identifying impairments early after injury is critical in order to incorporate effective treatment options to alter this negative course. In addition, recovery of quadriceps muscle strength on the injured limb as compared to the non-injured limb (limb symmetry index) is commonly used as a guide to decide if an athlete is ready to begin return to sport with their team (Roe et al., 2021). Despite the commonality of measuring quadriceps muscle strength, little work exists evaluating the effect of how it is reported. How muscle strength is expressed maybe important to define as many papers do not report which method they used and it is not clear if one can compare across papers using different methods(Lepley, 2015).

In addition to muscle strength, rate of torque development (RTD) is becoming an increasingly utilized as a metric to gauge athletic ability in return to sport decisions(Kline et al., 2015). The rate of torque development is typically measured as the slope along the linear portion of the ascending portion of the torque vs time curve of an isometric muscle contraction (Kline et al., 2015). Higher rates of RTD indicate a greater ability to quickly contract the quadriceps muscle

(Andersen & Aagaard, 2006). The ability to quickly contract the quadriceps muscle and generate force is critical for sport performance. The increased popularity of using this technique motivates the need to evaluate methods of reporting this data.

Several methods exist for how quadriceps strength data and rate of torque development is reported. One method is to take an average of muscle strength across multiple trials. Another common method is to take the peak value from amongst several trials. If the athlete is unable to provide a consistent effort across trials a significant difference between methods may be found. For example, if an athlete has one really strong effort for knee extension but the rest of the trials are low the average and peak method may yield very different results. In addition, significant differences between the average and peak values would indicate potential problems with muscle endurance or joint pain that could influence an athlete's readiness to return to sport. Prior work suggests that both methods are reliable (Grindstaff et al., 2019). Therefore, the purpose of this study was to evaluate the effect of how strength and RTD data is reported in athletes who have had an ACL tear. We hypothesized that there would be significant differences between using the average of several trials vs the single best trial within the injured limb. We also hypothesized that this would result in significant differences in the limb symmetry index. Lastly, we hypothesized that there would be a significant relationship between the methods of reporting quadriceps muscle strength and RTD.

METHODS: Participants: Following a protocol approved by the university institutional review board, 42 participants (23 males, 19 females; mean ± SD: age 21.2 ± 5.7 yr; BMI, 24.9 ± 4.3) who had a unilateral ACL tear provided their written informed consent. All ACL tears were confirmed by clinical evaluation and diagnostic testing performed by an orthopedic surgeon. To be included individuals must have had an ACL tear within the past 10 weeks, the injury must have been due to playing sports, and the participant must have been physically active. Potential participants were excluded if they had a history of previous ACL injury, sustained a complete knee dislocation, were skeletally immature, or had a BMI >35.

Participants completed maximal voluntary isometric knee extension strength testing of the involved and uninvolved limb on a Biodex System 4 isokinetic dynamometer (Biodex Medical Systems Inc). Participants performed a 5 minute warm up of treadmill walking. One submaximal effort practice trial was allowed to familiarize the participant with the testing procedure (Maffiuletti et al., 2016). Following the practice trails they performed four 5 second trials separated by 30 seconds of rest. Participants were informed to kick out as hard and fast as possible and maximal verbal encouragement was given to ensure full effort (Sahaly et al., 2001). Participants were secured in the dynamometer by a shoulder, lap, and thigh strap to ensure the isometric contraction was isolated to the knee joint (Folland et al., 2014). All trials were performed with the knee at 90° and hip flexed to 85°. Custom MATLAB code (MathWorks Inc, Natick, MA, USA) was used to calculate RTD by determining the slope of the torque–time curve between 20 and 80% of the first 200ms from the onset of torque production, defined as a 6 Nm signal threshold. The muscle strength and RTD data were then expressed in several forms. The average of the 4 trials was determined. In addition, the peak torque value and RTD amongst the 4 trials was identified. The data was also expressed as a limb symmetry index (Injured/Non-injured)*100. The different methods were compared with a paired t-test. The relationship between the methods was determined with Pearson product moment correlation coefficients.

RESULTS: We found that the peak quadriceps strength (145.1±60.5 Nm) was significantly higher than the average value (136.0±57.0 Nm) for isometric strength ($p<0.000$) as well as for RTD (457.5±224.8 Nm/s Peak vs 373.3±190 Nm/s Avg, $p<0.000$) but not for limb symmetry index (71.3±22 peak vs 71.0±22 Avg, $p=0.75$). We show in figure 1 one example of the inconsistency between peak and average trials within this population. We also found a strong correlation between peak and average strength values ($r=0.99$, $p<0.000$), peak and average RTD ($r=0.95$, $p<0.000$) as well as peak and average LSI ($r=0.98$, $p<0.000$).

DISCUSSION: The purpose of this study was to evaluate the effects of differing methods of reporting muscle strength in athletes who are ACL deficient. Establishing differences between techniques is important as it may affect return to sport decisions and the ability to compare studies that have used various methods of reporting strength and RTD. We found that taking the peak value was significantly higher than the average value for both strength and rate of torque development. We also found that average and peak values were highly associated with each other. The LSI between the two methods was not significantly different. These results have a number of important implications that effect decisions on return to sport as well as performance of the quadriceps muscle after an ACL tear.

The decision to allow an athlete to return to sport is informed by many factors with quadriceps strength being one of the key metrics used. To date, most return to sport decisions have been made using LSI. However, recently it has been advocated that an absolute amount of strength in the injured limb be used as the non-injured limb could also be changing in response to the injury (Pietrosimone et al., 2016). The results of this study indicate that using the peak strength would yield significantly higher values and may result in the athlete being allowed to return to sport sooner. Potentially, returning to sport earlier could put the athlete at risk for another subsequent injury, and additional work is needed to evaluate differences in timing for return to sport if using peak muscle strength.

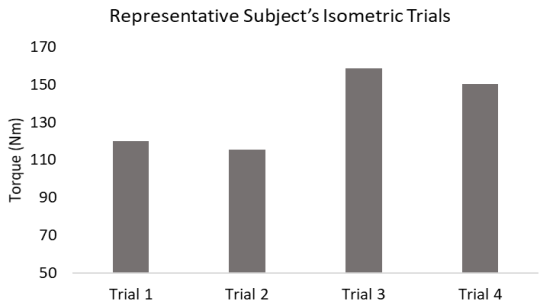

Figure 1. Representative subject's four isometric trials.

The differences between using the average and peak values for both peak strength and RTD also yield interesting insights into how consistent the athlete is able to produce force. If the athlete was able to consistently generate the same amount of force we would have expected there to be no minimal difference in measuring peak vs average force. These results indicate that the athlete may either build up to giving their best effort on the last trial or having given it their best effort on the first contraction is not able to maintain such an effort for the remaining trials. In either situation these results point to potential limitations in the muscle's endurance. Furthermore, an inability to consistently generate the same amount of force for a given effort could negatively affect athletic performance and potentially leave the athlete at risk for a subsequent injury. However, the two methods were highly associated with each other suggesting that even though the average value was less, those who had higher peak values were likely to also have higher average values.

The results of this study indicate that studies using different methods of reporting muscle strength cannot be compared. One suggestion could be to explicitly report whether the peak or average value was used to allow for more clear comparison between studies. Another potential solution would be to compare the LSI between studies as this ratio was not affected by the method of reporting to the same extent. This study is not without limitations. These data are only reported for an isometric contraction and cannot be extrapolated to other types of contraction (isokinetic or isotonic). Only the quadriceps muscle was tested in one position and more work is needed to consider how universal the differences between methods are if examining different muscles in various positions. We are also unable to establish if one method or the other is more sensitive in its ability to predict safe return to sports.

CONCLUSION: This study sought to evaluate the effect of various methods of reporting quadriceps strength and RTD in athletes who are ACL deficient. We found the peak value for both quadriceps strength and RTD was significantly higher than using the average value. These results suggest that athletes are not able to give a consistent effort indicating either

impairments in muscle endurance or neuronuclear control of the quadriceps. Potentially using the average value may yield a more conservative and thus more stringent level of performance needed to make a return to play decision. In addition, these results suggest that care should be taken when comparing studies that have used different methods of reporting muscle strength values. The LSI however was similar between methods and could be used as one method of evaluating results between studies. The choice of whether to choose the peak or average value should be considered carefully in light of these results and reflect whether the investigator or clinician are most interested in the absolute ability or the overall ability of the quadriceps to generate force.

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