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ORIGINAL ARTICLE

Use of ultrasonography to evaluate the dynamics of the infrapatellar fat pad after anterior cruciate ligament reconstruction: a feasibility study

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Abstract

Purpose There has been no specific study on the quantitative morphological changes that occur in the infrapatellar fat pad (IPFP) after anterior cruciate ligament (ACL) reconstruction. We used ultrasonography to evaluate the dynamics of the IPFP in knees after ACL reconstruction using the contralateral knees as controls.

Methods We enrolled 31 patients 3 months after they underwent ACL reconstruction. The thickness of the superficial part of the IPFP was measured using longitudinally oriented ultrasound images of the anterior part of both knees at 90° and 10° flexion. We then used these data to calculate the ratio of the change in thickness.

Results At 90° knee flexion, the superficial part of the IPFP was significantly thinner in the reconstructed knees (9.3 ± 3.4 mm) than in the contralateral knees (11.8 ± 4.6 mm). The thickness change ratio was significantly smaller in the reconstructed knees (188.6 ± 64.7%) than in the contralateral knees (249.7 ± 73.8%).

Conclusion When assessed 3 months after ACL reconstruction, the thickness of the superficial part of the IPFP at 90° knee flexion and the thickness change ratio of the IPFP were both significantly lower in the reconstructed knees than in the contralateral knees.

Keywords Anterior cruciate ligament · Anterior cruciate ligament reconstruction · Ultrasonography · Infrapatellar fat pad · Knee joint

Introduction

The infrapatellar fat pad (IPFP) is one of the four fat pads around the knee joint and is an intra-capsular but extrasynovial structure covered posteriorly by the synovial membrane [1, 2]. Although the precise function of the IPFP has not yet been elucidated, it may influence pathophysiological changes in the knee joint by secreting cytokines and adipokines in patients with osteoarthritis [3]. On the other hand, the IPFP fills the gap between the patella, femur, and tibia, and is thought to play a biomechanically important role in protecting the knee joint through the normal range of motion (ROM) [4]. In certain surgeries, such as total knee arthroplasty (TKA) or anterior cruciate ligament (ACL) reconstruction, the IPFP is often partially resected in order to expand the surgical field. Previous studies have investigated the effects of IPFP resection on TKA. One study showed that IPFP resection did not influence ROM or anterior knee pain [5], while another showed that it did cause discomfort and dysfunction of the knee joint [6]. Currently, there is no consensus among physicians on the precise postoperative effects of IPFP resection during surgery. However, studies have shown that fibrosis in the IPFP after ACL reconstruction leads to activity-related pain or stiffness of the knee joint [7]. Pain and restricted ROM around the knee joint sometimes lead to a delayed return to sports, and it can also adversely affect postoperative outcomes [8, 9]. In the early phase of rehabilitation after ACL reconstruction, pain around the knee joint sometimes caused insufficient ROM and quadriceps weakness [10]. For smooth progress of rehabilitation protocols, early recovery of knee function is important [11].

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Previous studies have described the diagnosis of fibrotic IPFP using arthroscopy [12] and the use of magnetic resonance (MR) elastography to evaluate the structure of the fat pad [13]. Using MR images, it is also possible to measure IPFP volume [14, 15]. However, this method is restricted by the fact that such a detailed examination is time consuming and expensive. When compared with MR elastography, ultrasonography allows the evaluation of the state of a target tissue in a noninvasive, low-cost, and real-time manner. Dynamic changes, such as in motion or change in shape of the IPFP during knee joint movement, can also be observed. Although one previous study described the qualitative dynamics of the IPFP [16], no study has purposefully evaluated the dynamics of the IPFP quantitatively, and the dynamics of IPFP function remain unclear. We hypothesized that the dynamics of the IPFP would decrease after ACL reconstruction. To verify this hypothesis, we compared the dynamics of the IPFP in reconstructed knees to those in contralateral knees using ultrasound images acquired from patients 3 months after ACL reconstruction.

Materials and methods

Patients

Between October 2015 and January 2017, 31 patients (13 men and 18 women) provided informed consent for the evaluation of their knees using ultrasonography 3 months after ACL reconstruction. Our research protocol conformed to the Declaration of Helsinki, and the study protocol was reviewed and approved by the Kanazawa University Hospital's ethics committee. If the subject was 20 years old or younger, we also obtained parental consent. Our inclusion criteria were patients who underwent anatomical single-bundle ACL reconstruction using a hamstring tendon autograft and who had an ROM of at least 90° knee joint flexion and at least − 10° extension. Our exclusion criteria were multiple ligament injuries and bilateral ACL injuries. The characteristics of our patients are shown in Table 1. After surgery, all patients followed the same rehabilitation protocol. Patients were allowed to flex their knee joint from 0° to 90° until 4 weeks postoperatively. Patients were allowed full weight-bearing at 2–4 weeks postoperatively and were recommended to wear a knee brace for 4 months. Jogging was allowed beginning at 3 months postoperatively, followed by a return to previous sports activities at 6–9 months postoperatively.

Table 1 Patient's demographic characteristics

Variable	
Sex (male:female)	13:18
Age (years)	21.1 ± 7.2
Height (cm)	166.2 ± 11.0
Weight (kg)	62.5 ± 11.8
Body mass index (kg/m^2)	22.5 ± 2.8

Data indicate mean ± standard deviation

Measurements

For evaluation, participants were placed in a sitting position. Ultrasound assessments were performed on each knee with a 5–10-MHz linear transducer (HI VISION Avius; Hitachi Aloka Medical, Tokyo, Japan). Each knee joint was set at 10° or 90° knee flexion using a goniometer, and longitudinally oriented ultrasonographic images of the anterior part of the knees were taken at the center of the patellar tendon (Fig. 1). Images were recorded in order to observe the IPFP, patellar apex, and tibial tuberosity. Then, the IPFP in the images was divided into superficial and deep parts. The superficial part of the IPFP was defined as a low-echo intensity area above the high-intensity septum in the middle region of the IPFP. IPFP thickness was measured 10 mm away from the patellar apex using the image analysis software Image J (National Institute of Health, Bethesda, MD,

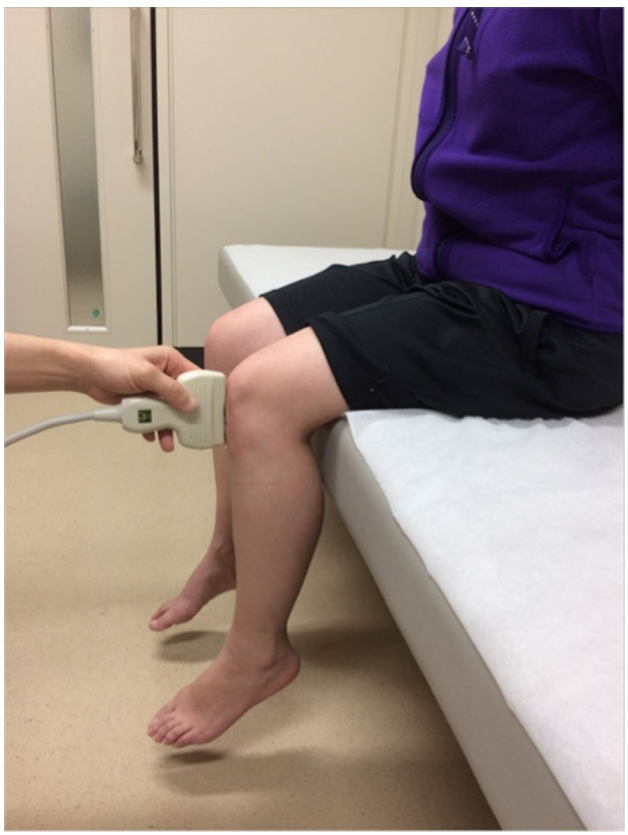

Fig. 1 Photograph showing how the ultrasound image is captured

USA) (Fig. 2). The thickness of the superficial part of the IPFP was measured at a 10° and 90° knee flexion on both the reconstructed knee and the contralateral knee. The ratio of the change in thickness of the IPFP between the two flexion angles was calculated using the following formula: IPFP thickness change ratio = (the thickness of the superficial part of the IPFP at 90° knee flexion)/(the thickness of the superficial part of the IPFP at 10° knee flexion). Prior to data acquisition, the ultrasound examiner established between-day inter-tester reliability by assessing 10 participants with the same inclusion/exclusion criteria as used in this study, separated by 7 days at each angle (intra-class correlation coefficient range ± standard error of measurement range = 0.78–0.93 ± 0.6–0.7 mm). Ultrasonographic images were obtained by one trained physical therapist (T.K.).

Statistical analysis

After confirming the normality of each index for the reconstructed knees and the contralateral knees using the Shapiro–Wilk test, we used the Wilcoxon signed-rank test for the univariate analysis of continuous variables between both sides. Statistical significance was defined as $P < 0.05$. For a comparison of thickness at 10° and 90° flexion and of the thickness change ratio between both sides, a statistical power calculation indicated that a total of 28 patients would be required to show a significant difference at an α level of 0.05 and a β level of 80%.

Results

At 90° knee flexion, the superficial part of the IPFP was significantly thinner in the reconstructed knees (9.3 ± 3.4 mm) than in the contralateral knees (11.8 ± 4.6 mm; $P < 0.05$). At 10° knee flexion, there was no significant difference in the thickness of the superficial part of the IPFP between the reconstructed knees (5.5 ± 2.8 mm) and the contralateral knees (5.0 ± 2.5 mm; $P = 0.20$). The thickness change ratio was significantly smaller in the reconstructed knees (188.6 ± 64.7%) than in the contralateral knees (249.7 ± 73.8%; $P < 0.05$).

Discussion

In this study, we hypothesized that the dynamics of the IPFP would decrease after ACL reconstruction. In support of this hypothesis, when evaluated 3 months after ACL reconstruction, the superficial part of the IPFP at 90° knee flexion was thinner and the thickness change ratio was smaller in reconstructed knees than in contralateral knees. These results suggest that flexibility in the IPFP was decreased during knee joint movement after ACL reconstruction.

It is possible that synovitis and effusion after arthroscopy may have been the cause of the observed reduction in the thickness of the superficial part of the IPFP at 90° knee flexion [17]. Intra-articular bleeding has been advocated as the main cause of effusion after knee arthroscopy [18]. In this

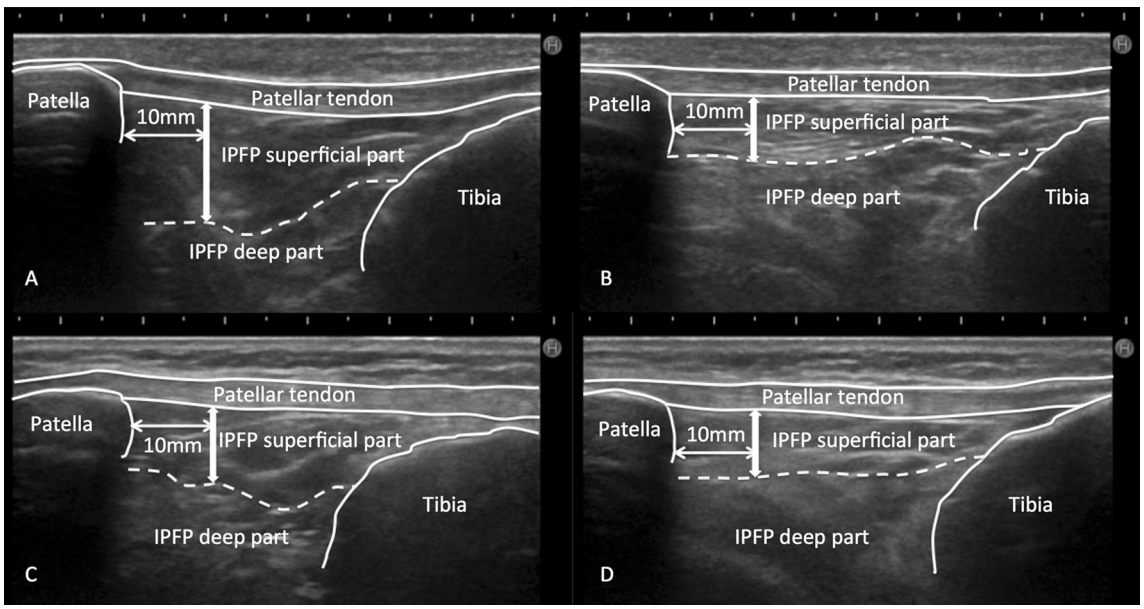

Fig. 2 The thickness of the superficial part of the IPFP was measured at a 90° (**a**, **c**) and 10° (**b**, **d**) knee flexion on both the reconstructed knees (**c**, **d**) and the contralateral knees (**a**, **b**). *IPFP* infrapatellar fat pad

study, we did not objectively measure the volume of joint effusion. Increased edema, however, may have caused an increase in intra-articular pressure and thus compressed the superficial part of the IPFP, leading to a reduction in thickness. During arthroscopic surgery of the knee joint, IPFP is sometimes partially resected in order to expand the surgical field. Although we could not evaluate the resection volume or the precise site of the IPFP in this study, the superficial part was presumably partially resected, which may have affected the thickness of the superficial part.

We consider that the underlying cause of the reduction in the thickness change ratio of the IPFP between each angle was a compositional change in collagen fibers. Studies have shown that there is an increased level of messenger ribonucleic acid expression of collagen types I and III in the IPFP during the early phase after ACL reconstruction, thus leading to increased cellular density. Another potential reason for the observed reduction in the thickness change ratio might be histopathological changes, such as fibrosis resulting from increased levels of transforming growth factor-β messenger ribonucleic acid expression [19]. Fibrosis is the generation of an abnormal tissue type that occurs as part of the tissue repair process accompanying inflammatory reactions after surgery or trauma. Previous studies using a rat model of osteoarthritis and a rat model of patellar tendinopathy showed that fibrosis of the IPFP is related to knee pain [20, 21]. Kanamoto et al. reported that IPFP inflammation was associated with anterior knee pain, while Mace et al. reported that abnormal dynamics of the IPFP were the cause of IPFP impingement [16, 22]. In our future research, we will examine the relationship between IPFP dynamics and knee joint function, including pain or ROM restriction. Using the interventions described in previous studies, we should be able to suppress excessive inflammation and fibrosis of the IPFP. It is also possible that deterioration in the dynamics of the IPFP can be alleviated by preventing a reduction in the thickness change ratio of the superficial part of the IPFP. For example, Tang et al. [21] reported that an intra-articular injection of hyaluronic acid into the IPFP should help alleviate IPFP fibrosis. Taping or strengthening the muscle around the knee joint through physical therapy should also be beneficial in reinforcing biomechanical functioning of the IPFP [4]. To confirm the usefulness or validity of our current method for evaluating the dynamics of the IPFP, it seems necessary to evaluate the thickness change ratio before and after treatments.

There were four limitations to the present study. First, we only evaluated the superficial part of the IPFP, and it was measured at only one time, i.e., 3 months after surgery. During arthroscopy of the knee joint, the deep region of the IPFP is also usually resected to expand the surgical field. However, we did not evaluate the thickness of the deeper part of the IPFP using ultrasound images. According to a study by Mace et al., the superolateral portion of the IPFP behaves in a relatively fluid state and changes its morphology to reduce patellofemoral contact pressure during knee movement [16]. In patients with lateral patellar compression syndrome, the IPFP is reportedly incarcerated by the lateral patellar facet and quadriceps tendon during knee extension. Evaluating the dynamics of the deeper or superolateral portion of the IPFP using ultrasound images or MR images may, therefore, reveal an association with clinical findings. We should evaluate the thickness before surgery to confirm whether the dynamics preoperatively existed or not. On the other hand, middle-term observation will also shed light on the clinical relevance of this method. Second, our current images were evaluated only at two angles (90° and 10°). It is thought that the IPFP undergoes three-dimensional deformation to absorb shock during knee movement [2]. It may, therefore, be useful to measure IPFP dynamics at other angles, as well. Cross-sectional ultrasonographic images would also be helpful for such evaluation. Third, the ultrasound images of the IPFP were captured under non-weight-bearing conditions. Knee pain often adversely affects activities of daily living or sports activities, especially in terms of movement, such as ascending and descending stairs or jumping. Although we were unable to evaluate IPFP dynamics under weight-bearing conditions, we should now consider other investigative methods, such as ultrasonography under loading conditions. Finally, since pathological examinations were not performed in the present study, the relationship between IPFP dynamics and fibrosis remains unclear. While pathological evaluation of tissues by arthroscopy is invasive, this method allows examination of the validity of measuring the thickness change ratio of the IPFP. Using MR images [23] or image analysis using real-time virtual ultrasonography [24], it should be possible to evaluate the severity of fibrosis in the IPFP. This method may be very useful after further investigation of the relationships between the thickness change ratio in patients after knee surgery and a variety of other conditions, including ROM, anterior knee pain, muscle strength, and knee instability. There is a possibility of reducing anterior knee pain or preventing restriction of the range of motion of the knee joint by regaining the normal dynamics of the IPFP after arthroscopy.

Conclusion

When evaluated 3 months after ACL reconstruction, the thickness of the IPFP at 90° knee flexion and the thickness change ratio of the IPFP during knee flexion were lower in reconstructed knees than in contralateral knees.

Compliance with ethical standards

Conflict of interest The authors have no sources of funding or conflicts of interest to declare.

Ethical statements All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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