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1 A KNEE BRACE ALTERS PATELLA POSITION IN PATELLOFEMORAL
2 OSTEOARTHRITIS: A STUDY USING WEIGHT BEARING MAGNETIC
3 RESONANCE IMAGING.

4

5 ABSTRACT

6 Objective: To assess using weight bearing MRIs, whether a patellar brace altered
7 patellar position and alignment in patellofemoral joint (PFJ) osteoarthritis (OA).

8

9 Design: Subjects age 40-70 years old with symptomatic and a radiographic K-L
10 evidence of PFJOA. Weight bearing knee MRIs with and without a patellar brace
11 were obtained using an upright open 0.25 Tesla scanner (G-Scan, Easote Biomedica,
12 Italy).

13 Five aspects of patellar position were measured: mediolateral alignment by the bisect
14 offset index, angulation by patellar tilt, patellar height by patellar height ratio (patellar
15 length / patellar tendon length), lateral patellofemoral contact area and finally a
16 measurement of patellofemoral bony separation of the lateral patellar facet and the
17 adjacent surface on the femoral trochlea (Figure 1).

18

19 Results: Thirty participants were recruited (mean age 57 SD 27.8; BMI 27.8 SD 4.2);
20 17 were females. Four patients had non-usable data. Main analysis used paired t tests
21 comparing within subject patellar position with and without brace.

22 For bisect offset index, patellar tilt and patellar height ratio there were no significant
23 differences between the brace and no brace conditions. However, the brace increased
24 lateral facet contact area ($p = .04$) and decreased lateral patellofemoral separation ($p =$
25 $.03$).

26 Conclusion: A patellar brace alters patellar position and increases contact area
27 between the patella and femoral trochlea. These changes would lower contact stress
28 at the PFJ. Such changes in patella position in weight bearing provide a possible
29 biomechanical explanation for the success of the PFJ brace in clinical trials on
30 PFJOA.

31

32 INTRODUCTION.

33 Patellofemoral (PF) osteoarthritis (OA), a common subtype of knee OA, is a major
34 cause of pain with stair climbing, arising from a chair and activities involving
35 kneeling or squatting. It is associated with pain, stiffness and functional limitation^{3, 5}.
36 Guidelines for the non-surgical management of generalised knee OA found 'fair'
37 quality of evidence for the use of knee braces and knee sleeves ^{21 9}. Treatment of
38 PFOA is similarly limited but one potential treatment is a patellar sleeve device.
39 Evidence for its clinical efficacy is provided by two clinical trials in PFOA^{1,8}. These
40 trials had positive effects on pain and structure from wearing a patellar sleeve brace
41 compared to no brace¹ and on pain with or without the patellar retaining strap.⁸
42 One of the proposed reasons for this clinical success is that the patellar brace may,
43 during weight bearing activities, change patellar alignment and alter patellar tracking
44 relative to the trochlear groove both of which are considered major contributions to
45 the pathomechanics of PF pain. Whilst a brace's effects on the biomechanics of the
46 PF joint are still not well understood, there is evidence from studies in non-arthritic
47 PF pain that it may correct malalignment¹⁷ and increase contact area of the PF joint¹⁸.
48 This distribution of forces over a greater area could decrease the contact stresses.
49 Several authors agree that magnetic resonance imaging (MRI), with its capability of
50 viewing the patellar position in various planes, is more useful and informative than

51 plain radiography^{6, 10,12}. MRIs also have the advantage of using non-ionising radiation
52 enabling repeated imaging, as in the present study, with and without a brace. Weight
53 bearing MRIs may give a more valid view of PF congruence and position under
54 natural loads exerted by body mass. Patellofemoral position is usually assessed
55 clinically through palpation of the patella through a range of motion or by observing
56 the motion of the skin over the patella. This assessment is commonly performed in a
57 seated, unloaded posture that does not reflect joint movement during functional,
58 weight bearing tasks.

59 To date, one study has used weight bearing MRIs to assess braces on non-arthritic,
60 symptomatic PF pain⁴. To our knowledge there have been none assessing PFOA,
61 although McWalter et al¹¹ assessed a knee sleeve in PFOA with *simulated* weight
62 bearing MRIs by applying 15% of body weight of axial load through the patient's
63 foot.

64 Since PFOA is likely to affect either medial or lateral patellar compartments⁷, the
65 effects of braces on patellar position might have a bearing on treatment choices and
66 brace design. Consequently, the weight bearing MRI may give a more realistic view
67 of PF congruence and be a more appropriate technique when assessing patella
68 position.

69

70 Purpose

71 The purpose of this study on PFOA was to use weight bearing MRIs to assess whether a
72 sleeve brace altered patellar position. The hypothesis was that there would be differences in
73 measures of PF position after the application of a patellar brace compared to no brace.

74

75

76 METHODS

77 The study was approved by the XXX Local Research Ethics Committee (Ethics number
78 09/H1012/35). It was performed at the XXXX and at the University XXXX

79

80 Subjects

81 We recruited a subset of subjects age 40-70 years who had been enrolled in a previous
82 randomized trial of patellar brace treatment for people with PFOA². They had a K-L
83 score grade 2 or 3 in the PF compartment which was greater than K-L score for the
84 tibiofemoral compartments (this score required at least probable narrowing of the PF
85 joint on X-ray and definite osteophytes in the PF compartment). Those who did not
86 have plain radiographs were assessed for PFOA by either MRIs or arthroscopy, for
87 which we required typical changes of OA with at least cartilage loss present in the PF
88 joint. Subjects were also assessed by an experience clinician for PF joint symptoms
89 such as pain reproduced with stair climbing, kneeling, prolonged sitting or squatting
90 or if they had lateral or medial patellar facet tenderness on palpation or a positive
91 patellar compression test. Pain must have been present daily for the previous 3 months
92 and the pain had to be sufficiently severe for a nominated aggravating activity to score
93 of 40 or above on a 0-100mm visual analogue scale (VAS_{NA}). The VAS_{NA} has been
94 found to be at least as sensitive, and in some cases more sensitive to change than the
95 KOOS or WOMAC questionnaires^{13, 14}. Typically, subjects' nominated aggravating
96 activities were stair climbing, kneeling, prolonged sitting or squatting.

97

98 Exclusion criteria

99 Participants were excluded if they had a previous patellar fracture or patellar
100 realignment surgery, if the predominant symptoms emanated clinically from the

101 tibiofemoral joint, from meniscal or ligament injury, if they had rheumatoid
102 arthritis or other forms of inflammatory arthritis or if they had an intra-articular
103 steroid injection into the painful knee in the previous month. For the purposes of
104 the MRI, patients were excluded if they had a cochlear implant, metal objects in
105 the body including a joint prosthesis, a cardiac or neural pacemaker, a
106 hydrocephalus shunt, an intrauterine contraceptive device or coil, if they had
107 kidney dysfunction or were undergoing renal dialysis.

108

109 MRI procedures

110 Participants had MRIs of their knee joint using an upright open 0.25 Tesla scanner
111 (G-Scan, Easote Biomedica, Italy). Participants first remained supine for
112 approximately 5 mins to enable the recovery of viscoelastic structures in the knee, as
113 the participant had been weight-bearing prior to entering the scanner. Following this
114 rest period, an initial positioning scan (scout) was performed followed by axial and
115 sagittal plane scans. Scans had a TR range of 690 - 830ms and TE range of 14-28ms
116 with a slice thickness of around 4mm and a gap between slices of 0.4mm. The bed of
117 the MR scanner was then be tilted into the upright position 4 degrees inclined from
118 the vertical to allow weight-bearing. Foot position was controlled by aligning the
119 great toe with a piece of tape on the platform. The scan time for each sequence was
120 2:43 mins, with 1 acquisition. Subjects were randomised to the order of brace or no
121 brace by sealed opaque envelopes under the supervision of the study statistician.

122 Images were viewed off line.

123

124 Study Intervention

125 The brace intervention consisted of a Bioskin Patellar Tracking Q Brace (Ossur UK,
126 Stockport, England) (figure 1).

127

128 Patellar Alignment Measurements

129 Medical imaging software Clear Canvas Workstation (Version 7.0.0.) was used. All
130 images were anonymised so that examiners were blinded to the patient identification
131 and group conditions (brace or no brace).

132 Five measurements of patellofemoral alignment and congruence were taken.

133 Bisect offset index assessed medio-lateral patellar displacement relative to the femur

134 The technique was initially described by Stanford et al²⁰ and used by Powers et al¹⁶.

135 A line was drawn connecting the posterior femoral condyles on the slice in which the
136 posterior condyles were most obvious and a perpendicular line was projected up

137 through the deepest point (apex) of the trochlea. Then another slice was found on

138 which the patellar width was clearest and on which a line could be drawn to measure

139 the width. Finally, these two slices were superimposed allowing us to project the line

140 anteriorly from the bisection of the posterior condylar line through the second line on

141 the patella ¹⁶. To determine the patellar displacement by the bisect offset, the extent of

142 the patella lateral or medial to the perpendicular midline was expressed as a

143 percentage of the total patellar width. (Figure 2).

144 Medio-lateral patellar tilt angle was measured as the angle formed by the lines joining

145 the maximum width of the patella and the line joining the posterior femoral condyles

146 ^{15, 16} (Figure 3).

147 Lateral patellofemoral joint contact area was defined as areas of patella and femur

148 approximation in which no distinct separation could be found between the cartilage

149 borders of the two lateral joint surfaces (Figure 4). A line of contact was drawn

150 between the patella and the femur¹⁷. The contact area for each slice was measured and
151 multiplied by the length of the contact line with the slice thickness (0.4mm). Each
152 sequential image was summed to obtain the total lateral contact area $\Sigma (CL \times$
153 $(SL \times SG))$ (CL = contact length; SL = slice length; SG = slice gap) x (slice length +
154 slice gap). Because cartilage was relatively bright on fat suppressed fast spoiled
155 gradient echo images, we used the operation definition of contact area as white on
156 white¹⁷. The determination of non-contact was made when a line of separation could
157 be observed between the articular surfaces of the patella and trochlear groove.
158 The level of agreement between the MRI and pressure sensitive film techniques in
159 cadaver specimens was for ICC 0.91 and for CV 13%. When averaged across all
160 specimens, the contact area obtained through MRI was 2.94 (SD 1.01 cm²) while
161 the contact area obtained using the pressure sensitive film technique was 3.05
162 (0.95 cm²). The average individual specimen difference between the two methods
163 was 10.9%.

164 The Insall-Salvati ratio was measured on the sagittal views by a ratio between patella
165 tendon length relative to the superior-inferior length of the patella (patellar length /
166 patellar tendon length)¹⁹.(Figure 5).

167 Patellofemoral distance (the distance between the patella and the femur) was
168 measured to assess if the brace reduced the distance between the opposing surfaces of
169 the patella and the femur, specifically the lateral patellar facet and the adjacent surface
170 on the lateral femoral trochlea. First, the area between patella and femur was
171 determined by drawing a trapezoid on an axial slice where patellofemoral distance
172 was greatest. The average distance between the patella and femur was measured by
173 dividing the area (automatically calculated by the Clear Canvas program) by the
174 longest side of the trapezoid (Figure 6).

175 Reliability

176 Inter rater reliability for the MRI measurements was assessed between two assessors
177 using a 2 way random model for absolute agreement inter-class correlation coefficient
178 ($ICC_{2,1}$). The results were for bisect offset index $ICC_{2,1}$ 0.97 (95%CI 0.96, 0.98) SEM
179 2.6, for patellar tilt angle $ICC_{2,1}$ 0.96 (95%CI 0.94, 0.97) SEM 1.43⁰, for lateral
180 patellofemoral joint contact area $ICC_{2,1}$ 0.73 (95%CI 0.53, 0.85), SEM 3.1cm², for the
181 Insall-Salvati ratio $ICC_{2,1}$ 0.95, (95%CI 0.80, 0.98) SEM 0.031, and for
182 patellofemoral distance $ICC_{2,1}$ 0.84, (95% CI 0.48,0.97), SEM 0.32cm.

183

184 Analysis

185 Data were visually analysed with histograms, Q-Q plots and Kolmogorov-Smirnov
186 tests which confirmed normality of distribution. The main within subjects analysis
187 used paired t tests comparing patellofemoral alignment and congruence with and
188 without a brace. Statistical significance was set at $p \leq 0.05$.

189

190 RESULTS

191 Thirty subjects with PFOA were recruited (mean age 57, SD 7.8years, BMI mean
192 27.8, SD 4.2); 17 were females (56%). Five subjects had their PFOA assessed by
193 MRIs or arthroscopy. Four patients had non-usable MRI data because of missing data
194 on some parameters or because of technical problems such as movement artefact.
195 Therefore 26 patients' data were analysed. There were no adverse events.
196 For bisect offset index, patellar tilt and patellar height ratio there were no significant
197 differences between the brace and no brace conditions. However, the brace significantly
198 increased lateral facet contact area (0.94cm², 95% CI 0.07, 1.8, $p = .04$) and decreased lateral
199 patellofemoral distance (-0.06cm 95% CI -0.12, -0.01, $p = .03$) (Table 1).

200 DISCUSSION

201 This is the first study using weight bearing MRIs on subjects with symptomatic PFOA
202 to evaluate the effects of bracing on the PF joint. It found that the brace significantly
203 increased the lateral contact area of the PF joint and decreased PF joint lateral
204 distance. The other measures of PF joint position (bisect offset index, patellar tilt and
205 patellar height ratio) were not altered significantly. MRIs are more useful and
206 informative than plain radiography by viewing the patellar position in various planes
207 ^{6, 10, 12}. MRIs also have the advantage of using non-ionising radiation enabling
208 repeated imaging, as in the present study, with and without a brace. Using a scanner
209 with the capability of providing standing weight bearing images adds to its usefulness.
210 Comparison with previous research is compromised by the few weight bearing studies
211 available, all of which were only done on non-arthritic PF pain. Draper et al.⁴ found a
212 patellar sleeve brace in females with non-arthritic PF pain produced non-significant
213 reductions in weight bearing patellar tilt (0°) and bisect offset (4%) at full knee
214 extension. Similarly, we did not find any significant differences in full knee extension
215 between our patellar brace and no brace in bisect offset (1.39%, 95% CI -2.3, 5.1) and
216 patellar tilt (-0.25° , 95% CI -1.61, 1.1). The reasons for different values recorded are
217 likely due to us assessing subjects with symptomatic PFOA and differences in the PF
218 brace design suggesting that commercially available braces may have different
219 biomechanical effects. McWalter et al.¹¹ is the only comparable study looking at the
220 same patellofemoral brace in the same knee condition, but differed from ours by using
221 knee flexion up to 50° and lying subjects in supine with a simulated body weight load
222 of 15%. They found the brace significantly altered patellar rotations and translations
223 compared to no brace but questioned its clinical significance because no reduction in
224 pain was observed in their parent trial⁸, which compared the brace with a modified

225 brace without a T-strap. The clinical significance of our findings for the parameters of
226 lateral contact area and lateral patellofemoral distance may also be questioned, even
227 though a clinically significant reduction in pain *was* observed in our parent trial which
228 compared the brace to no a brace control². As a result of our findings, we join with
229 Draper et al. ⁴ in asking whether the small changes observed with a brace are
230 sufficient to alter PF lateral contact area and lateral patellofemoral distance by a
231 clinically meaningful amount. The small increases we recorded in these parameters
232 concur with the work by Powers et al. ¹⁷ to explain the possible mechanism for the
233 decrease in PF pain. They found, albeit in non-arthritic PF pain, that compared to no
234 brace at full knee extension a PF brace had its greatest effect on lateral patellar facet
235 contact area, had clinically small but statistically significant effects on the bisect
236 offset index, but no effect on patellar tilt. They proposed the concept that the
237 increased contact area would result in a decrease in joint area stress. Our PFOA
238 subjects might have also benefitted from decreased joint area stress. Additionally,
239 they may have benefitted from a sense of stability and confidence created wearing the
240 brace. Although this was not objectively assessed in this study, patients in the parent
241 trial² reported that their knee felt more stable and secure from brace wearing.
242 All our subjects had an improvement in their VAS for a nominated activity and their
243 KOOS after wearing the patellar brace as part of a randomised trial². This trial, in
244 conjunction with the present study shows that a PF brace has both symptomatic and
245 biomechanical benefits for those with symptomatic PFOA.

246

247 LIMITATIONS

248 The limitations of this study are that the MRIs were taken only in a single WB
249 position, with no variability of knee flexion. The 0.2T field strength for the weight

250 bearing MRI scanner used in this study has implications for the contrast resolution
251 obtainable in an acceptable time. Participants were not blinded to the brace wearing
252 condition. Additionally, as this was a subgroup from a previous trial, there was no
253 further subgroup analysis of patients based on the severity or location of the PFOA.
254

255 CONCLUSION

256 A patellar brace significantly increases PFJ lateral contact area and decreases PFJ lateral
257 distance. This likely lowers contact stress at the PFJ. Such changes in PFJ position in
258 weight bearing provide a possible biomechanical explanation for the success of the PF
259 brace in clinical trials on PFOA.

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261 Trial participants

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263 Central Manchester NHS Foundation Trust,

264 Manchester Academic Health Sciences Centre, Manchester, UK

265 The R.O.A.M. team

266 Alex Ireland, at Manchester Metropolitan University

267 **Author contributions**

268 Conception and design: Callaghan, Felson, Reeves, Maganaris.

269 Analysis and interpretation of the data: Callaghan, Felson, Guney, Bailey, Hodgson.

270 Drafting of the article: Callaghan, Felson, Guney, Bailey, Hodgson.

271 Final Approval: Callaghan, Felson, Hodgson, Guney, Reeves.

272 Provision of study facilities or patients: Callaghan, Felson, Reeves, Maganaris,
273 Doslikova.
274 Statistical expertise: Felson, Callaghan, Hodgson.
275 Obtaining of funding: Felson, Reeves, Maganaris
276 Collection and assembly of data: Callaghan, Doslikova, Reeves, Maganaris, Bailey,
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278

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287

288 **Competing interests**

289 None of the authors have competing interests related to this work.

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Figure 1 The Bioskin Patellar Tracking Q brace.



Figure 2

Mediolateral displacement (Bisect Offset index)

Figure 2 a: ideal image to measure patellar width.

Figure 2 b: ideal image to view posterior condyles and trochlea

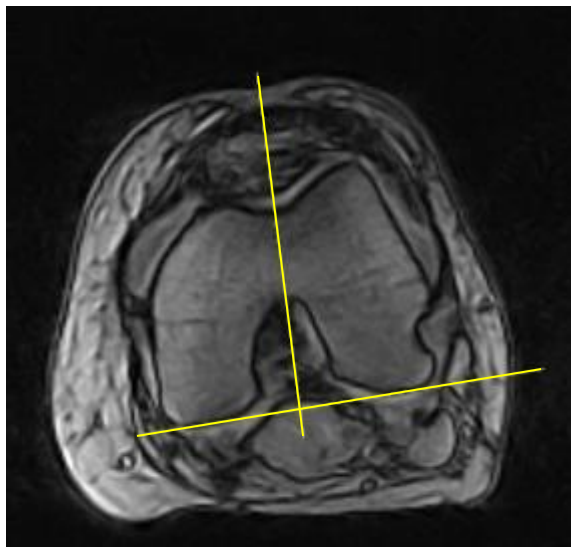
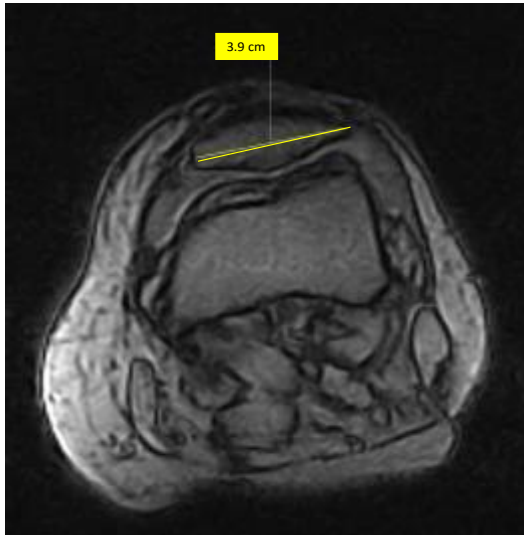


Figure 3
Patellar Tilt Angle

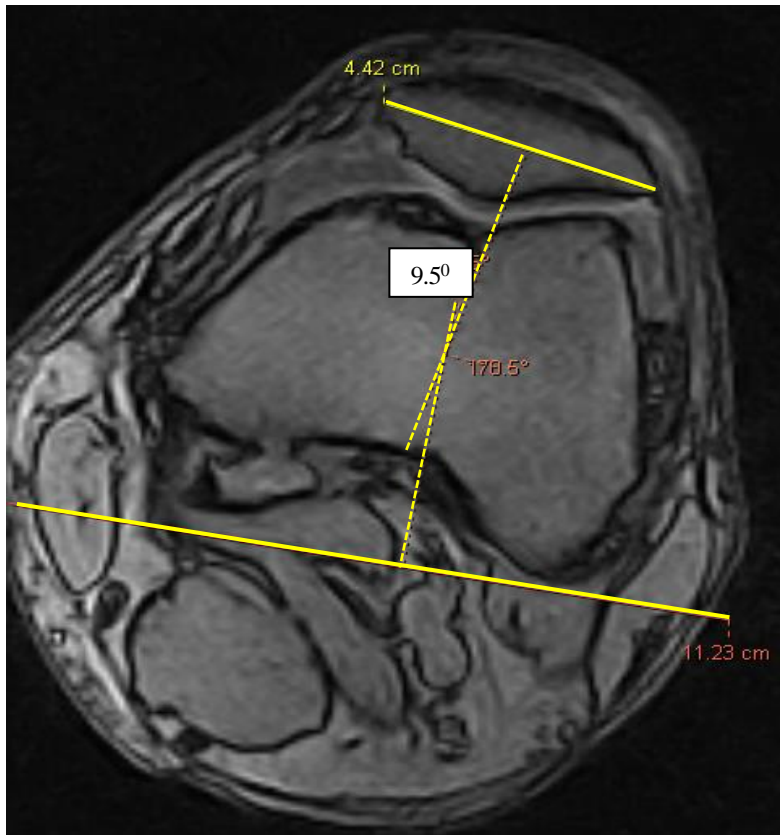


Figure 4
Lateral Patellofemoral Contact Area

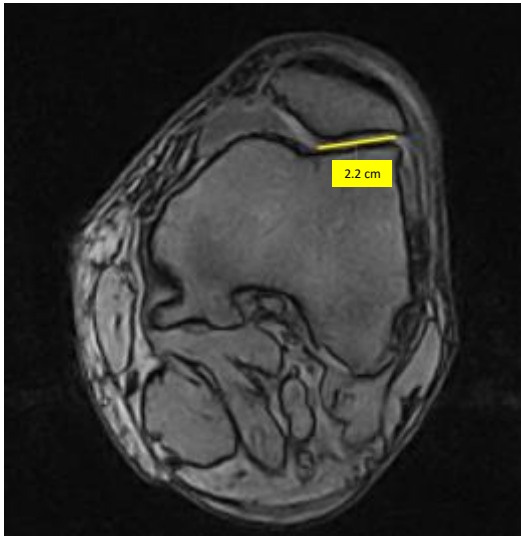


Figure 5
Insall-Salvati Ratio Patellar bone length / Patella tendon length



Figure 6
Patellofemoral Distance
Area of Trapezoid $a+b/2 \times h$ / length of lateral PF contact

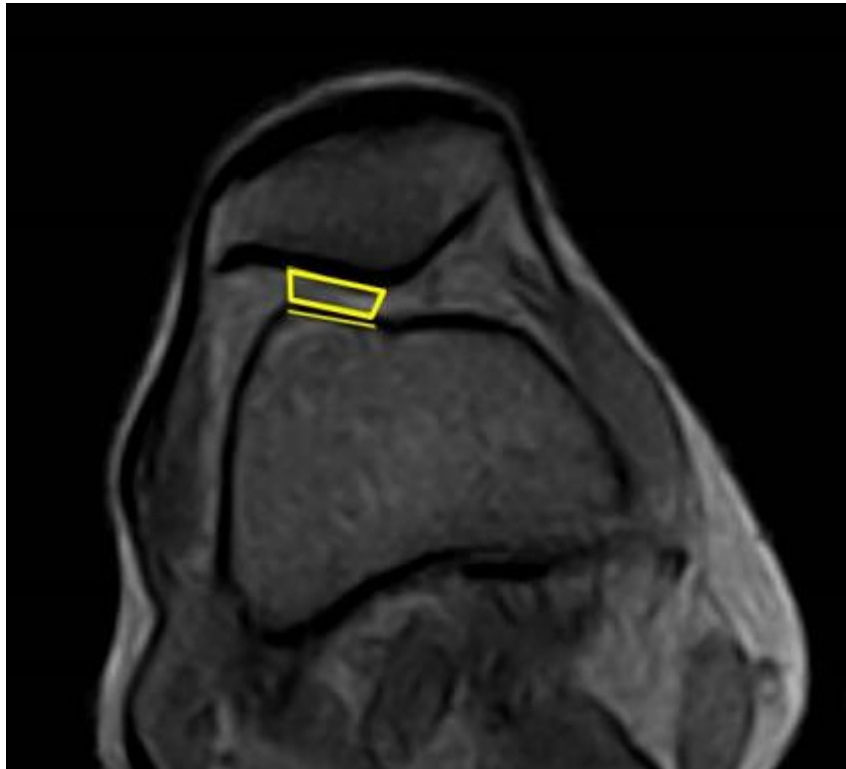


Table 1. Patients' Demographics

	Mean \pm SD
Age (year)	57.17 \pm 8.1
BMI (kg/m ²)	27.76 \pm 4.39
Gender (female/male)	15/13
K-L PFJ Score 3/2/1	12/6/1
K-L TFJ Score 3/2/1	12/5/2

Legend:

BMI = Body Mass Index
K-L = Kellgren Lawrence
PFJ = Patellofemoral Joint

Table 2 Results:

	Patellar tilt Mean (SD) deg N = 27	Bisect offset Index Mean (SD)% N = 27	Patellar length/ tendon length ratio Mean SD N = 27	Patellofemoral Lateral Contact area cm ² Mean SD N = 26	Patellofemoral Distance cm Mean SD N =26
Brace	8.63 (6.6)	72.4 (19.1)	1.0 (0.17)	2.73 (2.4)	0.27 (0.12)
No Brace	8.39 (4.9)	73.8 (18.4)	0.96 (0.13)	1.79 (2.2)	0.33 (0.13)
Mean difference	-0.25 (95% CI -1.61, 1.1)	1.39 (95% CI -2.3, 5.1)	0.05 (95% CI -0.01, 0.11)	0.94 (95% CI 0.07, 1.81)	-0.06 (95% CI -0.12, -0.01)
P value	0.71	0.44	0.09	0.04	0.03