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Trochleoplasty techniques provide good clinical results in patients with trochlear dysplasia

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Abstract
Purpose The aim of this systematic review is to compare the clinical outcomes of patients treated with different trochleoplasty procedures, the rate of complications and recurrence of patellar dislocation.
Methods A systematic review of the literature was performed, in accord with the PRISMA guidelines. PubMed, MEDLINE, CINAHL, Cochrane, EMBASE and Google Scholar databases were comprehensively searched using the keyword combinations, "Dejour trochleoplasty", "Bereiter Trochleoplasty", "Albee Trochleoplasty", "Recession Trochleoplasty", "Trochlear Dysplasia", "Instability", "Adult", "Clinical Outcome" and "Surgery".
Results Three-hundred and ninety-two knees in 371 patients were included. Bereiter U-shaped deepening trochleoplasty was the most commonly used technique for the treatment of trochlear dysplasia in the included studies with the lowest rate of recurrence and post-operative ROM deficiency. On the other hand, Dejour V-shaped deepening trochleoplasty showed the highest mean post-operative value of Kujala score with 79.3 (SD 8.4) points. Statistical differences were found in terms of redislocation rate between Goutallier procedure and Bereiter trochleoplasty ($p < 0.05$) and in terms of post-operative osteoarthritis between Bereiter and Dejour procedures ($p < 0.05$).
Conclusion Bereiter trochleoplasty seems to be the most efficiency procedure in terms of post-operative patellar redislocation, post-operative osteoarthritis and ROM, but the highest mean post-operative Kujala score is obtained by Dejour procedure. Therefore, none of the surgical techniques analysed highlighted a real superiority. Randomised clinical trials are needed to establish whether of available surgical technique is the best to treat patient with trochlear dysplasia. The clinical relevance of this paper is that the three most popular trochleoplasty techniques are associated with significantly improved stability and function, showing a relatively low rate of osteoarthritis and pain, and a moderate rate of complications.
Level of evidence Systematic review, Level IV.

Keywords Trochleoplasty · Trochlear dysplasia · Patellar instability · Knee · Patellofemoral

Introduction

Trochlear dysplasia is a condition in which the femoral trochlea has an abnormal shape and function. This condition occurs in <2% of the population; however, up to 85% of patients with recurrent patellar instability have trochlear dysplasia [13, 19]. Dejour et al. [12] proposed a classification of trochlear dysplasia based on the combined evaluation of axial and lateral radiographs, distinguishing four types of dysplasia. Type A is characterized by the presence of crossing sign in the lateral view, a shallow trochlea and a sulcus angle >145° on the axial view. Type B is characterized by a crossing sign and trochlear spur on lateral radiographs. Type C is characterized by a crossing sign and a double-contour sign (representing the medial hypoplastic facet) on the lateral view. Type D

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is characterized by crossing sign, supratrochlear spur and double-contour sign with asymmetry of the facet's height.

Trochleoplasty aims to change the shape of the trochlea in order to stabilize an unstable patella. Several trochleoplasty procedures have been proposed. Firstly, Albee [1] pioneered a procedure to elevate the lateral facet of the trochlea, to increase its obliquity and to restore the normal anatomy by an osteotomy and interposition of a tibial graft. This procedure may induce an increased pressure across the lateral facet of the patellafemoral articulation generating patellofemoral pain and subsequently patellofemoral osteoarthritis.

Secondly, the procedure proposed by Masse [25], later modified by Dejour and Saggin [11] and Dejour et al. [12], tried to decrease the prominence of the trochlea and create a new "V-shaped" groove with a normal depth using a straight midline skin incision carried out from the superior patellar margin to the tibiofemoral articulation (Fig. 1a: sulcus deepening trochleoplasty according to Dejour has the main goal to decrease the prominence of the trochlea and to create a new groove with normal depth, thus optimizing patellar tracking). Thirdly, Bereiter [5] described a "U-shaped" deepening trochleoplasty with a lateral parapatellar approach (Fig. 1b: Bereiter U-shaped" deepening trochleoplasty: a thin osteochondral flake with 2 mm of subchondral bone is elevated from the trochlea extending until the intercondylar notch; the distal femoral subchondral bone is deepened and refashioned with osteotomes and a high-speed burr. Next, the osteochondral flap is seated in the refashioned bed and fixed with 3-mm-wide vicryl bands, passing through the centre of the groove and exiting in the lateral femoral condyle. The periosteum is reattached to the edge of the cartilage and closure of the wound is performed). Finally, Goutallier proposed a "recession trochleoplasty" to eliminate the supratrochlear spur (Fig. 1c: Goutallier "recession trochleoplasty" aims to decrease patellofemoral compression by increasing the angle between the quadriceps muscle force and the patellar tendon force).

Trochleoplasty has been also combined with other surgical procedures to correct the associated factors of patellar instability in addition to severe trochlea dysplasia, such as tibial tuberosity medialization osteotomy, vastus medialis obliquus (VMO) plasty, reconstruction of the medial patellofemoral ligament (MPFL) or medial reefing [3, 10, 13, 32, 33].

The aim of this systematic review was to compare clinical outcomes and post-operative complication rates in patients who underwent different surgical trochleoplasties. No differences in terms of clinical outcomes and post-operative complication rate were expected amongst the analysed procedures.

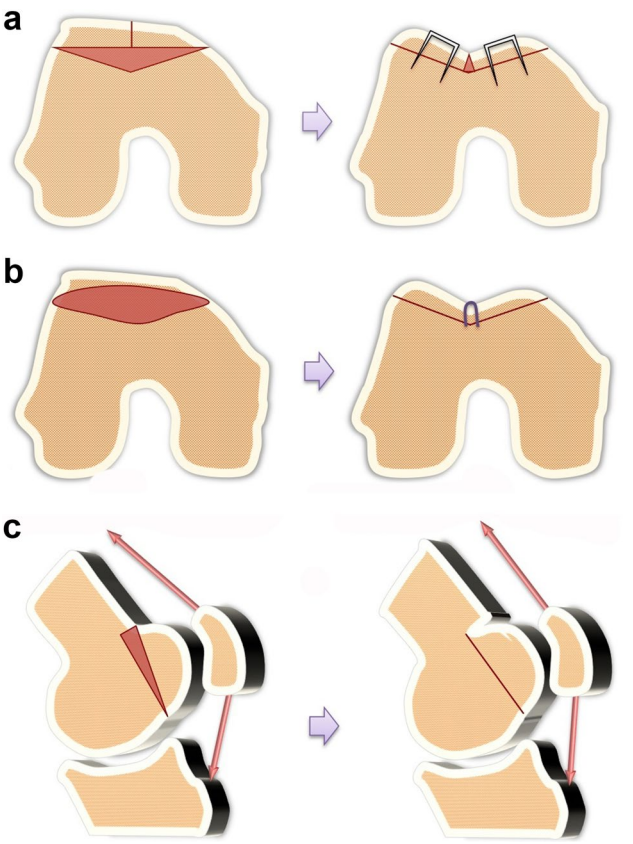

Fig. 1 **a** Sulcus deepening trochleoplasty according to Dejour. **b** Bereiter U-shaped" deepening trochleoplasty. **c** Goutallier "recession trochleoplasty"

Materials and methods

A systematic review of the literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines with a PRISMA checklist and algorithm. The search algorithm according to the PRISMA guidelines is shown in Fig. 2. A comprehensive search of PubMed, MEDLINE, CINAHL, Cochrane, EMBASE and Google Scholar data bases using various combinations of the keywords "Dejour trochleoplasty", "Bereiter trochleoplasty", "Albee trochleoplasty", "recession trochleoplasty", "trochlear dysplasia", "instability", "adult" and "clinical outcome" since the inception of the databases until 2016 was performed.

Three independent reviewers (U.G.L., V.C. and N.M.) conducted the search separately. All journals were considered, and all relevant studies were analysed. To qualify for the study, an article had to be published in a peer-reviewed journal. All articles were initially screened for relevance. The three investigators separately reviewed the

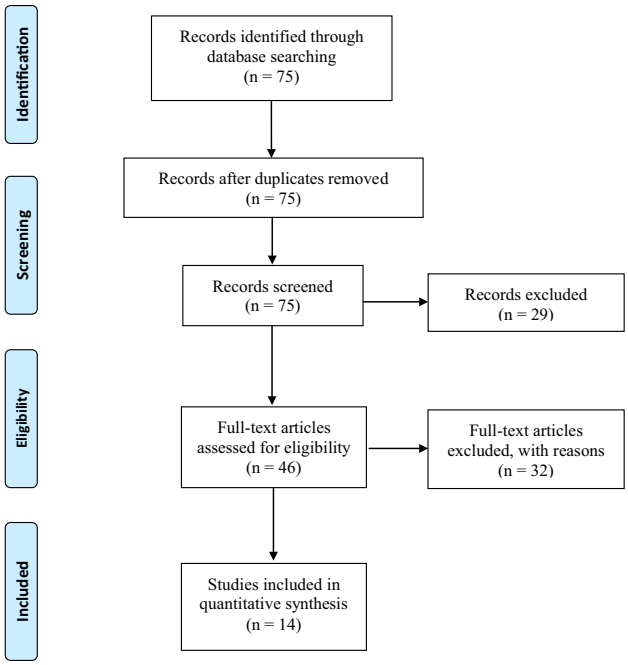

Fig. 2 PRISMA 2009 flow diagram

abstract of each publication and then performed a close reading of all articles and extracted data to minimize selection bias and errors. The last search was performed on 25 September 2016. According to the Oxford Centre of Evidence-Based Medicine, Level I to Level IV articles were found in the literature and included in our study. Articles only in English were included.

Articles that reported clinical outcome or rate of recurrence were included, or both, after a trochleoplasty procedure for the management of patients with trochlear dysplasia. Missing data pertinent to these parameters warranted exclusion from this systematic review. Literature reviews; case reports; studies on animals; on cadavers, or in vitro; biomechanical reports; technical notes; letters to editors; and instructional courses were excluded. Finally, to avoid bias, the selected articles, the relative list of references and the articles excluded from the study were reviewed, assessed and discussed by all the authors. All investigators independently extracted the following data: demographics, type of trochlear dysplasia, type of surgery for the treatment of trochlear dysplasia, additional procedures complications, previous surgery, clinical assessment, months of follow-up, complications and outcome scores.

Quality assessment

To assess the quality of the studies, we used the Coleman Methodology Score (CMS), which assesses methodology with the use of ten criteria, giving a total, score ranging between 0 and 100 points. A score of 100 indicates that the study largely avoids chance, various biases and confounding factors. The final score can be defined as excellent (85–100 points), good (70–84 points), fair (50–69 points) and poor (<50 points). The subsections that make up the CMS are based on the subsections of the CONSORT statement (for randomized controlled trials) and are modified to allow for other trial designs [2]. Coleman criteria were modified to make them reproducible and relevant for the systematic review on trochleoplasty techniques in patients with trochlear dysplasia. Each study was scored by three reviewers (U.G.L., M.C. and V.C.) independently and in triplicate for each of the criteria adopted to give a total CMS between 0 and 100. Each author performed this procedure twice.

Statistical analysis

Statistical analysis with Fisher's exact test was performed to establish whether the difference of percentage in terms of post-operative pain, patellar redislocation and osteoarthritis was statistical relevant. A p value <0.05 was considered significant.

Results

The literature search and cross-referencing resulted in a total of 75 articles. Finally 14 articles on the treatment of trochlear instability with Dejour V-shaped deepening trochleoplasty [9, 14, 30, 35, 42, 45], Bereiter U-shaped deepening trochleoplasty [4, 6, 15, 28, 37, 41, 43] and Goutallier recession trochleoplasty [39] were included in the final review (Fig. 2).

Demographics (Table 1)

A total of 392 knees in 371 patients were included, with a median age at surgery of 22.5 years ranging from 16 years [35] to 49 years [35]. Patients were assessed at follow-up for an average of 56.6 months (SD 44), ranging from 18 months [42] to 183.6 months [35].

Trochlear dysplasia (Table 1)

Only few authors reported the rate of trochlear dysplasia. Particularly, authors reported that 355 knees from 392 (90.6%) had trochlear dysplasia: 16 (4.5%) knees type A dysplasia according to Dejour's classification system [15, 35, 39]; 120 (33.8%) type B dysplasia [6, 9, 15, 30, 35, 37, 39, 43]; 34 (9.6%) type C dysplasia [6, 15, 35, 39]; 185 (52.1%) type D dysplasia [6, 9, 14, 15, 28, 30, 35, 39, 41].

Table 1 Demographics

Author	Type of study	Type of treatment	Additional procedures					Type of dysplasia				Previous surgery	Number of previous surgeries	Mean age at surgery (years)
			MELF surgery	Lateral release	Vastusmedialis oblique plasty	Tibial tuberosity transfer	Medial reefing	A	B	C	D			
Banke et al. [4]	LEVEL IV (prospective case series)	Bereiter trochleoplasty	18	0	0	0	0	–	–	–	–	None	0	22.2
Blønd and Haugegaard [6]	LEVEL IV (follow-up case series)	Arthroscopic deepening trochleoplasty (Bereiter)	37	0	0	0	0	0	10	11	16	None	0	19
Dejour et al. [9]	LEVEL IV (follow-up case series)	Dejour deepening trochleoplasty	14	6	10	16	0	0	7	0	17	All surgery for patellofemoral instability	24	23
Donell et al. [14]	LEVEL IV (consecutive case series)	Dejour deepening trochleoplasty	0	17	0	9	16	0	–	0	17	Arthroscopy (1), lateral release (2), lateral release and medial reefing (1), lateral release and arthroscopies (1),excision osteochondral fragment (2), Roux-Goldthwaite (1), lateral release and chondroplasty (1)	8	25

Table 1 continued

Author	Type of study	Type of treatment	Additional procedures					Type of dysplasia				Previous surgery	Number of previous surgeries	Mean age at surgery (years)
			MELF surgery	Lateral release	Vastusmedialis oblique plasty	Tibial tuberosity transfer	Medial reefing	A	B	C	D			
Fucentese et al. [15]	Human retrospective comparative study	Trochleoplasty (Bereiter and Gautier)	0	44	44	0	0	9	15	9	11	Arthroscopy (10), medial reefing or plication (6), lateral release (5) and/or tuberosity transfer (3)	24	18
Nelitz et al. [28]	LEVEL IV: prospective follow-up case series	Bereiter trochleoplasty	26	0	0	0	0	0	0	0	26	Medial reefing and lateral release (6), medial reefing (4), medial reefing supplemented by vastus medialis muscle (1), Roux-Goldthwait procedure medial reefing (2)	13	19.2
Ntagiopoulos et al. [30]	LEVEL IV: retrospective case series	Sulcus deepening trochleoplasty (Dejour)	5	21	26	21	0	0	12	0	19	None	0	21

Table 1 continued

Author	Type of study	Type of treatment	Additional procedures					Type of dysplasia				Previous surgery	Number of previous surgeries	Mean age at surgery (years)
			MELF surgery	Lateral release	Vastusmedialis oblique plasty	Tibial tuberosity transfer	Medial reefing	A	B	C	D			
Schöttle et al. [37]	LEVEL IV: case series	Bereiter trochleoplasty	0	19	19	0	0	0	19	0	0	Cartilage debridement (5), medial retinacular suture, lateral retinacular release, or medialization of the tibial tuberosity.	5	22
Thaunata et al. [39]	LEVEL IV: retrospective case series	Goutallier trochleoplasty	8	19	0	18	0	1	7	5	6	Lateral release (2), Elmslie–Trillat (4), arthroscopy, medial reefing (1), Albee trochleoplasty (1)	8	23

Table 1 continued

Author	Type of study	Type of treatment	Additional procedures					Type of dysplasia				Previous surgery	Number of previous surgeries	Mean age at surgery (years)
			MELF surgery	Lateral release	Vastusmedialis oblique plasty	Tibial tuberosity transfer	Medial reefing	A	B	C	D			
Utting et al. [41]	LEVEL IV: prospective case series	Bereiter-type trochleoplasty	4	59	19	4	14	0	0	0	59	Medialisations of the tibial tubercle (7), arthroscopies (6), lateral releases (5), medial reefing procedures (2), medial patellofemoral ligament reconstructions using a hamstring graft (2) and 1 Roux-Goldthwaite procedure.	23	21.5
Verdonk et al. [42]	Prospective	Dejour deepening trochleoplasty	0	–	–	–	–	–	–	–	–	Arthroscopy (10): lateral release musculotendinous procedures	10	27
VonKnoch et al. [43]	LEVEL IV: retrospective case series	Bereiter trochleoplasty	0	0	0	0	45	0	45	0	0	15 knees: debridement, medial retinacular reefing, lateral retinacular release or medialisation of the tibial tuberosity	15	22.2

Table 1 continued

Author	Type of study	Type of treatment	Additional procedures					Type of dysplasia				Previous surgery	Number of previous surgeries	Mean age at surgery (years)
			MELF surgery	Lateral release	Vastusmedialis oblique plasty	Tibial tuberosity transfer	Medial reefing	A	B	C	D			
Zaffagnini et al. [45]	Human retrospective study	Dejour deepening trochleoplasty	0	6	6	–	6	–	–	–	–	Lateral release (3), distal realignment (3), distal femoral osteotomy (1), lateral meniscectomy (1), medial meniscectomy (3), hardware removal (2)	13	26.9
												Tibial tubercle transfers (7), lateral retinacular resections (3), arthroscopic lavage (5), ablation of an intra-articular foreign body by open surgery (1)	13	27.8
Rouanet et al. [35]	LEVEL IV: retrospective case series	Dejour deepening trochleoplasty	0	0	34	17	–	6	5	9	14			
TOTAL			112	191	158	85	81	16	120	34	185		156	MEAN: 22.3 years
TOTAL number of dysplastic knees								355						

MELF medial patellofemoral ligament

Table 2 Type of trochleoplasty

	Bereiter U-shaped deepening	Dejour V-shaped deepening	Goutallier recession	Total
Number of studies	7	6	1	14
Number of procedures	248	125	19	392
% of total procedures (%)	63.3	31.9	4.8	100
Mean Kujala score (preoperative/post-operative)	53.8/64.5	54/79.3	*Not provided*/80(± 17)	
Increase in Kujala score	10.7	25.3	*Not provided*	

Surgical procedures (Tables 1, 2)

The most common procedure used for the treatment of trochlear instability was Bereiter U-shaped deepening trochleoplasty. It was used in 248 knees (63.3% of the procedures). The Dejour V-shaped deepening trochleoplasty, instead, was used in 125 knees (31.9% of the procedures), and the Goutallier recession trochleoplasty was used in 19 knees (4.8% of the procedures) (Table 1).

Other procedures were also performed, in addition to trochleoplasty, including lateral retinaculum release in 191 cases (48.7% of the knees) [9, 14, 15, 30, 37, 39, 41, 45], vastus medialis plasty in 158 cases (40.3% of the knees) [9, 15, 30, 35, 37, 41, 45], medial patellofemoral ligament reconstruction (MPFLR) in 112 cases (28.6% of the knees) [4, 6, 9, 28, 30, 39, 41], tibial tuberosity transfer in 85 cases (21.7% of the knees) [9, 14, 30, 35, 39, 41] and medial reefing in 81 cases (20.7% of the knees) [14, 41, 43, 45] (Table 1).

Outcome measurements and radiological assessment (Table 5)

Several outcome measures were reported in the included studies. The most frequently reported score was the Kujala score, used in 13 (92.9%) of 14 studies [4, 6, 9, 14, 15, 28, 30, 35, 37, 39, 41, 43, 45].

The overall mean value of preoperative and post-operative Kujala score was 53.8 (SD 22.2) and 74 (SD 6.3) points, respectively. Dejour V-shaped trochleoplasty procedure showed a mean preoperative Kujala score of 54 (SD 5.6) and a mean post-operative Kujala score of 79.3 (SD 8.4).The Bereiter U-shaped deepening trochleoplasty had a mean preoperative and post-operative value of 53.8 (SD 29.1) and 64.5 (SD 4.9) points, respectively. Finally in patients who underwent Goutallier recession trochleoplasty, the preoperative Kujala score was not available and the post-operative score was 80.

Four (28.6%) authors used in their studies only radiographs for radiological assessment [35, 42, 43, 45], 5 (35.7%) radiographs and computer tomography [9, 14, 30, 37, 39] and 5 (35.7%) radiographs and MRI [4, 6, 15, 28, 41] (Table 3).

Complications (Tables 3, 4)

The overall rate of complications was 157 (40% of the treated knees). The most common complication was increased pain. It was found in 43 patients (11% of knees) [6, 9, 15, 30, 35, 37, 42, 43]. Similar rate of pain was found between Bereiter U-shaped deepening trochleoplasty (10.8%, 25/248 knees) [6, 15, 37, 43] and Dejour V-shaped deepening trochleoplasty [9, 29, 35, 42] (14.4%, 18/125 knees). No statistical difference was found between the two groups (n.s.). On the contrary, Goutallier procedure did not show an increment of post-operative pain (0%, 0/19 knees).

The second most common complication was the deficit of range of motion (ROM) with an overall rate of 6.7%. In particular, the Bereiter trochleoplasty showed a rate of 2% [4, 14, 28, 39, 41, 42], Dejour procedure a rate of 16% [4, 14, 28, 35, 39, 41, 42] and Goutallier recession trochleoplasty [39] a rate of 5%.

Osteoarthritis occurred in 47 patients [35, 39, 43, 45] with a rate of 4.4% for Bereiter trochleoplasty [43, 45], 16% for Goutallier recession trochleoplasty [35, 39] and 26.5% for Dejour procedure [45]. Statistical differences were highlighted between Bereiter and Dejour procedures ($p < 0.05$). On the contrary, the different rate between Bereiter and Goutallier and between Dejour and Goutallier recession trochleoplasty showed no statistical difference (n.s.).

The overall rate of patella redislocation was 2%. In particular, the procedure that showed the highest rate was the Goutallier trochleoplasty with a rate of 10.5% [39], followed by Dejour [45] and Bereiter [15, 41] trochleoplasty with a rate of 3.2 and 0.8%, respectively. No statistical differences were found between Bereiter trochleoplasty and the Dejour procedure (n.s.); on the contrary between the first one and Goutallier trochleoplasty, statistical difference was found (n.s.).

Other less frequent complications reported in the included studies were: 5 arthrofibrosis (1.2% of the knees) [42]; 1 tibial tuberosity non-union (0.3% of the knees) [39]; 1 superficial wound infection (0.3% of the knees) [41]; 1 transient post-operative femoral nerve palsy after peripheral anaesthesia (0.3% of the knees) [15]; 1 wound-healing problem (0.3% of the knees) [15]; 1 complex regional pain

Table 3 Complications

Authors	Clinical assessment	Outcomes score- other					Follow-up months	No# knees with trochleoplasty	No# of patients	% of recurrence	Complications				
											Overview	Pain	TT non-union	ROM decreased	Arthritis
Banke et al. [4]	Subjective score, apprehension and pain	Tegner	Kujala	IKDC	VAS	Rx, MRI	30.5	18	17	None	Inability to bend the knee: 1, ROM deficit: 3, PFJ pain level increased: 2	2	0	3	0
Blønd and Haugegaard [6]	–	Tegner,	Kujala	KOOS	–	Rx, MRI	29	37	31	None	PFJ pain level increased: 3	3	0	0	0
Dejour et al. [9]	Subjective score	–	Kujala	IKDC	–	Rx, CT	66	24	22	None	PFJ pain level increased: 4	4	0	0	0
Donell et al. [14]	Subjective score, apprehension patellar tracking noted, crepitus.	–	Kujala	–	–	Rx, CT	36	17	15	0	mild residual apprehension: 7, ROM deficit: 5, knees showed marked crepitus: 6;	0	0	5	0
Fucentese et al. [15]	Walking and limping, clinical axis, Q-angle, swelling, tenderness, ROM, muscle status, mobility of patella and patellar tilt, retropatellar pain and crepitus, and apprehension test for patellar instability	–	Kujala	–	VAS	Rx, MRI	48	44	38	1	pain: 3, transient post-operative femoral nerve palsy after peripheral anaesthesia: 1, wound-healing problem: 1, complex regional pain syndrome: 1	3	–	–	–

Table 3 continued

Authors	Clinical assessment	Outcomes score- other					Follow-up months	No# knees with trochleoplasty	No# of patients	% of recurrence	Complications				
											Overview	Pain	TT non-union	ROM decreased	Arthritis
Nelitz et al. [28]	Crepitus, ROM, patellofemoral pain, and patellar apprehension	Tegner	Kujala	IKDC	VAS, ARS	Rx, MRI	30	26	23	None	ROM deficit: 1	0	0	1	0
Ntagiopoulos et al. [30]	Apprehension test, lateral patellar glide test, and patellar tracking		Kujala	IKDC	–	Rx, CT	84	31	27	None	hardware (staples) breakage: 2, deep venous thrombosis 1	0	0	0	0
Schöttle et al. [37]	Apprehension to lateral displacement, medial quadriceps tenderness, patellofemoral pain.	–	Kujala	–	–	RX, CT	36	19	16	None	PFJ pain level increased: 2	2	0	0	0
Thaunata et al. [39]	Clinical examination, assessment of symptoms (pain) and functional scores	–	Kujala	IKDC	KOOS	Rx, CT	34	19	17	2	Stiffness: 1, revision for tibial tuberosity non-union: 1;	0	1	1	3
Utting et al. [41]	–	–	Kujala	IKDC	Oxford Knee Score, WOMAC, Lysholm and Gillquist	Rx, MRI	24	59	54	1	Superficial wound infection: 1, ROM deficit: 1	0	0	1	0

Table 3 continued

Authors	Clinical assessment	Outcomes score- other					Follow-up months	No# knees with trochleoplasty	No# of patients	% of recurrence	Complications				
											Overview	Pain	TT non-union	ROM decreased	Arthritis
Rouanet et al. [35]	Clinical examination, assessment of symptoms (pain) and functional scores	–	Kujala	–	Lille score, IKS score, Oxford score	Rx	183.6	34	34	None	Pain: 8, postoperative stiffness at <90° flexion: 8, PFJ arthritis: 33	8	0	8	33
Verdonk et al. [42]	Larsen–Lauridsen score considering pain, stiffness, osteopatellar crepitus, flexion and loss of function	–	–	–	Larsen–Lauridsen score	Rx	18	13	12	None	Residual hydrops: 1, retropatellar crepitus: 7, arthrofibrosis: 5, impingement of the fixation material: 3, stiffness: 6, pain: 6	6	0	6	0
VonKnoch et al. [43]	Patellofemoral pain, instability, redislocation, level of sporting activities and overall satisfaction, apprehension sign, ROM, crepitus of the patellofemoral joint)	–	Kujala	–	–	Rx	99.6	45	38	None	PFJ pain level increased: 15, PFJ arthritis: 10, patella baja,: 1	15	0	0	10

Table 3 continued

Authors	Clinical assessment	Outcomes score- other					Follow-up months	No# knees with trochleoplasty	No# of patients	% of recurrence	Complications				
		Tegner	Kujala	IKDC	WOMAC, VAS pain, EQ-5D	Rx					Overview	Pain	TT non-union	ROM decreased	Arthritis
Zaffagnini et al. [45]	–										Patellar osteoarthritis: 1	0	0	0	1
						Average	56.6 months					43	1	26	
						Total		392	371	8	Total complications	157			47

IKDC International Knee Documentation Committee, *WOMAC* Western Ontario McMasters Osteoarthritis Index, *PFJ* patellofemoral junction, *ROM* range of movement, *CT* Computer Tomography, *TT* tibial tuberosity, *VAS* Visual Analogic Scale, *ARS* activity rating scale, *KOOS* Knee Osteoarthritis Outcome Score, *EQ-5D* European Quality of Life-5 Dimensions, *pre* preoperative, post post-operative

syndrome (0.3% of the knees) [15]; 1 residual patella baja (0.3% of the knees) [43]; 1 residual oedema (0.3% of the knees) [42]; and 1 deep venous thrombosis (0.3% of the knees) [30].

Quality assessment

The mean value of the CMS score was 76 points, with a range from 84 to 71, showing that the mean quality of included study was good. No statistically significant difference was found between mean values of CMS calculated by the three examiners.

Discussion

The most important findings of this systematic review were that the Bereiter U-shaped deepening trochleoplasty was the most commonly used technique for the treatment of trochlear dysplasia in the included studies with the lowest rate of recurrence and post-operative ROM deficiency. On the other hand, Dejour V-shaped deepening trochleoplasty showed the highest mean post-operative value of Kujala score with 79.3 points. Statistical differences were found in terms of redislocation rate between Goutallier procedure and Bereiter trochleoplasty ($p < 0.05$) and in terms of post-operative osteoarthritis between Goutallier procedure and Dejour V-shaped deepening trochleoplasty ($p < 0.05$).

The three major types of trochleoplasty were associated with significantly improved stability, function and Kujala scores and a relatively low rate of osteoarthritis and pain. Nevertheless, the risks of osteoarthritis from trochleoplasty procedures are unclear. Degenerative changes of patellofemoral joint can be found in most of the cases at the time of surgery [43], and a conservative management could lead to a high degree of osteoarthritis. The currently available evidence is not sufficient to prove that trochleoplasty procedures lead to patellofemoral osteoarthritis. Rouanet et al. [35] evaluated a series of sulcus deepening trochleoplasties with a mean post-operative follow-up of 15 years. Given the long follow-up period, this study is of course the right to consider the long-term effects of sulcus deepening trochleoplasty. Particularly, this study shows that sulcus deepening trochleoplasty leads to osteoarthritis: ten cases of preoperative patellofemoral osteoarthritis were identified, but none with >Iwano 2, whilst osteoarthritis was present in 33 of 34 cases at the final follow-up with 20 cases >Iwano 2 (65%). The limitation of this study is that trochleoplasty was never performed alone, so is difficult to evaluate exactly effect of this procedure.

Of the 392 knees treated, type D dysplasia was found to be the most common (47.1%).

Table 4 Complications following trochleoplasty

	Bereiter U-shaped deepening	Dejour V-shaped deepening	Goutallier recession	Total
Pain increase post-operatively (%)	10	14.4	0	
Patellar redislocations (%)	0.8	3.2	10.5	
Patients with ROM deficiency	5	20	1	26
% of patients with ROM deficiency (%)	2	16	5	

There is not a consensus on the correct management of patellar instability: it is a multifactorial condition and non-trochleoplasty procedures could have acceptable clinical outcomes and provide adequate stability [40]. On the other hand, recent studies reported negative clinical outcome after isolated MPFLR in treating patellar instability [44] with a high rate of recurrent instability [38], especially in patients with severely dysplastic trochleas. Other procedures, such as isolated tibial tubercle transfer, could leave recurrent instability in patients with dysplastic trochleas [24, 26]. The aim of transfer of the tibial tuberosity is to restore the tibial tuberosity–trochlear groove distance (TT–TG) and Q-angle and manage patellofemoral instability, lateral patellar overload, tilt, compression, and to unload lateral or distal patellar cartilage lesions [19]. Several procedures have been described. Roux firstly performed tibial tubercle medialization for instability of the patella [36]; Hauser, subsequently, reported a posterior and medial shift of the patella [36]. Maquet described an anteriorization of the tubercle. Later Elmslie–Trillat reported a technique for reduction in contact pressures, later modified by Fulkerson [19].

Elmslie–Trillat procedure (the pure medial transfer of the tibial tuberosity) is indicated for patients without osteoarthritis and has excellent outcomes [27]. However, it seems to lead to patella-femoral osteoarthritis during long-term follow-up [26]. On the other hand, Fulkerson procedure is the combination of medial and anterior transfer. This procedure provides excellent outcomes also in patients with severe patellofemoral osteoarthritis [7]. However, single application of Fulkerson procedure for recurrent patellar dislocation with severe patella alta increases the risk of post-operative patellar instability [40].

It has been well documented that to leave the dysplastic trochlea surface leads to unfavourable results [29]. Satisfactory clinical outcomes were reported after a trochleoplasty in patients with previous failed non-trochleoplasty management for patellar instability in whom dysplastic trochlea was left untreated [11].

Conversely, the main trochleoplasty procedures have been documented to be safe and successful in terms of post-operatively improvement in outcome scores [29, 37, 42, 45]. The purpose of these procedures is to improve patellofemoral congruency taking into consideration the abnormal shape of the opposing patella.

The Bereiter U-shaped deepening trochleoplasty was first described in 1994, whereby a lateral parapatellar approach is used to deepen the distal femoral subchondral bone (used in 248 knees, 63.3% of all procedures). Also used in the most studies (7 of 14), and with the lowest percentage of ROM deficiency (2%), it has been shown to be a safe technique with good outcomes [15, 25, 29].

However, this technique had many post-operative pain reports (10.08%). This is particularly important since pain was the most commonly reported complication post-operatively, found in 43 patients (11% of the knees). This shows that whilst a given trochleoplasty technique may perform well post-operatively in one area, it may disappoint in others.

Patellofemoral pain, presenting before trochleoplasty, may in part be explained by osteoarthritic changes of the patellofemoral joint in the long term, and the technique itself may represent a predisposing factor for osteoarthritis [20–23]. On the other side, the damage to the articular cartilage and the patellofemoral osteoarthritis may be caused by recurrent patellar dislocations without surgical intervention [18, 31, 34].

The Dejour V-shaped deepening trochleoplasty was used in 125 knees (31.9% of the procedures). In this procedure, the flap created by resection of cancellous bone forms the new trochlea and is fixed with two staples, restoring the normal trochlear groove proximally. Whilst the Dejour V-shaped deepening trochleoplasty had a rate of post-operative pain similar to Bereiter trochleoplasty, it had a low rate of patellar redislocations (3.2%) and the highest rate of patients with ROM deficiency (16%). The differences observed in post-operative stiffness and pain may be attributed to different surgical techniques amongst authors, different rehabilitation protocols after trochleoplasty, and different indications for trochleoplasty. This further substantiates the notion that different trochleoplasty techniques have their advantages and disadvantages and that there may not be one technique that stands out as superior.

The mean preoperative Kujala score in patients who underwent Dejour V-shaped deepening trochleoplasty score had increased 25.3 points post-operatively (54 points preoperatively to 79.3 points post-operatively). This was

Table 5 Outcomes

Authors	VAS pre/post	*p* value	KOOS pre/post	Tegner pre/post	*p* value	Kujala pre/post	*p* value	IKDC pre/post	*p* value	Other
Banke et al. [4]	5.6 ± 2.8/2.5 ± 1.7	<0.001	–	2 (0–4)/6 (3–8)	<0.001	51.1 ± 22.9/87.9 ± 12.9	<0.001	49.5 ± 20.7/80.2 ± 13.7	<0.001	
Blønd and Haugegaard [6]	–	–	86 (42–97)/94 (53–100)	64 (12–90)/95 (47–100)	<0.001	4 (1–6)/6 (4–9)	<0.001	–	–	ADL pre: 91 (31–99), post: 99 (69–100); sports pre: 40 (0–95), post: 85 (20–100); QDL pre: 25 (0–69), post: 75 (25–100).
Dejour et al. [9]	–	–	–	–	–	44.8 ± 15.0 (25–73)/81.7 ± 13.9 (61–100)	<0.001	51.4 ± 21.8 (23 to 75)/76.7 ± 13.0 (53 to 100)	<0.001	
Donell et al. [14]	–	–	–	–	–	48 (range 13–75)/75 (range 51–98)	<0.05.	–	–	–
Fucentese et al. [15]	8 (3–10)/2.5 ± 2.10	0.027	–	–	–	68 (29–84)/90 (42–100)	>0.001	–	–	–
Ntagiopoulos et al. [30]	–	–	–	–	–	59 (range 28–81)/87 (range 49–100)	<0.001	51 (range 25 to 80)/82 (range 40 to 100)	<0.001	–
Nelitz et al. [28]	3 (1–7)/1 (0–5)	<0.01	–	5.5 (2–8)/5 (2–8)	0.06	79 (21–100)/96 (74–100)	<0.01	74 (32 to 95)/90 (65 to 98)	<0.01	ARS pre: 6.5 (0–16); ARS post: 6 (0–12); $p = 0.21$
Schöttle et al. [37]	–	–	–	–	–	56 (27–67)/80 (43–99)	0.003	–	–	–
Thaunata et al. [39]	–	–	x/70 (± 18)	–	–	x/80 (±17)	–	x/67 (±17)	–	–
Utting et al. [41]	–	–	–	–	–	62 (29–92)/76 (26–100)	<0.001	54 (26 to 89)/72 (23 to 100)	<0.001	OKS: PRE: 26 (12 to 43) POST: 19 (12 to 44) $p < 0.001$; WOMAC score PRE: 23 (12 to 35) POST: 17 (12 to 34) $p < 0.001$. Lysholm score PRE: 57 (25 to 91) POST 78 (30 to 100) $p < 0.001$

Table 5 continued

Authors	VAS pre/post	*p* value	KOOS pre/post	Tegner pre/post	*p* value	Kujala pre/post	*p* value	IKDC pre/post	*p* value	Other
Verdonk et al. [42]	–	–	–	–	–	–	–	–	–	Larsen–Lauridsen scoring system: 7 scored poor, 3 fair and 3 good.
von Knoch et al. [43]	–	–	–	–	–	not available/94.9 (80–100)	–	–	–	–
Zaffagnini et al. [45]	60.8 ± 30.5/19.6 ± 22.0	0.0016	–	1 (1–9)/4 (2–9)	0.0273	41.0 ± 24.0/78.1 ± 20.3	0.0116	Subjective IKDC 34.7 ± 19.3/71.0 ± 23.7	Sub 0.0212	WOMAC pre 55.9 ± 27.2 post: 88.0 ± 15.0 $p = 0.0255$ Lille score: PRE: 53.3 (30–92) POST: 61.5 (25–93), IKS score PRE: 127.3 (54–184) POST: 152.4 (66–200)
Rouanet et al. [35]	–	–	–	–	–	55 (13–75)/76 (51–94)	<0.05.	–		
Banke et al. [4]	154.0 ± 13.5/143.3 ± 9.4	0.001	16.2 ± 5.7/10.7 ± 5.3	0.006	1.09 ± 0.16/1.0 ± 0.17	0.004	24.2 ± 7.5/15.8 ± 5.3	$p < 0.001$	–	–
Blønd and Haugegaard [6]	–	–	–	–	–	–	–	–	–	–
Dejour et al. [9]	153° ± 14° (130–177°)/141° ± 10° (122–163°)	<.0.01	16 ± 6 (5–30)/12 ± 2 (5–20)	<0.001	1.03 ± 0.28 (0.5–1.48)/0.95 ± 0.22 (0.69–1.29)	–	–	–	–	–
Donell et al. [14]	–	–	20.41 (range 8–32)/14.5 (range 2–29)		–	–	35 (range 15–62)/16.25 (range 5–37)	–	–	–
Fucentese et al. [15]	–	–	17 (11–30)/13 (0–21)	<0.001	1.04 (0.71–1.54)/0.94 (0.71–1.27)	<0.001	32 (11–60)/13 (-3 to 36)	<0.001	–	–
Nelitz et al. [28]	–	–	18 (range 12–22)/x	–	–	–	–	–	–	–
Ntagiopoulos et al. [30]	152 ± 16/141 ± 9	<0.01	19 ± 4/12 ± 5	<0.001	–	–	37 ± 7/15 ± 8	<0.001	–	–
Schöttle et al. [37]	–	–	20 (10–24)/9.9 (5–15)	0.001	–	–	22° (5–35)/8° (1–20)	< 0.001	0.6 (–3 to 3)/7 (4–9)	<0.001
Thaunata et al. [39]	–	–	12.84 (range −8\25)	–	–	–	14° (range 6° to 26°)/6° (range −1° to 24°)	–	4.8 (range 0 to 8)/−0.8 (range −8 to 6)	–

Table 5 continued

Authors	VAS pre/post	*p* value	KOOS pre/post	Tegner pre/post	*p* value	Kujala pre/post	*p* value	IKDC pre/post	*p* value	Other
Utting et al. [41]	–	–	–	–	–	–	–	–	–	–
Verdonk et al. [42]	–	–	–	–	–	–	–	–	–	–
von Knoch et al. [43]	–	–	–	–	–	–	–	–	−0.1 (−7 to +5)	<0.001
Zaffagnini et al. [45]	–	–	–	–	–	–	–	–	–	–
Rouanet et a. [35]	–	–	–	–	1.16 (0.8–2)/1.12 (0.7–1.2)	<0.005	–	–	–	–

VAS Visual Analogic Scale, *KOOS* Knee Osteoarthritis Outcome Score, *IKDC* International Knee Documentation Committee, *ADL* activities of daily living, *OKS* Oxford Knee Score, *WOMAC* Western Ontario McMasters Osteoarthritis Index, *TT–TG* tibial tuberosity–trochlear groove distance, *pre* preoperative, *post* post-operative, *x* not provided

compared to a mean increase in Kujala score of 10.7 for patients who underwent Bereiter U-shaped deepening trochleoplasty (53.8 points preoperatively to 64.5 points post-operatively). This demonstrates the clinical outcomes of the trochleoplasty procedures were significantly improved at the final follow-up in most of the studies (Table 5). In patients who underwent Goutallier recession trochleoplasty, the preoperative Kujala score was not available and the post-operative score was 80.

However, it cannot be said that the Dejour V-shaped deepening trochleoplasty is superior to the Bereiter U-shaped deepening trochleoplasty, based on the Kujala score alone. Firstly, as noted, the Kujala is a subjective scoring system and as such is liable to selection bias. Secondly, because there is a discrepancy in the number of procedures performed, with Dejour trochleoplasty being used in only 31.9% of knees, compared to the Bereiter trochleoplasty in 63.3% of knees, it is difficult to conclude that this is an accurate representation of the total population of patients undergoing these procedures [17].

The Goutallier recession trochleoplasty is performed by removing a supratrochlear spur alone, whilst preserving the shape of the trochlea [16]. Since this procedure was used in only 19 knees (4.8% of procedures), it is difficult to draw an accurate conclusion on the outcome scores and complication rates. This procedure was introduced in 2002, and uptake of the procedure amongst patella-femoral surgeons may be slow. None of the patients who underwent this procedure had pain post-operatively, but it had a high rate of patellar redislocations (10.5%).

The difference in numbers of surgical techniques warrants further investigation as to why this is the case. This may be purely as a result of surgeon preference. It is interesting to note that most authors agree that trochleoplasty is an extremely successful treatment for patellar dislocation in the setting of trochlea dysplasia, regardless of the type of technique [29]. Despite this, trochleoplasty has been described as a technically challenging and demanding procedure, and adaptations will continually be made wherever it is deemed beneficial. With such precise indications, trochleoplasty may not be a procedure that orthopaedic surgeons are greatly familiar with.

There are some limitations inherent within this study. These mainly include the lack of reporting in some of the studies that we have analysed and some concern regarding the methods used within those studies. First, it is difficult to evaluate the efficacy of trochleoplasty as a single procedure because most of the patients present concomitant anomalies that need associated correction.

Ideally, all of the studies should report the same standardized scoring systems, to make analysis more homogenous. However, the Tegner score, the International Knee Documentation Committee (IKDC) score, the

Knee Injury and Osteoarthritis Outcome Score (KOOS) and the WOMAC, Western Ontario McMasters Osteoarthritis Index, was used in only 4 (28.6%), 7 (50%), 2 (14.3%) and 2 (14.3%) studies, respectively. Also, the Oxford Knee Score, the activity rating scale (ARS), the Larsen–Lauridsen score and the Lysholm and Gillquist scores were only used in one study each. Furthermore, radiographic analysis, computer tomography and MRI, more objective outcome measures, were only used in 4 (28.6%), 5 (35.7%) and 5 (35.7%) studies, respectively. This makes comparing the different studies difficult, as each scoring system assesses a different aspect of post-operative performance.

The variability of different procedures previously undertaken may be a source of confounding. In order to truly characterize the differences between the main trochleoplasty procedures described earlier, all other variables in the studies analysed would ideally be the same. However, this level of control is impossible; large sample sizes should be analysed; therefore, a compromise must be made. Not only will the presence of previous surgery impact on the outcomes, but trochleoplasty is, out of necessity, combined with various other soft tissue procedures [8, 29].

Finally, the limitations of our review are similar to those of the articles that we assessed. Most of the studies we analysed were of Level IV evidence, consigning our systematic review to the same limitations inherent within this level of evidence. Also, since the method of data collection was mostly retrospective, this method is subject to limitations such as selection and information bias. Finally, retrospective analyses are not able to accurately determine the temporal relationship between procedural technique and outcomes post-operatively, compared to a prospective study.

The results of this study are useful for clinicians to compare clinical outcomes of patients treated with different trochleoplasty procedures, the rate of complications and recurrence of patellar dislocation.

Conclusion

Bereiter trochleoplasty is the most efficient procedure in terms of post-operative patellar redislocation, post-operative osteoarthritis and ROM, but the highest mean post-operative Kujala score is obtained by Dejour procedure. Therefore, none of the surgical techniques analysed have shown a real supremacy. This finding is probably due to the poor quality of studies available in the current literature resulting in the inability to perform a meta-analysis.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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