Meniscal extrusion predicts increases in subchondral bone marrow lesions and bone cysts and expansion of subchondral bone in osteoarthritic knees

Yuanyuan Wang1, Anita E. Wluka1, Jean-Pierre Pelletier2, Johanne Martel-Pelletier2, François Abram3, Changhai Ding1,4 and Flavia M. Cicuttini1

Abstract

Objectives. Meniscal extrusion is often present in knees with OA, and has been associated with cartilage changes. It is unknown whether meniscal extrusion is related to subchondral bone. The aim of the study was to examine the relationship between meniscal extrusion and knee cartilage and subchondral bone, and also changes in these structures over 2 years in a cohort with mild to moderate knee OA.

Methods. One hundred and seventeen subjects with knee OA entered the study and underwent MRI on their symptomatic knee at baseline and ~2 years later. Meniscal extrusion was assessed at baseline; tibial cartilage volume and plateau bone area, subchondral bone marrow lesions (BMLs) and bone cysts were measured at baseline and follow-up.

Results. At baseline, meniscal extrusion was associated with reduced tibial cartilage volume, increased tibial plateau area, increased prevalence of BMLs and bone cysts in both medial and lateral tibiofemoral compartments (all \( P \leq 0.001 \)). Baseline medial meniscal extrusion was associated with increased expansion of tibial plateau bone \( (P = 0.04) \), increases in BMLs \( (P = 0.02) \) and bone cysts \( (P = 0.003) \) in the medial tibiofemoral compartment over 2 years.

Conclusions. Meniscal extrusion predicts increases in subchondral bone lesions and tibial plateau bone expansion in patients with knee OA. These data suggest that subchondral bone changes are an early consequence of meniscal extrusion. This may reflect the impaired ability of an extruded meniscus to optimally distribute mechanical loading across the tibial plateau.

Key words: Meniscal extrusion, Osteoarthritis, Bone, Bone marrow lesions, Bone cysts, Cartilage, Magnetic resonance imaging, Knee.

Introduction

OA of the knee is a heterogeneous chronic disease involving the entire organ, including articular cartilage, subchondral bone, menisci and periarticular soft tissues such as synovium and ligaments. MRI allows all components of the knee joint to be visualized simultaneously, thus providing a useful tool to observe the pathological changes in knee structures non-invasively.

MRI of the knee is widely used to demonstrate meniscal pathological changes. The meniscus is considered ‘extruded’ when it extends beyond the tibial margin. Meniscal extrusion occurs frequently in knees with established OA \[1, 2\]. There is increasing evidence that
meniscal extrusion is associated with cartilaginous changes within the knee, such as joint space narrowing [1, 3], cartilage loss [4–9], meniscal tear [8–10] and chondral lesions [11]. However, the data are sparse on the relationship between meniscal extrusion and subchondral bone changes [9, 12].

Bone marrow lesions (BMLs) and bone cysts are frequently observed subchondral bone lesions in MRI; both present as an abnormally high signal (hypersignal) within the subchondral bone area [13–16]. BMLs consist of a number of heterogeneous histological abnormalities including bone marrow necrosis, trabeculae abnormalities, bone marrow fibrosis and oedema [17], and have been shown to be strongly associated with knee pain and progression of OA [14, 18–20]. Histological findings of bone cysts reveal necrotic bone fragments with dead denuclearized cells surrounded by a non-epithelial fibrous wall [13]. Subchondral bone cysts are known to be associated with OA [21] and cartilage loss [18]. However, there is little association of knee symptoms with bone cysts [15, 22]. In established knee OA, both BMLs and bone cysts tend to progress over time [14, 18]. Moreover, BMLs and bone cysts appear to be inter-related in that subchondral bone cysts develop in the pre-existing regions of BML-like signal in subjects with OA [23]. The aim of the present study was to examine the relationship between meniscal extrusion and knee cartilage and subchondral bone, and whether baseline meniscal extrusion affects subchondral bone and cartilage over 2 years in a cohort of participants with mild to moderate knee OA.

Patients and methods

Participants

Subjects with knee OA were recruited by using a combined strategy including advertising through local newspapers and the Victorian branch of the Arthritis Foundation of Australia, as well as in collaboration with general practitioners, rheumatologists and orthopaedic surgeons as previously described [24]. The study was approved by the ethics committee of the Alfred and Caulfield Hospitals in Melbourne, Australia. All subjects gave informed consent.

One hundred and thirty-two subjects entered the study. Inclusion criteria were age ≥40 years and symptomatic knee OA (score of ≥20% on at least one pain dimension of the WOMAC [25] and presence of osteophytes) according to the clinical and radiographic criteria of the ACR [26]. Subjects were excluded if any other form of arthritis was present, if there were any contraindications to MRI (e.g. pacemaker, cerebral aneurysm clip, cochlear implant, presence of shrapnel in strategic locations, metal in the eye or claustrophobia), or if they were unable to walk 50 feet without the use of assistive devices, had hemiparesis of either lower limb or were planning to undergo total knee replacement.

Anthropometric measurements and clinical evaluation

Weight was measured to the nearest 0.1 kg (shoes and bulky clothing removed) using a single pair of electronic scales. Height was measured to the nearest 0.1 cm (shoes removed) using a stadiometer. BMI [weight (kg)/height² (m²)] was calculated. Pain, stiffness and function were assessed using the WOMAC [25].

Knee X-ray

At baseline, each subject had a weight-bearing anteroposterior tibiofemoral radiograph taken of the symptomatic knee in full extension. Radiographs were independently scored by two trained observers, using a published atlas to classify disease in the tibiofemoral joint. The radiographical features of tibiofemoral OA were graded in each compartment on a 4-point scale (0–3) for individual features of osteophytes and joint space narrowing [27]. Intra-observer reproducibility for agreement on features of OA was 0.93 for osteophytes (Grades 0 and 1 vs Grades 2 and 3) and 0.93 for joint space narrowing (Grades 0 and 1 vs Grades 2 and 3). Inter-observer reproducibility was 0.86 for osteophytes and 0.85 for joint space narrowing (by k-statistic) [28]. Knee OA was graded using the Kellgren and Lawrence scale (0–4) [29]. Where both knees were symptomatic and showed changes of radiographic OA, the knee with the less severe radiographic OA was used.

Knee angle was measured by a single observer, as previously described [30]. Lines were drawn through the middle of the femoral shaft and through the middle of the tibial shaft. The angle subtended by the lines on the medial side was measured using Osiris software (Geneva, Switzerland). Thus, an angle <180° was more varus and an angle >180° more valgus. The intra-observer reproducibility for agreement was 0.98 [30].

Knee MRI. Each subject had an MRI performed on the symptomatic knee at baseline and ~2 years later. Knees were imaged in the sagittal plane on the same 1.5 T whole-body MR unit (Signa Advantage HiSpeed; General Electric Medical Systems, Milwaukee, WI, USA) using a commercial receive-only extremity coil. The following sequence and parameters were used: a T₁-weighted, fat-suppressed, 3D gradient recall acquisition in the steady state; flip angle 55°; repetition time 58 ms; echo time 12 ms; field of view 16 cm; 60 partitions; 512 × 192 matrix; and one acquisition, time 11 min 56 s. Sagittal images were obtained at a partition thickness of 1.5 mm and an in-plane resolution of 0.31 × 0.83 mm (512 × 192 pixels).

The extent of meniscal extrusion on the medial or lateral edges of the tibiofemoral joint space, not including the osteophytes, was evaluated at baseline for the anterior, middle and posterior horns of the menisci in which 0 = no extrusion, 1 = partial meniscal extrusion and 2 = complete meniscal extrusion with no contact with the joint space. Meniscal extrusion was evaluated by trained observers who were blinded to subject identification and the measurement of cartilage volume and bone lesions.
The intra- and inter-reader correlation coefficient ranged from 0.85 to 0.92 and \( \kappa \)-statistics ranged from 0.79 to 0.89 [6].

BMLs were subchondral regional areas with hyperintensity near fluid signal with ill-defined or irregular margins. A bone cyst was a subchondral, well-defined, well-margined, rounded, fluid signal intensity region. The extent of these bone lesions was assessed in the medial and lateral tibiofemoral compartments with the following semi-quantitative scale: 0 = absence of hypersignal; 1 = mild hypersignal (a small-sized lesion, <25% of the region); 2 = moderate hypersignal (a medium-sized lesion, 25-50% of the region); and 3 = severe hypersignal (a large-sized lesion, >50% of the region). The presence of subchondral bone lesions was defined as Grade \( \geq 1 \). Bone lesions were evaluated by trained observers who were blinded to subject identification, time sequences and the measurement of meniscal extrusion and cartilage volume. For BMLs, the intra- and inter-reader correlation coefficient ranged from 0.88 to 0.93 and the \( \kappa \)-statistics ranged from 0.78 to 0.87 [6]. For bone cysts, the consensus intra-reader correlation coefficient was 0.96 [18].

The medial and lateral tibial plateau bone areas were determined by means of image processing using the software program Osiris, by creating an isotropic volume from the input images, which were reformatted in the axial plane, and then areas were directly measured from these axial images, as previously described [31]. One trained reader made the measurements in duplicate, blinded to subject identification, time sequences and the measurement of meniscal extrusion and cartilage volume. The coefficients of variation (for the repeated image analysis) for the medial and lateral tibial plateau bone area were 2.3 and 2.4%, respectively [28].

The volumes of the individual tibial plateau cartilage plates (medial and lateral) were measured from the total volume, by manually drawing disarticulation contours around the cartilage boundaries on each section using the software program Osiris as described previously [24]. Two trained observers measured the cartilage volumes independently, both blinded to subject identification, time sequences and the measurement of meniscal extrusion and bone lesions. The coefficients of variation for the medial and lateral cartilage volume measurements were 3.4 and 2.0%, respectively [28].

Statistical analysis
Descriptive statistics for characteristics of the participants were tabulated. In cross-sectional analysis, the principal outcome measurements were the prevalence of BMLs and bone cysts (dichotomous variable), tibial plateau bone area and cartilage volume (continuous variable). In longitudinal analysis, the principal outcome measurements were the increase in BMLs or bone cysts (dichotomous variable, defined by any increase of bone lesion grade within the respective compartment at follow-up) and the annual percentage change in tibial plateau bone area and cartilage volume (continuous variable, calculated as the change of these parameters from baseline to follow-up divided by the period of time between MRI scans and respective baseline measures, then multiplied by 100). Multiple logistic or linear regression techniques were used to explore the association between meniscal extrusion and cartilage and bone, adjusting for potential confounders of age, gender, BMI, tibial plateau area for cartilage analysis and baseline variables for longitudinal analysis. A \( P < 0.05 \) (two-tailed) was regarded as statistically significant. All analyses were performed using the SPSS statistical package (standard version 16.0.0; SPSS, Cary, NC, USA).

Results
One hundred and thirty-two subjects fulfilled the study criteria and entered this study. MR images were available for the assessment of knee structures in 126 subjects. One hundred and seventeen subjects completed the longitudinal MRI component of the study over 2.0 (mean, s.d. 0.2) years. There were no significant differences between subjects who completed the study and those who did not (data not shown). Meniscal extrusion data were available in 100 subjects due to image quality not appropriate for reading in 17 subjects. There were no significant differences between the characteristics of subjects with assessable MRI and those without in terms of age [63.3 (10.4) vs 66.1 (9.4) years, \( P = 0.29 \)], severity of OA [severe OA 48 vs 41%, \( P = 0.58 \)] and annual tibial cartilage loss [5.6% (5.2%) vs 4.3% (5.3%), \( P = 0.37 \)]. Participants with assessable MRI were less likely to be female [54 vs 82%, \( P = 0.03 \)] and had greater BMI [29.2 (5.3) vs 26.5 (3.6), \( P = 0.05 \)] compared with those without.

Most of the subjects had mild to moderate tibiofemoral OA (Table 1). The prevalence of meniscal extrusion was 45% for the medial tibiofemoral and 13% for the lateral tibiofemoral compartment. BMLs and bone cysts were more prevalent in the medial tibiofemoral compartment compared with the lateral tibiofemoral compartment (48 vs 26% and 30 vs 23%, respectively). When compared with those without any meniscal extrusion at baseline, participants with any meniscal extrusion (53%) were more likely to be male, had more severe knee OA, larger tibial plateau bone, and higher prevalence of BMLs and bone cysts in the medial and total tibiofemoral compartment (Table 1).

Over 2 years, cartilage volume decreased by 4.8% (6.6%) for the medial and 5.4% (7.2%) for the lateral tibia per annum. Bone area increased by 2.2% (6.9%) for the medial and 1.5% (4.3%) for the lateral tibial plateau per annum. At the 2-year follow-up, MRI was readable for the assessment of subchondral bone lesions in 88 subjects. Increases in BMLs were observed in 30% (26/88; 5 incident BMLs and 21 progressed BMLs) for the medial and 14% (12/88; 3 incident BMLs and 9 progressed BMLs) for the lateral tibiofemoral compartment. Increases in bone cysts were observed in 23% (20/88; 6 incident cysts and 14 progressed cysts) for the medial and 10% (9/88; 3 incident cysts and 9 progressed cysts) for the lateral tibiofemoral compartment.
In univariate analysis, meniscal extrusion was significantly associated with increased tibial plateau bone area, an increased prevalence of BMLs and bone cysts in both the medial and lateral tibiofemoral compartments and reduced tibial cartilage volume in the lateral compartment (all \( P < 0.001 \); Table 2). After adjusting for the potential confounders of age, gender, BMI and tibial bone area for cartilage volume, these associations persisted to be significant, and the negative association between medial meniscal extrusion and medial tibial cartilage volume became significant (all \( P < 0.001 \); Table 2).

### Longitudinal analysis

Given the small numbers of subjects with lateral meniscal extrusion (\( n = 13 \)) and increased BMLs and bone cysts in the lateral tibiofemoral compartment (\( n = 12 \) and 9, respectively), we were not able to examine the relationship between baseline lateral meniscal extrusion and longitudinal knee structure changes in the lateral tibiofemoral compartment, thus the following analyses include only the medial tibiofemoral compartment (Table 3). Although medial meniscal extrusion was not significantly associated with the expansion of medial tibial plateau bone in univariate analysis, the association became significant after adjusting for age, gender, BMI and baseline tibial plateau area (\( P = 0.04 \)). In both univariate analysis and after adjusting for age, gender and BMI, medial meniscal extrusion was associated with a higher risk of increase in BMLs and bone cysts in the medial tibiofemoral compartment (\( P = 0.02 \) and 0.003, respectively, in multivariate analysis). In both univariate analysis and after adjustment for age, gender, BMI, baseline tibial plateau area and cartilage volume, medial meniscal extrusion was not significantly associated with medial tibial cartilage loss over 2 years (Table 3). With increasing grade of meniscal extrusion, there was a trend of increased annual percentage medial tibial cartilage loss (\( P = 0.06 \)) adjusted for age, gender, BMI, baseline tibial cartilage volume and bone area. However, only 10 subjects had complete (Grade 2) meniscal extrusion; we have limited power to examine this. There were no significant differences in the change in total WOMAC, and WOMAC pain, stiffness and function scores over 2 years between those with and without meniscal extrusion (data not shown).

Including baseline Kellgren and Lawrence score, radiographic features of OA (osteophyte score and joint space narrowing score), WOMAC score or knee angle in the above cross-sectional and longitudinal analysis models did not alter the results. There was no evidence of effect modification of gender on the association between meniscal extrusion and knee structure (data not shown).

### Cross-sectional analysis

In univariate analysis, meniscal extrusion was significantly associated with increased tibial plateau bone area, an increased prevalence of BMLs and bone cysts in both the medial and lateral tibiofemoral compartments and reduced tibial cartilage volume in the lateral compartment (all \( P < 0.001 \); Table 2). After adjusting for the potential confounders of age, gender, BMI and tibial bone area for cartilage volume, these associations persisted to be significant, and the negative association between medial meniscal extrusion and medial tibial cartilage volume became significant (all \( P < 0.001 \); Table 2).

### Table 1 Baseline characteristics of the study population

<table>
<thead>
<tr>
<th></th>
<th>With meniscal extrusion(^a) (( n = 53 ))</th>
<th>Without meniscal extrusion(^a) (( n = 47 ))</th>
<th>( P)-value(^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>64.7 (9.9)</td>
<td>61.6 (10.8)</td>
<td>0.14</td>
</tr>
<tr>
<td>Female, ( n ) (%)</td>
<td>24 (45)</td>
<td>30 (64)</td>
<td>0.06</td>
</tr>
<tr>
<td>BMI, kg/m(^2)</td>
<td>29.3 (5.4)</td>
<td>29.1 (5.1)</td>
<td>0.86</td>
</tr>
<tr>
<td>WOMAC score</td>
<td>438 (198)</td>
<td>398 (252)</td>
<td>0.38</td>
</tr>
<tr>
<td>Pain</td>
<td>82 (37)</td>
<td>76 (49)</td>
<td>0.54</td>
</tr>
<tr>
<td>Stiffness</td>
<td>43 (21)</td>
<td>35 (23)</td>
<td>0.07</td>
</tr>
<tr>
<td>Function</td>
<td>312 (152)</td>
<td>286 (187)</td>
<td>0.44</td>
</tr>
<tr>
<td>Kellgren and Lawrence score, ( n )(^b)</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>8 (17)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11 (21)</td>
<td>32 (68)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>41 (79)</td>
<td>7 (15)</td>
<td></td>
</tr>
<tr>
<td>Knee angle, degrees(^b)</td>
<td>180.1 (7.4)</td>
<td>181.2 (3.4)</td>
<td>0.36</td>
</tr>
<tr>
<td>Medial tibial cartilage volume, mm(^3)</td>
<td>1760 (429)</td>
<td>1797 (525)</td>
<td>0.70</td>
</tr>
<tr>
<td>Lateral tibial cartilage volume, mm(^3)</td>
<td>1900 (646)</td>
<td>2067 (501)</td>
<td>0.16</td>
</tr>
<tr>
<td>Medial tibial bone area, mm(^2)</td>
<td>2257 (336)</td>
<td>1887 (324)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lateral tibial bone area, mm(^2)</td>
<td>1527 (256)</td>
<td>1277 (205)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of medial tibiofemoral BMLs, ( n ) (%)</td>
<td>37 (70)</td>
<td>11 (23)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of lateral tibiofemoral BMLs, ( n ) (%)</td>
<td>15 (28)</td>
<td>11 (23)</td>
<td>0.58</td>
</tr>
<tr>
<td>Prevalence of total tibiofemoral BMLs, ( n ) (%)</td>
<td>45 (85)</td>
<td>19 (40)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of medial tibiofemoral cysts, ( n ) (%)</td>
<td>25 (47)</td>
<td>5 (11)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of lateral tibiofemoral cysts, ( n ) (%)</td>
<td>14 (26)</td>
<td>9 (19)</td>
<td>0.39</td>
</tr>
<tr>
<td>Prevalence of total tibiofemoral cysts, ( n ) (%)</td>
<td>34 (64)</td>
<td>13 (28)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data presented by mean (S.D.) or \( n \) (%). \(^a\)Meniscal extrusion data were available in 100 subjects due to image quality not appropriate for reading in 17 subjects. \(^b\)One radiograph was lost after the study commenced. \(^*\)Difference between two groups by using independent samples \( t \)- or \( \chi^2 \)-test.
In this prospective study of subjects with mild to moderate knee OA, meniscal extrusion was associated with reduced tibial cartilage volume, increased tibial plateau bone area and increased prevalence of subchondral BMLs and bone cysts in the medial and lateral tibiofemoral compartments in cross-sectional analyses. Over the 2-year follow-up, baseline medial meniscal extrusion predicted the increases in BMLs and bone cysts and the expansion of tibial plateau bone in the medial tibiofemoral compartment.

Meniscal extrusion is very common in subjects with knee OA [1, 2]. Most work has focused on examining its association with knee cartilage changes, including joint space narrowing [1, 3] and cartilage loss [4–9]. Consistent with a cross-sectional study that estimated cartilage loss as an ordinal variable (none, mild, moderate and severe) [9], we found an association between meniscal extrusion and reduced tibial cartilage volume at baseline. Previous studies have also found that meniscal extrusion was associated with increased tibiofemoral cartilage volume loss over 2 years [4, 6, 8]. The Boston Osteoarthritis of the Knee Study found meniscal malposition was associated with an increased risk of tibiofemoral cartilage loss over 30 months using a semi-quantitative scoring method [7]. Although we found a significant association of meniscal extrusion with reduced tibial cartilage volume cross-sectionally, we did not find a significant association with longitudinal cartilage change, which

### Table 2: Association between meniscal extrusion and knee structure in cross-sectional analysis

<table>
<thead>
<tr>
<th></th>
<th>Univariate analysis</th>
<th>Multivariate analysis</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Regression coefficient/odds ratio (95% CI)</td>
<td>P-value</td>
</tr>
<tr>
<td>Medial meniscal extrusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial tibial cartilage volume, a mm³</td>
<td>–60.6 (–250.6, 129.3)</td>
<td>0.53</td>
</tr>
<tr>
<td>Medial tibial plateau bone area, b mm²</td>
<td>378.7 (240.3, 517.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of medial tibiofemoral bone marrow lesions (yes/no)</td>
<td>11.3 (4.4, 28.9)c</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of medial tibiofemoral cysts (yes/no)c</td>
<td>12.5 (4.2, 37.2)c</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lateral meniscal extrusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral tibial cartilage volume, a mm³</td>
<td>–852.7 (–1155.0, –550.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lateral tibial plateau bone area, b mm²</td>
<td>299.7 (143.0, 456.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prevalence of lateral tibiofemoral BMLs (yes/no)c</td>
<td>9.3 (2.6, 33.7)c</td>
<td>0.001</td>
</tr>
<tr>
<td>Prevalence of lateral tibiofemoral cysts (yes/no)c</td>
<td>11.7 (3.2, 43.5)c</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

aAdjusting for age, gender, BMI and baseline tibial plateau bone area. bAdjusting for age, gender and BMI. cOdds ratio.

### Table 3: Association between meniscal extrusion and longitudinal changes in knee structure in the medial compartment over 2 years a

<table>
<thead>
<tr>
<th></th>
<th>Univariate analysis</th>
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</tr>
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<tbody>
<tr>
<td></td>
<td>Regression coefficient/odds ratio (95% CI)</td>
<td>P-value</td>
</tr>
<tr>
<td>Medial meniscal extrusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual medial tibial cartilage loss, b %</td>
<td>–1.2 (–3.8, 1.4)</td>
<td>0.37</td>
</tr>
<tr>
<td>Annual medial tibial plateau bone expansion, c %</td>
<td>–0.5 (–3.7, 2.8)</td>
<td>0.78</td>
</tr>
<tr>
<td>Increases in medial tibiofemoral BMLs (yes/no)d</td>
<td>3.2 (1.2, 8.4)e</td>
<td>0.02</td>
</tr>
<tr>
<td>Increases in medial tibiofemoral cysts (yes/no)d</td>
<td>7.3 (2.2, 24.4)e</td>
<td>0.001</td>
</tr>
</tbody>
</table>

aGiven the small numbers of subjects with lateral meniscal extrusion and increased BMLs and bone cysts in the lateral tibiofemoral compartment, only the medial compartment was examined. bAdjusting for age, gender, BMI, baseline tibial plateau bone area and cartilage volume. cAdjusting for age, gender, BMI and baseline tibial plateau bone area. dAdjusting for age, gender and BMI. eOdds ratio.

### Discussion

In this prospective study of subjects with mild to moderate knee OA, meniscal extrusion was associated with reduced tibial cartilage volume, increased tibial plateau bone area and increased prevalence of subchondral BMLs and bone cysts in the medial and lateral tibiofemoral compartments in cross-sectional analyses. Over the 2-year follow-up, baseline medial meniscal extrusion predicted the increases in BMLs and bone cysts and the expansion of tibial plateau bone in the medial tibiofemoral compartment.

Meniscal extrusion is very common in subjects with knee OA [1, 2]. Most work has focused on examining its association with knee cartilage changes, including cross-sectional analyses of knee OA subjects with meniscal extrusion.
may be a result of the heterogeneity of knee OA populations and the modest sample size. In our study, there was a trend of increased tibial cartilage loss with increasing severity of meniscal extrusion, although it did not reach statistical significance.

There are few data investigating the relationship between meniscal extrusion and subchondral bone alterations. Two previous studies reported an association of meniscal extrusion with osteophytes [9, 12]. Consistent with a previous study of a largely non-OA cohort [5], we found that meniscal extrusion was associated with increased tibial bone area in the medial tibiofemoral compartment. To our knowledge, this study is the first to report the associations between meniscal extrusion and the prevalence of subchondral BMLs and bone cysts cross-sectionally and the change of both longitudinally. Our study suggests that subchondral bone changes may occur earlier than cartilage changes due to meniscal extrusion. We found a cross-sectional association between meniscal extrusion and reduced cartilage volume, and it has been well-described that subchondral bone expansion, progression of BMLs and bone cysts are associated with cartilage loss [14, 18, 32].

The medial compartment is exposed to increased forces through the knee during weight-bearing activities [33]. The meniscus is an integral part of the biomechanical system of the knee. It is essential for the distribution of axial forces on the knee via its hoop mechanism and absorption of shock [34–36]. Meniscal extrusion may simulate a condition similar to complete meniscectomy [1] and result in alteration of meniscal function, modifying the pattern of load distribution and contributing to compartmental instability [37]. As a result, impact at the femoral and tibial bone surface is likely to increase the susceptibility of subchondral bone to trauma during dynamic movements of the knee. It has been shown that one response of the knee to increased load through the medial compartment is for the tibial plateau to expand [38], which may redistribute the mechanical load and enhance the mechanical competence of the bone [39]. Although the pathogenesis of BMLs and bone cysts has not been fully elucidated, they are thought to be interrelated [23]. BMLs have been associated with mechanical factors, such as knee alignment and trauma [19, 40], and the formation of bone cysts may result from bone contusion [41, 42]. The changed biomechanical environment at the knee due to meniscal extrusion thus appears to lead to the development or progression of BMLs and bone cysts and subchondral bone expansion, which have been associated with cartilage loss [14, 18, 32].

There are a number of limitations in this study. Since T2-weighted MRI was not available when we started the study, we used T1-weighted MRI to measure BMLs instead, which is likely to result in a more conservative analysis. For BMLs to be identified on T1 images, larger, more active lesions with significant oedema are required [43, 44]. Thus, measuring BMLs from T1 images may have led to underestimation of lesions with the likelihood of identifying large lesions only. Most participants of our study had mild to moderate knee OA, so our findings may not be applicable to a healthy population without knee OA or patients with severe disease. Although we had power to show the effect of meniscal extrusion on subchondral bone changes, our modest sample size may explain why we did not observe an effect of meniscal extrusion on longitudinal change in tibial cartilage volume.

In participants with established knee OA, meniscal extrusion was associated with reduced cartilage volume, increased tibial plateau bone area, increased prevalence of subchondral BMLs and bone cysts in cross-sectional analysis, and predicted increases in subchondral bone lesions and tibial plateau bone expansion over 2 years. These data suggest that subchondral bone changes are an early consequence of meniscal extrusion, which may reflect the impaired ability of an extruded meniscus to optimally distribute mechanical loading across the tibial plateau. Identifying ways to intervene in this pathway may offer novel insight to slow the progression of knee OA.

Rheumatology key messages

- Meniscal extrusion predicts increases in subchondral bone lesions and tibial plateau bone expansion in knee OA.
- Subchondral bone changes are an early consequence of meniscal extrusion.

Acknowledgements

We would like to acknowledge Judy Hankin and Judy Snaddon for their coordination of this study, the MRI Unit at the Alfred Hospital and Kevin Morris for technical support. We would especially like to thank the study participants who made this study possible.

Funding: This study was supported by the National Health and Medical Research Council (NHMRC) of Australia. Y.W. is the recipient of an NHMRC Public Health Fellowship (NHMRC 465142). A.E.W. and C.D. are recipients of NHMRC Career Development Awards (NHMRC 545876 and 490049, respectively).

Disclosure statement: J.-P.P. and J.M.-P. are consultants for and shareholders in ArthroVision Inc. F.A. is an employee of ArthroVision Inc. All other authors have declared no conflicts of interest.

References

Meniscal extrusion and subchondral bone


