Changes in Patellar Morphology Following Soft Tissue Surgical Correction of Recurrent Patellar Dislocation in Children With Low-grade Trochlear Dysplasia

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Research Article

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Abstract

Purpose: Studies indicated that patellofemoral joint dysplasia could be caused by patellar dislocation. The purpose of the study was to investigate the changes in patellar morphology following soft tissue surgical correction of recurrent patellar dislocation in children with low-grade trochlear dysplasia.

Methods: The prospective study was performed between November 2007 and December 2012. Finally, 25 cases, with the mean age of 8.4 years (range from 7 to 10 years), were admitted to our study. All patients were diagnosed as bilateral recurrent patellar dislocation associated with femoral trochlear dysplasia. The knee that had suffered an injury or dislocated most frequently was treated with medial patellar retinacular plasty (Group S). The contralateral knee, which served as a control was treated conservatively (Group C). Axial CT scans were undertaken in all patients to assess the patellar morphological characteristics on a particular axial image which was established at the point with the greatest patellar width based on measurements preoperatively and at the final follow-up.

Results: Preoperatively, there were no statistically significant differences between the patellar morphology in the two groups ($P>0.05$). Many radiological parameters of patellar morphology were significantly different between the two groups at the final follow-up, including well-known parameters, such as the mean patellar width (Group S, 40.58 mm (SD 1.26); Group C, 36.41 mm (SD 1.17); $p < 0.001$), the mean patellar thickness (Group S, 11.59 mm (SD 0.74); Group C, 9.38 mm (SD 0.56); $p < 0.001$) and the mean wiberg index (Group S, 0.54 (SD 0.06); Group C, 0.72 (SD 0.08); $p < 0.001$). Little known parameters such as the ratio of length of lateral patella to medial patella (Group S, 1.26 (SD 0.17); Group C, 1.69 (SD 0.21); $p < 0.001$), which is a measurement of facet asymmetry. However, the wiberg angle was not significantly different between the two groups (Group S, 128.63° (SD 9.05); Group C, 125.47° (SD 13.96); $p > 0.05$) at the final follow-up.

Conclusions: The patellar morphology can be significantly improved by early (before epiphyseal closure) soft tissue surgical correction in children with patellar instability associated with low-grade femoral trochlear dysplasia (Dejour A and B).

Introduction

Mechanical stress is the most important factor affecting the formation and development of bone[1,2]. This mechanism is supported by clinical findings. For example, acetabular dysplasia can be a secondary pathological change after hip dislocation[3]. It has also been reported that after reduction of the hip joint in children with acetabular dysplasia and hip dislocation, joint morphology is usually restored through remodelling[4,5]. Similar remodelling of articular cartilage has been documented in the shoulder[6,7].

In the patellofemoral joint, as in the hip and shoulder, stress is transmitted from the articular cartilage to the subchondral bone and then to the cancellous and cortical bone. This transmission of load during function stimulates the growth and remodelling of both the patella and femur[2]. The unique concavoconvex matching of the patella and femoral trochlea is the structural basis of its physiological and biomechanical function[8]. Our previous studies showed that patellar instability early in development can lead to trochlear dysplasia or flattening and that early relocation of the patella can prevent the development of trochlear dysplasia in growing rabbits[9,10]. Additionally, the femoral trochlear morphology can be improved by early (before epiphyseal closure) soft tissue surgical correction in children with recurrent patellar dislocation associated with femoral trochlear dysplasia[11,12].

The sectional shape and articular surface of the patella became more flattened after patella instability in growing rabbits, which indicates that patella dysplasia could be caused by patella instability[13]. Therefore, it is reasonable to propose that patella development can be influenced by the restoration of normal biomechanics in the patellofemoral joint. The aim of this prospective study was to investigate the changes in patella morphology following soft tissue surgical correction for recurrent patellar dislocation in children.

Patients And Methods

The study had ethical approval and all patients gave informed consent.

The inclusion criteria were: (1) bilateral recurrent patellar dislocation (recurrent being defined as more than one traumatic episode involving disruption of the normal position of the patella within the femoral groove[14]); (2) open growth plates (as no changes in bone morphology occur after physeal closure[12]); (3) Dejour A (shallow trochlea > 150°) and B (flat trochlea) trochlear dysplasia as described by Dejour et al[15,16,17,18]; (4) medial patellofemoral ligament (MPFL) injury.

The exclusion criteria were: (1) closed physes; (2) a sulcus angle (SA) of < 150° (an angle of > 150° suggests trochlear dysplasia in children[1,19]); (3) a high-grade trochlear dysplasia (Dejour C and D)[15,16,17,18] (when patellar dislocation is accompanied by severe trochlear dysplasia, simple soft-tissue balancing procedures cannot achieve satisfactory results, and artificial creation of a femoral sulcus is often required[20]); (4) concomitant cruciate ligament or collateral ligament injury; (5) rheumatoid arthritis or osteonecrosis with cartilage damage of greater than grade II[21].

The Consolidated Standards of Reporting Trials (CONSORT) flowchart showing the selection of patients is shown in Fig. 1. A total of 25 patients, with a mean age of 8.4 years (From 7 to 10 years) were enrolled. All had bilateral recurrent patellar dislocation associated with trochlear dysplasia. The knee that had suffered an injury at the time of presentation or that had dislocated most frequently was treated with medial patellar retinacular plasty (Group S). The contralateral knee, which served as a control was treated conservatively (Group C). All patients were treated either surgically or conservatively between November 2007 and December 2012, with a mean follow-up of 60.8 months (From 48 to 75 months). All patients had CT scans preoperatively and at the final follow-up, to assess the stability of the patellofemoral joint on axial slices and the patellar morphology on a particular axial image which was established at the point with the greatest patellar width based on measurements on axial slices[13,22,23]. In addition, we also evaluated the function of the knee joint by using the apprehension test[24] and subjective evaluation[25].

Operative technique

Arthroscopic exploration was performed to assess and address any possible chondral lesions and concomitant pathology before performing medial patellar retinaculum plasty in all patients. A force-directed medial shift of the patella of less than one-fourth the width of the patella indicates overtension of the lateral retinaculum structure, and in such cases, lateral retinacular release was performed[26].

In Group S, arthroscopic lateral retinacular release was performed in six patients. After removing the arthroscope, the concrete surgical procedure is as follows (Figure. 2A) A transverse incision was made at the junction of the vastus medialis obliquus (VMO) and the medial retinaculum. (Figure. 2B) The femoral attachment of medial patellofemoral ligament (MPFL) was dissected. (Figure. 2C) A transverse dissection was made to divide the medial retinaculum into two parts, a distal part, including both medial retinaculum and MPFL, and a proximal part, only including medial retinaculum. (Figure. 2D) The distal part of medial retinaculum was advanced proximally behind the medial femoral condyle and the proximal part of retinaculum, and then advanced distally over the retensioned distal part of medial retinaculum. (Figure. 2E) The isolated medial retinaculum of the patella was advanced proximally and laterally near to the upper pole ofthe patella, and then vastus medialis was advanced distally and laterally to the patella. Before the final tensioning, patellar tracking was observed manually, the patellofemoral congruence in full extension was noted and the tracking was checked throughout flexion arthroscopically (Figure. 3) and the tension of the medial retinaculum and vastus medialis (VM) was adjusted appropriately and the two sections were sutured together on the medial side of the patella. Finally, the overlapped tissues (including the medial retinaculum, VM, and proximal and distal sections of the medial retinaculum) were sutured together with PDS-1 sutures.

Conservative management

Implementation of the conservative treatment programme began at the same time as the surgery on the other knee. Conservative management in Group C included immobilization with a patellar brace (Tru-Pull Advanced System Brace; DJO Global, Vista, California)[27–29] and physical therapy beginning with isometric quadriceps exercises and progressing through closed and open chain rehabilitation[30–32]. The patellar brace is helpful in controlling lateral instability and maintaining a stretch in the tight lateral retinaculum, thus enhancing the rehabilitation programme[27–29], and the physical therapy can improve quadriceps strength and range of motion[30–32]. Osternig and Robertson[33] reported that prophylactic knee bracing can actually alter neuromuscular control around the joint. This suggests that true modification of patellar tracking may occur with brace use. In addition, McConnell[34] reported good success in patients with patellar instability using specific muscle strengthening and taping techniques to modify patellar tracking for a 12-month treatment period. Therefore, our study involved fixed treatment with the patellar brace for at least 12 months, and physical therapy was almost identical in these patients and was performed every day.

Assessment

The diagnosis of patellar dislocation was confirmed by a patellar apprehension test and CT of the patellofemoral joint with the non-weight-bearing knee in full extension. In addition, preoperatively and at the last follow-up, all patients underwent CT examination to assess the stability of the patellofemoral joint on axial slices and the patellar morphologic characteristics on a particular axial image which was established at the point with the greatest patellar width based on measurements on axial slices[13,22,23]. The methods used for the evaluation of patellar morphology are shown in Table 1 and Fig. 4[13,22,23]. All data were measured using Sante DICOM Viewer Free(64-bit) verson 5.2 (Santesoft, Inc. Athens, Greece), which has an accuracy of 0.01° for angles and 0.01 mm for distance[34]. In order to minimize errors of measurement, all measurements were performed under the same conditions by two authors (KF and YZ). After an interval of two weeks, one measured the 25 samples again and the intra and interobserver reliabilities were determined using intra-class and inter-class correlation coefficients (ICCs).

Table 1
Description of measurements

patellar morphological characteristics	
Patellar width (PW)[13,22,23]	The length between the most medial edge (A) and the most lateral edge (B) of the patella as the baseline (AB).
Patellar thickness (PT)[13,22,23]	The posterior patellar edge farthest from the baseline was defined as point D. The thickness of the patella was measured by the length of line CD vertical to the baseline.
Wiberg index (WI)[13,23]	The Wiberg index (length of BC/length of AB) was calculated.
The ratio of length of lateral patella to medial patella (EPIP)[23]	The length of the lateral (BD) and medial (AD) facet were measured and the facet ratio [(BD) / (AD)] was calculated.
Wiberg angle (WA)[13,23]	The angle (∠ADB) between the slopes of the medial and lateral patella.

The mean follow-up was 60.8 months (From 48 to 75 months). The apprehension test was also used[24] and we recorded the statement that best described the results of the treatment as described by Drez et al[25]: 1) The knee has markedly improved, and I have returned to all activities; 2) The knee has improved, but there is still occasional discomfort or problems in sports activities; 3) The knee has improved, but I am still unable to return to sports activities; and 4) The knee is not better or is worse than before surgery. The response yielded a subjective evaluation of excellent, good, fair, or poor, respectively. In addition, overall the patella form was rated according to the classification of Wiberg[35] on a particular axial image which was established at the point with the greatest patellar width[13,22,23]. And the trochlea form was rated according to the classification of Dejour[15,17,18] on a particular axial image which was established at the point with the greatest epicondylar width[12,36].

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 16.0 (SPSS, Chicago, Illinois). The Kolmogorov–Smirnov test was used to test the normality of numerical data. Levene's test was used to assess the homogeneity of the data. All numerical variables showed a normal distribution or equal variance. Differences between the two groups (evaluation indexes of stability of the patellofemoral joint and patella morphology) were analysed with a two-sample Student's *t*-test. The apprehension sign, subjective scores, patellar types and trochlear types were analyzed using Pearson's chi-squared test. Numerical data are shown as mean and standard deviation, and categorical data as numbers with percentages. A p-value of < 0.05 was considered statistically significant.

Results

The intra-class and inter-class correlation coefficients were high for all measurements (Table 2).

Table 2
Intra-observer and inter-observer agreement of geometric measurements with 95% confidence intervals.

Measurement	Intra-observer			Inter-observer		
	ICC	95%CI for ICC		ICC	95%CI for ICC	
		Lower	Upper		Lower	Upper
Pre-Group S-TT-TG	0.954	0.891	0.980	0.819	0.574	0.923
Pre-Group S-CA	0.938	0.855	0.974	0.701	0.291	0.873
Pre-Group S-PTA	0.965	0.916	0.985	0.835	0.612	0.930
Pre-Group S-PLS	0.991	0.978	0.996	0.907	0.781	0.961
Pre-Group S-PW	0.835	0.610	0.930	0.934	0.844	0.972
Pre-Group S-PT	0.915	0.801	0.964	0.991	0.979	0.996
Pre-Group S-WI	0.989	0.974	0.995	0.938	0.854	0.974
Pre-Group S-EPIP	0.829	0.597	0.928	0.978	0.948	0.991
Pre-Group S-WA	0.784	0.490	0.908	0.958	0.902	0.982
Post-Group S-TT-TG	0.902	0.768	0.958	0.908	0.782	0.961
Post-Group S-CA	0.735	0.375	0.888	0.710	0.317	0.877
Post-Group S-PTA	0.943	0.865	0.976	0.868	0.689	0.944
Post-Group S-PLS	0.985	0.964	0.994	0.899	0.761	0.957
Post-Group S-PW	0.975	0.942	0.990	0.909	0.786	0.962
Post-Group S-PT	0.979	0.950	0.991	0.891	0.742	0.954
Post-Group S-WI	0.976	0.944	0.990	0.911	0.790	0.962
Post-Group S-EPIP	0.503	0.171	0.789	0.768	0.452	0.901
Post-Group S-WA	0.695	0.281	0.871	0.840	0.624	0.932
Pre-Group C-TT-TG	0.945	0.871	0.977	0.763	0.440	0.899
Pre-Group C-CA	0.968	0.925	0.987	0.922	0.815	0.967
Pre-Group C-PTA	0.954	0.892	0.981	0.793	0.513	0.912
Pre-Group C-PLS	0.996	0.991	0.998	0.992	0.982	0.997
Pre-Group C-PW	0.991	0.979	0.996	0.981	0.955	0.992
Pre-Group C-PT	1.000	1.000	1.000	1.000	1.000	1.000

Measurement	Intra-observer			Inter-observer		
	ICC	95%CI for ICC		ICC	95%CI for ICC	
Pre-Group C-WI	0.926	0.825	0.969	0.987	0.970	0.995
Pre-Group C-EPIP	0.764	0.443	0.900	1.000	1.000	1.000
Pre-Group C-WA	0.991	0.979	0.996	0.948	0.877	0.978
Post-Group C-TT-TG	0.911	0.791	0.962	0.801	0.530	0.915
Post-Group C-CA	0.965	0.918	0.985	0.832	0.604	0.929
Post-Group C-PTA	0.952	0.886	0.979	0.776	0.473	0.905
Post-Group C-PLS	0.989	0.974	0.995	0.929	0.833	0.970
Post-Group C-PW	0.843	0.629	0.933	0.801	0.532	0.916
Post-Group C-PT	0.977	0.946	0.990	0.902	0.768	0.958
Post-Group C-WI	0.977	0.947	0.990	0.964	0.916	0.985
Post-Group C-EPIP	0.629	0.124	0.842	0.679	0.285	0.871
Post-Group C-WA	0.721	0.342	0.882	0.670	0.222	0.860

Evaluation indexes of patellofemoral joint stability.

Preoperatively, there were also no statistically significant differences between the patellofemoral joint stability in the two groups (tibial tuberosity-trochlear groove distance, $p > 0.05$; congruence angle, $p > 0.05$; patellar tilt angle, $p > 0.05$; patellar lateral shift, $p > 0.05$) (Table 3). At the final follow-up, these parameters were significantly different between the two groups, such as the tibial tuberosity-trochlear groove distance (Group S, 10.35 mm (SD 1.65); Group C, 15.82 mm (SD 1.73); $p < 0.001$), the congruence angle (Group S, 9.89° (SD 1.47); Group C, 21.97° (SD 3.51); $p < 0.001$), the patellar tilt angle (Group S, 8.16° (SD 1.52); Group C, 14.73° (SD 2.68); $p < 0.001$) and the patellar lateral shift (Group S, 9.59 mm (SD 2.71); Group C, 17.85 mm (SD 3.84); $p < 0.001$) (Table 4). Additionally, 15 patients in Group C had recurrent patellar dislocation. However, only two patients in Group S had a patellar lateral shift that exceeded 1.5 cm with a hard end point for the apprehension test, with a significant difference between the two groups. The subjective questionnaire revealed 14 (56%) excellent results in Group S and 0 (0%) in Group C; 0 (0%) patients in Group S and 10 (40%) patients in Group C answered ‘poor’, which was significant difference between the two groups.

Table 3
Preoperative evaluation of knee function

Indexes	Group S	Group C	*P* values
CT			
TT-TG(mm)	15.32 ± 1.56	15.16 ± 1.44	>0.05
CA(°)	21.75 ± 2.79	22.13 ± 2.76	>0.05
PTA(°)	14.69 ± 2.53	14.32 ± 2.61	>0.05
PLS(mm)	18.72 ± 3.05	19.13 ± 2.96	>0.05

TT-TG tibial tuberosity-trochlear groove distance, *CA* congruence angle, *PTA* patellar tilt angle, *PLS* patellar lateral shift.

Table 4
Follow-up results of knee function

Indexes	Group S	Group C	*P* values
CT			
TT-TG(mm)	10.35 ± 1.65	15.82 ± 1.73	<0.001
CA(°)	9.89 ± 1.47	21.97 ± 3.51	<0.001
PTA(°)	8.16 ± 1.52	14.73 ± 2.68	<0.001
PLS(mm)	9.59 ± 2.71	17.85 ± 3.84	<0.001
Apprehension sign[n/N(%)]			
<1.5cm	23/25(92)	4/25(16)	
>1.5cm	2/25(8)	21/25(84)	
Subjective questionnaire[n/N(%)]			
Excellent	14/25(56)	0/25(0)	
Good	9/25(36)	3/25(12)	
Fair	2/25(8)	12/25(48)	
Poor	0/25(0)	10/25(40)	

TT-TG tibial tuberosity-trochlear groove distance, *CA* congruence angle, *PTA* patellar tilt angle, *PLS* patellar lateral shift.

Evaluation indexes of patellar morphology.

Preoperatively, the data regarding the patellar morphological characteristics were not significantly different between the Groups ($p > 0.05$) (Table 5). Many measurements showed significant differences between the two groups at the last follow-up (Table 6). Significant differences were seen in well-known measurements such as the patellar width (PW) (Group S, 40.58 mm (SD 1.26); Group C, 36.41 mm (SD 1.17); $p < 0.001$), patellar thickness (PT) (Group S, 11.59 mm (SD 0.74); Group C, 9.38 mm (SD 0.56); $p < 0.001$), and wiberg index (WI) (Group S, 0.54 (SD 0.06); Group C, 0.72 (SD 0.08); $p < 0.001$). However, lesser-known measurements such as the ratio of length of lateral patella to medial patella (EPIP) (Group S, 1.26 (SD 0.17); Group C, 1.69 (SD 0.21); $p < 0.001$), which is a measurement of facet asymmetry, were also significantly different between the groups. However, the wiberg angle (WA) was not significantly different between the two groups (Group S, 128.63° (SD 9.05); Group C, 125.47° (SD 13.96); $p > 0.05$).

Table 5
Preoperative evaluation of patellar morphologic characteristics

Indexes	Group S	Group C	*P* values
CT			
PW(mm)	31.78 ± 1.49	32.56 ± 1.57	>0.05
PT(mm)	7.51 ± 1.26	7.64 ± 1.32	>0.05
WI	0.62 ± 0.08	0.61 ± 0.07	>0.05
EPIP	1.37 ± 0.25	1.34 ± 0.23	>0.05
WA(°)	134.72 ± 7.09	135.45 ± 5.86	>0.05

PW patellar width, *PT* patellar thickness, *WI* wiberg index, *EPIP* the ratio of length of lateral patella to medial patella,*WA* wiberg angle.

Table 6
Follow-up results of patellar morphologic characteristics

Indexes	Group S	Group C	*P* values
CT			
PW(mm)	40.58 ± 1.26	36.41 ± 1.17	<0.001
PT(mm)	11.59 ± 0.74	9.38 ± 0.56	<0.001
WI	0.54 ± 0.06	0.72 ± 0.08	<0.001
EPIP	1.26 ± 0.17	1.69 ± 0.21	<0.001
WA(°)	128.63 ± 9.05	125.47 ± 13.96	>0.05

PW patellar width, *PT* patellar thickness, *WI* wiberg index, *EPIP* the ratio of length of lateral patella to medial patella,*WA* wiberg angle.

The classification of patella and trochlea form.

Preoperatively, there were also no statistically significant differences between the classification of patella and trochlea form in the two groups ($p > 0.05$). (Tables 7 and 8). At the final follow-up, the patella form in Group S was classified as Wiberg-I in 10 (40%) cases, Wiberg-II in thirteen (52%) cases and Wiberg-III in two (8%) cases; in Group C was classified as Wiberg-I in 0 (0%) cases, Wiberg-II in fourteen (56%) cases and Wiberg-III in eleven (44%) cases, which was significant difference between the two groups. And the trochlea form in Group S was classified as the Normal in 10 (40%) cases, Dejour-A in thirteen (52%) cases, Dejour-B in two (8%) cases and Dejour-C/D in 0 (0%) cases; in Group C was classified as the Normal in 0 (0%) cases, Dejour-A in four (16%) cases, Dejour-B in nine (36%) cases, Dejour-C in eight (32%) cases and Dejour-D in four (16%) cases, which was significant difference between the two groups.

Table 7
Patellar types

Type[n/N(%)]	Wiberg classification		
	I	II	III
Pre-Group S	4/25(16)	21/25(84)	0/25(36)
Pre-Group C	5/25(20)	20/25(80)	0/25(36)
Post-Group S	10/25(40)	13/25(52)	2/25(8)
Post-Group C	0/25(0)	14/25(56)	11/25(44)

Table 8
Trochlear types

Type[n/N(%)]	Dejour classification				
	N	A	B	C	D
Pre-Group S	0/25(0)	9/25(36)	16/25(64)	0/25(0)	0/25(0)
Pre-Group C	0/25(0)	11/25(44)	14/25(56)	0/25(0)	0/25(0)
Post-Group S	10/25(40)	13/25(52)	2/25(8)	0/25(0)	0/25(0)
Post-Group C	0/25(0)	4/25(16)	9/25(36)	8/25(32)	4/25(16)

Discussion

Compared with conservative management, we found that the stability of the patellofemoral joint can be significantly improved by early (before epiphyseal closure) soft tissue operative intervention, with decreased recurrent instability. In the growing child, soft tissue methods are the only logical treatment options because bony procedures injure the proximal tibial physis and distal femoral physis, potentially leading to premature closure[11,37]. Lesions of the MPFL were found in almost all patients with patellar dislocation[38]. Balcarek et al.[39] reported that MPFL injury occurred in 98.6% of patients with patellar dislocation. Correlation studies have confirmed that the MPFL contributes about 53–67% of the total medial restraining force as a distinct restraining structure in the second layer of the medial soft tissues[40,41]. Therefore, all patients in Group S underwent surgical treatment (medial patellar retinaculum plasty). Ma et al.[12,24,42] mainly concentrated on repair of the MPFL and proved that this procedure can restore the anatomical function of the MPFL almost to its full capacity as well as restore the static and dynamic stability of the patella. However, conservative treatment cannot fundamentally solve the patellar imbalance induced by a loose medial patellar retinaculum and tight lateral patellar retinaculum. Therefore, while many patients treated nonoperatively do not develop recurrent patellar dislocation[43], long-term studies have demonstrated recurrent dislocation in 30–50% of patients, with others reporting subjective instability, pain, and persistent disability[44,45].

Patellar morphological characteristics were a major aspect of our study and yielded interesting results. The mean PWs were significantly different at the final follow-up (Group S, from 31.78 mm to 40.58 mm; Group C, from 32.56 mm to 36.41 mm). Fucentese SF et al.[23] reported mean values of 42.00 mm and 38.27 mm in the transverse plane with the widest diameter of the patella for controls and patients with patellofemoral joint dislocation (PFJD), which was significant difference between the two groups ($p = 0.005$). Therefore, our values are consistent with the results of Fucentese SF et al.[23] at the final follow-up.

The PT is also often used in the patellofemoral literature[13,22,23]. Fucentese SF et al.[23] reported that a mean of > 10.60 mm is normal and that < 9.59 mm indicates pathological for patellofemoral instability, which was significant difference between the two groups ($p = 0.015$). Our values of between 7.51 mm and 11.59 mm in Group S and between 7.64 mm and 9.38 mm in Group C reflected the similar results of Fucentese SF et al.[23] at the final follow-up.

The WI is another classic measurement of patellar morphological characteristics[13,23]. A mean of > 0.60 for patients with patellofemoral instability and a mean of < 0.54 for the controls were reported by Fucentese SF et al.[23], which was significant difference between the two groups ($p = 0.013$). Our values (Group S, from 0.62 to 0.54; Group C, from 0.61 to 0.72) reflected the same trend of Fucentese SF et al.[23] at the final follow-up.

Facet asymmetry is an aspect of patellar dysplasia that has attracted little attention until recently[23]. Our research showed that the length of the medial facet was shortened and the length of the lateral facet was essentially the same in comparison with Group S, leading to an increased facet ratio in Group C (Group S, from 1.37 to 1.26; Group C, from 1.34 to 1.69). Fucentese SF et al.[23] reported that a mean of < 1.15 is normal and that > 1.42 indicates patellar dysplasia. Therefore, compared with Group C, the mean EPIP in Group S was closer to normal at the end of the study.

The WA has also received little attention and their clinical significance remains unclear. Jinghui Niu et al.[13] reported mean values of 131.1° and 148.8° for controls and experimental group with patellofemoral joint dislocation (PFJD) in the animal experiment of growing rabbits, which was significant difference between the two groups ($p < 0.001$). However, Fucentese SF et al.[23] measured the WA (Group C, 129.36° (SD 7.02); Group S, 125.64° (SD 11.80); $p = 0.254$), no significant difference was found between controls and patients with patellar instability. Our values for the WA of between 134.72° and 128.63° in Group S and between 135.45° and 125.47° in Group C reflected no significant difference at the final follow-up, which is consistent with the results of Fucentese SF et al.[23]. Surprisingly, a flattening of the retropatellar Wiberg-angle, which may be the consequence of a missing trochlear groove, was not found. This was unexpected since it has been shown that a high-grade trochlear dysplasia (Dejour C and D) corresponds with decreased sulcus angle[46,47]. This can lead to severe patellar dysplasia (Wiberg III) corresponding with decreased wiberg angle[35]. There is no statistical difference in our results, which may suggest that severe patellar dysplasia (Wiberg III) is present in the conservative treatment group.

And the patella type, classified according to Wiberg, showed a significant prevalence of type I and II patellae in Group S and type II and III patellae in Group C at the final follow-up. Additionally, the trochlea type, classified according to Dejour, showed a significant prevalence of the Normal and type A trochlea in Group S and type C and D trochlea in Group C at the final follow-up. It can be seen that the patella types are consistent with our measured data of patellar morphological characteristics.

Studies have shown that patellofemoral dysplasia may be caused by patellofemoral dislocation, especially the development of patella has attracted people's attention in recent years[48]. A important conclusion can be drawn from these results, that patellar morphology can be improved following early (before epiphyseal closure) soft tissue surgical correction of patellar instability associated with low-grade trochlear dysplasia in children. In the patients of patellar instability, the key morphologic change of the patella was a decreased medial facet length[23]. This may explain the smaller patella, the increased Wiberg-index, the basically consistent Wiberg-angle, the increased facet ratio according with Servien et al.[49], and the incidence of patella types II and III in the Wiberg classification[35] in Group C. But what exactly is the mechanism that induces the transformation of the decreased medial facet length? The appropriate stimulation of stress guides the development of the bone[1,2,12]. The external displacement of patella leads to the disappearance of the normal matching relationship of the patellofemoral joint, resulting in abnormal force on the medial articular surface of the patella, which decreases or even does not bear, thus causing dysplasia of the medial articular surface of the patella (a decreased medial facet length)[48]. Therefore, for children with recurrent patellar dislocation, it is very necessary to restore the normal biomechanics of patellofemoral joint by soft tissue surgical correction in time.

This study had limitations. Firstly, CT can be used to describe the osseous contour which cannot be matched with the corresponding surface, which is covered with cartilage when viewed by MRI.[22,23,36] Secondly, single axial cuts on a CT scan cannot be used to elucidate the trochlear morphology. Additional axial slices are required to assess the geometry more accurately.[36]

In conclusion, compared with conservative management, early surgical treatment using medial patellar retinacular plasty is the preferred method for decreasing recurrent instability and improving the outcomes in children with recurrent patellar instability associated with low-grade trochlear dysplasia (Dejour A and B). Our main finding was that the patellar morphology can be significantly improved by early (before epiphyseal closure) soft tissue surgical correction in children with patellar instability associated with low-grade femoral trochlear dysplasia (Dejour A and B).

Declarations

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Authors' contributions

Fei Wang contributed to the conception of the study; Conglei Dong and Yanyang Wang measured and collected the data; Chao Zhao and Conglei Dong contributed significantly to the analysis and wrote the manuscript; Jinghui Niu, Wei Lin, Xiaobo Chen, Chenyue Xu and Maozheng Wei helped perform the analysis with constructive discussions. The authors read and approved the final manuscript.

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Ethics approval and consent to participate

The present study was approved by the Academic Ethics Committee of the Third Hospital of Hebei Medical University, and all patients provided their informed consent for participation and publication. All of the data and materials are available.

Competing interests

The authors declare that they have no competing interests

References

1. Brattström H. Shape of the intercondylar groove normally and in recurrent dislocation of patella: a clinical and x-ray-anatomical investigation. Acta Orthop Scand 1964;35 (Suppl 68):1–148.
2. Grelsamer RP, Dejour D, Gould J. The pathophysiology of patellofemoral arthritis. Orthop Clin North Am 2008;39:269–274.
3. Smith WS, Ireton RJ, Coleman CR (1958) Sequelae of experimental dislocation of a weight-bearing ball- and socket joint in a young growing animal; gross alterations in bone and cartilage. J Bone

Joint Surg Am 40-A:1121–1127.

4. Omeroglu H, Bicimoglu A, Agus H et al (2007) Acetabular development in developmental dysplasia of the hip. A radiographic study in anatomically reduced and uncomplicated hips. Bull NYU Hosp Jt Dis 65:276–279.
5. Theodorou SD, Gerostathopoulos N (1989) Congenital dislocation of the hip. Observations on the early diagnosis and results of treatment with an abduction brace in infants two to nine months of age in Greece. Clin Orthop Relat Res 246:22–29.
6. Waters PM, Smith RGR, Jaramillo D. Glenohumeral deformity secondary to brachial plexus birth palsy. J Bone Joint Surg [Am] 1998;80-A:668–677.
7. Hui JHP, Torode IP. Changing glenoid version after open reduction of shoulders in children with obstetric brachial plexus palsy. J Pediatr Orthop 2003;23:109–113.
8. Huri G, Atay OA, Ergen B, et al. Development of femoral trochlear groove in growing rabbit after patellar instability. Knee Surg Sports Traumatol Arthrosc 2012;20:232–238.
9. Li W, Wang Q, Wang F, et al. Femoral trochlear dysplasia after patellar dislocation in rabbits. Knee 2013;20:485–489.
10. Wang S, Ji G, Yang X, et. Femoral trochlear groove development after patellar subluxation and early reduction in growing rabbits. Knee Surg Sports Traumatol Arthrosc 2016;24:247–253.
11. Benoit B, Laflamme GY, Laflamme GH, et al. Long-term outcome of surgicallytreated habitual patellar dislocation in children with coexistent patella alta. J Bone Joint Surg [Br] 2007;89-B:1172–1177.
12. K. Fu,G. Duan,C. Liu,J. Niu,F. Wang. Changes in femoral trochlear morphology following surgical correction of recurrent patellar dislocation associated with trochlear dysplasia in children. Bone Joint J 2018;100-B:811–21.
13. Jinghui Niu, Qi Qi, Yingzhen Niu, Conglei Dong, Zhenyue Dong, Peng Cui and Fei Wang*. Patella morphological alteration after patella instability in growing rabbits.Journal of Orthopaedic Surgery and Research (2017) 12:106.
14. Ji G, Wang F, Zhang Y, et al. Medial patella retinaculum plasty for treatment of habitual patellar dislocation in adolescents. Int Orthop 2012;36:1819–1825.
15. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 1994;2:19–26.
16. Lippacher S, Dejour D, Elsharkawi M, et al. Observer agreement on the Dejour trochlear dysplasia classification: a comparison of true lateral radiographs to axial magnetic resonance images. Am J Sports Med 2012;40:837–843.
17. Dejour H, Walch G, Neyret P, Adeleine P. Dysplasia of the femoral trochlea. Rev Chir Orthop 1990;76:45– 54.
18. Dejour D, Reynaud P, Lecoultre B. Douleurs et instabilite´ rotulienne. Essai de classification. Med Hyg 1998;56:1466–71.

19. Larsen E, Lauridsen F. Conservative treatment of patellar dislocations: influence of evident factors on the tendency to redislocation and the therapeutic result. Clin Orthop Relat Res 1982;171:131–136.
20. Beals RK, Buehler K. Treatment of patellofemoral instability in childhood with creation of a femoral sulcus. J Pediatr Orthop 1997;17:516–519.
21. Outerbridge RE. The etiology of chondromalacia patellae. J Bone Joint Surg [Br] 1961, 43-B752–757.
22. Stäubli HU, Dürrenmatt U, Porcellini B, Rauschning W. Anatomy and surface geometry of the patellofemoral joint in the axial plane. J Bone Joint Surg (Br). 1999;81:452–8. doi:10.1302/0301-620X.81B3.8758.
23. Fucentese SF, von Roll A, Koch PP, Epari DR, Fuchs B, Schottle PB. The patella morphology in trochlear dysplasia—a comparative MRI study. Knee. 2006;13:145–50. doi:10.1016/j.knee.2005.12.005.
24. Ma LF, Wang CH, Chen BC, et al. Medial patellar retinaculum plasty versus medial capsule reefing for patellar dislocation in children and adolescents. Arch Orthop Trauma Surg 2012;132:1773–1780.
25. Drez DJr, Edwards TB, Williams CS. Results of medial patellofemoral ligament reconstruction in the treatment of patellar dislocation. Arthroscopy 2001;17:298–306.
26. Watanabe T, Muneta T, Ikeda H, Tateishi I, Sekiya I. Visual analog scale assessment after medial patellofemoral ligament reconstruction: with or without tibial tubercle transfer. J Orthop Sci 2008;13:32–38.
27. Lysholm J, Nordin M, Ekstrand J, Gillquist J. The effect of a patella brace on performance in a knee extension strength test in patients with patellar pain. Am J Sports Med 1984;12:110–112.
28. Møller BN, Krebs B. Dynamic knee brace in the treatment of patellofemoral disorders. Arch Orthop Trauma Surg 1986;104:377–379.
29. McConnell J. The management of chondromalacia patellae: a long-term solution. Aust J Physiother 1986;32:215–223.
30. Bitar AC, Demange MK, D'Elia CO, Camanho GL. Traumatic patellar dislocation: nonoperative treatment compared with MPFL reconstruction using patellar tendon. Am J Sports Med 2012;40:114–122.
31. Camanho GL, Viegas AC, Bitar AC, Demange MK, Hernandez AJ. Conservative versus surgical treatment for repair of the medial patellofemoral ligament in acute dislocations of the patella. Arthroscopy 2009;25:620–625.
32. Sillanpää PJ, Mattila VM, Mäenpää H, et al. Treatment with and without initial stabilizing surgery for primary traumatic patellar dislocation. A prospective randomized study. J Bone Joint Surg [Am] 2009;91-A:263–273.
33. Osternig LR, Robertson RN. Effects of prophylactic knee bracing on lower extremity joint position and muscle activation during running. Am J Sports Med 1993;21:733–737.
34. Fonseca EMM, Dinis JC, Noronha JK, Vaz MAP. Evaluation of the cortical bone thickness in eight different human mandibles. http://hdl.handle.net/10198/6425 (date last accessed 25 April 2018).

35. Wiberg G. Roentgenographic and anatomic studies on the femoropatellar joint. Acta Orthop Scand 1941;12:319–410.
36. Charles MD, Haloman S, Chen L, et al. Magnetic resonance imaging–based topographical differences between control and recurrent patellofemoral instability patients. Am J Sports Med 2013;41:374–384.
37. Heywood AWB. Recurrent dislocation of the patella: a study of its pathology and treatment in 106 knees. J Bone Joint Surg [Br] 1961;43-B:508–517.
38. Nomura E, Horiuchi Y, Inoue M. Correlation of MR imaging findings and open exploration of medial patellofemoral ligament injuries in acute patellar dislocations. Knee2002;9:139–143.
39. Balcarek P, Ammon J, Frosch S. Magnetic resonance imaging characteristics of the medial patellofemoral ligament lesion in acute lateral patellar dislocations considering trochlear dysplasia, patella alta, and tibial tuberosity-trochlear groove distance. Arthroscopy2010;26:926–935.
40. Davis DK, Fithian DC. Techniques of medial retinacular repair and reconstruction. Clin Orthop Relat Res 2002;402:38–52.
41. Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the human knee. Am J Sports Med 1998;26:59–65.
42. Ma LF, Wang F, Chen B- C, et al. Medial retinaculum plasty versus medial patellofemoral ligament reconstruction for recurrent patellar instability in adults: a randomized controlled trial. Arthroscopy 2013;29:891–897.
43. Magnussen RA, Duffee AR, Kalu D, Flanigan DC. Does early operative treatment improve outcomes of primary patellar dislocation? A systematic review. Curr Orthop Pract 2015;26:281–286.
44. Mäenpää H, Lehto MU. Patellar dislocation. The long-term results of nonoperative management in 100 patients. Am J Sports Med 1997;25:213–217.
45. Mäenpää H, Huhtala H, Lehto MU. Recurrence after patellar dislocation. Redislocation in 37/75 patients followed for 6-24 years. Acta Orthop Scand 1997;68:424–426.
46. Schottle PB, Fucentese SF, Pfırrmann C, Bereiter H, Romero J. Trochleaplasty for patellar instability due to trochlear dysplasia. Acta Orthop Scand 2005;76:693–8.
47. Fucentese SF, Schottle PB, Pfırrmann CW, Romero J. CT changes after trochleaplasty for recurrent patellofemoral instability. Lausanne' International Patellofemoral Study Group Meeting; 2005.
48. Niu J, Qi Q, Hao K, et al. The morphology of patella changed significantly after soft tissue correction for children with recurrent patella dislocation. BMC Musculoskelet Disord. 2020;21:833.
49. Servien E, Ait Si Selmi T, Neyret P. Study of the patellar apex in objective patellar dislocation. Rev Chir Orthop Reparatrice Appar Mot 2003;89:605– 12.

Figures

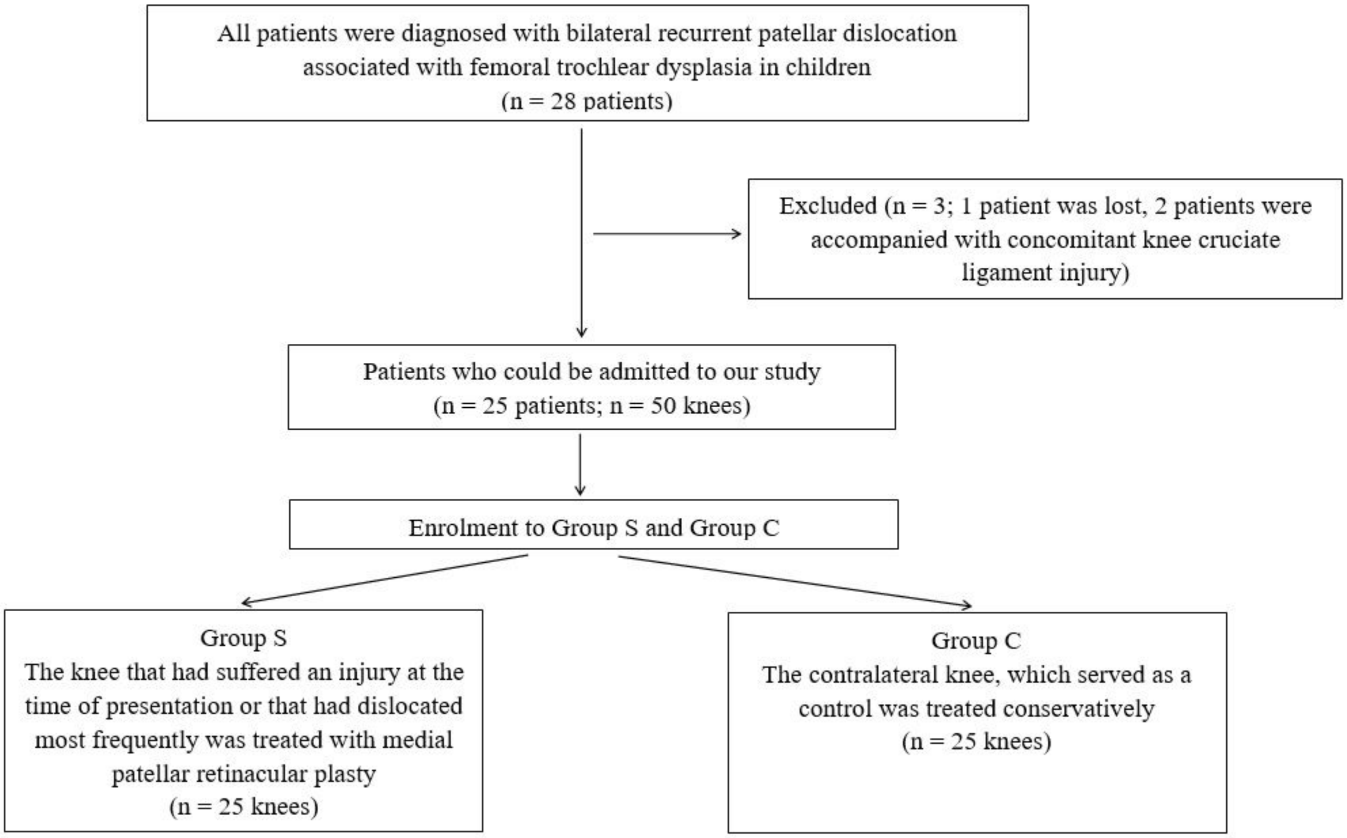

Figure 1

Consolidated Standards of Reporting Trials (CONSORT) flowchart of patient selection.

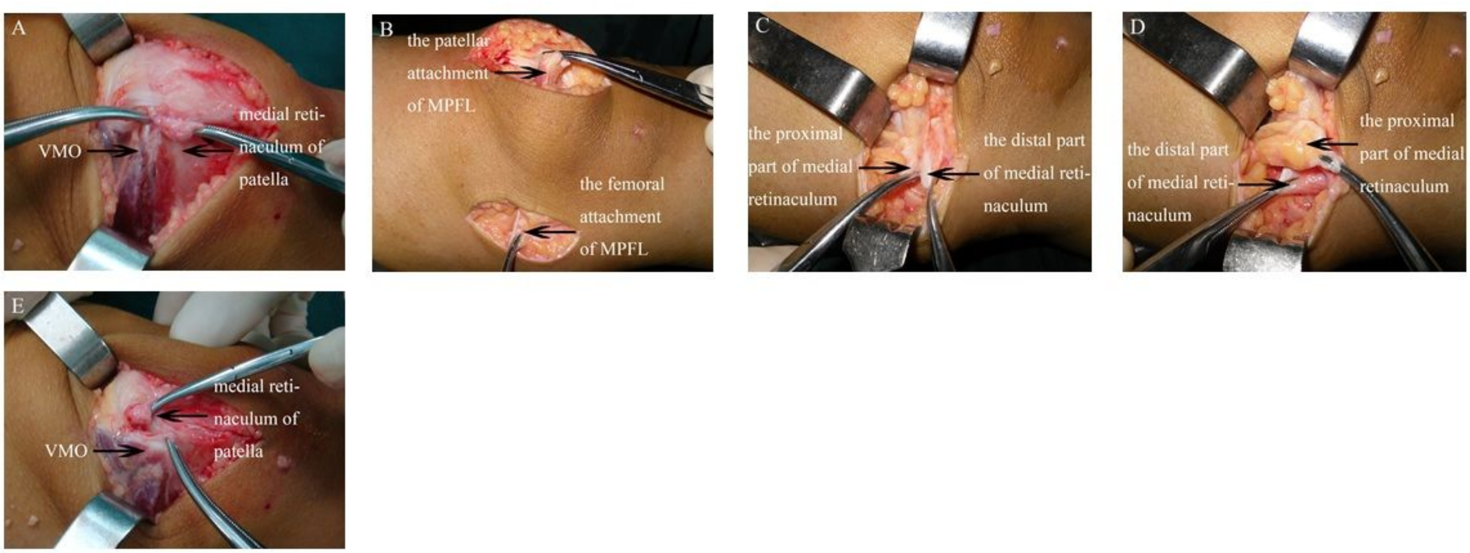

Figure 2

A) A transverse incision was made at the junction of the vastus medialis obliquus (VMO) and the medial retinaculum. B) The femoral attachment of medial patellofemoral ligament (MPFL) was dissected. C) A transverse dissection was made to divide the medial retinaculum into two parts, a distal part, including both medial retinaculum and MPFL, and a proximal part, only including medial retinaculum. D) The distal part of medial retinaculum was advanced proximally behind the medial femoral condyle and the proximal part of retinaculum, and then advanced distally over the retensioned distal part of medial retinaculum. E) The isolated medial retinaculum of the patella was advanced proximally and laterally near to the upper pole ofthe patella, and then vastus medialis was advanced distally and laterally to the patella.

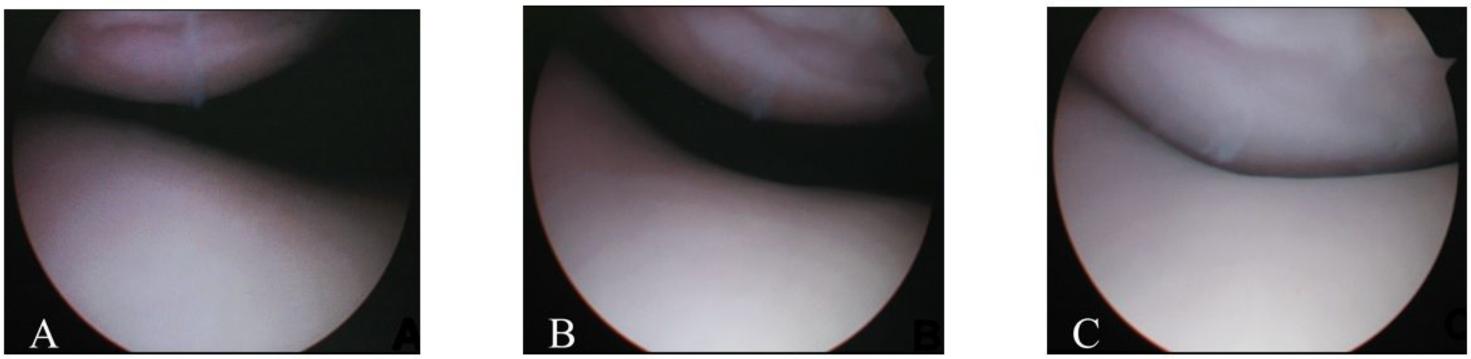

Figure 3

A) Preoperative appearance of patellar dislocation. B) Postoperative fine congruence of patellofemoral joint with the knee in full extension. C) The patella stabilized to the trochlea in 10° flexion.