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ORIGINAL ARTICLE

The influence of patellofemoral stabilisation surgery on joint congruity: an MRI surface mapping study

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Abstract

Background In the unstable patellofemoral joint (PFJ), the patella will articulate in an abnormal manner, producing an uneven distribution of forces. It is hypothesised that incongruency of the PFJ, even without clinical instability, may lead to degenerative changes. The aim of this study was to record the change in joint contact area of the PFJ after stabilisation surgery using an established and validated MRI mapping technique.

Methods A prospective MRI imaging study of patients with a history of PFJ instability was performed. The patellofemoral joints were imaged with the use of an MRI scan during active movement from 0° through to 40° of flexion. The congruency through measurement of the contact surface area was mapped in 5-mm intervals on axial slices. Post-stabilisation surgery contact area was compared to the pre-surgery contact area.

Results In all, 26 patients were studied. The cohort included 12 male and 14 female patients with a mean age of 26 (15–43). The greatest mean differences in congruency between pre- and post-stabilised PFJs were observed at 0–10 degrees of flexion (0.54 cm^2 versus 1.18 cm^2, $p=0.04$) and between 11° and 20° flexion (1.80 cm^2 versus 3.45 cm^2; $p=0.01$).

Conclusion PFJ stabilisation procedures increase joint congruency. If a single axial series is to be obtained on MRI scan to compare the pre- and post-surgery joint congruity, the authors recommend 11° to 20° of tibiofemoral flexion as this was shown to have the greatest difference in contact surface area between pre- and post-operative congruency.

Keywords MRI · Congruency · Patellofemoral joint · Stabilisation

Introduction

The patellofemoral joint (PFJ) is geometrically intricate, asymmetric and influenced by stabilising ligaments and kinematic forces about the knee. The movements of the patellofemoral joint are complex as reported by Goodfellow and colleagues [1]. The congruence of the patella within the trochlear groove provides stability and dispersion of force across the articulating surfaces throughout movement. Instability of the patella has been shown to decrease the articular surface contact area throughout active knee range of movement [2]. In a previous MRI mapping study of the PFJ, mean patellofemoral contact area was demonstrated to be greater in all ranges of movement in case control patients when compared to patients with known instability [2].

We hypothesise that surgical stabilisation of the PFJ will result in a demonstrable increase in congruency of the joint through active range of movement, when mapped on a multiple sequence MRI scan. PFJ stabilisation surgery may not

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only alleviate symptoms of instability but may influence the longevity of the joint by increasing congruency and therefore decreasing joint pressure.

While MRI mapping studies have demonstrated a statistically significant difference in the contact area of the PFJ between patients with and without instability, to our knowledge no study to date has measured the effect of stabilisation surgery on the congruence of the joint using MRI [2]. The purpose of this study was to record the change in joint contact area of the PFJ after stabilisation surgery using an established and validated MRI mapping technique [2]. We sought to identify the knee position at which the change in congruence was most apparent and performed multiple regression analysis in an attempt to identify significant predictors of change in congruence.

Methods

Ethical approval was sought and approved from the Southwest Research Ethics Committee via the Integrated Research Application System (IRAS) and all participants gave written informed consent. A single centre, prospective MRI imaging study of patients with PFJ instability (cases $n=26$) was performed. An MRI scan was used to capture the PFJ articular cartilage contact area in a range of degrees of flexion during quadriceps active knee movement. Inclusion criteria for the study cohort comprised PFJ instability in patients consented for surgical management (Fig. 1). The diagnosis of instability was a culmination of history, examination, and imaging investigations. The exclusion criteria included patients who were unable to provide valid consent, were unwilling to participate, aged 14 years or less due to skeletal immaturity, suffered degenerative knee joint disease (including any evidence of osteoarthritis observed on AP, lateral and skyline radiographic views), were pregnant, a history of metal objects in the soft tissues, or if they were un-contactable by telephone (Fig. 1). The patient group was recruited from the surgical waiting list at a tertiary elective orthopaedic unit. A single surgeon cohort of patients was studied. The nature of the operation was not influenced by participation in this study or results from the MRI imaging. Seventy-two patients identified as meeting the inclusion criteria were contacted by telephone to discuss participation. Thirty-nine of these patients agreed to participate in the study with 31 patients eventually undergoing the initial pre-surgery MRI scan. Although all these patients underwent surgery, only 26 underwent the post-surgical follow-up MRI scan (Fig. 1).

Statistical methods

The distribution of the data was assessed with a D'Agostino and Pearson test. If data were normally distributed, they are presented as mean and standard deviation (SD); conversely, if data were not normally distributed, they are presented as median and interquartile range (IQR). An independent sample, two-tailed t-test was used to compare mean joint congruence pre- and post-surgery. A multiple regression analysis was performed to determine predictors of change in mean congruence (cm^2), and independent predictors used in the model were whether the procedure involved a trochleoplasty, a tibial tubercle osteotomy or a medial patellofemoral ligament reconstruction, laterality, sex, age at time of surgery, tibial tuberosity–trochlear groove, Insall–Salvati ratio, Biedert patellotrochlear index, Dejour grade (B or higher), number of previous dislocations (2 or more) and Beighton score (4 or higher). The R2 values were inspected to determine whether multicollinearity was a problem in the model, if the R2 value was > 0.9 then the included variables were rationalised. Statistical significance was considered to be met at $p < 0.05$. Statistical analyses were carried out with GraphPad Prism (version 8.10, GraphPad Software Inc., San Diego, CA).

Information pertaining to age, symptoms, previous dislocations, hypermobility and imaging results (tibial tuberosity–trochlear groove, Insall–Salvati ratio, Biedert patellotrochlear index, Dejour grade) were obtained from patient records and measurements performed on the local picture archiving and communications systems (PACS). Based on history, examination, and investigations, one of five surgical procedures were performed for each patient. These include: trochleoplasty, trochleoplasty with tibial tuberosity osteotomy, medial patellofemoral ligament reconstruction, medial patellofemoral ligament reconstruction with tibial tuberosity osteotomy, and tibial tuberosity osteotomy in isolation. The post-surgery MRI scan was performed between six and nine months after the procedure.

MRI scanning protocol

MRI was performed with a GE Discovery MR450 1.5 T scanner (GE Healthcare, Waukesha Wisconsin, USA) and an eight-channel cardiac coil. The subject underwent a standard checklist where they were asked specific questions regarding comfort and safety in the MRI scanner. The patient was positioned supine with a triangular foam pillow under the knee. A beach ball was placed anterior

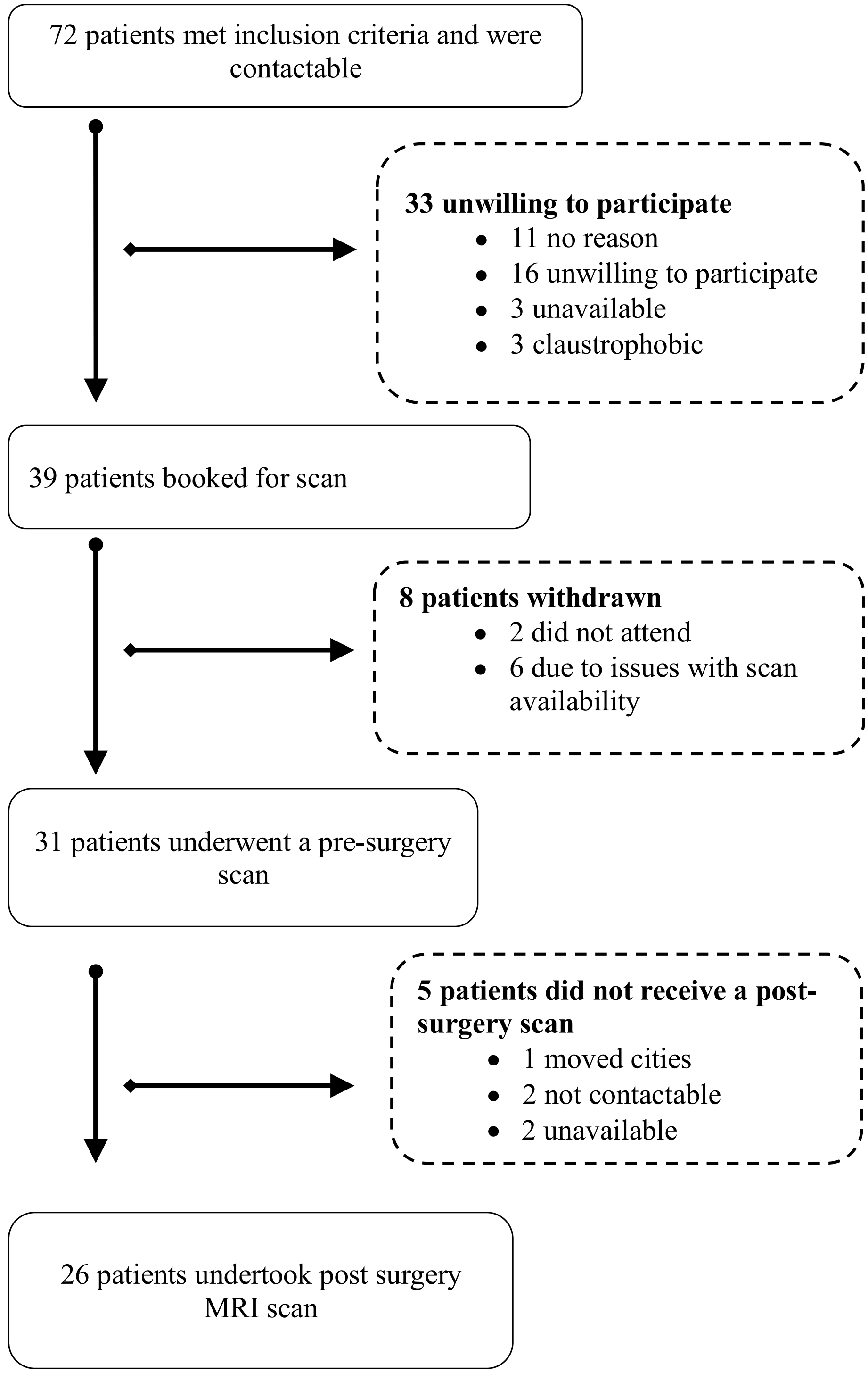

Fig. 1 Flow chart of case inclusion and exclusion

to the tibia with a valve under the control of the subject as described by Clark et al. [2]. The subject was asked to extend the knee, pushing the lower leg against the balloon and causing it to deflate. Subjects were advised that it would be expected to take two minutes to achieve this. The MRI operator informed the subject that the scan was due to start so as to coincide this with the beginning of the scan. As the knee extended, the scan was commenced and repeated, while the subject deflated the balloon. In any given scan, up to five axial images demonstrated contact between the patella and the trochlea and at any given moment, the entire trochlea was captured in order to ensure all the relevant images along the path of the patella were captured. Established dynamic MRI contact surface area techniques were employed to calculate the contact surface area of the joint [2]. This involves calculating surface contact area in the axial plane at 5 mm intervals. Each sliced surface is then summed to reach the surface area in contact between the articulating surfaces. This was recorded on a ‘flattened’ 2D coronal plane image for visual interpretation of contact area (Fig. 2).

Results

The mean age was 26 years (15 to 43). There were 14 female and 12 male patients. Laterality (side studied) was 8 left knees and 18 right knees. All patients had sustained patellofemoral dislocations with 15 (58%) sustaining more than one dislocation. Eleven (42%) patients had hypermobility with a Beighton score of four or more. Seventeen (65%) patients demonstrated a normal trochlear groove with the remaining patients demonstrating Dejour B, C and D abnormalities. Three patients had a history of failed operative intervention, with two previously undergoing MPFL reconstruction and one undergoing lateral release.

Five types of stabilisation procedures were performed; four patients underwent trochleoplasty, three underwent trochleoplasty with tibial tuberosity osteotomy, eight underwent medial patellofemoral ligament reconstruction, nine underwent tibial tuberosity osteotomy and the remaining two had tibial tuberosity osteotomy plus medial patellofemoral ligament reconstruction. The results from the MRI sequence for ranges between hyper-extension through to flexion beyond 40° are displayed in Table 1. Statistically significant mean difference in joint congruence pre- and post-operatively was found between 0 to 10 degrees flexion (0.64 cm^2; $p=0.04$) and between 11 to 20° flexion (1.65 cm^2; $p=0.01$). Pre- and post-operative joint congruence with confidence interval is presented diagrammatically in Fig. 3. Sub-analysis of change in joint congruence by type of procedure is shown in Table 2. Joints that required only MPFL reconstruction (mean difference = 0.91 cm^2; $p=0.69$) had the least change in congruency, whereas knees that required trochleoplasty (mean difference = 3.12 cm^2; $p=0.04$) or TTO (mean difference = 1.62 cm^2; $p=0.08$) had the greatest change. The multiple regression showed that none of the independent variables significantly predicted the change in mean joint congruence pre- to post-surgery, although trochleoplasty ($p=0.073$) and a Beighton score (≥ 4) ($p=0.057$) approached significance. (Table 3). No adjustment of the include variables was required due to multicollinearity (overall R2 0.76).

Discussion

The unstable PFJ is a difficult clinical and morphological condition to address both operatively and non-operatively. Maltracking is hypothesised to lead to early degenerative changes of the joint secondary to non-physiological joint contact and point loading [3–6]. While symptom relief and preservation of the joint remain the goals of treatment, improvement of congruency should be considered a

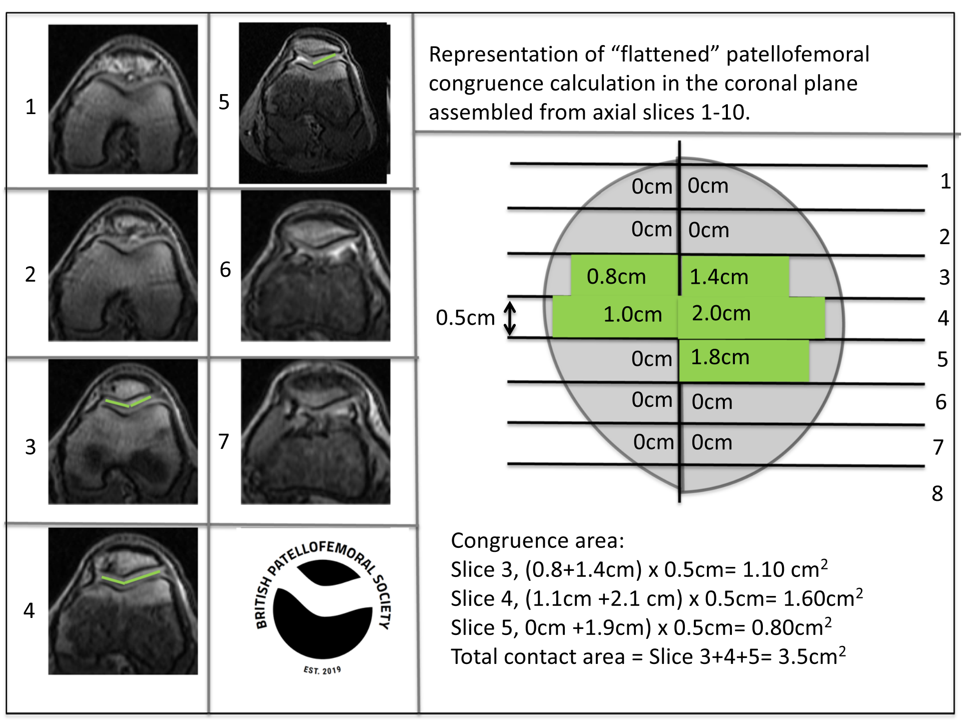

Fig. 2 "Flattening" of axial imaging. Slices are at 5 mm intervals. The width of each slice in which there is contact between femur and patella cartilage is multiplied by 5 mm. Each measurement is then summed to give a total area of congruence

Table 1 Mean joint congruence between < 0 to 40 + active knee range of movement, pre- and post-surgery

Active quadriceps contraction: knee position in degrees (°)	Pre- and post-operative	Number of patients	Mean joint congruence cm^2 (SD)	95% CI	Mean difference	*p* value
< 0°	Pre-operative	5	0.40 (0.09)	−0.07–0.15	0.17	0.36
	Post-operative	6	0.23 (0.44)	−0.23–0.70		
0°–10°	Pre-operative	19	0.54 (0.81)	0.15–0.92	0.64	**0.04**
	Post-operative	19	1.18 (1.06)	0.68–1.70		
11°–20°	Pre-operative	20	1.80 (1.34)	1.16–2.42	1.65	**0.01**
	Post-operative	22	3.45 (1.50)	2.90–4.11		
21°–30°	Pre-operative	19	3.10 (1.47)	2.39–3.81	1.01	0.11
	Post-operative	11	4.11 (1.83)	2.88–5.35		
31°–40°	Pre-operative	13	3.93 (1.35)	3.11–4.75	0.46	0.30
	Post-operative	15	4.39 (0.88)	3.90–4.89		
40° +	Pre-operative	8	3.73 (1.61)	2.38–5.08	0.82	0.29
	Post-operative	5	4.55 (0.16)	4.35–4.74		

Results obtained using an independent samples t-test to compare joint congruence before and after surgery. Significant values are highlighted

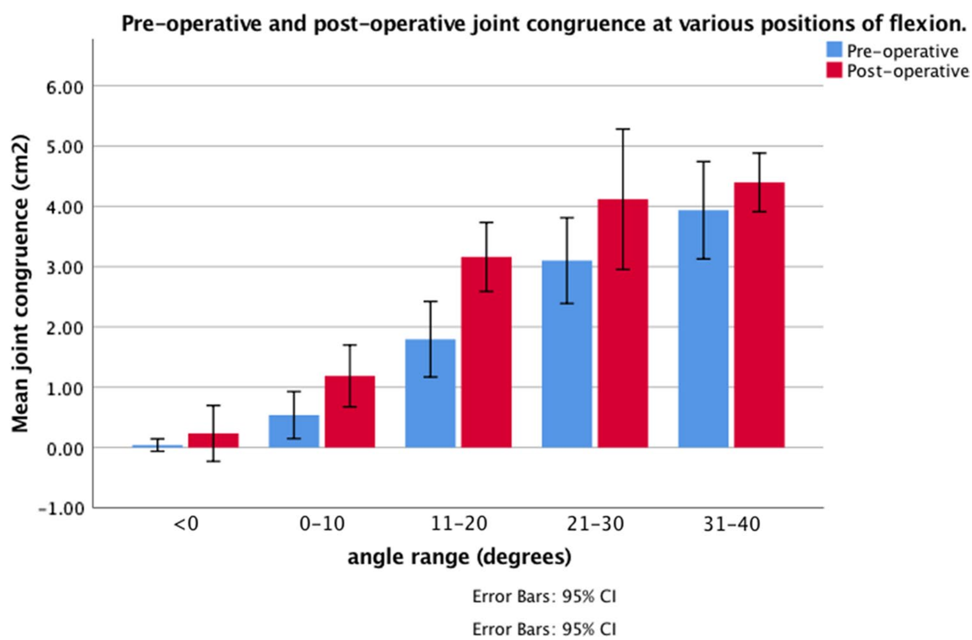

Fig. 3 The following is a representation of pre-operative joint congruency (blue bars) compared with post-operative joint congruence (red bars). Confidence intervals are also represented (black interval line)

Table 2 Sub-analysis of change in joint congruence by type of procedure

Surgical procedure performed	Number of patients	Pre-operative mean joint congruence in cm^2 (SD) CI	Post-operative mean joint congruence in cm^2 (SD) CI	Mean difference in cm^2	p value (independent samples t-test)
Tibial tubercle osteotomy	9	1.81 (1.75) 0.46–3.15	3.42 (1.95) 2.02–4.82	1.62	0.08
MPFL reconstruction	7	2.20 (0.75) 1.52–2.87	3.11 (1.01) 2.26–3.96	0.91	0.69
Trochleoplasty	4	1.06 (1.01)−0.55–2.67	4.19 (.954) 2.67–5.70	3.12	**0.04**

Using an independent samples t-test, the mean difference between pre- and post-operative joint congruence was evaluated by surgical procedure. Significant values are highlighted

Table 3 Multiple regression model investigating the change in joint congruence between 11 and 20 degrees of knee flexion between various different predictor variables examined in the model, including demographic factors, surgical procedure and other clinical parameters related to PFJ instability

Predictor variable	Coefficient	95% confidence interval	*t* ratio	*p* value
Trochleoplasty	2.51	−0.28–5.29	1.98	**0.073**
Tibial tubercle osteotomy	1.80	−0.58–2.93	1.48	0.168
Medial patellofemoral ligament reconstruction	1.67	−0.67–4.01	1.57	0.144
Laterality	−0.21	−1.59–1.17	0.34	0.743
Sex	−0.48	−1.85–0.90	0.77	0.459
Age at time of surgery	−0.04	−0.14–0.06	0.89	0.394
Tibial tuberosity–trochlear groove	0.04	−0.10–0.18	0.64	0.532
Insall–Salvati ratio	1.62	−1.93–5.18	1.00	0.337
Biedert patellotrochlear index	0.01	−0.04–0.05	0.39	0.707
Dejour ≥ grade B	−0.09	−1.43–1.25	0.15	0.884
Previous dislocations (≥ 2)	0.56	−0.60–1.72	1.06	0.312
Beighton score (≥ 4)	−1.13	−2.17 to −0.08	1.98	0.057

Values approaching significance are highlighted

necessary secondary outcome. Patella instability and maltracking are associated with patellofemoral arthritis [5]. We would not go so far as to claim that restoring congruence of the joint will prevent arthritis. Congruence is only part of the syndrome with pre-existing cartilage injuries, hypermobility association, abnormal forces, unbalanced tissues and gait anomalies all playing their parts. However, restoring joint congruence to a near normal value should be considered an achievable and measurable outcome.

Features of PFJ maltracking associated with instability are well established on MRI studies [7]. Studying the effect of intervention on dynamic MRI scan requires specific alterations to standard procedures [2, 8, 9]. Determining the effect of bracing on dynamic quadriceps active knee movement has previously been achieved; however, to date, no study has utilised dynamic MRI to study the contact surface area in a cohort of patients pre- and post-stabilisation surgery [10, 11].

Imaging studies that attempt to quantify contact surface area are difficult to perform. They ideally should be dynamic and information more consistent with the in vivo situation will be conveyed in active movement. In this study, the authors used axial MRI images in an active range of movement to compare the PFJ contact area pre- and post-stabilisation surgery.

The greatest mean differences between pre- and post-stabilisation of patellofemoral joint congruency were observed between 11 and 20° (1.80 cm^2 vs 3.45 cm^2, $p = 0.01$) of active flexion. This is important as lateral patellar displacement has been shown to occur with the lowest restraining forces required at 20° of knee flexion [12]. The mean contact surface area between 0 and 40° of active flexion pre-operation was 2.34 cm^2. The mean contact surface area post-operation between 0 and 40 degrees of active flexion was 3.34 cm^2 which equates to a 30% increase in PFJ surface contact area post-stabilisation.

Clark et al. studied both stable and unstable PFJ congruency and reported a mean contact area between 11 and 20° of active flexion of 1.73 cm^2 for unstable PFJs and 4.00 cm^2 for stable PFJs ($p < 0.001$) [2]. While the mean contact area in this study improved from 1.80 cm^2 to 3.45 cm^2, it fell short of the reported mean contact area of 4.00 cm^2 for PFJs with no history of instability. Trochleoplasty had the greatest increase in contact area after surgery (3.12 cm^2) and this was statistically significant ($p = 0.04$) followed by TTO (1.62 cm^2) and MPFL (0.91 cm^2), which did not meet significance.

This study provides additional insight into the effect of joint stabilisation surgery on PFJ contact surface area: however, the current results should be evaluated in the context of some limitations. Despite the small sample size of this study, there were significant differences in the contact area at all ranges between 0 and 40° when comparing cases. One of the disadvantages of dynamic MRI imaging is the potential for generation of movement artefact. The issue of motion artefact was minimal as the rapid sequence MRI scan coupled with stabilisation of the femur with the described technique resulted in clear and accurate images for interpretation. Despite the risk of motion artefact, the authors believe dynamic imaging of the PFJ may be more representative of the physiologic conditions that are present during ambulation. The range of movement for this technique is limited to 40° of flexion due to the physical constraints of the MRI scanner.

Conclusion

The present study illustrated a clear relationship between joint stabilisation procedures and increased joint congruency. This approach to mapping PFJ congruency produces a measurable outcome and can be utilised to determine the effect of intervention and correlate congruency with clinical outcome. In combination with clinical outcomes, this MRI mapping technique pre- and post-surgery may facilitate the design of new procedures or combinations of procedures for patients with PFJ instability. If a single axial series is to be obtained on MRI scan to compare the pre- and post-surgery joint congruity, the authors recommend 11° to 20° of tibiofemoral flexion as this was shown to have the greatest difference in contact surface area between pre- and post-operative congruency.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical approval Ethical approval was sought and approved from the Southwest research ethics committee via the Integrated Research Application System (IRAS) and all participants gave written informed consent. (12/SW/0155).

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