Dong *et al. BMC Musculoskeletal Disorders* (2024) 25:727
https://doi.org/10.1186/s12891-024-07794-3

BMC Musculoskeletal Disorders

RESEARCH

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The vastus medialis oblique compensates in current patellar dislocation patients with the increased femoral anteversion

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Abstract

Purpose The purpose of this study was to investigate whether the vastus medialis oblique (VMO) muscle compensates in patellar dislocation (PD) patients with the increased femoral anteversion angle (FAA).

Methods Between 2021 and 2024, we included 60 patients with recurrent PD (RPD group). Inclusion criteria were at least two episodes of PD, as well as complete CT scans of the knee and hip. Exclusion criteria included traumatic or habitual dislocation, previous knee surgery, etc. Of these patients, 30 with excessive FAA (≥ 30°) were assigned to the A group, and 30 without excessive FAA (< 30°) to the B group. A control group of 120 patients without patellofemoral disorders was also included (C group). The cross-sectional areas of the VMO and vastus lateralis muscle (VLM) were measured 20 mm above the patella on CT scans, and the VMO/VLM area ratio was calculated. The correlation between FAA and the VMO/VLM ratio was analyzed.

Results The RPD group had a significantly larger FAA (15.0 ± 1.9° vs. 30.1 ± 9.6°, $P = 0.040$) and a smaller VMO/VLM ratio (4.2 ± 1.5 vs. 3.5 ± 1.0, $P = 0.014$) compared to the C group. Within the RPD group, the A group had a higher VMO/VLM ratio than the B group (4.0 ± 1.1 vs. 3.0 ± 0.7, $P = 0.029$). The B group's VMO/VLM ratio was lower than that of the C group (3.0 ± 0.7 vs. 4.2 ± 1.5, $P = 0.004$). However, there was no significant difference in the VMO/VLM ratio between the A group and the C group. The VMO/VLM ratio showed a moderate positive correlation with FAA in the RPD group, with a correlation coefficient of $r = 0.4$ ($P = 0.012$), indicating a statistically significant relationship between the two.

Conclusion Patients with recurrent PD showed a smaller VMO/VLM ratio compared to controls. Increased FAA was correlated with compensatory thickening of the VMO and a higher VMO/VLM ratio in PD patients. This suggests that increased FAA may drive biomechanical adaptations in the quadriceps, stabilizing the patella. Clinicians should consider changes in FAA when assessing and treating PD.

Level of evidence Level III.

Keywords Vastus medialis oblique, Femoral anteversion, Computed tomography, Patellar dislocation, VMO/VLM area ratio

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Introduction

Patellar dislocation (PD) occurs when the patella breaks out of the femoral trochlear groove during movement [1]. The incidence of primary acute PD in the general population is 7–49 cases per 100,000 people [2, 3]. With nonoperative management, the rate of recurrent lateral PD after acute injury has been reported to be as high as 44% [4]. Repeated dislocation can lead to cartilage wear, ligament damage, and knee joint and hip joint instability, causing symptoms such as persistent pain, knee weakness and mechanical limitations [5]. Correcting PD is important for preventing these complications [6].

The causes of PD are considered multifactorial, including congenital and acquired factors. The most common cause of PD is injury to the medial patellofemoral ligament, which plays a critical role in stabilizing the patella [7]. Abnormal femoral torsion is another significant factor, characterized by excessive internal rotation of the femur. This developmental deformity is clinically marked by in-toeing, internal rotation of the hip and knees, and abnormal lower limb appearance [6]. Femoral torsion, also known as femoral anteversion, can lead to a range of medical conditions when abnormal [8]. Excessive femoral anteversion can result in increased stress on the iliopsoas muscle and upper acetabulum, potentially leading to anterior hip pain and labral tears [9], It also increases abnormal contact stress in the patellofemoral joint, leading to joint instability [10]. Studies have shown that in frog-leg squatting mimicking patients, abnormal femoral torsion can be accompanied by gluteal muscle contracture [11].

Quantitative indicators of femoral anteversion, such as the femoral anteversion angle (FAA), are crucial for clinical assessments. FAA is defined as the angle between the femoral neck axis and the transfemoral posterior condyle axis. Surgical correction is recommended when the FAA exceeds 30 degrees to improve axial alignment. The relationship between femoral anteversion and knee pain is a biomechanical factor worthy of attention [12, 13].

The quadriceps muscles are vital for knee extension and stability, consisting of the muscle rectus femoris, vastus medialis muscle, vastus lateralis muscle (VLM), and muscle vastus intermedius [14]. The vastus medialis oblique (VMO) muscle, the distal fibers of the vastus medialis muscle, plays a crucial role in maintaining patellar alignment and limiting lateral movement [15]. The lateral pull of the VLM is balanced by the VMO to ensure patellar stability. An imbalance can lead to abnormal lateral tracking of the patella, often due to VMO insufficiency from atrophy or hypoplasia [16]. In patients with increased femoral anteversion, the need to limit excessive knee joint torsion may result in inappropriate or excessive extension of the VMO. Especially in patients with recurrent PD, the properties of the VMO might be affected by changes in mechanical requirements due to alterations in the musculoskeletal system's overall strength [17].

Despite the recognition of excessive femoral anteversion as a risk factor for PD, limited research has explored its impact on the quadriceps muscle group, particularly the VMO [18]. Current literature does not adequately address how changes in femoral anteversion affect the muscle balance between the VMO and VLM, which is crucial for patellar stability. This study aims to fill this gap by investigating the compensatory changes in the VMO and VLM in PD patients with increased FAA and examining the correlation between FAA and the VMO/VLM ratio. This study provides new insights into the biomechanical adaptations of the quadriceps muscle group in response to altered femoral anteversion in patients with patellar dislocation.

By examining the compensatory thickening or atrophy of the VMO and VLM, this study not only advances our understanding of muscle adaptation mechanisms in PD patients but also provides valuable clinical insights for developing personalized treatment strategies aimed at improving treatment outcomes and prognosis for PD patients. We hypothesize that an increased FAA results in compensatory thickening of the VMO and a positive correlation between FAA and the VMO/VLM ratio.

Materials and methods

General information

Institutional review board approval was acquired from the ethics committee of the Third Hospital of Hebei Medical University (No. Ke2023-002-1), and informed consent was obtained from all patients before the initiation of this retrospective study.

The study was conducted from January 2021 to January 2024 and included 60 patients diagnosed with recurrent PD and 120 control patients without patellofemoral disorders. The inclusion criteria were as follows: (1) at least two episodes of PD; (2) aged between 18 and 45 years; (3) patients with complete CT scans of the knee and hip; and (4) a history of PD with symptoms of patellar instability (pain, subluxation, or both) for more than 3 months. The exclusion criteria were as follows: (1) traumatic or habitual dislocation; (2) previous knee surgery patients; (3) concomitant ligament reconstruction (cruciate ligament or collateral ligament); (4) revision cases; (5) missing clinical data; (7) patellofemoral arthritis greater than Iwano grade II [19]; and (8) high-grade trochlear dysplasia (grades B, C or D of Dejour's classification [20]).

Inclusion criteria were carefully selected to ensure that the study focused on a relevant and homogeneous group of patients with PD. Patients were required to have at least two episodes of PD to confirm the recurrence of the condition, which is essential for studying compensatory mechanisms like those involving the VMO. Complete

CT scans of the knee and hip were necessary to accurately measure the FAA and the VMO/VLM ratio, critical parameters in this study. Patients with symptoms of patellar instability for over 3 months were included to ensure chronicity, allowing for the assessment of long-term biomechanical adaptations. The exclusion criteria were designed to eliminate confounding factors that could affect the study's outcomes. Traumatic or habitual dislocations were excluded because they may have different underlying mechanisms compared to recurrent PD without such clear mechanical triggers. Previous knee surgery, ligament reconstruction, and revision cases were excluded to avoid the influence of surgical alterations on muscle structure and function. Patients with missing clinical data were excluded to ensure data completeness and accuracy. Patellofemoral arthritis greater than Iwano grade II was excluded to avoid the impact of severe joint degeneration on muscle function. High-grade trochlear dysplasia was excluded to prevent the confounding effects of anatomical abnormalities on patellar stability.

These criteria were chosen to ensure that the study sample was representative of patients with recurrent PD and to minimize variability caused by other factors. This approach helps to isolate the effects of FAA on the VMO and its potential compensatory role, thereby improving the reliability of the study's conclusions.

The control group consisted of 120 patients selected from our hospital's case system without patellofemoral disorders, matched in a 1:2 ratio by age, sex, height, and weight, during the same period for comparison. Patients with a history of patellofemoral instability, ligament laxity, meniscus injuries, patellar trajectory abnormalities, and abnormal anatomical morphology of knee joints, such as tumors or discoid meniscus, were excluded. Patients with a previous history of knee joint trauma and knee joint surgery were also excluded to ensure comparability with the study group.

According to the inclusion and exclusion criteria, patients with PD were included in the RPD group ($n=60$) and divided into two subgroups with and without excessive FAA (A group, FAA ≥ 30, $n=30$; B group, FAA < 30, $n=30$). And 120 patients were included in the normal control (C group).

Radiological assessments

In this study, CT scans were utilized to measure the cross-sectional areas of the VMO and VLM. CT imaging was chosen over other modalities such as MRI or ultrasound due to its high precision in assessing bony structures and muscle morphology [21]. CT provides accurate and reproducible measurements of the FAA and detailed visualization of the quadriceps muscles, making it an ideal choice for quantifying muscle size and analyzing anatomical relationships in the context of PD [22]. Additionally, CT scans are more readily available and cost-effective compared to MRI, making them practical for a study of this scope. All patients received a 1-mm thickness CT scan (Somatom, Sensation 16, Siemens Medical Solutions, Erlangen, Germany) in a supine position with the knee extended and quadriceps muscle relaxed. The limbs were immobilized with devices to reduce arbitrary movements. All measurements were conducted on axial CT images. The VMO and VLM cross-sectional areas and FAA were measured using the Image Storage and Communication System (PACS) workstation (Centricity, GE Healthcare, St. Gilles, UK).

The cross-sectional areas of the VMO and VLM were measured 20 mm above the upper pole of the patella, as this was the representative measurement site of the VMO [15, 23] (Fig. 1). The angle formed by the projection of the line between the central axis of the neck of the femur and the midpoint of the internal and external condyle of the femur was defined as the FAA, and researchers defined the pathologic threshold as 30° [12, 24, 25]. The central axis of the femoral neck was determined by the following two points: one was the center of the femoral head, the other was the center of the base of the femoral neck, and the connection between the two points was defined as the axis of the femoral neck. Bilateral condylar axis: The line parallels the last two points of the medial and lateral femoral condyle and passing through the center point of the knee (Fig. 2). Two trained observers independently repeated the measurements with an interval of four weeks.

Statistical analysis

The statistical difference of all measurements was examined using software SPSS (version 26.0; SPSS Inc., Chicago, IL, USA). The data are presented as the means and standard deviations for continuous variables and as numbers and percentages for categorical variables. The Kolmogorov-Smirnov test was used to determine the normality of the data. The analysis was performed with the two-tailed Student's t test for data with a normal distribution or the Mann-Whitney U test for nonparametric data. $P<0.05$ was considered statistically significant. Spearman correlation analysis was used to explore the correlation between the FAA and VMO/VLM ratio. The interobserver and intraobserver agreement of the indicators was calculated. The intraclass correlation coefficient (ICC) values with 95% confidence intervals were calculated, and an ICC value > 0.8 indicated excellent reliability [26].

Sample size calculation was performed using G*Power 3 (Heinrich Heine, Universität Düsseldorf, Düsseldorf, Germany). An a priori power analysis with a prespecified $\alpha<0.05$ and an effect size of 0.8 showed that a minimum

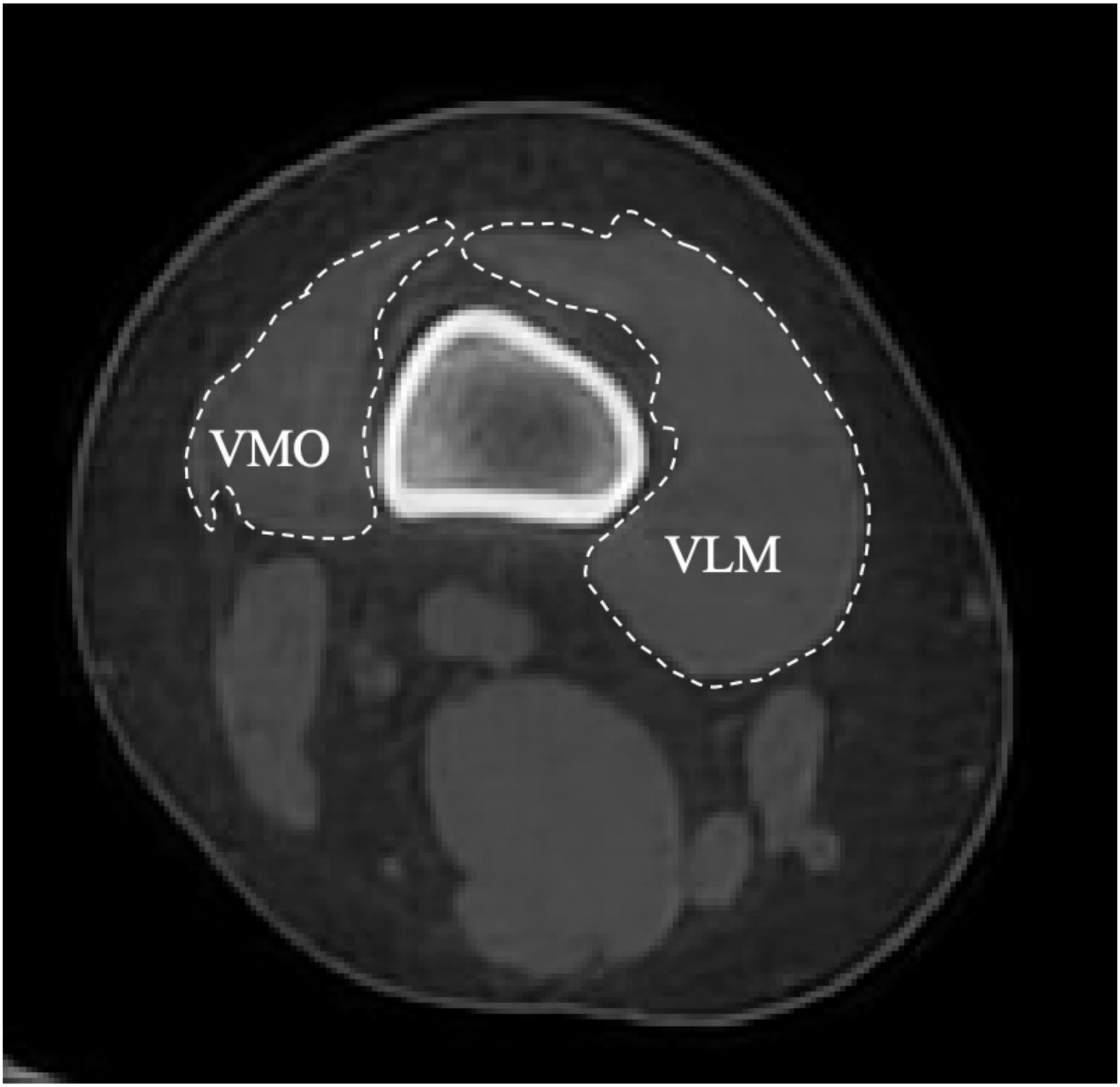

Fig. 1 The cross-sectional areas of the VMO and VLM. *VMO*: vastus medialis oblique; *VLM*: vastus lateralis muscle

sample size of 52 patients was adequate to detect significant differences with a statistical power of 0.8.

Results

The demographics of the patients were summarized in Table 1. All measurements had good intra-observer and inter-observer reliability (Table 2).

The study found that patients in the RPD group had a significantly larger FAA and a smaller VMO/VLM ratio compared to the control group (C group). Specifically, the FAA was 30.1±9.6° in the RPD group versus 15.0±1.9° in the C group (P=0.040), while the VMO/VLM ratio was 3.5±1.0 in the RPD group versus 4.2±1.5 in the C group (P=0.014).

Within the RPD group, patients with excessive FAA (≥30°, A group) showed a higher VMO/VLM ratio than those without excessive FAA (<30°, B group), with ratios of 4.0±1.1 and 3.0±0.7, respectively (P=0.029). The VMO/VLM ratio in the B group was lower than that in the C group (3.0±0.7 vs. 4.2±1.5, P=0.004). There was no significant difference in the VMO/VLM ratio between the A group and the C group (Table 3).

The correlation analysis revealed a moderate positive correlation between FAA and the VMO/VLM ratio in the

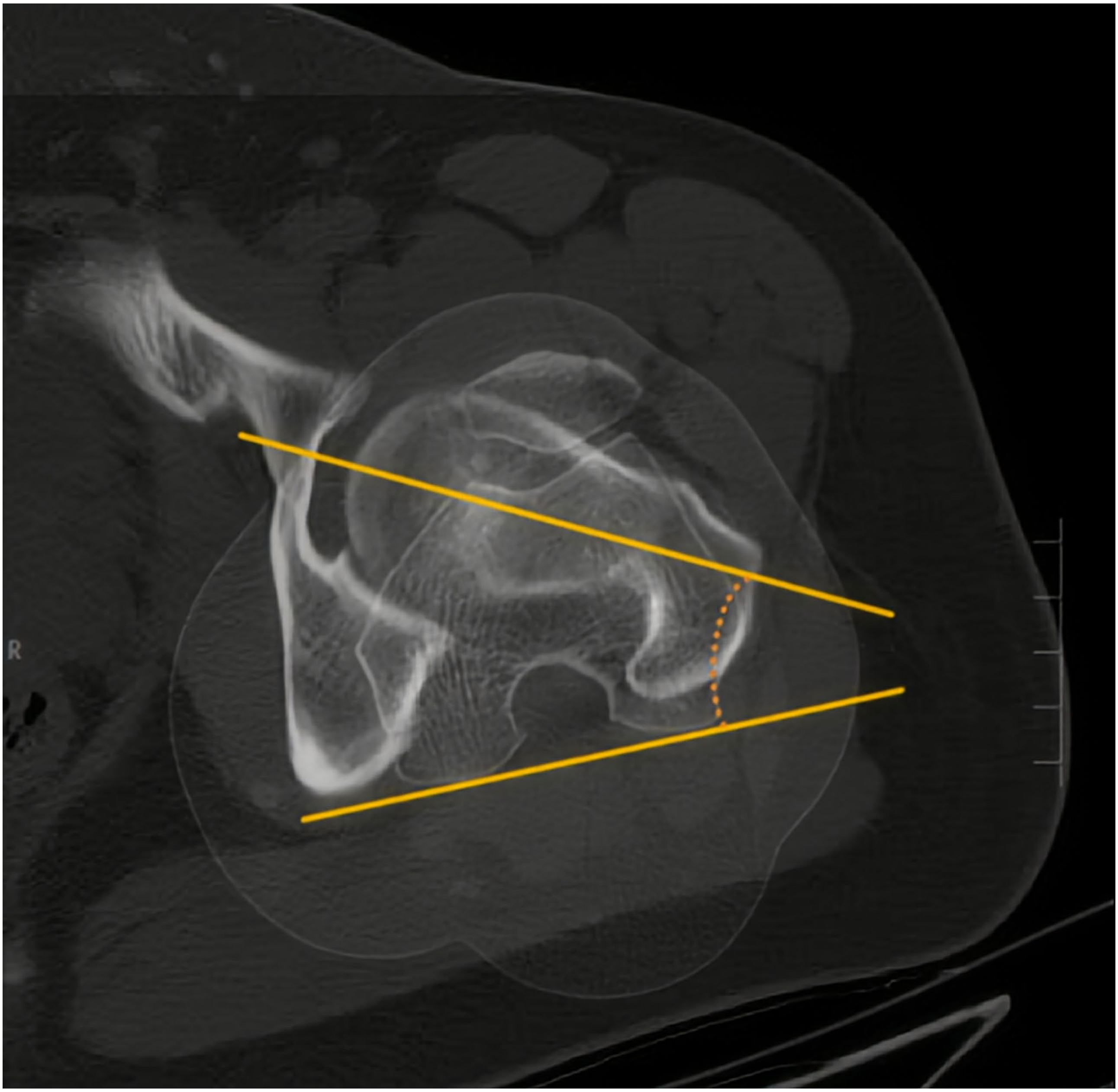

Fig. 2 The schematic diagrams of measurement of FAA. FAA: the angle between the axis of the femoral neck connecting the center of the femoral head and the midpoint of the femoral neck, and the posterior condylar line connecting the most posterior points of the medial and lateral femoral condyles; FAA: femoral anteversion angle

RPD group, with a correlation coefficient of $r = 0.4$ and an exact *P*-value of 0.012 (Table 4). This correlation suggests that as the FAA increases, there is a compensatory thickening of the VMO relative to the VLM, which may serve as a biomechanical adaptation to help stabilize the patella in patients with recurrent PD.

Discussion

The most important finding of this study was that patients with recurrent PD had larger FAA and smaller VMO than normal people. There was a positive correlation between FAA and the VMO/VLM ratio in patients with PD [15, 23]. This finding explained the compensatory thickening of the VMO in response to increased FAA with PD in humans. The present study supported the rationale of the derotational femoral osteotomy (DFO) in correcting the malalignment of lower limbs in the treatment of patients with recurrent PD [27, 28].

It has been proven that the cross-sectional area can be used to assess the force-producing ability of muscle and can be measured [29]. We used the ratio to personalize the cross-sectional areas, which are more likely to

Table 1 Patient information and statistics

Variable	C group	RPD group	A group	B group
Age (year)	18.9 ± 3.5	18.8 ± 3.4	19.7 ± 5.6	17.9 ± 5.1
Gender (F/M)	76/44	38/22	17/13	21/9
BMI	20.6 ± 1.9	21.0 ± 1.7	21.3 ± 1.5	20.7 ± 1.8
Time between first dislocation (month)	-	4.3 ± 2.4	4.4 ± 2.4	4.2 ± 2.6
VMO/VLM ratio	4.2 ± 1.5	3.5 ± 1.0	4.0 ± 1.1	3.0 ± 0.7
FAA (deg)	15.0 ± 1.9	30.1 ± 9.6	36.5 ± 8.6	23.7 ± 3.3

C group: patients without patellofemoral disorders; *RPD group*: patients with recurrent patellar dislocation; *A group*: patients with patellar dislocation and FAA ≥ 30°; *B group*: patients with patellar dislocation and FAA < 30°; *F/M*: female/male; *BMI*: body mass index; *VMO*: the cross-sectional area of the vastus medialis oblique; *VLM*: the cross-sectional area of the vastus lateralis muscle; *FAA*: femoral anteversion angle

Table 2 The inter- and intraobserver reliability of different measurement

	Interobserver reliability	Intraobserver reliability
FAA	0.99 (0.99–0.99)	0.99 (0.98–0.99)
VMO/VLM ratio	0.99 (0.98–0.99)	0.99 (0.98–0.99)

VMO: the cross-sectional area of the vastus medialis oblique; *VLM*: the cross-sectional area of the vastus lateralis muscle; *FAA*: femoral anteversion angle

Table 3 Comparison of FAA and VMO/VLM ratio among groups

Group	VMO/VLM ratio	FAA (deg)
C group	4.2 ± 1.5	15.0 ± 1.9
RPD group	3.5 ± 1.0	30.1 ± 9.6
P-value	0.014*	0.040*
B group	3.0 ± 0.7	23.7 ± 3.3
A group	4.0 ± 1.1	36.5 ± 8.6
P-value	0.029*	0.034*
C group	4.2 ± 1.5	15.0 ± 1.9
A group	4.0 ± 1.1	36.5 ± 8.6
P-value	0.671	0.043*
C group	4.2 ± 1.5	15.0 ± 1.9
B group	3.0 ± 0.7	23.7 ± 3.3
P-value	0.004*	0.031*

C group: patients without patellofemoral disorders; *RPD group*: patients with recurrent patellar dislocation; *A group*: patients with patellar dislocation and FAA ≥ 30°; *B group*: patients with patellar dislocation and FAA < 30°; *VMO*: the cross-sectional area of the vastus medialis oblique; *VLM*: the cross-sectional area of the vastus lateralis muscle; *FAA*: femoral anteversion angle; *: $P < 0.05$

Table 4 Correlation coefficients betweenVMO/VLM ratio and FAA

	VMO/VLM ratio	FAA
FAA	0.407*	1
VMO/VLM ratio	1	-

VMO: the cross-sectional area of the vastus medialis oblique; *VLM*: the cross-sectional area of the vastus lateralis muscle; *FAA*: femoral anteversion angle; *: $P < 0.05$

show significant differences. Shu et al. [30] demonstrated that abnormalities of the VMO were clearly present in patients with recurrent PD compared with normal people, which is consistent with our research findings. The VMO serves as a crucial dynamic stabilizer, working to counteract the propensity for PD. At the onset of knee flexion, the patella does not initially contact the trochlea, and the risk of PD is mitigated by the combined action of the VMO and the medial patellofemoral ligament. An in vitro study illustrated that weakened VMO muscles correlate with increased patellar displacement within the range of 0–15° of knee flexion [31]. Between 20° and 90° of knee flexion, relaxation of the VMO can decrease the resistance against lateral displacement of the patella by 30% [32]. Consequently, abnormalities in the VMO may contribute to lateral dislocation.

Femoral anteversion is commonly larger in adolescents than the adults and returns to normal levels with growth [33]. In this study, the patients with open osteoepiphysis were excluded. Increased FAA could cause the internal rotation of the distal femur and has been reported to be related to the patellofemoral pain syndrome (PFPS) [12, 13]. Pattyn et al. [16] suggested that VMO atrophy is present in patients with patellofemoral pain and is a contributing factor to PFPS. Moreover, the idea that the functional status of the VMO is closely related to recurrent PD was verified in a diffusion tensor imaging study [34]. In this study, CT scans of the lower limbs were applied to analyze the anomalies of both the osseous and musculoskeletal factors. We found that the VMO/VLM ratio of PD patients in A group (FAA ≥ 30) increased, but there was no significant difference compared with C group (normal population).

It is generally believed that the normal femoral anteversion has a large range between 10° and 22°, with a mean of 10° to 15° for most adults, and more than 30° indicates a more severe increase in femoral rotation [35, 36]. The increase of FAA could lead to the in-toeing gait of humans, which changes the line of force of human lower limbs, leading to compensatory external torsion of the tibia and lateral patellar tilt, which can easily cause the patellar instability and damage of VMO and VLM [29, 33, 37]. In addition, the internal rotation of the distal femur leads to the lateralization of patellar tracking relative to the femoral trochlea, which may increase the burden on the VMO in patients with PD and might lead to compensatory thickening. Increased FAA is known to alter the biomechanics of the lower extremity, leading to changes in knee joint dynamics [38]. Femoral anteversion can cause internal rotation of the femur, which may increase lateral tracking forces on the patella and result in joint instability [39]. To counteract these forces, the VMO, which plays a critical role in stabilizing the patella medially, may undergo hypertrophy to provide additional support [40]. The VMO exerts a medial pull on the patella, opposing the lateralizing force generated by the quadriceps muscle and the lateral patellar retinaculum [41]. The compensatory thickening of the VMO in response to increased FAA could be an adaptive mechanism to maintain patellar alignment and reduce the risk of dislocation. This adaptation is crucial, especially in individuals with PD, as it may help mitigate symptoms of instability, such as pain and subluxation.

The possibility of using distal femoral osteotomy (DFO) in treating excessive FAA has been suggested to correct femoral rotation and improve knee joint alignment [10, 26]. Surgical indications for increased FAA were patients with poor patellofemoral joint force line symptoms and FAA greater than 25° to 30°, and DFO was usually performed. The malalignment on the transverse plane could be corrected by DFO. This study may support DFO as an additional treatment option combined with reconstruction of soft tissue for patients with recurrent PD and excessive femoral anteversion [28, 42]. By addressing the underlying anatomical issues, DFO can help reduce the compensatory demands on the VMO, potentially leading to more sustainable patellar stability. Clinicians should consider FAA when evaluating and treating PD patients. Patient selection for DFO should involve assessing the extent of FAA and the compensatory thickening of the VMO. By tailoring interventions to the patient's specific anatomical and biomechanical profile, clinicians can optimize outcomes. Our study adds to this body of literature by providing empirical evidence of the correlation between FAA and VMO/VLM ratio, further supporting the idea that anatomical and biomechanical adaptations occur.

Our study had several limitations. The small sample size limited our ability to explore the relationship between results and additional factors. As a single-center, cross-sectional study, it did not account for the influence of age and gender. Long-term and large-scale follow-up studies are needed to better understand the relationship between FAA and VMO. We also did not specifically account for variables such as physical activity levels, previous treatments, or interventions targeting VMO or knee stability, which could influence muscle size and function. As a retrospective study, there were inherent limitations in collecting detailed data on these variables. Future studies should include these factors to enhance the validity and strength of the conclusions. Acknowledging these potential confounders is crucial, as they may affect the generalizability of the findings.

Conclusion

This study found that patients with recurrent PD had a smaller VMO/VLM ratio compared to the normal control group. An increased FAA was positively correlated with compensatory thickening of the VMO and a higher VMO/VLM ratio in PD patients. These findings support the hypothesis that increased FAA may lead to biomechanical adaptations in the quadriceps muscle group, providing a compensatory mechanism to stabilize the patella in PD patients. Clinicians should consider changes in FAA when assessing and treating PD. Future research should explore specific therapeutic interventions aimed at strengthening the VMO to improve clinical outcomes in this patient population.

Abbreviations

PD	Patellar Dislocation
FAA	Femoral Anteversion Angle
VMO	Vastus Medialis Oblique
VLM	Vastus Lateralis Muscle
DFO	Derotational Femoral Osteotomy
ICC	Intraclass Correlation Coefficients
PFPS	Patellofemoral Pain Syndrome

Acknowledgements

Thanks for the technical support from the Department of Imaging of the Third Hospital of Hebei Medical University.

Author contributions

FW contributed to the conception of the study; CD and ZH measured and collected the data and wrote the manuscript; ZH, YN and HK made deep reflection on the analysis of the discussion; The authors read and approved the final manuscript.

Funding

No funding was received.

Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The present study was approved by the Academic Ethics Committee of the Third Hospital of Hebei Medical University (No. Ke2023-002-1), and all patients provided their informed consent for participation and publication.

Consent for publication

Written informed consent was obtained from all patients to authorize the publication of their data.

Competing interests

The authors declare no competing interests.

Received: 19 June 2024 / Accepted: 19 August 2024
Published online: 10 September 2024

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