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RESEARCH ARTICLE

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Derotational distal femoral osteotomy yields better outcomes in patellar subluxation with proximal femoral torsion compared with distal femoral torsion: A retrospective comparative study

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Abstract

Background Controversy exists regarding the origin of femoral torsion, and specific treatment rules regarding the optimal position of femoral osteotomy in patients with recurrent patellar subluxation and excessive femoral torsion are scarce.

Purpose To establish a novel classification system for such patients, and to compare clinical and radiological outcomes after distal derotational femoral osteotomy (DDFO) between femoral torsion at proximal (neck and shaft) and distal levels.

Methods Between January 2014 and June 2019, patients who underwent DDFO were retrospectively reviewed. The segmental torsion analysis was performed to establish a novel classification system, and classify included patients into two groups: 35 patients in proximal torsion group and 38 patients in distal torsion group. These patients were followed-up for at least 3 years. Clinical evaluations included functional outcomes, physical examinations, quality of life, activity level, satisfaction, and complications. Radiological outcomes included patellofemoral osteoarthritis, congruence, and alignment.

Results Type I was defined as the proximal torsion. Type II was defined as the distal torsion. Proximal torsion group had lower postoperative femoral torsion (12.6 ± 2.6° vs. 14.8 ± 3.6°; P = .004) and higher surgical correction angle (21.6 ± 5.0° vs. 19.1 ± 3.0°; P = .009). All clinical and radiological outcomes improved significantly in both groups, but proximal torsion group had significantly higher quality of life (EQ-5D-5L: 0.96 ± 0.06 vs. 0.91 ± 0.07; P = .003. EQ-VAS: 92.0 ± 6.0 vs. 88.7 ± 5.8; P = .021) and Tegner activity score (5.2 ± 1.5 vs. 4.5 ± 1.4; P = .040), and fewer patellofemoral osteoarthritis (8.6% vs. 26.3%; P = .048). Two patients in the distal torsion group had subjective patellar instability. The percentage of patients with anterior knee pain was higher in the distal torsion group.

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Conclusion A novel classification system for patients with recurrent patellar subluxation and excessive femoral torsion based on segmental femoral torsion analysis was established. DDFO was more appropriate for patients with proximal torsion, yielding higher surgical correction angle, and better clinical and radiological outcomes.

Study design Cohort study; Level of evidence, 3.

Keywords Patellar dislocation, Derotational distal femoral osteotomy, Femoral torsion, Quality of life, Patellofemoral osteoarthritis

Introduction

Recurrent patellar subluxation is a debilitating and complex knee condition in active children and adolescents, which is multifactorial and associated with various pathoanatomical factors [10, 12, 16] Of all the anatomic variants, excessive femoral torsion that has been underestimated may play an important role, and lead to anterior knee pain, patellar maltracking, abnormal Q angle, and early cartilage degeneration [22, 27]. In addition, excessive femoral torsion creates a persistent force vector applied on the patella towards the lateral side, increases loading forces on the reconstructed medial patellofemoral ligament (MPFL), and even results graft failure and patellar redislocation [13].

Derotational femoral osteotomy (DFO) has been proposed as an alternative surgical treatment for recurrent patellar subluxation with excessive femoral torsion based on the concept that the main anatomical abnormalities should be corrected, but there is still a general lack of knowledge on the origin of femoral torsion, and specific treatment rules regarding the optimal position of osteotomy are scarce [22]. The segmental analysis in patients with patellar instability showed that femoral torsion was the main embodiment of the malrotation at the different levels of the femur, and femoral neck, shaft, and distal femur were all possible origins of total femoral torsion [22, 25, 27]. In theory, DFO should be performed at the original location of the deformity to prevent adverse impacts caused by leverage after incorrect correction of femoral torsion [6]. DFO performed at an undesirable location might not achieve satisfactory outcomes. However, to date, supracondylar distal derotational femoral osteotomy (DDFO) was the most commonly used DFO regardless of the exact location of the torsional deformity in patients with recurrent patellar subluxation and excessive femoral torsion, while there is a lack of studies investigating outcomes after supracondylar DDFO between patients with different femoral torsion segments.

Therefore, there are two issues to be solved. The objectives of this study were thus as follows. First, we sought to establish a novel classification system for patients with recurrent patellar subluxation and excessive femoral torsion based on segmental femoral torsion analysis. Second, we compared clinical and radiological outcomes after supracondylar DDFO between patients with femoral torsion at proximal (neck and shaft) or at distal femur after a minimum of 3 years follow-up. It was hypothesized that patients with femoral torsion at proximal femur achieved better long-term outcomes. The new findings of the present study could provide meaningful guidance to assist surgeons in decision making whether an additional DDFO should be performed in patients with recurrent patellar subluxation and excessive femoral torsion.

Methods

Patient selection

Institutional review board approval was obtained from the ethics committee of our hospital, and informed consent was acquired from all included patients before the commencement of this retrospective study. The medical records of the patients with unilateral recurrent patellar subluxation who underwent DDFO between January 2014 and June 2019 at our hospital were identified and reviewed. The inclusion criteria were: (1) at least one episode of patellar subluxation; (2) at least one symptom of patellar instability (pain, subluxation, or both) for more than 3 months; (3) femoral torsion > 30°; (4) skeletal maturity.

The exclusion criteria were: (1) Tibial tuberosity-trochlear groove (TT-TG) distance > 20 mm; (2) high grade trochlear dysplasia (grades B, C or D) according to Dejour's classification [4]; (3) patella alta with Caton-Deschamps index > 1.2; (4) malalignment of the lower limb (> 5° varus or valgus); (5) generalized or localized joint laxity; (6) fracture around the knee; (7) habitual or traumatic dislocation; (8) previous knee surgery; (9) concomitant ligament reconstruction (collateral ligaments or cruciate ligaments); (10) revision surgery. Patients with criteria (1) to (3) had to receive other bony procedures, and thus were excluded. Patients with patellofemoral osteoarthritis, osteonecrosis, rheumatoid arthritis, and other disorders that seriously impaired neuromuscular function were also excluded. Based on above-mentioned criteria, 76 patients were included from a total of 145 reviewed patients. All patients were followed up for at least 3 years.

To identify the characteristics of femoral torsion and establish the new classification system for patients with recurrent patellar subluxation and excessive femoral torsion, 40 patients with isolated meniscus or soft tissue injury were recruited as the control group. Demographic and clinical data were collected from the medical records, including gender, age, height, and weight.

Parameters of femoral torsion

The measurement of segmental torsion of the femur (neck, shaft, and distal femur) was described and verified by Ferlic et al [5] and Chen et al [3] using four lines in four different segments on computed tomography (CT) images (Fig. 1). The first line (proximal femur axis, PFA) was drawn through the center of the femoral head and neck on the slices showing the entire femoral head and neck. The second line (lesser trochanter line, LTL) was drawn through the center of the femoral shaft and the midpoint of the lesser trochanter at its greatest prominence. The third line (distal femur shaft line, DFSL) was defined by a tangent to the posterior aspect of the distal femur on the slice just proximal to the attachment of the gastrocnemius heads. The fourth line (posterior condylar line, PCL) was drawn tangent to the medial and lateral posterior condyles on the slice showing the intact "Roman Arch". The parameters of femoral torsion were evaluated by the angles formed between these lines. Neck torsion was formed between PFA and LTL. Shaft torsion was formed between LTL and DFSL. Distal torsion was formed between DFSL and PCL. The total femoral torsion was measured between PFA and PCL.

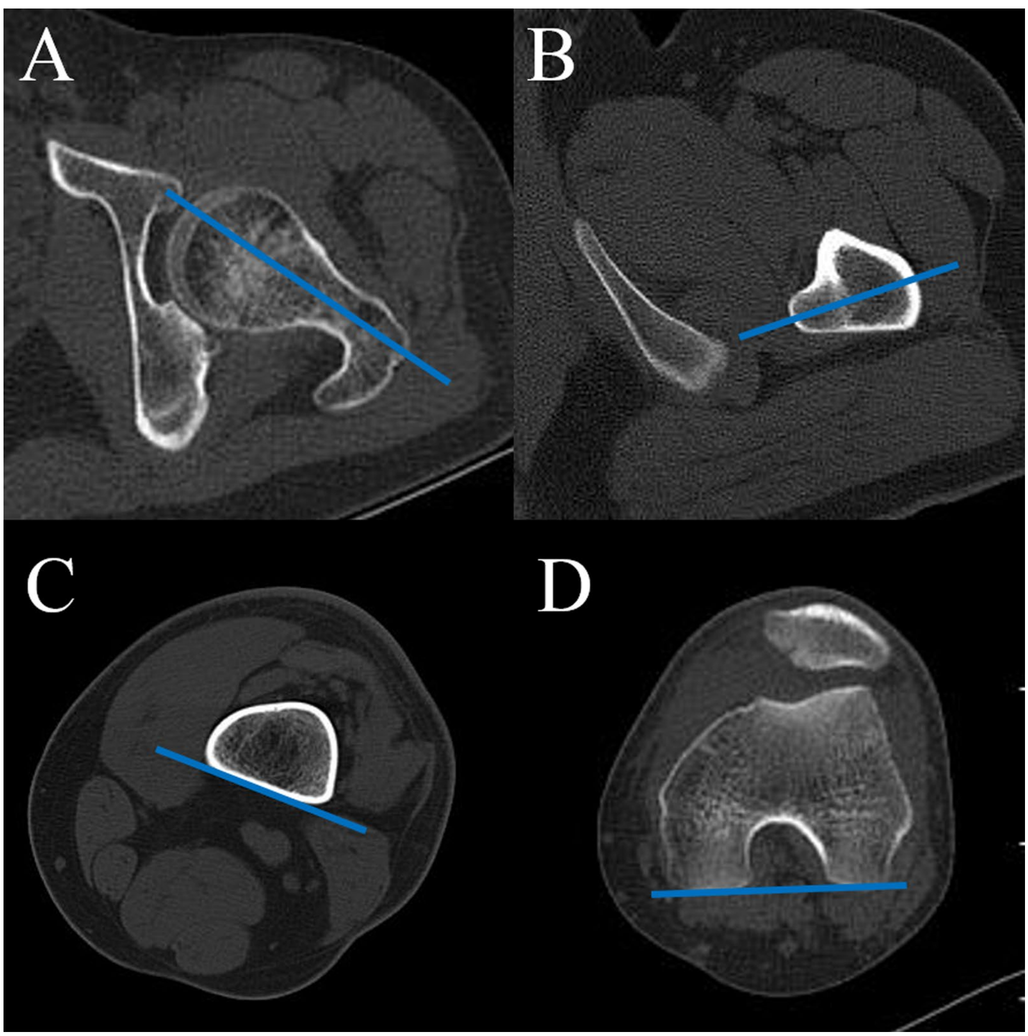

Fig. 1 The measurement of the segmental torsion of the femur. **A** Proximal femur axis. **B** Lesser trochanter line. **C** Distal femur shaft line. **D** Posterior condylar line

Classification criteria

This study developed a novel classification system for patients with recurrent patellar subluxation and excessive femoral torsion according to the femoral torsion segment which contributed most to the total femoral torsion. The new classification system included two types. Type I was defined as the proximal torsion in which neck and shaft segments contributed most to total femoral torsion. Type II was defined as the distal torsion in which distal femur segment contributed most to total femoral torsion.

Patients included with recurrent patellar subluxation and excessive femoral torsion were further classified into two groups according to this classification. The proximal torsion group comprised 36 patients with type I femoral torsion, and the distal torsion group comprised 40 patients with type II femoral torsion. Three patients were lost to follow-up, leading to 35 patients in the proximal torsion group and 38 patients in the distal torsion group (Fig. 2). Patient demographics and clinical data were shown in Table 1. There was no significant difference among the three groups regarding these parameters.

Surgical technique

All patients included in the torsion groups received DDFO combined with medial patellofemoral ligament reconstruction (MPFLR) performed by the same experienced senior surgeon. The DDFO was performed on the lateral thigh along the longitude axis of the distal femur. The distal femoral shaft was exposed through the intermuscular space. The supracondylar osteotomy line was set parallel to the tibiofemoral joint line. Then the Kirschner wires were inserted into osteotomy line to determine the rotational angle, which was based on the preoperative measurement, and was verified by intraoperative fluoroscopy. The distal femur was externally rotated to the predetermined angle, and fixed using a lateral Tomofix distal femoral plate with locking screws (DePuy Synthes, Umkirch, Germany) after checking the reduction of the femur through fluoroscopy.

The double-bundle anatomic MPFLR was performed using ipsilateral gracilis tendon prepared in a Y shape. The femoral and patellar tunnels were located according to the native MPFL anatomy [24]. The position of the femoral tunnel was based on the osseous landmarks

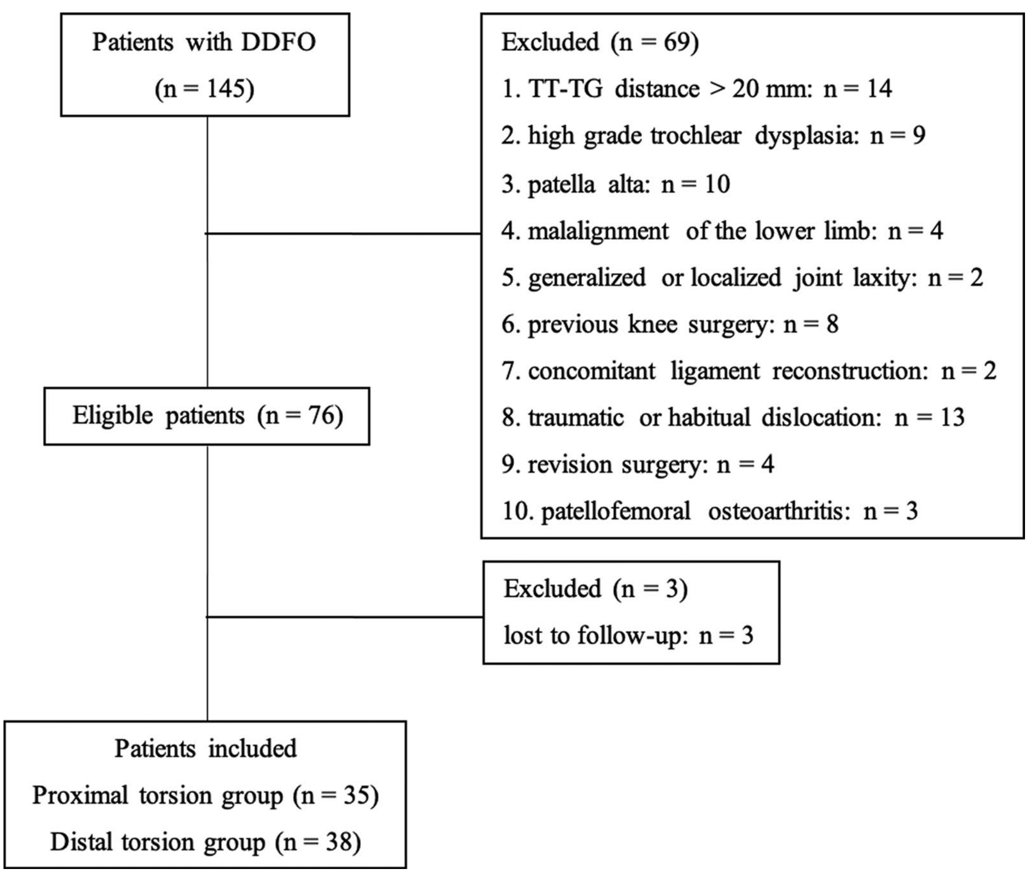

Fig. 2 Flowchart of the patient selection in proximal torsion group and distal torsion group. DDFO, derotational distal femoral osteotomy; TT-TG, tibial tuberosity-trochlear groove

Table 1 Patient demographics and clinical data in proximal torsion group, distal torsion group, and control groupα

Variable	Proximal torsion group	Distal torsion group	Control group	*P* value
Number of patients	35	38	40	–
Gender (male/female)	9/26	10/28	15/25	.445
Age (year)	25.1 ± 6.2	24.3 ± 8.3	25.8 ± 4.2	.593
Body mass index	26.0 ± 3.6	25.1 ± 4.3	25.3 ± 3.8	.570
Side (left/right)	20/15	22/16	17/23	.310
Follow-up (month)	42.9 ± 6.4	43.6 ± 9.1		.690
TT-TG distance (mm)	16.6 ± 1.8	17.0 ± 2.1		.438
Tibial torsion angle (deg)	30.2 ± 5.2	30.0 ± 5.1		.885
Caton-deschamps index	1.1 ± 0.1	1.1 ± 0.1		.109
Valgus angle (deg)	1.4 ± 0.8	1.5 ± 0.8		.663

TT-TG, tibial tuberosity-trochlear groove

αData are expressed as n or mean ± standard deviation

between the adductor tubercle and the medial femoral epicondyle, which was verified using fluoroscopy [11]. Two patellar tunnels were drilled in the upper corner and the center of the medial edge of the patella. The gracilis tendon was passed through the tunnels, and fixed in the femoral tunnel at 90° of knee flexion. Further release of the lateral retinaculum was performed if there was tightness. The preoperative and postoperative radiographs and CT images in the proximal torsion group and distal torsion group were shown in Figs. 3 and 4.

Postoperative rehabilitation

All patients received a standard phase-based rehabilitation protocol, including weightbearing exercise, range of motion (ROM) training, and quadriceps muscle strength exercise. Patients were required to wear knee braces in full extension during the first 6 weeks after surgery. Full weightbearing exercise was permitted at 6 weeks after surgery. The ROM was gradually increased to 90° in the first 2 weeks, and to 120° in the following 4 weeks. The quadriceps muscle strength exercise was encouraged early after surgery. Daily activities were allowed after 2 months, and sports such as jogging and running were allowed after 3 months if the muscle strength had been fully recovered.

Fig. 3 The preoperative and postoperative radiographs in the **A** proximal torsion group and **B** distal torsion group

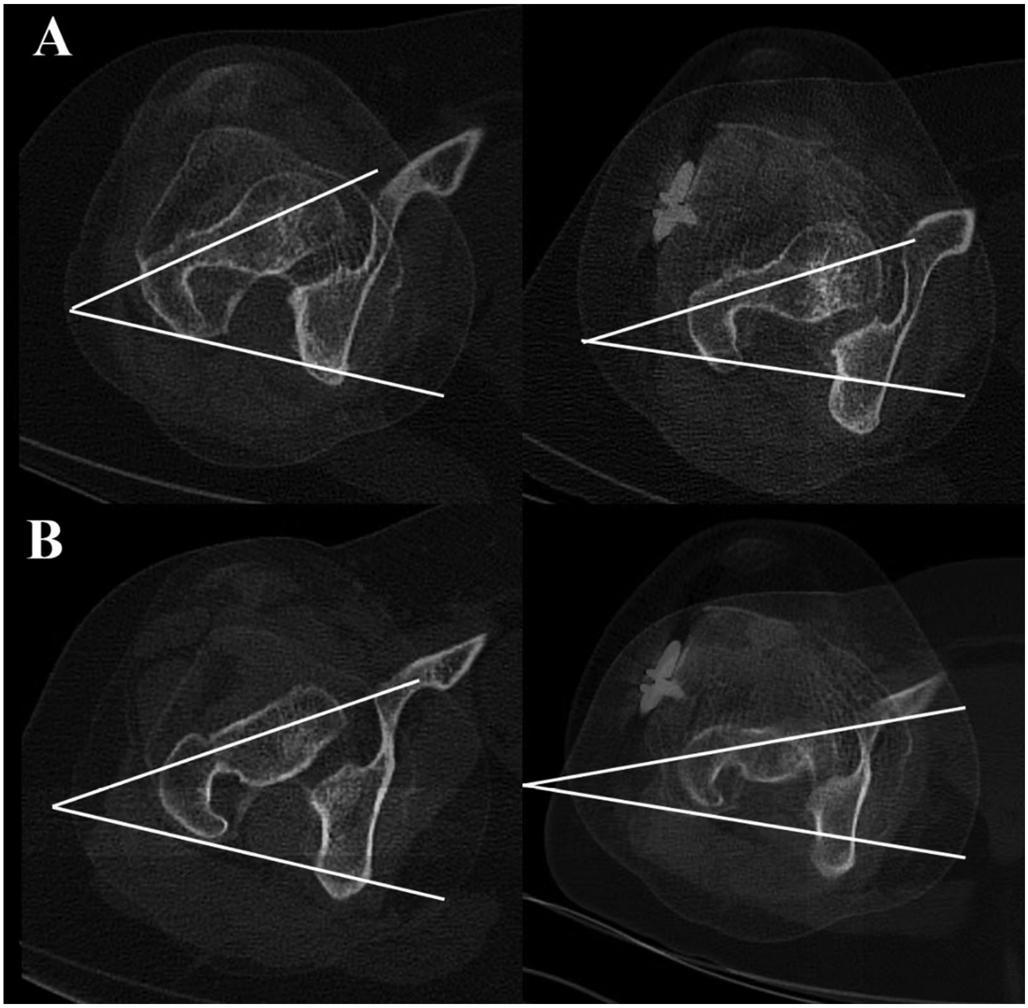

Fig. 4 The preoperative and postoperative computed tomography images in the **A** proximal torsion group and **B** distal torsion group

Clinical evaluation

Clinical evaluation was performed before and 3 years after surgery, including functional outcome, physical examination, quality of life, activity level, satisfaction, and complication. Physical examination consisted of patellar apprehension test and ROM. Functional outcomes included Kujala score, Lysholm score, and International Knee Documentation Committee (IKDC) subjective knee evaluation score [8, 15, 19]. Quality of life was evaluated using the five-level EuroQol five-dimensional questionnaire (EQ-5D-5L), and the vertical visual analogue scale (EQ-VAS) [9, 20]. The activity level was evaluated using the Tegner activity score and rate of return to sports [26]. Patients were asked whether they returned to the same, lower, or higher level of activities compared with preoperative level, and the reasons not returning to sports. Satisfaction was evaluated and further divided into four levels: very satisfied, satisfied, partially satisfied, and not satisfied at all. The recurrence of subluxation/dislocation, and other complications, such as nonunion of the osteotomy area, anterior knee pain, stiffness, and patellar fracture, were recorded during the follow-up.

Radiological evaluation

Radiological evaluation was performed within 1 week before surgery and at 3 years after surgery, including patellofemoral osteoarthritis, alignment, and congruence. Patellofemoral osteoarthritis was assessed routinely using patellar skyline views taken at knee flexion of 45°, which was graded according to the Iwano classification with grades I-IV [11]. Patellofemoral alignment was evaluated using the TT-TG distance measured between two lines perpendicular to the PCL on two overlapped axial CT slices. One line was drawn from the deepest point of the trochlear sulcus, and another line was drawn from the center of the tibial tuberosity on the slice showing approximately proximal one-third of the tibial tuberosity. [21]

Patellofemoral congruence was evaluated using patella tilt angle (PTA), patellar congruence angle (PCA), and patella-trochlear groove distance (PTGD) on axial CT images (Fig. 5). The PTA was measured between the maximum width axis of the patella and the PCL [14]. The PCA was measured between the line passing through the lowest point of the patella and the deepest point of the sulcus, and the line bisecting sulcus angle that formed by the tangent lines of medial and lateral articular aspects of the trochlea [28]. The PTGD was defined as the distance between the perpendicular line of the PCL passing through the deepest point of the sulcus, and the medial margin of the patella [30]. The tibial torsion angle was formed between the line passing through the midpoints of the medial and lateral malleoli, and the line tangent to the posterior margin of the tibial plateau. [22]

Measurements of parameters

All measurements were performed by 2 independent researchers who were blinded to the patient grouping and research hypothesis in a randomized fashion to determine inter-observer reliability. The average values were used in the final analysis. To evaluate intra-observer reliability, one researcher reexamined all the measurements after 6 weeks. The intraclass correlation coefficient (ICC) values were calculated, and the ICC value > 0.8 indicated excellent reliability. All the measured parameters showed excellent inter-observer reliability with ICC values ranging from 0.854 to 0.912, and intra-observer reliability with ICC values ranging from 0.885 to 0.947.

Statistical analysis

The data were described as means and standard deviations for continuous variables, and number and percentage for categorical variables. After normal distribution of all parameters were confirmed using the Kolmogorov–Smirnov test, the differences were analyzed using the two-tailed Student's *t*-test between 2 groups or within a group, and one-way analysis of variance (one-way ANOVA) among 3 groups. The chi-square test was performed for the categorical variables. Statistical significance was set at $P < 0.05$. All statistical analyses were performed with SSPS version 21.0 (SPSS Inc., Chicago, IL, USA) software. G*Power 3 (Heinrich Heine, Universität Düsseldorf, Düsseldorf, Germany) was applied to determine the suitable sample size. An a-priori power analysis with the $\alpha < 0.05$ and the effect size of 0.8 showed that a minimum number of 34 patients in each group were adequate to detect significant differences with a power of 90%.

Results

Classification characteristics of femoral torsion

The total and segmental femoral torsion angles were shown in Table 2. In the proximal torsion group with type I femoral torsion, neck and shaft contributed most to total femoral torsion, while in the distal torsion group with type II femoral torsion, distal femur contributed most to total femoral torsion. These results showed significantly differences in segmental femoral torsion characteristics between the two types. The total femoral torsion, proximal torsion, and distal torsion were significantly higher in torsion groups than the control group.

As for DDFO, there was significant reduction in total femoral torsion in both torsion groups. However, there was a significant lower postoperative femoral torsion ($P = 0.004$) and a higher surgical correction angle ($21.6 \pm 5.0°$ vs $19.1 \pm 3.0°$; $P = 0.009$) in the proximal torsion group compared with the distal torsion group, indicating that DDFO had more ability to correct excessive femoral torsion in patients with proximal femoral torsion.

Clinical outcomes

All functional outcomes (Kujala, Lysholm, and IKDC scores) improved significantly from pre- to postoperative ($P < 0.001$) in the proximal torsion group and distal

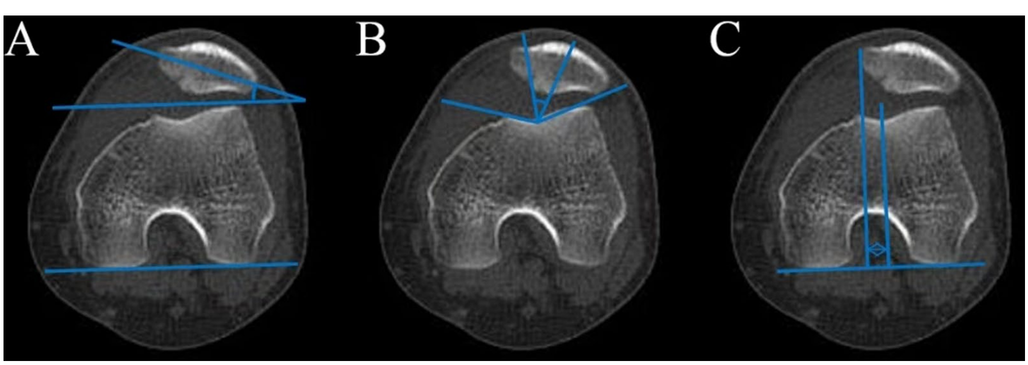

Fig. 5 The measurement of patellofemoral congruence. **A** Patella tilt angle. **B** Patellar congruence angle. **C** Patella-trochlear groove distance

Table 2 The total and segmental femoral torsion angles in proximal torsion group, distal torsion group, and control groupα

Variable	Proximal torsion group	Distal torsion group	Control group	*P* value
Total femoral torsion (deg)				
Preoperative[a]	34.2 ± 4.1	33.9 ± 2.8	11.4 ± 3.9	< .001
Postoperative	12.6 ± 2.6	14.8 ± 3.6	–	.004
P value	< .001	< .001	–	
Proximal torsion (deg)	19.0 ± 2.2	15.4 ± 2.3	2.9 ± 1.6	< .001
Distal torsion (deg)	15.2 ± 3.0	18.5 ± 3.6	8.5 ± 2.2	< .001
Correction torsion (deg)	21.6 ± 5.0	19.1 ± 3.0	–	.009

α Data are expressed as mean ± standard deviation. [a]For the comparison between the proximal torsion group and distal torsion group, $P = .699$. Values in bold indicate statistical significance ($P < .05$)

Table 3 Comparison of functional scores, quality of life, and activity level between proximal torsion group and distal torsion groupα

Variable	Proximal torsion group	Distal torsion group	*P* value
Kujala score			
Preoperative	54.0 ± 9.1	53.5 ± 8.1	.790
Postoperative	86.1 ± 6.8	85.1 ± 7.4	.541
P value	< .001	< .001	
Lysholm score			
Preoperative	57.8 ± 8.5	58.5 ± 9.7	.774
Postoperative	87.5 ± 6.3	86.4 ± 7.8	.498
P value	< .001	< .001	
IKDC score			
Preoperative	54.9 ± 9.2	53.5 ± 8.9	.501
Postoperative	86.8 ± 6.0	85.9 ± 9.1	.636
P value	< .001	< .001	
EQ-5D-5L			
Preoperative	0.65 ± 0.10	0.64 ± 0.08	.570
Postoperative	0.96 ± 0.06	0.91 ± 0.07	.003
P value	< .001	< .001	
EQ-VAS			
Preoperative	69.1 ± 6.4	68.2 ± 6.0	.533
Postoperative	92.0 ± 6.0	88.7 ± 5.8	.021
P value	< .001	< .001	
Tegner activity score			
Preoperative	3.8 ± 0.8	3.7 ± 0.9	.707
Postoperative	5.2 ± 1.5	4.5 ± 1.4	.040
P value	< .001	< .001	

α Data are expressed as mean ± standard deviation. Values in bold indicate statistical significance ($P < .05$). IKDC, International Knee Documentation Committee; EQ-5D-5L, EuroQol five-dimensional questionnaire; EQ-VAS, EuroQol visual analogue scale

Table 4 Return to sports and satisfaction in proximal torsion group and distal torsion groupα

Variable	Proximal torsion group (%)	Distal torsion group (%)	*P* value
Return to sports			
Same, or a better level	29 (82.8)	27 (71.1)	.233
Lower level	3 (8.6)	6 (15.8)	.349
Not return to sports	3 (8.6)	5 (13.1)	.531
Satisfaction			
Very satisfied	28 (80)	28 (73.7)	.524
Satisfied	4 (11.4)	6 (15.8)	.588
Partially satisfied	3 (8.6)	4 (10.5)	.777
Not satisfied	0 (0)	0 (0)	–

α Data are expressed as n (percentage)

torsion group at the final follow-up. The comparisons between the two groups demonstrated that proximal torsion group had slightly higher postoperative scores, but without significant difference (Table 3). There were 29 (82.9%) knees in proximal torsion group and 32 (84.2%) knees in distal torsion group with positive apprehension sign preoperatively, with no significant difference ($P = 0.876$). The apprehension sign was negative in both groups postoperatively.

Quality of life measured with EQ-5D-5L and EQ-VAS improved significantly from pre- to postoperative ($P < 0.001$) in both groups at the final follow-up, but proximal torsion group had significantly higher EQ-5D-5L and EQ-VAS than distal torsion group ($P = 0.003$ for EQ-5D-5L, and 0.021 for EQ-VAS), indicating a better quality of life in the proximal torsion group after DDFO (Table 3). The activity level measured with the Tegner activity score improved significantly from pre- to postoperative ($P < 0.001$) in both groups, but the score was significantly higher in the proximal torsion group ($P = 0.040$) (Table 3). All patients in both groups participated in sports preoperatively, and the percentage of patients returning to sports at final follow-up was higher in the proximal group, but without significance (91.4% vs 86.9%, $P = 0.531$) (Table 4). For patients not returning to sports, 3 patients (2 in the distal torsion group and 1 in the proximal torsion group) reported decreased knee function as their reasons, and other patients attributed their limited participation to fear of re-injury or lack of time, rather than conditions associated with surgery or complications. There was no significant difference in the time from surgery to return to sports between the proximal torsion group and distal torsion group (8.9 ± 2.6 months vs 9.3 ± 3.0 months; $P = 0.640$).

As for complications, two patients in the distal torsion group reported subjective patellar instability during sports activity after 8 and 15 months, respectively, and they received conservative treatments because of no surgery indication. Six patients in the distal torsion group and 3 patients in the proximal torsion group reported anterior knee pain. Seven of these patients had pain relief with conservative treatments, while other 2 patients in the distal torsion group had persistent mild pain. Four patients in the distal torsion group and 2 patients in the proximal torsion group had limited ROM after surgery, and required a prolonged rehabilitation. The full ROM was gradually regained in the following two to five months by intensified active and passive ROM exercises. All patients had achieved bone healing of the osteotomy site. None of the patients developed wound infection, patellar fracture, deep vein thrombosis, and other major complications. The percentage of patients being very satisfied or satisfied was higher in the proximal torsion group compared with the distal torsion group, but without significant difference ($P = 0.777$) (Table 4).

Radiological outcomes

No patients developed patellofemoral osteoarthritis in the two groups prior to surgery. At the final follow-up, 3 (8.6%) patients in the proximal torsion group and 10 (26.3%) patients in the distal torsion group showed signs of patellofemoral osteoarthritis (grades II-IV) with significant difference ($P = 0.048$). This showed more progression of patellofemoral osteoarthritis in the distal torsion group with marked narrow patellofemoral joint space, and demonstrated the advantage of DDFO in patients with proximal torsion over distal torsion in terms of preventing patellofemoral osteoarthritis.

The PTA, PCA, PTGD, and TT-TG distance decreased significantly from pre- to postoperative ($P < 0.001$) in both groups (Table 5). The proximal torsion group had slightly better patellofemoral congruence indicated by PTA, PCA, and PTGD, compared with the distal torsion group, but without significance. The Caton-Deschamps index and tibial torsion angle did not change significantly in both groups after surgery.

Table 5 Comparison of radiological outcomes between proximal torsion group and distal torsion groupα

Variable	Proximal torsion group	Distal torsion group	*P* value
PTA (deg)			
Preoperative	33.1 ± 5.6	32.2 ± 4.8	.505
Postoperative	12.1 ± 4.0	13.5 ± 4.2	.153
P value	< .001	< .001	
PCA (deg)			
Preoperative	37.5 ± 6.1	38.4 ± 4.8	.480
Postoperative	14.3 ± 4.8	15.5 ± 5.4	.329
P value	< .001	< .001	
PTGD (mm)			
Preoperative	21.5 ± 7.1	20.4 ± 6.8	.535
Postoperative	8.5 ± 2.1	9.1 ± 3.8	.348
P value	< .001	< .001	
TT-TG distance (mm)			
Preoperative	16.6 ± 1.8	17.0 ± 2.1	.438
Postoperative	14.9 ± 1.5	15.0 ± 1.9	.892
P value	< .001	< .001	

α Data are expressed as mean ± standard deviation. Values in bold indicate statistical significance ($P < .05$). PTA, patella tilt angle; PCA, patellar congruence angle; PTGD, patella-trochlear groove distance; TT-TG, tibial tuberosity-trochlear groove

Discussion

The most important findings of this study were as follows. First, this study proposed a novel classification system including two types for patients with recurrent patellar subluxation and excessive femoral torsion based on the torsion segment that contributed most to total femoral torsion. Second, although DDFO achieved significant improvements in clinical and radiological outcomes regardless of locations of femoral torsion, higher surgical correction angle and better outcomes were demonstrated in patients with proximal femoral torsion compared with distal torsion. This is particularly important when surgeons plan to perform an DDFO, and suggested that individual determination of femoral torsion origins was meaningful in such patients.

To date, disagreement still prevails regarding where abnormal femoral torsion exactly exists, and what level should DFO be performed in patients with recurrent patellar subluxation and excessive femoral torsion. Seitlinger et al [25] first proposed the concept of segmental analysis of femoral torsion, and reported that all 3 levels contributed to total femoral torsion. Qiao et al [22] and Xu et al [27] found that femoral shaft and distal femur were the main contributors to total femoral torsion. Archibald et al [1] reported that neck torsion contributed slightly more than shaft to overall torsion, and neither level could completely predict total torsion.

These results indicated that surgeons cannot identify a definite optimal location for DFO based on total femoral torsion, because excessive femoral torsion could mainly originate from the neck, shaft, distal femur, or from a combination of several levels. In addition, these results were not completely consistent with each other, indicating that individual determination of femoral torsion origins may be important.

Therefore, this study sought to establish a novel classification system for patients with recurrent patellar subluxation and excessive femoral torsion based on segmental femoral torsion analysis. Type I was defined as the proximal torsion in which neck and shaft segments contributed most to total femoral torsion. Type II was defined as the distal torsion in which distal segment contributed most. There were significant differences in segmental torsion between the two types. This new classification is helpful for surgeons to improve surgery plans when correcting excessive femoral torsion.

Supracondylar DDFO was the most commonly used DFO in most literature despite that DFO should be performed at the original location of the deformity [2, 10, 28–30]. Although these studies reported satisfactory results, they did not distinguish the location of deformity, and it is still unclear whether DDFO could achieve the desired amount of rotation and satisfactory outcomes in patients with different locations of femoral torsion. Therefore, in this study, a direct comparison was further performed between patients with femoral torsion at proximal (type I) and distal (type II) levels in terms of clinical and radiological outcomes after DDFO. The patients in both groups achieved significant improvements in clinical outcomes, including knee function, pain relief, quality of life, and activity level, accompanied by a low redislocation rate. The improved functional scores indicated that the healing of the osteotomy line did not cause potential risks for the recovery of knee function. As for radiological outcomes, excessive femoral torsion was significantly reduced in both groups, accompanied by improved patellofemoral congruence and alignment.

There were indeed significant differences between the two groups after DDFO. First, the lower postoperative femoral torsion and higher surgical correction angle in the proximal torsion group showed more ability of DDFO in correcting excessive femoral torsion for patients with proximal torsion. Second, quality of life and activity level were higher in patients with s proximal torsion, which is important for such young and active patients in the long-term. Third, complications were more common in patients with distal torsion. Two patients in the distal torsion group had subjective patellar instability, while none in the proximal torsion group. The percentage of patients with anterior knee pain or ROM restriction was also higher in the distal torsion group.

Fewer patellofemoral osteoarthritis in the proximal torsion group was another important advantage of DDFO in treating patients with proximal torsion, which may be related to the lower postoperative femoral torsion and higher surgical correction. Patients in the proximal torsion group also had a slightly better patellofemoral congruence, indicating a better mechanical environment of patellofemoral joint, which is critical to prevent patellofemoral osteoarthritis in the long-term. Better radiological outcomes were consistent with better clinical outcomes in the proximal torsion group.

In summary, considering the advantages of supracondylar DDFO in terms of higher correction ability, quality of life, and activity level, and fewer complications and patellofemoral osteoarthritis in the proximal torsion group over the distal torsion group, DDFO was more appropriate for patients with recurrent patellar subluxation and proximal torsion rather than other sites of the deformity to achieve better long-term outcomes and prognosis.

A critical factor associated with inferior outcomes after DDFO in the distal femoral torsion is femoral trochlear dysplasia and posterior femoral condyle dysplasia. Previous studies have shown that patients with patellar dislocation were often accompanied by longer medial posterior condyles and shorter lateral posterior condyles [3, 18, 23]. Liebensteiner et al [17] reported that distal femoral torsion was strongly associated with femoral trochlear dysplasia and trochlea height. Hao et al [7] highlighted that distal torsion showed significant correlations with higher-grade trochlear dysplasia, a flatter trochlear sulcus, and shorter anterior condyles. Therefore, in patients with femoral torsion mainly at distal level who underwent DDFO, abnormalities in femoral condyles and trochlea still exist, which may adversely affect postoperative outcomes in such patients. In conclusion, combined bony deformities including dysplastic trochlea and posterior condyles should be considered carefully before decision-making for DDFO.

The present study had several limitations. First, this was a retrospective study with its inherent weaknesses. Second, the number of patients included was relatively small. Third, we failed to establish thresholds for the novel classification system due to the small sample size. Fourth, although femoral torsion > 30° was defined as the indication for DDFO in this study, there is no clear threshold for excessive femoral torsion in clinical practice. Fourth, there was an unequal gender proportion. Although the prevalence of recurrent patellar subluxation was higher in female than male population, gender difference might affect the results.

Regarding the clinical relevance, the establishment of the novel classification system can help surgeons identify the origin of femoral torsion in patients with recurrent patellar subluxation and excessive femoral torsion, which is meaningful for planning location of the DFO. In addition, this study further confirmed that supracondylar DDFO yielded better long-term clinical and radiological outcomes for patients with proximal torsion. The findings can assist surgeons in surgical decision making whether an additional DDFO should be performed when encountering patients with recurrent patellar subluxation and excessive femoral torsion. Considering that the location of femoral torsion may have important consequences for such patents, individualized surgical plans should be considered.

Conclusion

A novel classification system with two types for patients with recurrent patellar subluxation and excessive femoral torsion based on segmental femoral torsion analysis was established. In addition, DDFO was more appropriate for patients with proximal torsion, yielding higher surgical correction angle, and better clinical and radiological outcomes. The new findings are meaningful for surgeons when planning to perform an DDFO in patients with excessive femoral torsion.

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Author contributions
Leilei Zhai, Hongwei Bao and Ran Sun contributed to the conceptualization and project administration of the study; Yanfeng Jia contributed significantly to analysis and draft manuscript; Jingzhao Hou helps emendation manuscript and edit figures; Zhao Wang performed the parameter measurements and reviewed the literature; Junjie Jiang performed the data analyses and manuscript preparation; Xiaofeng Wang advised on the scientific aspect of the study and parameter measurements; The first draft of the manuscript was written by Yanfeng Jia and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and material
The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Third Hospital of Hebei Medical University.

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

Consent for publication
Patients signed informed consent regarding publishing their data and photographs.

Competing of interest
The authors declare no conflict of interest. No benefits in any form have been, or will be, received from a commercial party related directly or indirectly to the subject of this manuscript.

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