

1 ABSTRACT

2 **Background:** In patients with patellar instability and severe trochlear dysplasia, trochleoplasty has become
3 increasingly used as part of the surgical management.

4 **Hypothesis:** Deepening trochleoplasty for severe dysplasia in patellofemoral instability improves function and
5 increases sports participation.

6 **Study Design:** Case series; Level of evidence, 4.

7 **Methods:** Between 1995 and 2010 the thick-flap deepening trochleoplasty was performed in 90 patients (107
8 knees) with severe trochlear dysplasia. Data was collected prospectively pre-operatively, at 6 weeks and 1-year
9 follow-up. The patients were surveyed retrospectively to determine the clinical and functional outcomes
10 including sports and exercise participation at a minimum of 2 years, with complete data available in 92%.

11 **Results:** With a minimum follow-up of 2 years, average of 6 years (range 2 – 19 years). The Kujala score had a
12 median and interquartile range (IQR) of 63 (47-75) pre-operatively rising to 79 (68-91) at 1 year follow-up and
13 84 (73-92) at final follow-up ($p < 0.05$). Seventy-two per cent were satisfied with their knee function at 1 year
14 follow-up rising to 79% at final follow-up ($p < 0.0001$). Sports and exercise participation increased from 36
15 patients (40%) pre-operatively to 60 (67%) at final follow-up. The numbers involved in competitions increased
16 slightly from 10 (11%) to 11 (12%). Of those sports that involved twisting (e.g. soccer, cricket, badminton), the
17 proportion of patients participating increased from 16 (18%) to 22 (24%), whereas in non-twisting sports (e.g.
18 running, swimming, cycling) it increased from 24 (27%) to 47 (52%) of whom 14 (16%) used walking as
19 exercise.

20 **Conclusion:** The thick-flap deepening trochleoplasty improves the clinical and functional outcomes for patients
21 with symptomatic patellar instability with severe trochlear dysplasia. These results improve over time and
22 beyond the 1 year clinical follow-up. However trochleoplasty does not lead to a significant improvement in
23 sports participation at a competitive level. It does improve the sports and exercise patient participation,
24 principally in non-twisting sports activities.

25 **Keywords:** Patellar dislocation; trochleoplasty; mid-term; clinical outcomes, sports

26 **What is known about the subject:** Trochleoplasty is an increasingly popular operation for severe trochlear
27 dysplasia. A number of series have shown satisfactory outcomes with minimal complications

28 **What this study adds to existing knowledge:** This is the first study to report sports outcomes for this
29 operation. A new variant of the operation is presented using a thick osteochondral flap and arthroscopy-assisted
30 technique.

31 INTRODUCTION

32 Trochlear dysplasia is increasingly recognised to be an important anatomical abnormality in those patients
33 presenting with patellar instability^{9,17}. Correction of the dysplasia encompasses a number of techniques which
34 can be classified into: trochlear lengthening osteotomy⁷, proximal open trochleoplasty¹,
35 deepening trochleoplasty^{6,13} and arthroscopic deepening⁸. The deepening trochleoplasty has two main
36 described methods; the Bereiter^{6,27,34} and the Dejour^{12,13,26}. The former raises a thin flexible flap of articular
37 cartilage and then removes the excess subchondral bone fashioning a groove. The thin flap is then anchored by
38 an absorbable tape along the depth of the groove. In the latter subchondral bone is removed but leaves an even
39 thickness of subchondral bone along the flap and the new groove is formed by an osteotomy of the flap and
40 depressing the two sides. These are then held with staples.

41 This paper reports the results of a cohort of patients who have undergone a deepening trochleoplasty
42 that is a modification of the Dejour technique. Two triangular flaps (lateral and medial trochlear facets) are
43 created where the subchondral bone is removed under arthroscopic guidance leaving cancellous bone attached.
44 The flaps are depressed and held with absorbable sutures. The principle is that the patella articulates and
45 maintains congruence with the lateral trochlear facet. The medial facet is depressed posteriorly to avoid
46 incongruence. The aim of this paper is to report the mid-term results of this trochleoplasty including the sports
47 and exercise activities of the cohort. Our hypothesis was that the operation would improve knee function and
48 lead to an increase in sports participation in the patients.

49 PATIENTS AND METHODS

50 Patients

51 Between January 1995 and December 2010, 102 patients (122 knees) underwent a trochleoplasty at the Norfolk
52 & Norwich University Hospital identified from the institution's prospective database. All had been referred to a
53 dedicated Patellar Instability Clinic from various parts of the United Kingdom and abroad.

54 The indications for the trochleoplasty were patients with recurrent symptomatic patellar instability,
55 with at least one documented dislocation of the patella that had either failed physical therapy and/or previous

56 patellar stabilisation procedure(s), with a severe trochlear dysplasia as defined on a lateral plain radiograph with
57 a boss height of ≥ 4 mm.

58 Clinical assessment and outcome scores

59 The data was collected using the Bluespier Data Management software (Bluespier Int, Droitwich, UK). Its use
60 for research purposes and report writing has been granted by the National Research Ethics Service. A standard
61 pre-operative clinical assessment that included assessment of patellar apprehension (graded from 0 to three
62 pluses where 0 equalled no apprehension, + discomfort on extreme lateral, translation of the patellar in
63 extension, ++ true apprehension with voluntary quadriceps contraction on lateral translation in extension and
64 +++ when the patient stops the clinician touching the patella), patellar tracking and patellofemoral crepitus¹⁴.
65 Pre-operatively, all patients completed the Kujala Patellofemoral Disorder Score ²¹. Post-operative outcome
66 scores were performed by postal questionnaire and collected between June and December 2013. Data routinely
67 collected included: questions on return to sports, satisfaction (very satisfied, satisfied, disappointed, unsatisfied),
68 and the Norwich Patellar Instability (NPI) Score ³¹. The NPI score is a 19 item validated patient reported
69 outcome measure for patellar instability symptoms. The best score is 0% and worst 100%. For all non-
70 responders of the postal questionnaire, data was collected through a supplementary telephone questionnaire one
71 month after the initial posting to collect the same data.

72 Sporting activity was defined by the major exercise performed. This was graded as to whether the
73 patient took part in competitions, played regularly, or participated as a leisure activity according to the Arpège
74 scoring system ². Those that were active in sports had this graded by the Tegner Activity score ³³ where
75 swimming was defined as level 4. Walking was defined as a sport if undertaken regularly as part of a deliberate
76 attempt to stay fit.

77 Patients were stratified into weight classes according to their body mass index. Obesity was defined as
78 a BMI ≥ 30 kg/m². Hypermobility was measure using the Beighton score ⁵ and was defined as a score ≥ 4 . The
79 Beighton score was only routinely recorded from 2007.

80 Successful outcome at sports and exercise

81 A successful outcome was defined as returning to sports and exercise at the same level or better, or commencing
82 sports and exercise having previously not done so. An unsuccessful outcome was defined as reducing sporting
83 activity including downgrading level of sport e.g. from competitive to recreational.

84 Radiographic assessment

85 Radiographic assessment included: plain anteroposterior, true lateral and skyline weight-bearing radiographs
86 performed at 30 degrees knee flexion. Trochlear dysplasia was defined radiographically on the true lateral
87 radiograph as a boss height measuring more than 4 mm (see Fig 1). Dejour¹³ defined the boss height at 6mm.
88 This was reduced by the senior author in the light of experience; 6mm in a tall patient may not be significant
89 whereas 4mm in a short patient is. The dysplasia was classified using both Dejour systems^{11,13}. Patellar height
90 was measured using the Caton-Deschamps classification¹⁰.

91 Operative intervention

92 All operations were performed by the senior author using a previously reported technique¹⁵ which was a
93 development of that described by Ntagiopoulos et al²⁶. In summary, through a standard medial parapatellar
94 approach, a wedge of subchondral bone is removed deep to the trochlea with its apex at the anterior end of the
95 intercondylar notch (see Fig 2). Viewed from the anterior surface, the wedge on the lateral view is a rhomboid
96 shape (see Fig 3). The new groove is cut with an osteotome or fine saw from the apex in line with the
97 anatomical axis of the femur. This results in two triangular osteochondral flaps. The lateral flap has a more acute
98 angle so that as it folds down it re-creates the lateral flare. The medial flap folds on a near transverse line to
99 displace it posteriorly; this helps avoid impingement on the medial facet of the patella when it is realigned. The
100 flaps are depressed after removing bone up to the cartilage along the flap line (see Fig 4). They are then held in
101 place with absorbable sutures, although a variety of materials from metallic and absorbable screws, as well as
102 suture anchors were used in the cohort. A bare area of cancellous bone is created proximally that that is partially
103 covered by the synovium overlying the supracondylar fat pad (see Fig 5). Lateral release is rarely needed as the
104 retinaculum is relaxed by reducing the patella into the new groove. Double-breasting medial reefing was always
105 performed as the medial retinacular flap overlies the new patellar position. The medial soft tissue is reinforced
106 with a medial patellofemoral reconstruction when the double-breasting medial reefing is deemed inadequate due
107 to poor quality tissue allowing lateral tracking of the patella.

108

109 No chemical thromboprophylaxis was given at the start of the study. For the last 5 years the patients are given
110 chemical thromboprophylaxis according to hospital guidelines. The rehabilitation protocol has been previously
111 reported ²⁸. In essence, patients are immediately commenced on unrestricted continuous passive motion (CPM)
112 whilst an epidural catheter is *in situ*. This continues until the patient can independently manage their early
113 exercise regime of knee range of motion exercises and a quadriceps strengthening regime. Patients commence
114 mobilisation as soon as possible, with no restriction on range of motion or weight-bearing. Only patients who
115 undergo a tibial tubercle transfer require a brace; this is initially limited from 0° to 90° during the initial 6 post-
116 operative weeks. Rehabilitation continues in an out-patient setting. This focuses on a graded-exercise
117 programme with the aim of returning patients to their desired level of functional and sporting capability. The
118 patients are routinely followed up at 6 weeks where complications are recorded and at 1-year where they
119 undergo clinical and radiological assessments.

120 Statistical analysis

121 Following assessment of data distribution, results were initially analysed using descriptive statistics (median and
122 inter-quartile range) pre- and post-operatively (12 months and final follow-up). Difference in pre- to post-
123 operative clinical and radiological outcomes were assessed using non-parametric Wilcoxon Matched Pairs test
124 with data presented with 95% confidence interval. Assessment of frequency to return to sporting participation
125 and level of sporting participation was assessed at the final follow-up. All analyses were performed on SPSS
126 (PASWStatistics 18.0 software), with statistical significance set at a $p < 0.05$ level.

127 RESULTS

128 Cohort Characteristics

129 Of the 102 patients, six patients were excluded because the diagnosis was patellofemoral arthritis. A further six
130 were excluded because they underwent a different type of trochleoplasty (Bereiter $n = 2$, modified Albee $n = 1$,
131 Excision $n = 3$). Therefore the trial cohort consisted of 90 patients with 107 affected knees. Of these patients, 20
132 had had bilateral trochleoplasties but three of these knees were excluded as one knee was operated on for pain
133 alone without patellar dislocation, and two knees were operated after the study period. Fifty-four (60%) were

134 female, and 36 (40%) male. The average follow-up was 6 years (range 2 to 19 years). Fifty (56%) of the patients
135 were from outside the local area. The right knee was operated on in 49 (46%) and the left in 58 (54%). Forty-
136 five (42%) of the knees had undergone previous surgery of which seven had had multiple procedures, 19 had a
137 patellar stabilisation, six had had an arthroscopic lateral release and 11 had had an arthroscopy, usually to
138 remove a loose body. Forty of the knees underwent trochleoplasty alone. At the same time as the trochleoplasty
139 a further 14 had a medial patellofemoral ligament reconstruction in addition, and a medialisation tibial tubercle
140 osteotomy in 10, which occurred in the first 20 knees. One patient with a permanent dislocation underwent
141 proximalisation of the tibial tubercle because of a patella infera. The initial 10 patients had metal screw fixation
142 following which bioabsorbable screws were used in 54 of which five had suture anchors used for the medial
143 flap. The final 43 had absorbable sutures to fix the flaps. A patelloplasty (usually a microfracture) was
144 performed in 16, excision of a medial ossicle in 10, and a lateral release in 28 of which five just involved
145 releasing the deep transverse ligament from the patella. Four patients had metalwork removed from previous
146 surgery.

147 The average age at first dislocation was 13.7 years (range 1 to 28 years). The mean age at operation
148 was 23 years-old (range 12y to 49y). The average BMI was 24kg/m² with four patients underweight, 54 of
149 normal weight, 31 overweight, six obese, and one severely obese. The Beighton score was recorded in 60
150 patients of whom 20 (34%) were hypermobile. The heterogeneity of the cohort with respect to positive family
151 history, hypermobility, and obesity of those patients is shown in Fig 6.

152 Clinical outcomes

153 The clinical findings with respect to apprehension, tracking type and range of knee motion at 1 year are shown
154 in Table 1. The mean time to return to work or school was 7 weeks (IQR 4 to 12). . At 1 year six knees had
155 persistent swelling associated with instability from poor muscle control. The Kujala score had a median and
156 interquartile range (IQR) of 63 (47-75) pre-operatively rising to 79 (68-91) at 1 year follow-up and 84 (73-92) at
157 final follow-up (p < 0.5, Mann-Whitney U test pre-operative vs final follow-up). The NPI score at final follow-
158 up had a median of 29% (IQR 5% to 44%). The satisfaction scores significantly improved between 1 year post-
159 operatively and final follow-up (Table 2).

160 Post-operative complications

161 In the first 6 post-operative weeks two patients had a venous thrombotic event, one deep vein thrombosis and
162 one pulmonary embolus. The latter went on to require an open arthrolysis and still had a stiff knee at final
163 follow-up. Four knees had a superficial wound infection; there were no deep infections. Four patients
164 complained of significant crepitus at 1 year of whom two had had a patelloplasty.

165 Further operations

166 Further operations were undertaken in 19 knees of which were 10 MPFL reconstructions (for continuing
167 instability symptoms and a mediolateral glide in extension of more than two quadrants displacement) within
168 which two were revisions, seven arthroscopic arthrolyses (from the early cohort of patients before post-operative
169 continuous passive motion was introduced) and two removal of loose absorbable screw heads, one was an open
170 arthrolysis (in the patient who had had a pulmonary embolus), and one patient required arthroscopic
171 debridement of a notch “osteophyte” where a drill hole had been inadvertently made through the notch during
172 the trochleoplasty.

173 Radiological outcomes

174 The pre-operative dysplasia type was B in 49, C in 3, and D in 54 knees; one was unclassifiable. The operation
175 removed the supratrochlear spur in all cases. The radiological outcomes are shown in Table 3. Patella alta was
176 present in 16 knees prior to surgery. Patients did not undergo distalisation of the tibial tubercle. In these knees
177 the pre-operative mean patellar height was 1.31 (sd 0.11) changing to 1.11 (sd 0.16, $p = 0.0008$) post-
178 operatively. Four knees remained with a patella alta, two higher than pre-operatively.

179 Sports and exercise

180 The pre- and final follow up sports and exercise data are shown in Table 4. The dominant post-operative sport
181 was swimming ($n = 16$ or 27% of the sports active cohort). A further 18 (30%) undertook exercise that directly
182 reflected activities undertaken during rehabilitation (gym, and walking) of whom 10 had not undertaken regular
183 exercise pre-operatively. The median time to return to sports was 24 weeks (IQR 20 to 36).

184 Successful outcome for sports and exercise

185 A successful outcome with respect to sports was found in 54 patients and unsuccessful in 33 (three were
186 excluded for lack of data). Success at sports did not correlate with gender, age at first dislocation, age at

187 operation, whether the patient had had previous surgery, a positive family history, hypermobility syndrome, pre-
188 operative Kujala score, pre-operative apprehension grade, pre-operative tracking type or the presence of a
189 quadriceps lag pre-operatively.

190 DISCUSSION

191 This study shows that patients undergoing the thick-flap deepening trochleoplasty for symptomatic recurrent
192 patellar dislocation improve significantly functionally and that this improvement continues over time. Sports
193 and exercise participation, in an amateur population, improved from 40% of the cohort to 67% with the
194 dominant activity being non-twisting. Swimming was the commonest exercise undertaken following the
195 operation. Improvements in Kujala score matched those from other studies ^{3,25,27,34}, however it should be noted
196 that the thick-flap trochleoplasty does not require normal articular cartilage whereas the thin flexible flap created
197 in the Bereiter technique does. Therefore this study's cohort of patients overall had a severity of trochlear
198 dysplasia with chondral changes not matched by other series. Patients with severe trochlear dysplasia and
199 chondral damage are treated with patellofemoral arthroplasty.

200 Patient selection for a deepening trochleoplasty depends on the level of symptoms, the aims of the
201 patient with respect to activities, and the severity of the trochlear dysplasia. The definition of severe trochlear
202 dysplasia is imprecise and has not been universally agreed. Both quantitative measurements and the Xray
203 classification are used ²². The quantitative measurements are not stated but the use of measurements such as the
204 sulcus angle is implied. The inter- and intra-observer reliability of the radiological measurements used in
205 patellar instability is generally poor ³⁰. David Dejour's classification ¹¹ based on trochlear shapes classified from
206 Type A to D is also recommended²². However the prevailing view is that severe trochlear dysplasia is defined
207 by Dejour Types B to D ^{3,4,32}. Henri Dejour's classification ¹³ was used in this study with the indication being a
208 boss height of > 4mm. Having said that the senior author's view is that there is still a qualitative element in the
209 decision making. This includes the patient's personality and the likelihood of their undertaking rehabilitation.
210 Patients who are obese are routinely advised to lose weight are generally excluded from this surgery. In addition
211 patients with hypermobility may be treated with an MPFL reconstruction alone since the elasticity of the
212 ligaments allows for the anterior displacement of the patella as it tracks over the trochlear boss. Patients with a
213 positive family history often decline surgery and treat by self-reduction and rehabilitation after a dislocation
214 episode.

215 In this cohort the patients underwent the Dejour protocol ¹³ with medialisation of the tibial tubercle for
216 an excessive tibial tubercle-trochlear groove (TTTG) distance (>20mm). It subsequently became apparent that
217 the TTTG is reduced by the trochleoplasty and that a distal procedure was unnecessary. Although the current
218 view is that distalisation of the tibial tubercle should be performed when patella alta is present, it should be
219 noted, from this study, that the trochleoplasty procedure itself tends to lower the patella. This suggests that the
220 combination of an open approach and medial reefing leads to a distal soft tissue contracture. It is unlikely that
221 the posterior displacement of the patella is automatically coupled with a distalisation. The distalisation is an
222 advantage as most patients have a patella alta, which is then corrected. The patient with a significant pre-
223 operative patella infera was corrected with a formal proximalisation of the tibial tubercle (the osteotomy also
224 aided exposure). As a rule distal procedures are avoided as it typically stops kneeling. However patients with a
225 permanent dislocation always need extensive multiple procedures that may include lateral release and
226 disinsertion of the quadriceps, tibial tubercle osteotomy, and rotational osteotomies of the femur and/or tibia.

227 Combining an MPFL reconstruction with the trochleoplasty as a routine has been advocated ^{4,25}. This is
228 stated to improve the stability of the patellofemoral joint. In this study, where 14 of the cohort had an MPFL
229 combined with the trochleoplasty, a further eight required the procedure subsequently. However 81 (87%) did
230 not. An unstable patella can be due to a severe trochlear dysplasia and/or an abnormal soft tissue envelope. The
231 MPFL stops lateral displacement of the patella and can be measured clinically by the mediolateral glide test. A
232 trochleoplasty alone should not be expected to correct patellar maltracking *per se*. It is probable that those
233 patients who needed a subsequent MPFL reconstruction had insufficient medial tissues and reflects a failure of
234 the double-breasting medial reefing. It is therefore perfectly logical to suggest that an MPFL reconstruction
235 should be always added to a trochleoplasty.

236 The importance of considering the tunnel position in the presence of severe trochleoplasty has recently
237 been reported ²⁰; performing a trochleoplasty should mean that the anatomical position has become near normal.
238 The two revision MPFLs reported were patients with open physes at the time of the trochleoplasty who had a
239 free hamstrings MPFL reconstruction. Revision using adductor magnus tendon left distally inserted in the
240 adductor tubercle was then chosen although this method is known to be less satisfactory in a paediatric
241 population ²³,

242 The potential problems of a trochleoplasty include chondrolysis and the development osteoarthritis. No
243 study has reported these to have occurred ^{3,25,26,27,34}, although von Knoch et al ³⁵ reported radiological changes in
244 33 knees out of 45 with 10 knees showing an Iwano grade of 2 or more.at an average follow-up of 8.3 years.
245 This study did not include radiological imaging at final follow-up. It can be inferred that since the Kujala and
246 satisfaction scores improved from 1 year to final follow-up then rapid degenerative changes are unlikely to be
247 occurring. It is known from the historical literature ²⁴ knees operated for patellar dislocation had a higher rate of
248 subsequent osteoarthritis than unoperated knees (NB the former were more symptomatic). The logic of the
249 trochleoplasty is to create a groove and reduce the patellofemoral joint reaction forces, and hopefully reduce the
250 risk of developing OA. This will require follow-up studies of 20 to 30 years duration. The alternative to a
251 trochleoplasty for reducing the patellofemoral joint reaction force is to perform an anteromedial tibial tubercle
252 osteotomy ¹⁸. This may well be satisfactory for patients with milder forms of trochlear dysplasia, especially in
253 the presence of severe cartilage lesions and pain, but it is difficult balancing a tennis ball on a football.

254 The problem with research in patellofemoral instability is that there is no consensus on; definitions of
255 terminology ¹⁹, relevant descriptors of cohort heterogeneity, clinical examination tests and their outcome
256 measures ²⁹, or an examination tool for the unstable patella (cf the KT-1000 for ACL rupture which
257 revolutionised research in the subject). Only recently has a validated dedicated outcome measure become
258 available ³¹. The current radiological assessments have poor inter- and intra-observer agreement ^{16,29}. The
259 weaknesses in this study relate to the retrospective nature of the final outcome data, and the lack of a dedicated
260 patellar instability pre-operative score. In addition there is no tool available that accurately assesses the level of
261 sports in an amateur population. Here the dominant sport was chosen, yet most amateurs undertake a number of
262 activities, all of which contribute to their overall fitness. The definition of success at sports can also be
263 criticised, however the population with severe trochlear dysplasia includes patients with severe problems and
264 limited goals. Typically a young adult female wants to be able to climb and descend stairs carrying a baby
265 safely. For them achieving regular walking as a fitness activity is a triumph.

266 The weakness of this study is that the final follow-up is remote and does not include a clinical and
267 radiological assessment. However this is the first study in a population of patients with recurrent patellar
268 dislocation that reports on their sports and exercise activities. The population cohort has an extreme level of
269 anatomical abnormalities far greater than would be seen in a typical sports practice with a knee interest. It is

270 important to note that functional improvement and satisfaction continues in the follow-up period and would
271 appear to reflect improving muscle function. This study also reports on a method of undertaking a deepening
272 trochleoplasty where the aim is to keep patellofemoral congruence by rotating the patella with the new lateral
273 facet of the femur in the hope of reducing the risk of later-onset osteoarthritis.

274 Conclusions

275 The thick-flap deepening trochleoplasty improves the clinical and functional outcomes for patients with
276 symptomatic patellar instability with severe trochlear dysplasia. These results improve over time and beyond the
277 1 year clinical follow-up. However trochleoplasty does not lead to a significant improvement in sports
278 participation at a competitive level. It does improve the sports and exercise patient participation, principally in
279 non-twisting sports activities.

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361 **Figure legends**

362

363 Fig 1. Pre-operative lateral radiograph showing a type III / D trochlear dysplasia in a patient who had
364 undergone a previous medialisation of the tibial tubercle.

365 AB is the extension line of the anterior femoral cortex

366 CD is the boss height (measures 6mm)

367 Fig 2. Lateral radiograph of the knee showing the wedge of subchondral bone removed as part of the
368 trochleoplasty

369

370 Fig 3. Intra-operative photograph of a dysplastic trochlea with the hip to the left

371 AB is the lateral fold line,

372 AC is the medial fold line.

373 AD is the proposed new groove line.

374

375 Fig 4. Intra-operative photographs of a left knee seen from the foot showing the trochlea before and after the
376 deepening trochleoplasty

377

378 Fig 5. Intraoperative photograph showing the completed trochleoplasty from the lateral side (hip is to the
379 right) with the supracondylar synovium reattached.

380

381 Fig 6. Diagram of the heterogeneity of the patient population with respect to family history, obesity and
382 hypermobility.