Factors affecting proprioceptive recovery after anterior cruciate ligament reconstruction

ZHOU Mou-wang, GU Li, CHEN Ya-ping, YU Chang-long, AO Ying-fang, HUANG Hong-shi and YANG Yan-yan

Keywords: anterior cruciate ligament reconstruction; proprioception; muscle strength

Background Proprioception plays an important role in knee movements. Since there are controversies surrounding the overall recovery time of proprioception following surgery, it is necessary to define the factors affecting proprioceptive recovery after anterior cruciate ligament (ACL) reconstruction and to investigate the relationship between proprioception and muscle strength.

Methods A total of 36 patients who had their ACL reconstructed with a semitendinosus/gracilis graft (reconstructed group: 6 months post-surgery) and 13 healthy adults without any knee injury (control group) were included in the study. Knee proprioception was evaluated with a passive reproduction test. Isokinetic strength was measured using the Biodex System. Statistical analysis was used to compare proprioception of the reconstructed group versus the control group, and to define causal factors, including sex, hamstring/quadriceps ratio, and the course of injury before reconstruction. We also investigated the correlation between the passive reproduction error and quadriceps index.

Results There was a significant difference in proprioception between the reconstructed and control groups (P <0.05). When the course of injury before reconstruction was less than 4 months, there was a linear correlation with proprioception 6 months after the operation (r=0.713, P <0.05). There was a positive correlation between post-surgery proprioception and the quadriceps index at 6 months post-surgery.

Conclusions Impaired knee proprioception is observed 6 months after ACL reconstruction. Within 4 months of injury, early undertaking of reconstruction is associated with better proprioception outcome. Patients with enhanced proprioception have a better quadriceps index.

Methods

Patients The reconstruction surgery group comprised 36 patients who had undergone unilateral ACL reconstruction with a semitendinosus/gracilis (STG) graft in our hospital between July and November in 2006. Patients were 30 male and 6 female, and aged 15–40 years, with a mean value of (26.0±5.8) years. All informed consents were obtained. Individuals were eligible for inclusion in the reconstructed group if their operation occurred within 9 months of injury and they had no posterior cruciate ligament (PCL) or medial collateral ligament (MCL) injury, no previous ACL surgery, no neural or vascular injury, but with normal hip and ankle joint function; achieved full range of motion (both active and passive) in the operated knee joint; and suffered no significant pain or obvious swelling in the operated knee with either light recreational activities or normal daily activities at 6 months post-surgery (Lysholm score was >85, including

Department of Rehabilitation Medicine (Zhou MW, Gu L, Chen YP, Huang HS and Yang YY); Department of Sports Medicine (Yu CL and Ao YF), Peking University Third Hospital, Beijing 100191, China

Correspondence to: Dr. ZHOU Mou-wang, Department of Rehabilitation Medicine, Peking University Third Hospital, Beijing 100191, China (Tel: 86-10-82265861. Email: zhoumouwang@medmail.com.cn)
≥20 for pain and ≥6 for swelling). Exclusion criteria included any cardiovascular, respiratory, systemic, or metabolic condition resulting in limited exercise tolerance. The mean period of time since surgery to follow-up was (189±11.2) days. The control group comprised 13 healthy adults (11 male and 2 female with a mean age of (26.4±3.9) years) who had no injury history of lower extremities or any other diseases which could limit exercise tolerance. The ages of both the reconstructed and control groups were normally distributed according to normality tests (P >0.05), with no significant difference between the two groups’ ages according to independent-samples t test (P >0.05).

Proprioception training
All patients followed our proprioception rehabilitation protocol soon after reconstruction, including early progressive weight bearing, proprioception training by balance training board, close chain exercises (stationary bicycle, semi-squat), and agility exercises (shuttle run and “S” run) (Table). After 6-month training, patients’ proprioception and muscle strength were evaluated to indicate the level of recovery.

Table. Proprioception rehabilitation protocol

<table>
<thead>
<tr>
<th>Proprioception training</th>
<th>Postoperative weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial to full weight bearing</td>
<td>1–2</td>
</tr>
<tr>
<td>Balance training board</td>
<td>3–4</td>
</tr>
<tr>
<td>Unilateral weight-bearing</td>
<td>5–6</td>
</tr>
<tr>
<td>Semi-squat</td>
<td>7–12</td>
</tr>
<tr>
<td>Stationary bicycle</td>
<td>13–24</td>
</tr>
<tr>
<td>Shuttle run and “S” run run</td>
<td></td>
</tr>
</tbody>
</table>

Assessment of proprioception
Knee proprioception was evaluated by examining joint position sense with a Biodex system 3 (SHIRLEY, USA) dynamometer using a passive reproduction test. The knee was slowly flexed by the machine at an angle velocity of 2° per second, stopped at a randomly determined angle between 0° and 100°, and then returned to 0°. The subject was instructed to memorize this angle and push a hold switch of the Biodex to the same angle. The error angle which was the difference between the angle initially determined by the examiner and the angle recalled by the subject was measured. The test was performed twice with each angle range (extension range 0°–20°, middle range 40°–60°, and flexion range 80°–100°), and the mean error angle was used for analysis (Figure 1).

Assessment of isokinetic strength
Maximum isokinetic strength of the quadriceps was assessed using the Biodex system 3 dynamometer at an angle velocity of 60° per second. Peak torque measurements were made on both sides, and the quadriceps index was defined as the ratio of the injured/intact side (Figure 2).

Statistical analysis
The computer software package SPSS 10.0 was used for the data analysis. We compared the passive reproduction error (PRE) between groups and gender using independent-samples t test. The Spearman correlation analysis and linear regression were used to observe correlations between the PRE and causal factors (i.e. course of injury before reconstruction and hamstring/quadriceps ratio (H/Q)), and between the PRE and the quadriceps index. A P <0.05 was considered statistically significant.

RESULTS
Deficits in knee proprioception remained 6 months after ACL reconstruction. The mean PRE in the reconstruction group was 5.59 ± 2.57, with 4.34 ± 1.08 in the control group. There was a significant difference in the PRE between the two groups at 6 months after surgery (P=0.023).

For analysis of causal factors, we found a negative correlation between the course of injury and post-surgical proprioception. A scatter plot graph revealed that the earlier the reconstruction was performed, the better proprioception outcomes were achieved within 4 months of injury, with a regression equation of Y=2.770+1.581X (r=0.713, P <0.05) (Figure 3). Although a linear relationship appeared to exist between the injury course and PRE which represented the proprioception within 4 months, definitive conclusions regarding the correlation cannot be carried out owing to the limited sample size. No association between the injury course more than 4 months and PRE could be observed.

There was no significant associations between PRE and gender (P=0.299) or pre-surgical H/Q peak torque (P=0.152) (Figure 4). Correlations were observed between the quadriceps index and the PRE, and between strength and the proprioception. In patients with greater strength, the PRE was reduced (r=−0.405, P <0.05).

DISCUSSION
It is often recommended that patients can return to sporting activities at 6 months after ACL reconstruction because of the reliable rigidity of the STG graft. However,
few reports refer to the proprioceptive recovery of the operated knee at the 6th month. Laboratory experiments in rats showed that the ACL graft exhibited neurophysiologic activity within a few weeks after reconstruction. To date, the earliest proprioceptive recovery referred to in clinical practice is at 6 months after reconstruction.22-24

Many methods are used to evaluate the knee proprioception, including the active/passive reproduction test, detection of passive motion, and somatosensory evoked potential testing. All of these evaluation methods have their advantages and limitations in terms of sensitivity, accuracy, manageability, and intuitionistic ability. There is currently no standard regulation or point of reference about the proprioception evaluation, which is also not a conventional assessment after ACL injury.3 To date, the earliest proprioceptive recovery referred to in clinical practice is at 6 months after reconstruction.22-24

Several studies have reported that bilateral proprioceptive defects were found in patients with a unilateral ACL reconstruction.6,25 An ACL injury-induced bilateral quadriceps inhibition may also indicate bilateral abnormality of afferent nerves.25 To date, no studies have included a healthy control group.

Since previous reports suggested that mechanoreceptors in ACL could be absent for up to 9 months post injury,21,26 we selected patients whose injury had occurred within 9 months of reconstruction. We evaluated the PRE of the reconstructed knee at 6 months post-surgery and found that the knees retained some proprioception deficit, suggesting that patients’ proprioception was still abnormal. Salmon et al27 showed that reinjury after ACL reconstruction occurred in 6% of patients over 5 years. It was unknown whether the proprioception deficit was correlated with the high reinjury ratio. According to studies by Roberts et al28 and Katayama et al,29 the proprioceptive deficit which would impair knee stability was correlated with the functional performance.

According to our correlation analyses, in the first 4 months following injury, the earlier an operation and rehabilitation protocol are undertaken, the better the proprioception outcome is at 6 months after surgery. In other studies, morphologically normal mechanoreceptors remained in the untreated ACL for 3 months following injury, before gradually decreasing and disappearing at 9 months post injury.3,26 We propose that the function of mechanoreceptors is already impaired before morphological changes are observed, and that the surviving mechanoreceptors may lose their normal function post injury. In our opinion, after ACL injury, patients should receive a reconstruction as soon as possible if surgery is required. If the patients have a late ACL reconstruction, the rehabilitation protocol should be adjusted according to their different recovery abilities.

For the other causal factors analyzed in our study, such as gender and H/Q ratio, no influence on proprioception is found. It is well known that females have a greater risk of ACL rupture compared with males, and studies have attributed this increased risk to differences in anatomic, hormonal, and material properties and movement patterns.30-32 In contrast, there is no evidence to suggest a proprioceptive difference between males and females.

Due to the anatomy, hamstrings function to prevent front translation of the tibia and help maintain knee stability after ACL injury.33 Although we hypothesize that increasing hamstring strength would protect against loss of proprioception, a linear correlation between H/Q ratio and proprioception is not observed in our study. Owing to weakness or other factors, the H/Q ratio was distributed over a wide range (12%–158%) which far exceeded the normal range (60%–70%).34 The marked imbalance of hamstrings and quadriceps would affect proprioception, irrespective of whether the H/Q ratio was higher or lower than normal.

There still remain other factors which may affect proprioceptive recovery, such as age, pain, methods of
surgical operation, rehabilitation training, and recovering duration. In our study, we design the same training protocol and unify the timing of follow-up in order to diminish the causal factors’ effects. Because there were few patients operated with ruptured ACL residual preservation in our study, we did not group the subjects according to “residue preserved or not”. In another research of ours, we are going to investigate if preservation of the ruptured ACL residue would affect the recovery of proprioception of the patients.

Studies suggested that persistent quadriceps weakness was common in the ACL-reconstructed leg. We also investigate the correlation between strength and proprioception and find that there is a positive correlation between proprioception and quadriceps muscle strength. This observation corroborates the previous studies which demonstrated that there was no consequential correlation between muscle weakness and atrophy using several evaluation methods, such as MRI, EMG, and ergometer, in which the authors suggested that weakness after ACL injury and reconstruction was attributable to incomplete voluntary activation of the muscle. This concept revealed that improving proprioception signal input could increase voluntary activation of the muscle and suggested a novel method of proprioception training alone could induce isokinetic strength gains. Konishi et al suggested that restoration of the sensory function of ACL was necessary to improve muscle strength, based on the abnormal γ-loop of vastus lateralis and vastus medialis muscles after ACL reconstruction. Another study showed that muscle strength training alone promoted proprioception. However, although we find a positive correlation existed between the muscle strength and proprioception, we can not conclude which of the two plays the active role in the causality. Because proprioception training could affect muscle strength, we propose a novel way to solve the problem of quadriceps weakness. Conversely, strength training could improve not only strength but also proprioception.

In summary, our findings demonstrate that proprioception deficit of the reconstructed knee remains 6 months after surgery, and that the course of injury before reconstruction affects the recovery of proprioception. We show that within 4 months of injury, the earlier patients receive reconstruction, the better the outcome for proprioception at 6 months post-surgery is. We do not find a relationship between gender, pre-surgical H/Q ratio, and PRE. With regard to causal factors, patients whose proprioception might not recover within 6 months post-surgery should be given proprioception emphasized training to improve proprioception and to permit a safe return to sporting activities. In addition, the positive correlation between proprioception and muscle strength suggests that strength training and proprioception training could be mutually beneficial.

Acknowledgments: We are grateful to Mr. LIU Xiao-peng and Mrs. AN Hua for their technical assistance.

REFERENCES
14. Øksen Dahl HL, Fleming BC, Blanpied PR, Ritter M, Hullstyn


(Received November 25, 2007) Edited by HAO Xiu-yuan and JI Yuan-yuan