Osteoarthritis and Cartilage 24 (2016) 2055–2060

Osteoarthritis and Cartilage

OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

A knee brace alters patella position in patellofemoral osteoarthritis: a study using weight bearing magnetic resonance imaging

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A R T I C L E I N F O

Article history:
Received 6 August 2015
Accepted 8 July 2016

Keywords:
Arthritis
Patellofemoral joint
Knee braces
Weight bearing MRI

S U M M A R Y

Objective: To assess using weight bearing magnetic resonance imaging (MRIs), whether a patellar brace altered patellar position and alignment in patellofemoral joint (PFJ) osteoarthritis (OA).
Design: Subjects age 40–70 years old with symptomatic and a radiographic Kellgren–Lawrence (K–L) evidence of PFJOA. Weight bearing knee MRIs with and without a patellar brace were obtained using an upright open 0.25 T scanner (G-Scan, Easote Biomedica, Italy).
Five aspects of patellar position were measured: mediolateral alignment by the bisect offset index, angulation by patellar tilt, patellar height by patellar height ratio (patellar length/patellar tendon length), lateral patellofemoral (PF) contact area and finally a measurement of PF bony separation of the lateral patellar facet and the adjacent surface on the femoral trochlea (Fig. 1).
Results: Thirty participants were recruited (mean age 57 SD 27.8; body mass index (BMI) 27.8 SD 4.2); 17 were females. Four patients had non-usable data. Main analysis used paired *t* tests comparing within subject patellar position with and without brace.
For bisect offset index, patellar tilt and patellar height ratio there were no significant differences between the brace and no brace conditions. However, the brace increased lateral facet contact area ($P = .04$) and decreased lateral PF separation ($P = .03$).
Conclusion: A patellar brace alters patellar position and increases contact area between the patella and femoral trochlea. These changes would lower contact stress at the PFJ. Such changes in patella position in weight bearing provide a possible biomechanical explanation for the success of the PFJ brace in clinical trials on PFJOA.

Introduction

Patellofemoral osteoarthritis (PFOA), a common subtype of knee OA, is a major cause of pain with stair climbing, arising from a chair and activities involving kneeling or squatting. It is associated with pain, stiffness and functional limitation[1,2]. Guidelines for the non-surgical management of generalised knee OA found 'fair' quality of evidence for the use of knee braces and knee sleeves[3,4]. Treatment of PFOA is similarly limited but one potential treatment is a patellar sleeve device. Evidence for its clinical efficacy is provided by two clinical trials in PFOA[6,15]. These trials had positive effects on pain and structure from wearing a patellar sleeve brace compared to no brace[15] and on pain with or without the patellar retaining strap.[6]

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http://dx.doi.org/10.1016/j.joca.2016.07.003
1063-4584/

One of the proposed reasons for this clinical success is that the patellar brace may, during weight bearing activities, change patellar alignment and alter patellar tracking relative to the trochlear groove both of which are considered major contributions to the pathomechanics of PF pain. Whilst a brace's effects on the biomechanics of the PF joint are still not well understood, there is evidence from studies in non-arthritic PF pain that it may correct malalignment[7] and increase contact area of the PF joint[8]. This distribution of forces over a greater area could decrease the contact stresses.

Several authors agree that magnetic resonance imaging (MRI), with its capability of viewing the patellar position in various planes, is more useful and informative than plain radiography[9–11]. MRIs also have the advantage of using non-ionising radiation enabling repeated imaging, as in the present study, with and without a brace. Weight bearing MRIs may give a more valid view of PF congruence and position under natural loads exerted by body mass. PF position is usually assessed clinically through palpation of the patella through a range of motion or by observing the motion of the skin over the patella. This assessment is commonly performed in a seated, unloaded posture that does not reflect joint movement during functional, weight bearing tasks.

To date, one study has used weight bearing MRIs to assess braces on non-arthritic, symptomatic PF pain[12]. To our knowledge there have been none assessing PFOA, although McWalter *et al.*[13] assessed a knee sleeve in PFOA with simulated weight bearing MRIs by applying 15% of body weight of axial load through the patient's foot.

Since PFOA is likely to affect either medial or lateral patellar compartments[14], the effects of braces on patellar position might have a bearing on treatment choices and brace design. Consequently, the weight bearing MRI may give a more realistic view of PF congruence and be a more appropriate technique when assessing patella position.

Purpose

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

Methods

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

Subjects

We recruited a subset of subjects age 40–70 years who had been enrolled in a previous randomised trial of patellar brace treatment for people with PFOA[15]. They had a Kellgren–Lawrence (K–L) score grade 2 or 3 in the PF compartment which was greater than K–L score for the tibiofemoral compartments (this score required at least probable narrowing of the PF joint on X-ray and definite osteophytes in the PF compartment). Those who did not have plain radiographs were assessed for PFOA by either MRIs or arthroscopy, for which we required typical changes of OA with at least cartilage loss present in the PF joint. Subjects were also assessed by an experience clinician for PF joint symptoms such as pain reproduced with stair climbing, kneeling, prolonged sitting or squatting or if they had lateral or medial patellar facet tenderness on palpation or a positive patellar compression test. Pain must have been present daily for the previous 3 months and the pain had to be sufficiently severe for a nominated aggravating activity to score of 40 or above on a 0–100 mm visual analogue scale (VAS_{NA}). The VAS_{NA} has been found to be at least as sensitive, and in some cases more sensitive to change than the Knee injury and Osteoarthritis Outcome Score (KOOS) or Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaires[16,17]. Typically, subjects' nominated aggravating activities were stair climbing, kneeling, prolonged sitting or squatting.

Exclusion criteria

Participants were excluded if they had a previous patellar fracture or patellar realignment surgery, if the predominant symptoms emanated clinically from the tibiofemoral joint, from meniscal or ligament injury, if they had rheumatoid arthritis or other forms of inflammatory arthritis or if they had an intra-articular steroid injection into the painful knee in the previous month. For the purposes of the MRI, patients were excluded if they had a cochlear implant, metal objects in the body including a joint prosthesis, a cardiac or neural pacemaker, a hydrocephalus shunt, an intrauterine contraceptive device or coil, if they had kidney dysfunction or were undergoing renal dialysis.

MRI procedures

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

Study intervention

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

Patellar alignment measurements

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

Five measurements of PF alignment and congruence were taken.

Bisect offset index assessed medio-lateral patellar displacement relative to the femur. The technique was initially described by Stanford *et al.*[18] and used by Powers *et al.*[19]. A line was drawn connecting the posterior femoral condyles on the slice in which the posterior condyles were most obvious and a perpendicular line was projected up through the deepest point (apex) of the trochlea. Then another slice was found on which the patellar width was clearest and on which a line could be drawn to measure the width. Finally, these two slices were superimposed allowing us to project the line anteriorly from the bisection of the posterior condylar line through the second line on the patella[19]. To determine the patellar displacement by the bisect offset, the extent of the patella lateral or medial to the perpendicular midline was expressed as a percentage of the total patellar width (Fig. 2).

Fig. 1. The Bioskin Patellar Tracking Q brace.

Medio-lateral patellar tilt angle was measured as the angle formed by the lines joining the maximum width of the patella and the line joining the posterior femoral condyles[19,20] (Fig. 3).

Lateral patellofemoral joint (PFJ) contact area was defined as areas of patella and femur approximation in which no distinct separation could be found between the cartilage borders of the two lateral joint surfaces (Fig. 4). A line of contact was drawn between the patella and the femur[7]. The contact area for each slice was measured and multiplied by the length of the contact line with the slice thickness (0.4 mm). Each sequential image was summed to obtain the total lateral contact area $\sum(CL \times (SL \times SG)$ (CL = contact length; SL = slice length; SG = slice gap) × (slice length + slice gap). Because cartilage was relatively bright on fat suppressed fast spoiled gradient echo images, we used the operation definition of contact area as white on white[7]. The determination of non-contact was made when a line of separation could be observed between the articular surfaces of the patella and trochlear groove.

The level of agreement between the MRI and pressure sensitive film techniques in cadaver specimens was for inter-class correlation coefficient (ICC) 0.91 and for coefficient of variation (CV) of 13%. When averaged across all specimens, the contact area obtained through MRI was 2.94 (SD 1.01 cm^2) while the contact area obtained using the pressure sensitive film technique was 3.05 (0.95 cm^2). The average individual specimen difference between the two methods was 10.9%.

The Insall-Salvati ratio was measured on the sagittal views by a ratio between patella tendon length relative to the superior–inferior length of the patella (patellar length/patellar tendon length)[21] (Fig. 5).

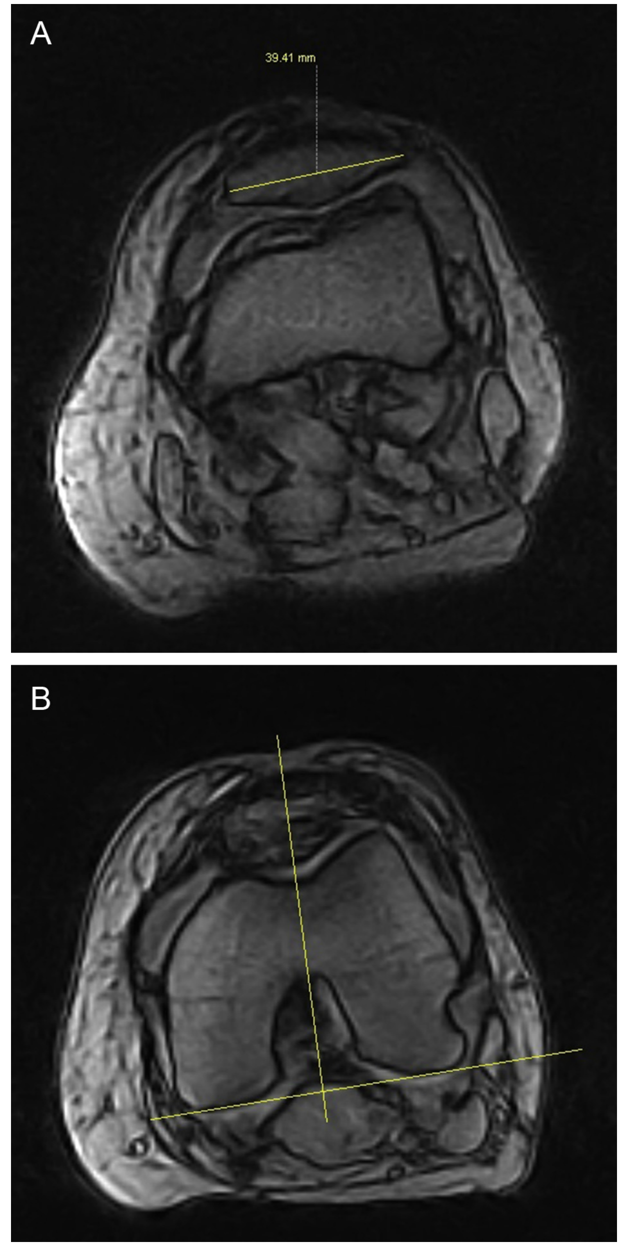

Fig. 2. Mediolateral displacement (bisect offset index). a: ideal image to measure patellar width. b: ideal image to view posterior condyles and trochlea.

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

Reliability

Inter rater reliability for the MRI measurements was assessed between two assessors using a two way random model for absolute agreement inter-class correlation coefficient ($ICC_{2,1}$). The results

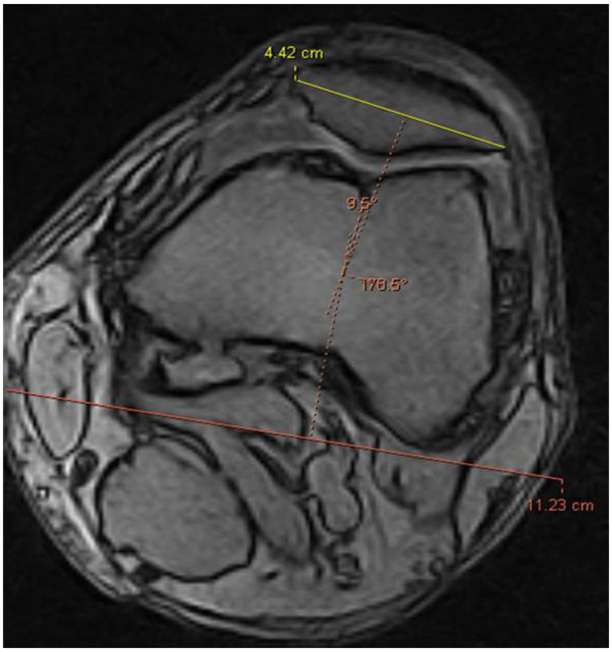

Fig. 3. Patellar tilt angle.

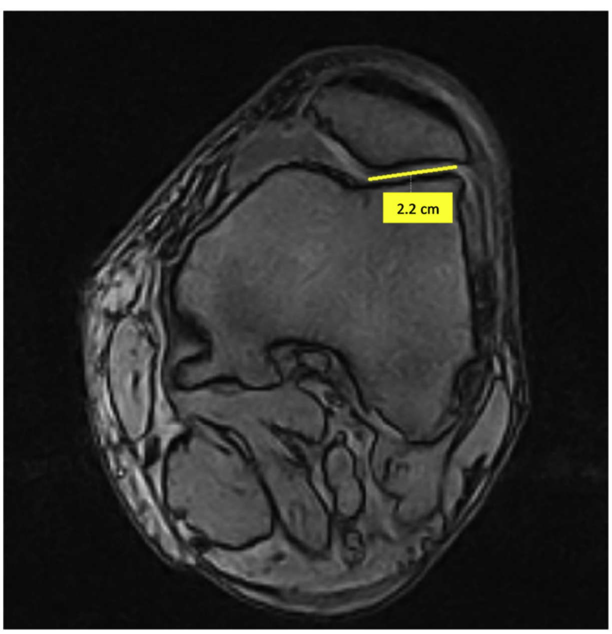

Fig. 4. Lateral Patellofemoral contact area.

were for bisect offset index $ICC_{2,1}$ 0.97 (95% CI 0.96, 0.98) SEM 2.6, for patellar tilt angle $ICC_{2,1}$ 0.96 (95% CI 0.94, 0.97) Standard Error of Measure (SEM) 1.43°, for lateral PFJ contact area $ICC_{2,1}$ 0.73 (95% CI 0.53, 0.85), SEM 3.1 cm^2, for the Insall-Salvati ratio $ICC_{2,1}$ 0.95, (95% CI 0.80, 0.98) SEM 0.031, and for PF distance $ICC_{2,1}$ 0.84, (95% CI 0.48,0.97), SEM 0.32 cm.

Analysis

Data were visually analysed with histograms, Q–Q plots and Kolmogarov–Smirnov tests which confirmed normality of distribution. The main within subjects analysis used paired *t* tests comparing PF alignment and congruence with and without a brace. Statistical significance was set at $P \leq 0.05$.

Fig. 5. Insall-Salvati ratio patellar bone length/patella tendon length.

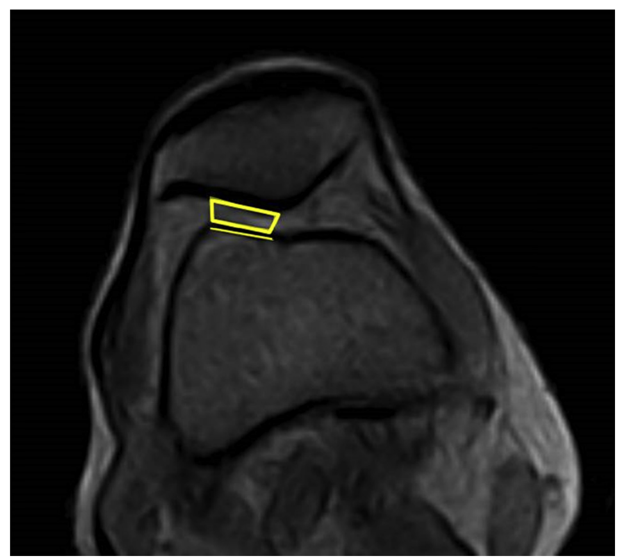

Fig. 6. Patellofemoral distance. Area of trapezoid a + b/2 × h/length of lateral PF contact.

Results

Thirty subjects with PFOA were recruited (mean age 57, SD 7.8 years, body mass index (BMI) mean 27.8, SD 4.2); 17 were females (56%). Five subjects had their PFOA assessed by MRIs or arthroscopy. Four patients had non-usable MRI data because of missing

Table I
Patients' demographics

	Mean ± SD
Age (year)	57.17 ± 8.1
BMI (kg/m^2)	27.76 ± 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

BMI = Body Mass Index; K-L = Kellgren Lawrence; PFJ = Patellofemoral Joint; TFJ = Tibiofemoral joint.

Table II
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

data on some parameters or because of technical problems such as movement artefact. Therefore 26 patients' data were analysed. There were no adverse events.

For bisect offset index, patellar tilt and patellar height ratio there were no significant differences between the brace and no brace conditions. However, the brace significantly increased lateral facet contact area (0.94 cm^2, 95% CI 0.07, 1.8, $P = .04$) and decreased lateral PF distance (−0.06 cm 95% CI −0.12, −0.01, $P = .03$) (Tables I and II).

Discussion

This is the first study using weight bearing MRIs on subjects with symptomatic PFOA to evaluate the effects of bracing on the PF joint. It found that the brace significantly increased the lateral contact area of the PF joint and decreased PF joint lateral distance. The other measures of PF joint position (bisect offset index, patellar tilt and patellar height ratio) were not altered significantly. MRIs are more useful and informative than plain radiography by viewing the patellar position in various planes[9–11]. MRIs also have the advantage of using non-ionising radiation enabling repeated imaging, as in the present study, with and without a brace. Using a scanner with the capability of providing standing weight bearing images adds to its usefulness. Comparison with previous research is compromised by the few weight bearing studies available, all of which were only done on non-arthritic PF pain. Draper *et al.*[12] found a patellar sleeve brace in females with non-arthritic PF pain produced non-significant reductions in weight bearing patellar tilt (0°) and bisect offset (4%) at full knee extension. Similarly, we did not find any significant differences in full knee extension between our patellar brace and no brace in bisect offset (1.39%, 95% CI −2.3, 5.1) and patellar tilt (−0.25°, 95% CI −1.61, 1.1). The reasons for different values recorded are likely due to us assessing subjects with symptomatic PFOA and differences in the PF brace design suggesting that commercially available braces may have different biomechanical effects. McWalter *et al.*[13] is the only comparable study looking at the same PF brace in the same knee condition, but differed from ours by using knee flexion up to 50° and lying subjects in supine with a simulated body weight load of 15%. They found the brace significantly altered patellar rotations and translations compared to no brace but questioned its clinical significance because no reduction in pain was observed in their parent trial[6], which compared the brace with a modified brace without a T-strap. The clinical significance of our findings for the parameters of lateral contact area and lateral PF distance may also be questioned, even though a clinically significant reduction in pain was observed in our parent trial which compared the brace to no a brace control[15]. As a result of our findings, we join with Draper *et al.*[12] in asking whether the small changes observed with a brace are sufficient to alter PF lateral contact area and lateral PF distance by a clinically meaningful amount. The small increases we recorded in these parameters concur with the work by Powers *et al.*[7] to explain the possible mechanism for the decrease in PF pain. They found, albeit in non-arthritic PF pain, that compared to no brace at full knee extension a PF brace had its greatest effect on lateral patellar facet contact area, had clinically small but statistically significant effects on the bisect offset index, but no effect on patellar tilt. They proposed the concept that the increased contact area would result in a decrease in joint area stress. Our PFOA subjects might have also benefitted from decreased joint area stress. Additionally, they may have benefitted from a sense of stability and confidence created wearing the brace. Although this was not objectively assessed in this study, patients in the parent trial[15] reported that their knee felt more stable and secure from brace wearing.

All our subjects had an improvement in their VAS for a nominated activity and their KOOS after wearing the patellar brace as part of a randomised trial[15]. This trial, in conjunction with the present study shows that a PF brace has both symptomatic and biomechanical benefits for those with symptomatic PFOA.

Limitations

The limitations of this study are that the MRIs were taken only in a single WB position, with no variability of knee flexion. The 0.2 T field strength for the weight bearing MRI scanner used in this study has implications for the contrast resolution obtainable in an acceptable time. Participants were not blinded to the brace wearing condition. Additionally, as this was a subgroup from a previous trial, there was no further subgroup analysis of patients based on the severity or location of the PFOA.

Conclusion

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

Author contributions

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

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

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

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

Provision of study facilities or patients: Callaghan, Felson, Reeves, Maganaris, Doslikova.

Statistical expertise: Felson, Callaghan, Hodgson.

Obtaining of funding: Felson, Reeves, Maganaris.

Collection and assembly of data: Callaghan, Doslikova, Reeves, Maganaris, Bailey, Hodgson.

Competing interests

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

Role of the funding source

This work was funded by Arthritis Research UK special strategic award Number 18676.

The funding source had no role in the design, analysis nor interpretation of data, nor in the writing of the manuscript.

This report includes independent research supported by the National Institute for Health Research Biomedical Research Unit (NIHR BRU) Funding Scheme. The views expressed in this publication are those of the author(s) and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health.

Acknowledgements

The trial participants. NIHR Manchester Musculoskeletal Biomedical Research Unit, Central Manchester NHS Foundation Trust, Manchester Academic Health Sciences Centre, Manchester, UK. The R.O.A.M. team at the University of Manchester. Alex Ireland at Manchester Metropolitan University.

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