Correlation between proprioception, muscle strength, knee laxity, and dynamic standing balance in patients with chronic anterior cruciate ligament deficiency

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ABSTRACT

Proprioception and muscle strength are both reported to influence single-limb stance balance in patients with chronic anterior cruciate ligament (ACL) injuries. However, the effects of these parameters on dynamic stance balance in such patients are currently unknown. This study was undertaken to ascertain whether proprioception, muscle strength, and knee laxity are correlated with dynamic standing balance in patients with ACL deficiency. Ten young men with unilateral ACL deficiency participated in this study. The mean time interval from the injury to the study was 12.8 months. Knee laxity measurements, passive re-positioning (PRP) proprioception tests, quadriceps and hamstring muscle strength tests, and dynamic single-limb balance tests were performed for both injured and uninjured limbs. Significant differences between the injured and uninjured sides were observed for all test parameters. As independent variables, knee laxity, PRP proprioception, and muscle strength did not correlate with dynamic standing balance for the injured limb. However, a significant positive correlation (P<0.05) between TTDPM proprioception and dynamic single-limb stance balance was observed for the injured limb. To improve dynamic single-limb stance balance in patients with ACL injuries, training in TTDPM proprioceptive ability is recommended as the most important initial approach for such patients.

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1. Introduction

Injury to the anterior cruciate ligament (ACL) leading to defects in passive joint stability and disruption of proprioceptive function is a common occurrence in young athletes [1]. Proprioception, the ability to sense stimuli arising within the body, includes the capacity to sense joint position and joint motion [2]. Proprioceptive mechanoreceptors, such as Ruffini endings, Pacinian corpuscles, and Golgi tendon organs, are present in the ACL [3–5]. Quick-adapting mechanoreceptors, such as the Pacinian corpuscles, are thought to mediate the sensation of joint motion; whereas slow-adapting mechanoreceptors, such as the Ruffini endings and Golgi tendon organs, are thought to mediate the sensation of joint position [6]. A statistically significant decrease in proprioceptive ability in patients with ACL-deficient knees has been observed in several studies [7–9]. The sensory information derived from proprioception, as well as from the vestibular and visual systems, contributes to the maintenance and control of posture and balance in a particular position or during movement [10]. Any type of dysfunction in proprioception, as well as in the vestibular or visual systems, may, therefore, impair postural control.

Balance requires the continuous adjustment of muscle activity and joint position to retain the body’s center of gravity over the base of support [11]. Factors with the potential to influence balance include muscle fatigue or weakness, age, sex, level of physical activity, and previous injury to a lower-extremity [12]. Impaired single-limb stance balance, measured by a force platform, has been reported for individuals with chronic ACL injuries [13–15]. However, relatively few studies have been performed that examine the relationship between impaired proprioception and standing balance in these individuals. Ageberg et al. [16] examined the influence of knee laxity, proprioception, and muscle strength on balance in a single-limb stance in patients with chronic ACL injuries. Stabilometry, including the amplitude and average speed of the center of pressure movements, for single-limb stance balance was measured on a static force platform. Their findings revealed that proprioception and the strengths of the quadriceps and hamstring muscles significantly influenced the average speed of the center of pressure among women. Poor proprioception and high muscle strength values reduced the movement speed of the center of pressure.

The proprioception test can be used to measure either the threshold for detection of passive motion [16,17] or the sense of joint repositioning [2,17], while the balance test can be performed
either on a firm stable platform (stabilometry) [16] or on a moveable or in firm (not fixed on the ground) platform (the dynamic test) [2,12]. O’Connell et al. [18] suggested that the use of a postural sway meter (stabilometry) for predicting function and stability during dynamic activities in patients with ACL deficiency may be inappropriate. The present study was therefore undertaken to assess the influence of knee laxity, proprioception, and muscle strength on dynamic balance in the single-limb stance for patients with chronic ACL injuries. We hypothesized that a positive correlation existed between muscle strength, proprioception, and dynamic balance.

2. Methods

2.1. Participants

Twelve patients, 10 men and two women, participated in this study. Inclusion criteria were as follows: (1) age between 15 and 30 years; (2) presence of unilateral, chronic ACL deficiency not treated surgically and without associated lesions on other structures of the knee; and (3) absence of history of neurological disease or of vestibular or visual disturbance [16]. The mean age was 23.1 years (range, 20 to 26), the mean height was 167.6 cm (range, 155 to 176), and the mean body weight was 62.2 kg (range, 52 to 67). The mean interval from the time of injury to the time of testing was 12.8 months (range, 9 to 24). The characteristics of the participants are given in Table 1; most ACL injuries (75%) were incurred while playing basketball. All participants signed informed consent forms, and all tests were approved by the Research Ethics Committee at our institute (HML). The tests described below were performed in the following order: (1) knee laxity, (2) proprioception, (3) dynamic balance, and (4) muscle strength. The test order was selected on the basis of the study of Ageberg et al. [16], and we also believe each previous test will not influence the result of the subsequent test.

2.2. Measurement of knee laxity

Anterior displacement of the tibia relative to the femur was measured using a KT-1000 arthrometer (MEDmetric Corp., San Diego, CA) with a 148 N (30 lb) force. The arthrometer was fixed to the limb with the knee flexed at 30°. Anterior displacement was recorded in millimeters.

Table 1
Basic characteristics of 12 participants with chronic ACL injuries.

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Activity causing injury</th>
<th>Months from injury to testing</th>
<th>Lysholm score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>24.2</td>
<td>58</td>
<td>173</td>
<td>Basketball</td>
<td>13</td>
<td>78</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>23.3</td>
<td>61</td>
<td>162</td>
<td>Jogging</td>
<td>12</td>
<td>86</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>20.2</td>
<td>60</td>
<td>168</td>
<td>Basketball</td>
<td>10</td>
<td>81</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>21.8</td>
<td>64</td>
<td>167</td>
<td>Basketball</td>
<td>12</td>
<td>77</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>26.6</td>
<td>63</td>
<td>155</td>
<td>Basketball</td>
<td>24</td>
<td>82</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>23.3</td>
<td>67</td>
<td>171</td>
<td>Basketball</td>
<td>11</td>
<td>77</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>21.9</td>
<td>52</td>
<td>158</td>
<td>Soccer</td>
<td>12</td>
<td>77</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>23.1</td>
<td>68</td>
<td>171</td>
<td>Basketball</td>
<td>9</td>
<td>74</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
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<td>62</td>
<td>176</td>
<td>Basketball</td>
<td>10</td>
<td>69</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>25.7</td>
<td>65</td>
<td>168</td>
<td>Basketball</td>
<td>16</td>
<td>74</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>24.2</td>
<td>65</td>
<td>172</td>
<td>Basketball</td>
<td>10</td>
<td>81</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>20.8</td>
<td>61</td>
<td>170</td>
<td>Jogging</td>
<td>15</td>
<td>77</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>23.1</td>
<td>62.2</td>
<td>167.6</td>
<td></td>
<td>12.8</td>
<td>77.75</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>1.8</td>
<td>4.1</td>
<td>6.0</td>
<td></td>
<td>3.9</td>
<td>4.23</td>
</tr>
</tbody>
</table>
Table 2
Mean values with standard deviations and ranges for knee laxity, proprioception, muscle strength, and dynamic standing balance for 10 male participants with ACL injuries.

<table>
<thead>
<tr>
<th>Variable (unit)</th>
<th>Injured side (n = 10)</th>
<th>Uninjured side (n = 10)</th>
<th>P values</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee laxity (mm)</td>
<td>11.8 ± 2.10 (8–15)</td>
<td>4.70 ± 1.64 (2–7)</td>
<td>&lt;0.001</td>
<td>1.0</td>
</tr>
<tr>
<td>PRP (°)</td>
<td>4.64 ± 1.70 (2.3–8.6)</td>
<td>3.33 ± 1.30 (2.1–7.0)</td>
<td>0.001</td>
<td>0.35</td>
</tr>
<tr>
<td>TTDPM (°)</td>
<td>3.76 ± 2.60 (0.7–8.0)</td>
<td>2.61 ± 1.95 (0.6–5.6)</td>
<td>0.015</td>
<td>0.17</td>
</tr>
<tr>
<td>Quadriceps strength (N·m)</td>
<td>121.0 ± 52.1 (60–168)</td>
<td>155.9 ± 38.8 (88–216)</td>
<td>&lt;0.001</td>
<td>0.25</td>
</tr>
<tr>
<td>Hamstring strength (N·m)</td>
<td>99.1 ± 22.2 (44–122)</td>
<td>122.9 ± 28.8 (63–171)</td>
<td>&lt;0.001</td>
<td>0.50</td>
</tr>
<tr>
<td>H/Q ratio (100%)</td>
<td>82.7 ± 9.7 (64–98)</td>
<td>79.4 ± 10.2 (70–94)</td>
<td>0.460</td>
<td>0.10</td>
</tr>
<tr>
<td>Tilt angle of balance (°)</td>
<td>6.08 ± 2.28 (2.3–9.8)</td>
<td>5.41 ± 1.92 (1.9–7.4)</td>
<td>&lt;0.001</td>
<td>0.25</td>
</tr>
</tbody>
</table>

2.3. Proprioception test

Proprioception was measured with a self-designed apparatus as described previously [17,19]. In the passive re-positioning (PRP) test, participants sat on a Con-Trex MJ bed (Con-Trex, Zurich, Switzerland) with their knee at 45° of flexion. A pneumatic compression cuff was placed on the foot of the tested limb to reduce the contribution of cutaneous stimuli to the sense of position. The cuff was attached to the L-shaped arm of the proprioception testing apparatus (PTA) (Fig. 1). To eliminate visual clues to knee position, all participants were blindfolded. To eliminate auditory clues to the start of knee flexion, participants wore a set of earphones and listened to white noise during the test. The PTA rotated the knee along the axis of the joint toward extension (from 45° flexion to extension) or toward flexion (from 45° flexion to 90° flexion) then passively positioned back to the starting point (45° flexion) at a velocity of 0.5°/s. When the subject felt his or her knee was passively positioned back to the reference angle (45° of knee flexion), he/she flipped a switch. Three test trials were administered, and the mean absolute differences between the target and the reproduced angles were used for statistical analyses.

Measurement of the threshold for detection of passive motion (TTDPM) was performed toward flexion and extension from the starting position with the knee flexed at 45°. The PTA rotated the knee at an angular velocity of 0.5°/s. The participants were asked to “concentrate on the knee” and respond when they felt any sensation of movement or change in position by flipping a switch. Three trials were administered, and mean errors were also recorded.

2.4. Dynamic balance test

The dynamic balance test was administered in a self-designed, computerized, balance-testing apparatus as described previously [19].

This apparatus consists of a dynamic platform, A/D converter, self-designed software, and a real-time display monitor for visual biofeedback (Fig. 2). A ball-bearing with small frictional resistance is located beneath the geometric center of the stance platform. Two linear variable differential transformers (LVDT), located on the horizontal plane of the platform, record the profile of positional information. The tilt angle of the stance platform relative to the vertical axis can then be calculated. The maximum tilt angle for this platform is 15° in any direction. During the dynamic balance tests, participants stood on the affected limb first. They then stood on the unaffected limb with the stance foot centered on the platform and with the contralateral knee in slight flexion. Participants wore suspension harnesses to protect against falls and were instructed to maintain their standing balance via real-time visual biofeedback. Three trials were given, and the mean tilt angle obtained for a 30-s dynamic balance test was used for statistical analysis. Higher tilt angles indicated poorer maintenance of dynamic balance.

2.5. Muscle strength measurements

The isokinetic muscle strengths of the quadriceps and hamstring muscles were measured with a Con-Trex MJ dynamometer (Con-Trex, Zurich, Switzerland). To stretch their muscles, participants underwent a bicycling warm-up period of 10 min before testing. Participants were placed in an upright position with the hip flexed at 90° on the dynamometer chair and with the chest, thigh, and ankle secured with straps. The resistance pad was placed as distally as possible on the tibia without decreasing dorsiflexion at the ankle. The center of motion of the lever arm was aligned as accurately as possible with the epicondylar axis of the knee joint. The range of motion of the knee joint was set from 0° to 100°. The peak torque for the quadriceps and hamstring was recorded at an angular velocity of 60°/s. Measurements for injured and uninjured sides were performed in random order.

2.6. Statistical analyses

Application of the Kolmogorov–Smirnov normality test (SPSS software, SPSS Inc., Chicago, IL) confirmed the normal distribution of all measurements. The paired t test was used to determine the differences between the injured and uninjured sides for the test parameters of knee laxity, proprioception, muscle strength, and tilt angle in the dynamic balance test. The Pearson’s coefficient of correlation was used to determine the level of association between the independent variables of knee laxity, proprioception, and muscle strength and the dependent variable, the tilt angle in the dynamic balance test. To eliminate the effect of sex difference, the 2 female participants were excluded before the final data analysis. Statistical

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![Fig. 3. Tracings of the sway paths in the single-limb stance balance test for a participant with (A) an uninjured leg and (B) an ACL-injured leg.](image-url)
the injured leg disclosed that the center of gravity consistently tilted in one direction and standing balance for the injured leg. However, a significant Knee laxity, PRP proprioception, and muscle strength did not influence the dynamic standing balance (Table 2). The hamstring/quadriceps (H/Q) ratio for the injured side was not significant different from that of the uninjured side (P = 0.46). The tracing of the sway path in the dynamic balance test of the uninjured leg revealed that the test participants could adjust their posture to keep their center of gravity located on the center of platform (Fig. 3A). By contrast, tracing of the sway path during testing of the injured leg disclosed that the center of gravity consistently tilted in one direction and could not be readjusted to the center of the platform (Fig. 3B). As independent variables, knee laxity, PRP proprioception, and muscle strength did not influence the dynamic standing balance for the injured leg. However, a significant positive correlation was observed between TTDPM proprioception and dynamic stance balance with respect to the injured limb (Table 3). Poorer TTDPM proprioception resulted in poorer dynamic stance balance in the injured limb. For the uninjured limb, TTDPM proprioception and the H/Q ratio were both found to influence the dynamic standing balance (Table 3). Poorer TTDPM proprioception and higher H/Q ratio resulted in poorer dynamic stance balance in the uninjured limb.

4. Discussion

Findings of the present study showed that PRP proprioception did not correlate with the dynamic standing balance of patients after ACL injury. By contrast, TTDPM proprioception was found to be strongly correlated with dynamic single-limb stance balance after ACL injury. Proprioception is defined as the afferent information arising from the internal peripheral area of the body and contributing to postural control, joint stability, and specific conscious sensations [20]. A reduction in knee proprioception has been reported to occur after ACL injury [7–9], presumably because of disruption of mechanoreceptors within the ligament [3–5]. Because impairment of proprioception may lead to increased postural sway and, potentially, the loss of balance [18], reports of compromised knee proprioception after ACL injury have prompted researchers to study standing balance in patients with such injuries [13–15]. It has been reported that knee joint laxity does not correlate with single-limb static standing balance in legs of patients with ACL injuries [16]. In the present study, comparable results were obtained using the single-limb dynamic standing balance test. Additionally, no correlation between knee joint laxity and single-limb dynamic standing balance was observed for the uninjured knee. It should be noted that Snyder-Mackler et al. [21] found no correlation between the magnitude of passive knee laxity after ACL injury and functional outcome. Knee joint laxity is therefore not likely to serve as a good predictor for balance control and functional outcome.

Gibson et al. [22] examined the changes in the peak torque ratios of the quadriceps and hamstring for persons with chronic ACL deficiency. Peak torque values were found to be significantly decreased in the ACL-deficient as compared with the uninjured limb; the peak torque of the quadriceps decreased to a greater extent than that of the hamstring in the ACL-deficient limb. In addition, the concentric hamstring/quadriceps peak torque ratio tends to be higher in the ACL-deficient (0.71) than in the uninjured (0.65) limbs, but this difference is not significant [22]. Identical findings were obtained in the present study (Table 2). One possible explanation for the greater decrease in quadriceps peak torque is an adaptive change in thigh muscle force, brought about by the need to reduce the anterior tibial translation in the ACL-deficient knee.

The muscle strength (peak torque for quadriceps plus peak torque for hamstring) in the ACL-injured leg does not correlate with balance in the single-limb static stance [16]. In the present study, neither quadriceps nor hamstring strength was found to correlate with single-limb dynamic standing balance. However, muscle strength is only one measure of muscle function. Other measures, such as muscle onset time, muscle contraction time, muscle endurance, and muscle recruitment order, may be of greater importance in maintaining postural balance than muscle strength [17]. Investigation of these measures is needed in order to elucidate more fully the relationship between muscle function and single-limb stance balance in ACL-deficient patients.

It has been proposed that decreased postural control as defined by higher amplitudes of center of pressure movements and decreased proprioception as defined by higher TTDPM values are both features of ACL injury [16,22]. In the present study, TTDPM proprioception, but not RPP proprioception, was found to correlate positively with dynamic single-limb stance balance. These observations may be explained by the different requirements of the two forms of balance. In particular, maintenance of dynamic stance balance requires a greater input of information from quick-adapting mechanoreceptors and, therefore, represents a greater challenge than does maintenance of static balance.

Certain limitations of the present study should be addressed. First, only 12 participants (10 men and 2 women) were recruited, and only the 10 men were included in the analysis. The small size of this group reduces the statistical power of the findings. The power is especially low for the values of TTDPM and H/Q ratio. Although some parameters are significantly different between the injured and uninjured sides in the paired-t test, the parameters with low power have a high possibility for type II error and, an increase in sample size is needed in future studies. Second, visual biofeedback was used to control dynamic stance balance in this study. Visual input has the capacity to improve dynamic stance balance and to compensate for reductions in muscle strength or proprioception in patients with ACL injuries. Studies comparable to the present study that examines ACL patients under visually-blinded conditions are, therefore, planned.

5. Conclusions

TTDPM proprioception strongly correlated with dynamic single-limb stance balance in patients with ACL injuries. By contrast, dynamic single-limb stance balance in these individuals does not show significant correlation with knee laxity or the strength of the knee muscles. Rehabilitation programs that improve TTDPM proprioceptive ability, therefore, represent the most important approaches to improving dynamic single-limb stance balance in patients with chronic ACL injuries.

6. Conflict of interest statement

All authors disclose that no financial or personal relationships with other people or organizations exist that could inappropriately influence (bias) this work.

References


