



# The Association of Quadriceps Femoris Atrophy with Patellofemoral Magnetic Resonance Imaging Alterations after Hamstring Autografts for Single-Bundle Anterior Cruciate Ligament Reconstruction

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**How to cite this paper:** Gululi, D., Johanes, K. and Mgweno, P. (2026) The Association of Quadriceps Femoris Atrophy with Patellofemoral Magnetic Resonance Imaging Alterations after Hamstring Autografts for Single-Bundle Anterior Cruciate Ligament Reconstruction. *Open Access Library Journal*, **13**: e15185.

<https://doi.org/10.4236/oalib.1115185>

**Received:** March 16, 2026

**Accepted:** April 20, 2026

**Published:** April 23, 2026

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## Abstract

**Objective:** To ascertain the association of congruence instability of patellofemoral joint and quadriceps femoris strength deficits after hamstring tendon harvest and Anterior Cruciate ligament-Reconstruction (ACL-R), and to propose a new index to clarify the likely significant influence on patellofemoral pain and early onset of patellofemoral joint osteoarthritis after ACL-R surgery. **Methods:** 20 patients underwent Magnetic Resonance Imaging (MRI) scan before anterior cruciate ligament reconstruction and at every two weeks after surgery, and every two weeks until 12 weeks. Merchant's patellar congruence angle, lateral inclination angle, and quadriceps femoris muscle cross-sectional area were measured, and multiple regression analysis was used to analyze the relationship between merchant's patellar congruence angle, lateral inclination angle and the ratio of quadriceps femoris atrophy. **Results:** The merchant's patellar congruence angle and lateral inclination angle significantly changed after surgery and the alterations of the following angles were significantly corrected with the quadriceps femoris atrophy ratio. **Conclusion:** These findings show that the choice of hamstring autografts for ACL reconstruction can reduce patellofemoral joint dysfunction to a certain extent. However Post operative time period the unbalanced atrophy of quadriceps femoris does disturb the stability and congruence of the patellofemoral joint, which is thought to be one among the causes of patellofemoral pain and early osteoarthritis. Rehabilitation training for quadriceps femoris muscle especially the Vastus medialis is therefore not unconnected with post-surgery (ACL-reconstruction) approaches.

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## Subject Areas

Orthopedics Sports Medicine and Arthroscopy

## Keywords

Patellofemoral Pain, Patellofemoral Osteoarthritis, Quadriceps Atrophy, Merchant Congruence Angle, Lateral Patellar Tilt, Anterior Cruciate Ligament Reconstruction

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## 1. Introduction

Anterior cruciate ligament (ACL) injury is one of the most frequent injuries associated with athletic activity, and anterior cruciate ligament reconstruction (ACL-R) is a common procedure to re-establish knee stability and function [1]. Nevertheless, the effectiveness of ACL-R in preventing osteoarthritis (OA) is still contentious. A relatively high incidence of osteoarthritis, especially the patellofemoral joint osteoarthritis (PFOA) after ACL-R many researchers report [2]-[5]. And patellofemoral pain (PFP) is common among those following ACL-R [6]. Significant tibiofemoral kinematics alterations have been recognized in knees with ACL failure which may contribute to OA [7]. However, few studies have highlighted the femoropatellar kinematic alterations in post-ACL reconstruction patients [8].

Quadriceps femoris plays an important role in maintaining patellofemoral joint stability [9]. The strength deficits and atrophy of quadriceps femoris are common in patients after ACL-R and they may affect patellofemoral joint [10]. However, the relationships between the alterations of femoropatellar kinematics and the quadriceps femoris atrophy are still unclear [11].

Muscle strength is often measured by dynamometry technology. However, it is incapable of evaluating contributions of the individual quadriceps subregions which may be important since imbalance of the medial (vastus medialis) and lateral (vastus lateralis) forces may affect femoropatellar kinematics resulting in PFOA [12]. Magnetic resonance imaging (MRI) is one technique that is capable of measuring muscle cross-sectional area (CSA) and its measurement is gaining popularity as a surrogate measure of individual vasti muscle strength [13] [14]. In this study, we sought to define the relationship between the alterations of femoropatellar kinematics and the quadriceps femoris atrophy through the MRI observation of the muscle CSA and femoropatellar kinematics. The results of our research provide new insight into the high incidence of patellofemoral pain and patellofemoral joint osteoarthritis after ACL-R.

## 2. Materials and Methods

### 2.1. Patients

A continuous series of 20 knees from 20 patients 11 males and 9 females; mean age: 26.1 years old (15 - 40 years)] were subjected to ACL-R between 2003 and

2004. The Ethics Committees of Fukushima Medical University (Fukushima, Japan) approved the study protocol, and all patients provided informed consent.

## 2.2. Operative Technique

All surgeries were performed by the same group of authors in Fukushima Medical University. An air tourniquet was placed around the thigh and inflated to a pressure of 250 - 300 mmHg after exsanguination. Gracilis and semitendinosus from the ipsilateral side were harvested as autografts, and single bundle ACL-R was performed. The femoral tunnel was prepared using a trans-tibial tunnel technique, and grafts were fixed by TRANSFIX and INTRAFIX© fasteners (DepuyMitek, USA). The same postoperative rehabilitation program was introduced to all the patients.

## 2.3. MRI Investigation

All the 20 patients underwent MRI scan every two weeks after surgery, until 12 weeks. MR images of the ACL-reconstructed knees on a 1.5 Tesla MR scanner (General Electric Healthcare, USA) were obtained by a phase-array torso coil. The knees were flexed at about 30°. Sagittal T1-weighted spin echo (repetition time ms/echo time: 400 - 600/10 - 14 ms) or proton density-weighted fast-spin echo [2000 - 4000/30 - 40 (effective), echo train length = 4] was obtained using an extremity coil, a 15 cm field of view, a matrix of 256 × 192, and a 4 mm slice thickness with 1 mm interslice gap.

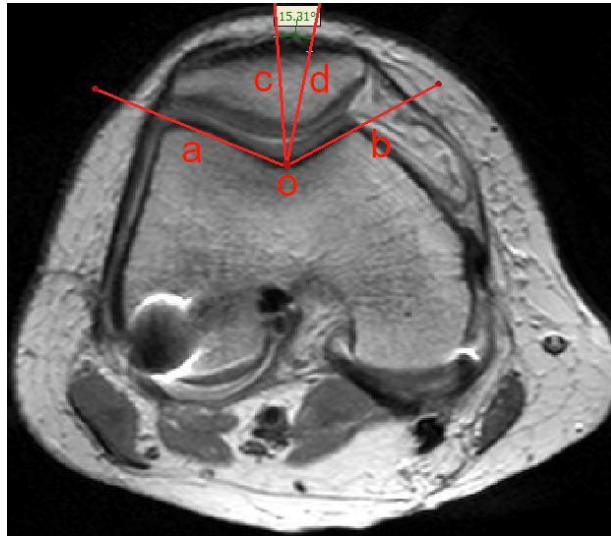
Two independent observers performed all the evaluations of the MRI images. All images were analysed individually. All were consultants in orthopaedic surgery and familiar with the MRI evaluation of the knee and the surrounding musculatures.

The Merchant's patellar congruence angle, the lateral inclination angle, and quadriceps femoris muscle cross-sectional area were measured by mimics 22.0 software (International Business Machines Corporation, USA). The merchant's patellar congruence angle, lateral inclination angle was measured on MRI images of knee joint on the first layer displaying femoral epicondylar axis from distal to proximal. The congruence angle is the angle between a line bisecting the sulcus angle and a line drawn through the lowest point of the articular ridge of the patella and the vertex of the sulcus angle (**Figure 1**). The lateral patellofemoral angle is the angle between a line drawn across most anterior aspect of the femoral condyles and a line along lateral patellar facet on axial imaging (**Figure 2**). The CSA of the quadriceps femoris muscles was measured on 100mm upper layer (**Figure 3**).

## 2.4. Statistical Analysis

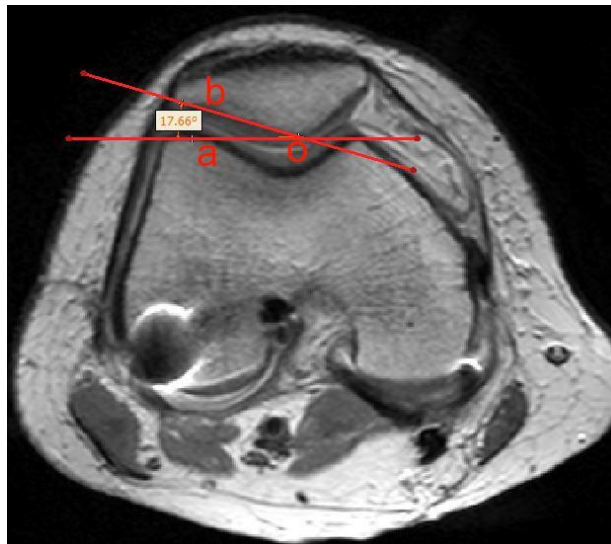
Intraclass correlation coefficients were analysed to evaluate intra- and interobserver reliability of our measurement. All indexes were shown as mean ± standard deviation. A paired-samples T-test was conducted to analyse the difference of merchant's patellar congruence angle and lateral inclination angle between pre-

operative and postoperative. Multiple linear regression analysis was used to analyse the relationship between merchant's patellar congruence angle, lateral inclination angle and the ratio of quadriceps femoris atrophy. SPSS Statistics 22.0 (Inc., Chicago, USA) software was used for analysis. The results were considered significant at  $p < 0.05$ .



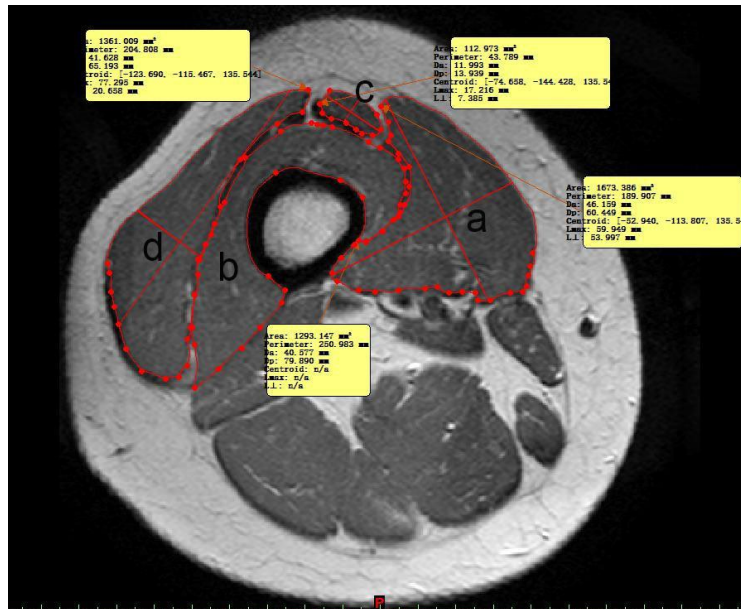
Line "c" bisects the sulcus angle ( $\angle aob$ ). Line "b" joins the vertex of the angle ( $\angle aob$ ) to the lowest point of the patellar crest. The merchant's patellar congruence angle is the angle between line "c" and line "d" ( $\angle cod$ ). When line "d" is medial to line "c", the merchant's patellar congruence angle is defined as negative.

**Figure 1.** Measurement of merchant's patellar congruence angle.



Line "a" joins the anterior limits of the medial and lateral femoral condyles. Line "b" is tangential to the lateral facet of the patella. The lateral inclination angle is the angle between line "a" and line "b" ( $\angle aob$ ). The lateral inclination angle is defined as negative when line "a" is in front of line "b".

**Figure 2.** Measurement of lateral inclination angle.



The areas were manually circumscribed and then automatically calculated in the yellow box. Area a: vastus medialis; Area b: vastus intermedius; Area c: rectus femoris; Area d: vastus lateralis.

**Figure 3.** Measurement of the quadriceps femoris CSA.

### 3. Results

#### 3.1. Intra- and Interobserver Reliability of Measurement

**Table 1** shows the intra-observer reliability calculated based on the two estimates of observer 1. The intra-observer reliability of the following 6 measurements was almost perfect for all ICC values  $> 0.90$ . Interobserver reliability of our study is shown in **Table 2** based on estimates between observer 1 and observer 2. All ICC values were  $> 0.90$ , and it indicated the measurements of excellent interobserver reliability.

**Table 1.** Interobserver measurements.

	ICC	95% ICC	p value
vastus medialis	0.984	(0.978, 0.988)	$p < 0.05$
vastus intermedius	0.956	(0.941, 0.968)	$p < 0.05$
rectus femoris	0.960	(0.945, 0.970)	$p < 0.05$
vastus lateralis	0.978	(0.970, 0.984)	$p < 0.05$
merchant's patellar congruence angle	0.984	(0.979, 0.988)	$p < 0.05$
lateral inclination angle	0.985	(0.979, 0.989)	$p < 0.05$

#### 3.2. Effect of ACLR on Quadriceps Femoris CSA, Merchant's Patellar Congruence Angle and Lateral Inclination Angle

As the results in **Table 3** show, the CSA of each quadriceps femoris was not significantly different after ACL-R. The merchant's patellar congruence angle was

3.69° ± 6.62° before surgery, which significantly decreased after ACL-R (-3.59° ± 6.01°). The mean value of lateral inclination angle before surgery was 6.81° ± 6.19°, and this value was significantly higher in the postoperative patients (12.61° ± 5.40°) as shown in **Table 3**.

**Table 2.** Interobserver measurements.

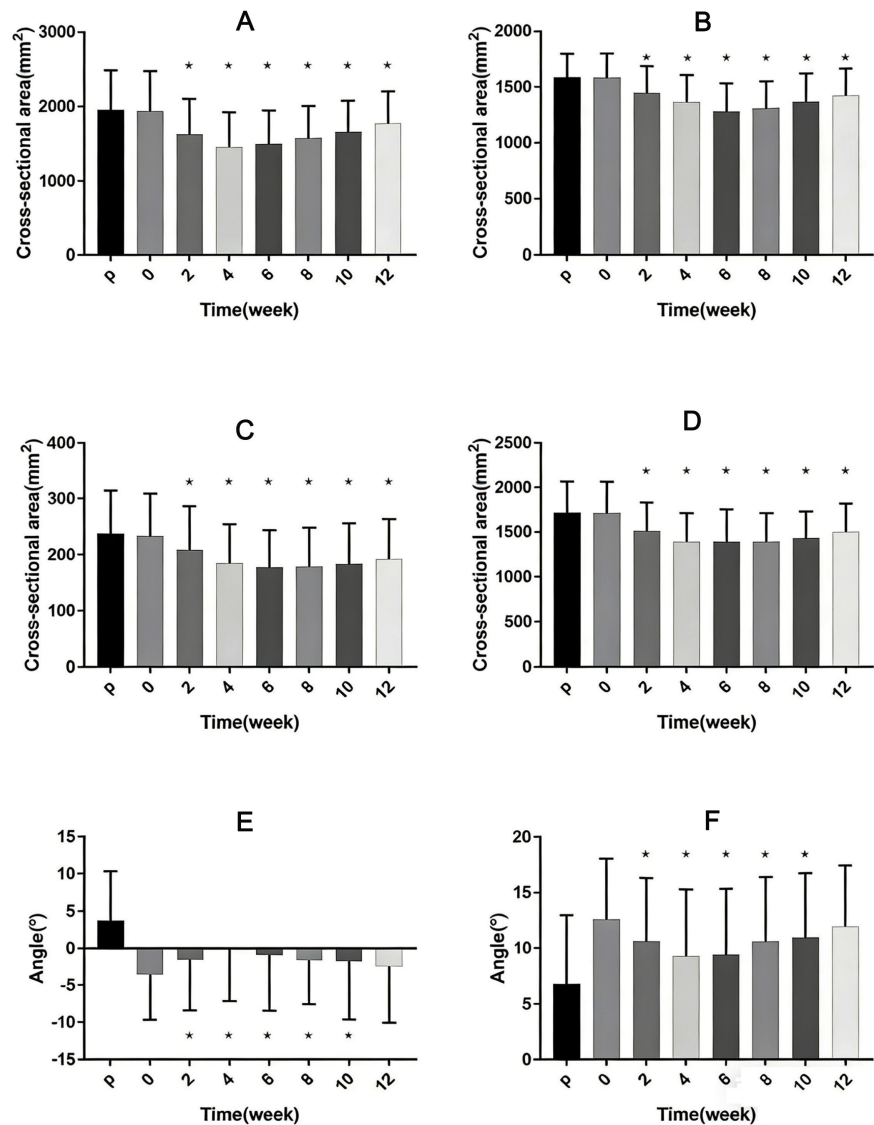
	ICC	95% ICC	p value
vastus medialis	0.987	(0.982, 0.990)	p < 0.05
vastus intermedius	0.970	(0.959, 0.978)	p < 0.05
rectus femoris	0.963	(0.950, 0.973)	p < 0.05
vastus lateralis	0.979	(0.971, 0.984)	p < 0.05
merchant's patellar congruence angle	0.991	(0.988, 0.994)	p < 0.05
lateral inclination angle	0.992	(0.989, 0.994)	p < 0.05

**Table 3.** Intraclass correlation coefficients for quadriceps femoris components, merchant's patellar congruence angle, and lateral inclination angle measurements.

	Preoperative	Postoperative	p value
vastus medialis (cm <sup>2</sup> )	1960.99 ± 526.63	1953.63 ± 530.73	0.135 (>0.05)
vastus intermedius (cm <sup>2</sup> )	1587.29 ± 210.55	1578.58 ± 220.50	0.090 (>0.05)
rectus femoris (cm <sup>2</sup> )	238.30 ± 76.22	234.51 ± 74.18	0.112 (>0.05)
vastus lateralis (cm <sup>2</sup> )	1711.75 ± 353.46	1706.87 ± 355.05	0.216 (>0.05)
merchant's patellar congruence angle (°)	3.69 ± 6.62	-3.59 ± 6.01	3.63E <sup>-7</sup> (<0.05)
lateral inclination angle (°)	6.81 ± 6.19	12.61 ± 5.40	5.16E <sup>-6</sup> (<0.05)

### 3.3. Measurement of Quadriceps Femoris, Merchant's Patellar Congruence Angle and Lateral Inclination Angle during the 12-Week Follow-Up

**Figure 4** shows the measurement results of quadriceps femoris, merchant's patellar congruence angle and lateral inclination angle in the 12 weeks follow-up taken every two weeks. The CSA of quadriceps femoris were significantly less in the 12 weeks follow-up (**Figures 4(A)-(D)**). The vastus medialis CSA showed the greatest atrophy ratio at 4 weeks after surgery, and then the CSA gradually increased with time (**Figure 4(A)**). However, the smallest CSA of vastus intermedius, rectus femoris and vastus lateralis was observed 6 weeks after ACLR (**Figures 4(B)-(D)**). As shown in **Figure 4(E)**, the merchant's patellar congruence angle in the 10 weeks follow-up was significantly higher than that in two days after surgery and reached the biggest angle in 4 weeks after surgery. Interestingly, the mean value of merchant's patellar congruence angle after surgery were all negative (**Figure 4(E)**). A similar variation trend was found in lateral inclination angle (**Figure 4(F)**). The two angles recovered within 12 weeks after surgery, as there was no significant difference between the "0" group and the "12" group (**Figure 4(E)** and **Figure 4(F)**).



(A): The CSA of vastus medialis; (B): The CSA of vastus intermedius; (C): The CSA of rectus femoris; (D): The CSA of vastus lateralis; (E): The merchant's patellar congruence angle; (F): The lateral inclination angle. The "p" in abscissa means the MRI was taken in preoperative time; other numbers indicate the time in weeks after surgery (where "0" signifies the MRI taken two days after surgery). The paired-samples T test was taken between the "0" group and the other group and the "\*" means there was significant difference ( $p < 0.05$ ).

**Figure 4.** Measurement results of quadriceps femoris, merchant's patellar congruence angle and lateral inclination angle in the 12 weeks follow-up taken every two weeks.

### 3.4. Multiple Linear Regression Analysis of the Relationship between Changes in Merchant's Patellar Congruence Angle, Lateral Inclination Angle and Quadriceps Femoris Atrophy Ratio

A significant correlation was observed between the alterations of the merchant's patellar congruence angle and the atrophy ratio of quadriceps femoris ( $R^2 = 0.407$ ,  $p < 0.05$ ). As shown in **Table 4**, the atrophy ratio of vastus medialis and vastus

lateralis were all significantly correlated with the alterations of the merchant's patellar congruence angle for  $p < 0.05$ . The standardized coefficient of vastus medialis was  $-0.68$ , and its absolute value was larger than that of vastus lateralis ( $0.44$ ). The data indicated that the atrophy ratio of vastus medialis might have a greater influence on the merchant's patellar congruence angle than the vastus lateralis (Table 4). Another multiple linear regression also showed significant correlation between the alterations of lateral inclination angle and the atrophy ratio of quadriceps femoris ( $R^2 = 0.829$ ,  $p < 0.05$ ). The atrophy ratios of quadriceps femoris except rectus femoris were found to be significantly corrected with the alterations of the lateral inclination angle (Table 5). However, the standardized coefficient of rectus femoris is much smaller than that of vastus medialis and vastus lateralis (absolute value), as shown in Table 5 and the rectus femoris might have a lower impact on the lateral inclination angle. From Table 4 and Table 5, some coefficients were negative, indicating that the angle increased with an increase in the atrophy ratio of the muscle, while positive coefficients indicated that the angle decreased with an increase in the atrophy ratio of the muscle.

**Table 4.** Comparison of quadriceps femoris components, merchant's patellar congruence angle, and lateral inclination angle between preoperative and postoperative measurements.

Variables	Coefficients	95% CI	Standardized Coefficients	p value
vastus medialis	-15.76	(-19.56, -11.95)	-0.68	0.000 (<0.05)
vastusintermedius	-1.90	(-6.83, 3.04)	-0.07	0.448 (>0.05)
rectus femoris	1.32	(-1.42, 4.06)	0.09	0.342 (>0.05)
vastus lateralis	8.35	(-6.83, 3.04)	0.44	0.000 (<0.05)

**Table 5.** The relationship between alterations in the lateral inclination angle and the atrophy ratio of quadriceps femoris, as determined by multiple linear regression.  $R^2 = 0.829$ ,  $p < 0.05$ .

Variables	Coefficients	95% CI	Standardized Coefficients	p value
vastus medialis	20.62	(18.76, 22.45)	0.99	0.000 (<0.05)
vastusintermedius	2.484	(0.09, 4.88)	0.10	0.042 (<0.05)
rectus femoris	-0.047	(-1.80, 0.86)	-0.34	0.486 (>0.05)
vastus lateralis	-11.38	(-13.29, -9.47)	-0.67	0.000 (<0.05)

#### 4. Discussion

The postoperative complications of PFP and PFOA had a negative effect on the quality of life and physical activity of the patients after ACL-R [15]. It was reported that the degeneration of patellofemoral articular cartilage in patients with ACL-R after 7 - 11 years was 30 times as high as that in normal controls as observed via MRI [16]. Patients under 30 years old, undergoing ACL-R, had earlier PFOA symptoms [17]. During a 12-year follow-up after anterior cruciate ligament injury

and reconstruction, patellofemoral osteoarthritis was significantly associated with tibiofemoral osteoarthritis, and they often co-existed [18]. Conservative measures for osteoarthritis have limited success, and early-onset osteoarthritis increases the risk of joint replacement surgery at a younger age [19] [20]. Therefore, sufficient attention should be paid to PFOA after ACLR, and the study of its pathogenesis is the key to preventing its onset.

Several factors have been identified as contributors to secondary PFOA after ACL-R [21]. The graft selection of bone-patellar tendon-bone was also thought to increase the incidence of PFP resulting in PFOA [22]. However, no significant difference was found in the incidence of PFOA compared to the hamstring graft use and PFOA has also been problematic after ACL reconstruction with hamstring graft [23]. Accompanying meniscus injuries were found to be other contributors, and patients with such injuries were significantly more likely to develop radiographic evidence of osteoarthritis than those with normal menisci [24]. Age, sex and body mass index might also have an influence. However, the abnormal kinematics of the unstable PF joint might be the most important factor contributing to the cartilage degeneration after ACL-R [11].

Double-bundle technique is now accepted by many researchers with the advantage of controlling rotational stability and reducing abnormal joint kinematics [25]. In our study, we found that the ACL-R ameliorated the femoropatellar kinematics index but still had a difference compared to normal individuals, which complies with Diego's report [26]. The reason might be the single-bundle technique we employed in our study. Nevertheless, some patients, treated by double-bundle technique, still had early signs of osteoarthritis [27]. The atrophy of quadriceps femoris might also play a pivotal role. It was reported that the recovery of quadriceps strength has a strong relationship with good outcome after ACL-R [28]. In our study, we found that femoropatellar kinematics alterations were caused by the unbalanced atrophy of quadriceps femoris and it might be an important contributor to PFP and PFOA. In the present study, we found that there was a certain degree of atrophy of quadriceps femoris with time. Interestingly, some differences in the degree of atrophy of each muscle were found, and the duration and recovery time of atrophy also differed between the four muscles. Even at the 12 weeks after surgery, the CSA of the quadriceps femoris was less compared to that preoperatively. The unbalanced atrophy of quadriceps femoris might have an effect on the femoropatellar kinematics alterations.

Congruence angle and lateral patellofemoral angle also changed with time in our study and the data revealed the changes were related to the atrophy of vastus medialis and vastus lateralis. Congruence angle reflects the relationship of the patellar articular ridge to intercondylar sulcus [29]. It was reported that the mean value of this angle was  $-6^{\circ} \pm 11^{\circ}$ , the lateral shift of the patella relative to the femoral trochlea is larger when the angle increase [30]. Our research data showed the angle was larger in the preoperative patients and was reduced after ACL-R. In the follow-up, the angle changed due to muscle atrophy which might result in

abnormal femoropatellar kinematics and PFP. Lateral patellofemoral angle reflects the inclination of the patella [31]. The inversion of this angle may occur when the patella seriously tilts laterally and the angle becomes negative. Our study showed that the angle was larger after the ACL-R. However, it changed in the follow-up and was related to the atrophy of vastus medialis and vastus lateralis. The data revealed that the angle was at its minimum 4 weeks after surgery, which was significantly smaller than the first MRI observation after surgery. As a result, the patella may tilt seriously laterally leading to abnormal stress in patellofemoral joint. In conclusion, the ACL-R can regain the above angle of patella orientation to a certain extent, the unbalanced atrophy of the quadriceps femoris nevertheless led to some adverse changes in the angles, which may cause significant changes to femoropatellar biomechanics and result in PFP and PFOA.

Through the multiple linear regression analysis in our study, the regression coefficient ( $\beta$ ) of vastus medialis was found to be much larger than that of vastus lateralis. We hypothesize that this might result from the angle between the muscle retraction direction and the equilibrium direction of the patella and the insertions of vastus medialis in the distal upper third or upper half of the patella [32] [33]. These findings suggest that more attention should pay more attention to the rehabilitation training of vastus medialis. In some early published studies, it was suggested that the vastus medialis was related to the incidence of PFP [34] [35]. According to the present results, there was severe atrophy of vastus medialis at 4 weeks after surgery. So, in the coming weeks, more muscle rehabilitation should be taken to minimize the atrophy. Furthermore, at this time, no significant fatty degeneration of quadriceps femoris was found, which was the same as the results of Marcon and colleagues' study [36]. This prompted that a good effect of muscle rehabilitation exercise could be achieved in this period. Isometric quadriceps exercises were safe and advised from the first postoperative week [37]. Then electrostimulation and closed kinematic chain might be useful in the following weeks [38]. Especially, selective vastus medialis oblique exercises such as functional electrical stimulation might be strongly suggested according to our study.

There were still some limitations in our study: 1) The indication of femoropatellar kinematics in our study was all static, not dynamic, such as the patellar tracking. However, the data from our study can still reflect the stability and adaptability of the patellofemoral joint [39]-[41]. 2) Muscle strength was not directly researched although the decrease of muscle cross-sectional area is related to the muscle weakness [42] [43]. More cases and further study need to be performed to clarify the relation between the femoropatellar alterations and quadriceps femoris atrophy.

Though this study observed age selection to be included in the study for MRI examination of 15 to 40 years, because old age may contribute to muscle atrophy and hence affect the MRI findings but contrary to that. Importantly, the study did not exclude some conditions for patients that would present with morphological or joint geometrical abnormalities which could mimic patellofemoral instability.

thereby affecting the MRI findings and the study over hamstring harvest effects, for example high patella (Insall-Salvati index greater than 1.3). Morphological abnormalities in the intercondylar fossa of the femur (e.g., trochlear dysplasia) were not excluded.

## 5. Conclusion

Our work strongly suggests that the anterior cruciate ligament played an important role in maintaining patellofemoral joint stability, and ACL-R can reduce the dysfunction of patellofemoral joint to a certain extent. During a period of time after operation, the unbalanced atrophy of quadriceps femoris once again destroyed the stability of patellofemoral joint, which may be one of the causes of PFP and early osteoarthritis. Rehabilitation training of quadriceps femoris, especially the vastus medialis, after surgery is suggested.

## Ethical Approval

“All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments, or comparable ethical standards.”

## Acknowledgements

The authors acknowledge the devoted help of (Department of Orthopaedics, Renmin Hospital of Wuhan University) in the measurement.

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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