THE EFFECT OF MUSCLE STRENGTH ON PROPRIOCEPTIVE FUNCTION AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION OF THE KNEE

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Abstract

Loss of proprioceptive feedback in knees with anterior cruciate ligament (ACL) deficiency is well documented. Joint mechanoreceptors are present in the ACL and in surrounding structures. The muscle spindle receptors may assist patients to compensate for the lack of proprioceptive sensibility after ACL injury. Therefore, exercises for the surrounding knee muscles during treatment after ACL reconstruction might improve proprioceptive performance and functional ability. The purpose of this study was to investigate whether muscle strength after ACL reconstruction can influence proprioceptive function. Sixteen patients who underwent ACL reconstruction were evaluated before surgery, then six and twelve months after surgery. Knee proprioception was evaluated using a robotic proprioceptive device, and muscle strength was evaluated using an isokinetic Biodes system.

Six months after surgery there was no correlation between the proprioceptive sensitivity (position sense) and the hamstring/quadriceps H/Q ratio, but there was a correlation at twelve months \( r=0.66, P<0.05 \). There was no correlation between motion sense and the H/Q ratio. These results indicate that recovery of muscle strength after ACL reconstruction may contribute to proprioceptive sensibility.

(key word: Anterior cruciate ligament, Proprioception, Hamstring/quadriceps ratio)

I. INTRODUCTION

One of the most challenging aspects for the clinician is to understand the recovery of proprioception-mediated neuromuscular control after joint injury and its restoration through rehabilitation\(^1\). Proprioception has important functions, such as joint position sense and kinesthesia. This sensibility relies on the integration of sensory receptors, called mechanoreceptors, that are located in the joint capsule, ligaments, tendons, skin (i.e. Ruffini receptors) and muscle (i.e. spindle receptors)\(^2\). Previous studies suggest that tears or disruption of the anterior cruciate ligament (ACL) cause a decline in proprioceptive feedback in the knee\(^3\,4\). Damage of intra- and periarticular structures due to knee trauma adds to the proprioceptive deficit\(^5\). The decline in proprioceptive function after ACL injury may contribute to the progressive instability and disability of the knee joint. Thus, it is becoming increasingly clear that knees with ACL rupture gradually develop changes not only in performance but also in proprioception\(^6\).

The presence of joint mechanoreceptors-transducers that convert mechanical load to afferent impulses have been reported in the ACL\(^7\). After an ACL reconstruction, the reduction of proprioception and the subsequent compensation by the surrounding tissues are necessary to re-establish the lack of sensibility. Evidence suggests that proprioception—specifically, position sense—is mediated in part by muscles\(^8\,9\). In addition, because of individual anatomical structure, degree of ligamentous laxity and muscle tonus, certain patients may be able to compensate for the loss of proprioception through muscle–spindle receptors\(^10\). Voight et al.\(^11\) concluded that muscle fatigue adversely alters joint proprioception and impairs neuromuscular control in the lower extremities. Furthermore, Corrigan et al.\(^4\) described a correlation between position and motion sense with the hamstring/quadriceps (H/Q) ratio in patients with ACL tears. This parameter, the H/Q...
ratio, is commonly used to describe muscle–strength properties around the knee joint, and is a measure of the maximal isokinetic hamstrings muscle strength relative to the maximal isokinetic quadriceps muscle strength\textsuperscript{12}. These findings suggest that the application of strengthening exercises for the routine treatment of the surrounding knee muscle might improve proprioceptive performance and functional ability.

Accordingly, the purpose of this study was to investigate whether changes in muscle strength after an ACL reconstruction can influence proprioceptive function. We suggest that, through the muscle receptors, muscle strength could be related to proprioceptive sensitivity.

II. METHODS

II. 1. Subjects

Sixteen patients who were treated at Hiroshima University Hospital for knee injuries were included in this study. Each of the patients had an acute injury to a previously normal knee. There were 6 males and 10 females; the average age was 28±2.3 years. Their average height was 163.6±4.5 cm and their average weight was 62.9±3.6 kg. ( All values are given as mean±standard deviation ) Complete ACL tears were confirmed by arthroscopy, and all patients underwent arthroscopic ACL reconstruction with autogenous semitendinosus and gracilis tendons. None of the patients had experienced any injuries or had any complaints regarding the contralateral knee, and none had experienced any other ligament disorder or patellofemoral dysfunction in the injured knee. The average period between the lesion and the surgery was approximately 9.3±6.0 months; in addition, there was no impairments of pain nor swelling that might interfere in the measuring of strength as well as sensitivity during the different stages of the rehabilitation. The experimental protocol was approved by the ethical committee of Hiroshima University.

II. 2. Rehabilitation procedure

All patients underwent the same postoperative rehabilitation programme. After ACL reconstruction, each subject was given a soft-type knee brace ( Konishi Apparatus Co., Japan ) that prevented the full extension of the knee. This is a flexible brace with firm, foam padding that is attached by a uniaxial hinge with an extension–range adjuster. For the 2 months following surgery, the extension was limited up to 10° with this brace. Postoperatively, there was no restriction placed on the knee–flexion movement.

At 2 weeks post-surgery, subjects were instructed to do quadriceps isometric setting exercises at a joint position of 90° knee flexion\textsuperscript{13}, as well as open kinetic chain(OKC) exercises, using rubber tubing, for the hamstrings. All patients were allowed partial body-weight bearing on the operated leg 2 weeks after surgery and full body-weight bearing after 3 weeks. After 3 weeks, subjects were instructed to do closed kinetic chain(CKC) exercises, such as squats and lateral step-ups, with gradual body-weight bearing\textsuperscript{14}. After 4 weeks, bike exercises were commenced. At 3 months post-surgery, most subjects were able to fully extend the knee and commenced walking/running exercises. Full participation in sports activities was restricted for up to 8 months after surgery. Any ballistic-type exercises that would put stress on isolated hip extensions/flexions, hip internal/external rotations and ankle dorsiflexion/plantar flexions were prohibited for up to 1 year after surgery.

For the first month after surgery, physical therapists were assigned to all patients to supervise their rehabilitation process in the hospital, monitoring the compliance with the postoperative rehabilitation protocol. After 1 month of supervised rehabilitation, all patients were instructed with for home-based rehabilitation programs. The progress of the patients’ rehabilitation was then checked by an assigned therapist once a week at the time of their hospital visits.

II. 3. Proprioceptive test

Patients underwent two types of test. Joint posi-
tion sense, also called reproduction of passive positioning (RPP), was tested by examining the ability of patients to reproduce an angle at which the joint had been placed previously. The second test was kinesthesia, the threshold to detection of passive motion (TTDPM)\textsuperscript{15}. The subjects were seated and a lever arm of a robotic proprioceptive device (Sensor Oyo, Hiroshima, Japan) was aligned with the lateral epicondyle of the knee (Fig. 1). The accuracy of this device was 0.28°. The reproducibility of the measurement system showed a mean variation of 6.1 ± 3.4° (95% CI 4.71–7.49). Subjects wore eye masks and headphones to avoid any visual or acoustic stimulation and were given three practice runs in each test to familiarize themselves with the procedure. Their legs were hanging freely over the end of

the seat at a distance of 4–6 cm proximal to the popliteal fossa. An inflated air splint was positioned around the patient’s foot to reduce cutaneous sensory input to the lower limb. Movement of the extremity was accomplished by a mechanical arm attached with a holder; this was fixed to the air splint by Velcro straps.

The RPP procedure was performed according to the method of Iwasa et al.\textsuperscript{16}, with some modifications. RPP was tested by examining the ability to reproduce a target angle. The starting position was set at the knee–flexion angle of 90°. The selected target angles were 5°, 10°, 15°, 20°, 25° and 30°, and were randomly introduced. The leg was passively moved to extension at a steady speed of 10°/s. When the leg reached the knee target angle, it was held in this position for 5 s. Then, the subject was asked to concentrate and memorize the present knee angle. The leg was returned to the starting position and was passively moved to extension. The subject was asked to press the button when he or she thought the target angle was reached. Absolute error was determined by calculating the difference between the target angle and the reproduced joint angle.

The TTDPM procedure was performed according to the method of Lephart et al.\textsuperscript{17}, with some modifications. TTDPM was measured by threshold to detect passive motion. The threshold to detect passive motion for flexion and extension was tested from two starting positions. The starting positions selected were 15° and 45° of knee flexion. From these starting positions, the knee was passively moved at a slow and constant angular velocity of 0.5°/s. The subjects pressed the button as soon as motion was perceived. The threshold to detect passive motion was recorded as angular displacement in degrees. Proprioceptive tests were performed before surgery, then 6 and 12 months after surgery.

II. 4. Isokinetic strength test

To determine the muscle strength of the lower limb, patients were examined using an isokinetic Biodex system (Biodex Medical Systems, Shirley,

![Figure 1. Subject is undergoing proprioception testing. A robotic proprioceptive device is attached to the lateral aspect of the limb. The device passively positions the limb and, subsequently, the subject attempts to match the knee–joint angle. The subject wears an eye mask and headphones to avoid external stimulation or assistance. The subject presses a trigger when they believe the knee joint reaches the target angle.](image-url)
NY, USA). The subjects were seated and strapped with the dynamometer force-sensing arm secured to the ankle. The knee was positioned at 60° of flexion, with the lateral femoral epicondyle as an anatomical reference to the dynamometer’s axis of rotation. A thigh strap, waist strap and two chest straps were then secured to stabilize the subject in the dynamometer chair. The patients completed five concentric repetitions of flexion and extension of each knee at a speed of 60°/s and ten concentric repetitions at 180°/s. The test speeds used in this study were selected from previous studies by Wu et al. and Warming and Jorgensen. Patients were instructed to extend and flex the knee at full force throughout the test. Before each task, they were allowed to flex and extend the knee a few times at each speed to acquaint themselves with the test. Peak torques for both flexion and extension were recorded for determining the H/Q ratio, the data was normalized in Nm/Kg and the normal values range from 0.6 to 0.8. An isokinetic strength test was performed before surgery, then 6 and 12 months after surgery.

II. 5. Statistics

The Wilcoxon signed-ranks test was used to compare the two starting positions, moving into extension and flexion in TTPDM. Regression analysis was performed to determine if the level of muscle strength influenced proprioceptive sensibility. Statistical analysis was performed using the commercially available software Stat View 5.0J (SAS Institute Inc., USA). For all analyses, statistical significance levels were set at $P<0.05$.

III. RESULTS

The absolute error of RPP in the operated and non-operated knees was $4.8 \pm 1.8°$ and $4.3 \pm 1.6°$, respectively, before surgery; $3.6 \pm 1.5°$ and $4.3 \pm 1.7°$, respectively, at 6 months after surgery; and $5.4 \pm 2.8°$ and $5.4 \pm 2.6°$, respectively, at 12 months after surgery.

The H/Q ratio at 60°/s in the operated and non-operated knees was $0.47 \pm 0.09$ and $0.44 \pm 0.09$ Nm/Kg, respectively, before surgery; $0.54 \pm 0.24$ and $0.42 \pm 0.10$ Nm/Kg respectively, at 6 months after surgery; and $0.54 \pm 0.13$ and $0.45 \pm 0.09$ Nm/Kg, respectively, at 12 months after surgery.

The H/Q ratio at 180°/s in the operated and non-operated knees was $0.56 \pm 0.12$ and $0.47 \pm 0.11$ Nm/Kg, respectively, before surgery; $0.52 \pm 0.15$ and $0.49 \pm 0.07$ Nm/Kg, respectively, at 6 months after surgery; and $0.49 \pm 0.09$ and $0.49 \pm 0.10$ Nm/Kg, respectively, at 12 months after surgery.

The displacement angle of TTDPM from 15° and 45° to extension in the operated knee was $0.9 \pm 0.1$ and $0.9 \pm 0.3$, respectively, before surgery; $0.8 \pm 0.2$ and $0.8 \pm 0.2$, respectively, after surgery.

<table>
<thead>
<tr>
<th></th>
<th>Before surgery</th>
<th>6 months after surgery</th>
<th>12 months after surgery</th>
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<tr>
<td></td>
<td>Operated</td>
<td>Non-operated</td>
<td>Operated</td>
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<tr>
<td>RPP Absolute error</td>
<td>$4.8 \pm 1.8°$</td>
<td>$4.3 \pm 1.6°$</td>
<td>$3.6 \pm 1.5°$</td>
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<tr>
<td>H/Q ratio; 60°/s</td>
<td>$0.47 \pm 0.09$</td>
<td>$0.44 \pm 0.09$</td>
<td>$0.54 \pm 0.24$</td>
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<td>H/Q ratio; 180°/s</td>
<td>$0.56 \pm 0.12$</td>
<td>$0.47 \pm 0.11$</td>
<td>$0.52 \pm 0.15$</td>
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H/Q ratio, hamstring/quadriceps ratio; RPP, reproduction of passive positioning.
0.5 and 0.9±0.6, respectively, at 6 months after surgery; and 0.8±0.2 and 0.9±0.6, respectively, at 12 months after surgery. The displacement angle of TTDPM from 15° and 45° to flexion in the operated knee was 0.9±0.4 and 0.9±0.2, respectively, before surgery; 0.9±0.5 and 0.8±0.6, respectively, at 6 months after surgery; and 0.9±0.5 and 0.8±0.4, respectively, at 12 months after surgery. With the same starting position and speed, the displacement angle to extension of the non-operated knee was 0.9±0.5 and 0.9±0.4, respectively, before surgery; 0.9±0.1 and 0.9±0.4, respectively, at 6 months after surgery; and 0.9±0.3 and 0.9±0.9, respectively, at 12 months after surgery. The displacement angle of TTDPM from 15° and 45° to flexion in the non-operated knee was 0.9±0.4 and 0.8±0.3, respectively, before surgery; 0.9±0.3 and 0.8±0.8, respectively, at 6 months after surgery; and 0.9±0.6 and 0.8±0.2 at 12 months after surgery (Table 2).

No significant differences in RPP or TTDPM were found between the reconstructed and uninjured limb before surgery, or at 6 and 12 months after surgery. No significant correlation was found between TTDPM and muscle strength at 60°/s or 180°/s (H/Q ratio) at the three times when data was collected in the operated or the non-operated knees.

There was no significant correlation between RPP

<table>
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<tr>
<td></td>
<td>Operated</td>
<td>Non-operated</td>
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<tr>
<td>15° to Ext</td>
<td>0.9±0.1</td>
<td>0.9±0.5</td>
</tr>
<tr>
<td>45° to Ext</td>
<td>0.9±0.3</td>
<td>0.9±0.4</td>
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<tr>
<td>15° to Flex</td>
<td>0.9±0.4</td>
<td>0.9±0.4</td>
</tr>
<tr>
<td>45° to Flex</td>
<td>0.9±0.2</td>
<td>0.8±0.3</td>
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Ext, extension; Flex, flexion; TTDPM, the threshold to detection of passive motion.

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<tr>
<td></td>
<td>Operated</td>
<td>Non-operated</td>
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<tr>
<td>Extensors: 60°/s</td>
<td>0.44</td>
<td>0.34</td>
</tr>
<tr>
<td>Flexors: 60°/s</td>
<td>0.46</td>
<td>0.41</td>
</tr>
<tr>
<td>Extensors: 180°/s</td>
<td>0.44</td>
<td>0.34</td>
</tr>
<tr>
<td>Flexors: 180°/s</td>
<td>0.35</td>
<td>0.37</td>
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<tr>
<td>H/Q: 60°/s</td>
<td>0.43</td>
<td>0.37</td>
</tr>
<tr>
<td>H/Q: 180°/s</td>
<td>0.38</td>
<td>0.29</td>
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*Significantly different from position sense (P<0.05).
H/Q ratio, hamstring/quadriceps ratio.
and the extensor or flexor muscles at both speeds of isometric strength test (Table 3). The relationship between the mean absolute error of RPP and muscle strength showed no significant correlation in the operated knee before surgery \( r = -0.43, P < 0.14 \) or at 6 months after surgery \( r = -0.48, P < 0.20 \). On the other hand, at 12 months after surgery, there was a significant correlation between RPP and the H/Q ratio at 60º/s \( r = -0.54, P < 0.05 \) (Fig. 2). No significant correlation was found between RPP and the H/Q ratio at 180º/s at the three times when data was collected in the operated or the non-operated knees.

**IV. DISCUSSION**

The purpose of this study was to investigate whether changes in muscle strength after an ACL reconstruction can influence proprioceptive function. This research clarifies the significant relationship between the H/Q ratio at 60º/s with RPP \( r = -0.54, P < 0.05 \) in ACL-reconstructed knees at 12 months after surgery. This result suggests that there might be a mechanism to compensate for the loss of afferent input from ACL through input from other mechanoreceptors that are located in muscles at 12 months after surgery. Noyes et al.\(^{22}\) investigated the symptoms in ACL-deficient knees, showing that there might be a mechanism to compensate for the loss of afferent input from the ACL through input from muscle or tendon receptors. Corrigan et al.\(^{43}\) compared the position sense in injured patients with a control group. They reported a significant correlation between the H/Q ratio and position sensitivity in patients with ACL tears. However, subjects were examined lying in a reclining position on a couch with the limb being moved at a constant rate of 10º/s for RPP. In a supine position, the quadriceps muscle will be stretched when the knee is moved to the flexion position, thereby facilitating the proprioceptive sensibility.

There was no significant relationship between RPP (position sense) and muscle strength at 60º/s or 180º/s prior to surgery and at 6 months after surgery. There was no significant relationship between extensor and flexor muscle strength with RPP. It propose that the reason for these lack of differences may be due to the time elapsed after surgery and the effects of joint effusion. The effects of joint effusion are known to decrease muscle–spindle input, which would therefore reduce prop-

![Figure 2](image-url)  
**Figure 2.** The relationship between the H/Q ratio at 60º/s of the operated knee with the absolute error in the 16 subjects at 12 months after anterior cruciate ligament reconstruction. The H/Q ratio is measured in Nm and the absolute error is in degrees. The coefficient of correlation in this case is \( r = -0.54 \) and the statistical significance is \( P < 0.05 \).
rioseptive tasks. However, since none of the patients in this investigation present these symptoms that might alter the results, it is unknown for us to conclude which was the cause of this lack of difference.

In this study, no significant differences were found in TTDPM between the starting positions (15° and 45°) and displacement moving into extension or flexion angle before surgery, and at 6 and 12 months after surgery. Lephart et al. 17), who evaluated proprioception after ACL tears, reported a significant difference in TTDPM (motion sense) during knee-joint movement into extension. This study did not describe the type of subjects included in their study, but their follow-up time was 11−24 months after surgery. Our findings, however, support those of Risberg et al. 23) who found no differences in TTDPM between the ACL reconstructed and uninjured limbs 1 year or more after surgery. This investigation also collected data from subjects within 1 year after ACL reconstruction surgery and, as in our study, the device was calibrated to move the knee passively at an angular velocity of 0.5°/s. The type of subjects included (acute or chronic, and isolated or combined ACL injuries), the postoperative rehabilitation programme and the differences in measurement technique may explain some of the inconsistencies in the results reported in the literature.

No significant relationship was found between TTDPM and muscle strength at 60°/s or 180°/s before surgery, or at 6 or 12 months after surgery. There was no significant relationship between extensor and flexor muscle strength with TTDPM. This disagrees with Corrigan et al. 4) who found a correlation between TTDPM and muscle strength. In their research, however, subjects were tested in a supine position with their knee at 35° of flexion; this decubitus might have facilitated the perception when the limb was passively moved.

In this study, we found that the H/Q ratio was lower not only at sites where ACL reconstruction was performed but also in the uninjured knee. Previous studies reported a concentric amplitude ratio of 0.6 and 0.8 for an uninjured lower limb. A possible reason for this low H/Q ratio may be the non-accelerated rehabilitation programme that the patients underwent. It is also noticed that there was only significant difference at 60°/s but not at 180°/s; we consider that this disparity is because the H/Q values at 60°/s were closer to the accepted values in the operated leg at that period of the rehabilitation, therefore being more probable to correlate with the proprioception sensitivity.

Our findings suggest that RPP could be recovered at 12 months after surgery, which differs from what Barrack et al. found. 24 They reported that free patellar tendon grafts showed evidence of re-inervation at 6 months after ACL reconstruction. This concurs with the results of Goertzen et al. 25), who reported that mechanoreceptors were present at the attachment site of the ligament at 12 months after reconstruction; and may explain the reason why there was no significant difference at 3 and 6 months.

Our results reveal that there was a significant correlation between RPP and muscle strength at 12 months after surgery, whereas there was no significant correlation between TTDPM and muscle strength. According to Guyton et al. 26), this could be explained physiologically: the most important receptors for determining joint angulation are the muscle spindles. When the angle of a joint is changing, some muscles are being stretched while others are being loosened, and the stretch ‘information’ from the spindle is passed into the system of the spinal cord and higher regions of the dorsal column system, which ultimately deciphers the complex interrelations of joint angulations. The pacinian corpuscles are especially adapted for detecting rapid rates of change. Therefore, it is likely that these are the receptors that are most responsible for detecting the rate of movement.

The limitations of our study are noted. The non-accelerated rehabilitation programme could influence the healing progress and could make it difficult to compare our results with other studies.
In conclusion, there was a correlation between RPP and the H/Q ratio at 60°/s at 12 months after ACL reconstruction. This suggests that there might be a mechanism to compensate for proprioceptive dysfunction after ACL reconstruction by using other sources of afferent information. This has important implications for the rehabilitation management of patients after ACL reconstructive surgery. Rehabilitation programmes may be ideally structured to address identified deficits in proprioception by emphasizing the functional and muscular aspects of limb performance.

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