Magnetic Resonance Imaging of Asymptomatic Knees in Collegiate Basketball Players: The Effect of One Season of Play

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Objective: To determine the prevalence of abnormal structural findings using 3.0-T magnetic resonance imaging (MRI) in the asymptomatic knees of male and female collegiate basketball players before and after a season of high-intensity basketball.

Design: Institutional review board–approved prospective case series.

Participants: Asymptomatic knees of 24 NCAA Division I collegiate basketball players (12 male, 12 female) were imaged using a 3.0-T MRI scanner before and after the end of the competitive season. Three subjects did not undergo scanning after the season.

Main Outcome Measures: Images were evaluated for prepatellar bursitis, fat pad edema, patellar and quadriceps tendinopathy, bone marrow edema, and articular cartilage and meniscal injury.

Results: Every knee imaged had at least 1 structural abnormality both preseason and postseason. A high preseason and postseason prevalence of fat pad edema (75% and 81%), patellar tendinopathy (83% and 90%), and quadriceps tendinopathy (75% and 90%) was seen. Intrameniscal signal change was observed in 50% preseason knees and 62% of postseason knees, but no discrete tears were found. Bone marrow edema was seen in 75% and 86% of knees in the preseason and postseason, respectively. Cartilage findings were observed in 71% and 81% of knees in the preseason and postseason, respectively. The cartilage injury score increased significantly in the postseason compared with the preseason ($P = 0.0009$).

Conclusions: A high prevalence of abnormal knee MRI findings was observed in a population of asymptomatic young elite athletes. These preliminary data suggest that high-intensity basketball may have potentially deleterious effects on articular cartilage.

Key Words: MRI, articular cartilage, bone marrow edema, meniscus

INTRODUCTION

Magnetic resonance imaging (MRI) is an accurate tool for identifying articular cartilage lesions,1–2 meniscal tears,3–5 ligament injury,5,7 and bone marrow edema (BME).8,9 However, previous work has shown that positive MRI findings may not always be symptomatic, especially among athletic populations.10–13 Previous studies of asymptomatic knees of collegiate and professional basketball players have shown rates of one or more abnormalities in up to 89% of knees imaged, including high rates of articular cartilage lesions (41%–50%), meniscal lesions (20%–54%), BME (25%–41%), joint effusion (29%–35%), and patellar tendinopathy (24%–39%).14–16

Previous MRI studies of basketball players were performed using 0.3-Tesla and 1.5-Tesla (T) scanners. However, 3.0-T MRI is more sensitive, specific, and accurate for the assessment of articular cartilage lesions and meniscal tears.3,17,18 The higher magnetic field strength allows for increased signal-to-noise ratios (SNRs), thus permitting higher spatial resolution and thinner slice thickness.19

This study used a 3.0-T MRI scanner to more accurately determine the prevalence of anatomic knee lesions in asymptomatic elite athletes. Moreover, previous studies have evaluated subjects at only 1 time point during the preseason. In contrast, this study examined both male and female subjects before and after their competitive season to assess the effect of 1 season of high-intensity basketball. We hypothesized that 3.0-T MRI of the knee in asymptomatic basketball players during the preseason would reveal a higher prevalence of articular cartilage lesions, meniscus signal, BME, patellar and quadriceps tendinopathy fat pad edema, and prepatellar bursitis than previously reported with lower field strength scanners. Furthermore, we hypothesized that these pathological findings would increase after a single season of high-intensity collegiate basketball.
METHODS

Subjects
A total of 24 asymptomatic knees from 24 NCAA Division I collegiate basketball players (12 men and 12 women, age 18–22) were imaged before and after the competitive season.

Ethical Considerations
The study was approved by the university institutional review board and all subjects provided informed written consent. Before scanning, subjects completed a questionnaire that assessed history of knee pain, injections, or surgeries. Athletes were included if they had at least 1 knee that was asymptomatic at the time of the study and no history of injury to, or surgery on, that knee.

Image Acquisition and Analysis
The asymptomatic knee of each player was imaged within 2 weeks before the NCAA official start of practice. If both knees were asymptomatic, the more dominant knee (used for takeoff and landing) was imaged. The same knee was reimaged within 4 weeks of the completion of the basketball season (including any postseason tournament play). A 3.0-T MRI scanner (Signa Excite; GE Healthcare, Milwaukee, WI) was used. Preseason and postseason scans used identical imaging protocols (Table 1).

All preseason and postseason scans were graded by an experienced musculoskeletal radiologist, an experienced orthopedic sports medicine surgeon, and an orthopedic sports medicine fellow. Any discrepancies were discussed and graded by consensus. The scans were graded for prepatellar bursitis, fat pad edema, patellar and quadriceps tendinopathy, BME, articular cartilage lesions, and meniscal lesions. A score of 0 was assigned for normal anatomy. Prepatellar bursitis, fat pad edema, patellar and quadriceps tendinopathy, and BME were rated as mild (1), moderate (2), or severe (3). The images were also evaluated for the presence or absence of joint effusion, Baker’s cysts, and Osgood–Schlatter disease.

Both articular cartilage irregularity and BME were evaluated in the medial and lateral femoral condyle, medial and lateral tibial plateau, patella, and trochlea. Because of the large joint reaction forces within the patellofemoral compartment of basketball players, an increased prevalence of BME and cartilage findings was expected in the patella and trochlea.12,14,16 Therefore, 2 distinct additive scores were formulated to compare BME and cartilage findings. First, a patellofemoral score was constructed as the sum of the highest grade finding in the patella and the highest grade finding in the trochlea. Second, the extent of abnormal findings observed across all 3 compartments in the knee was estimated by summing the highest grade finding in all 6 regions: medial and lateral femoral condyle, medial and lateral tibial plateau, patella, and trochlea. For example, a knee with moderate (grade 2) BME of the patella and trochlea and mild (grade 1) BME of the lateral femoral condyle and medial tibial plateau would have a patellofemoral bone marrow edema (BME PF) score of 4 (=2 + 2) and a summed bone marrow edema (BME Sum) score of 6 (=2 + 2 + 1 + 1).

<table>
<thead>
<tr>
<th>TABLE 1. MRI Parameters</th>
<th>Axial Proton Density</th>
<th>Sagittal Proton Density</th>
<th>Sagittal T2-Weighted</th>
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<tbody>
<tr>
<td>Parameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TR (ms)</td>
<td>4000</td>
<td>5000</td>
<td>4000</td>
</tr>
<tr>
<td>TE (ms)</td>
<td>30</td>
<td>30</td>
<td>68</td>
</tr>
<tr>
<td>Field of view (cm)</td>
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<td>16 × 16</td>
<td>16 × 16</td>
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<tr>
<td>Pixel matrix</td>
<td>320 × 192</td>
<td>512 × 224</td>
<td>320 × 160</td>
</tr>
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<td>Slice thickness (mm)</td>
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<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Interslice gap (mm)</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fat saturation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

TE, echo time; TR, repetition time.
Articular cartilage was rated using a modified Noyes scoring system (1 = signal change, 2 = surface fissuring or superficial erosion involving less than 50% of the cartilage depth, 3 = deep fissuring or erosion involving greater than 50%, 4 = full-thickness chondral defect with exposure of underlying subchondral bone). Two additive cartilage scores were constructed to compare patellofemoral and total cartilage findings within each knee. The patellofemoral cartilage score (Noyes PF) was calculated from the sum of the modified Noyes scores in the patellar and trochlear cartilage. A second composite score (Noyes SUM) was formulated to estimate the overall level of cartilage irregularity throughout the entire knee and was calculated as the sum of the modified Noyes scores in the patella, trochlea, medial femoral condyle, lateral femoral condyle, medial tibial plateau, and lateral tibial plateau.

The medial and lateral menisci were scored based on the classification described by Crues et al (1 = intrasubstance signal, 2 = linear intrameniscal signal not extending to meniscal surface, 3 = linear signal extending to articular surface, suggesting tear). Preseason and postseason meniscus score was calculated for each knee as the sum of the medial and lateral meniscus scores (eg, for grade 1 intrameniscal signal present in both medial and lateral menisci, a score of 2 was assigned).

Preseason and postseason scores were compared using exact 1-sided (post > pre) paired Wilcoxon tests. The number of male and female subjects was deemed too small to directly test the effect of gender; however, the effect was accounted for by stratifying according to gender. Statistical significance level was set to an unadjusted \( P < 0.05 \), which corresponded to a Bonferroni-adjusted \( P < 0.0056 \) (9 multiple comparisons). Statistical analyses were performed using R version 2.9.2 (www.r-project.org).

**RESULTS**

Twenty-one college basketball players completed the study, with 24 players (12 male and 12 female) participating in the preseason scan. Three players (2 male and 1 female) were not able to complete the postseason scan, leaving 10 males and 11 females with both preseason and postseason scans. None of the athletes had any time off during the season. All players remained asymptomatic with respect to the study knee throughout the season, with the exception of 1 female player who sustained an acute chondral injury 6 weeks after her preseason scan. Her preseason MRI demonstrated grade 1 and 2 changes in the articular cartilage of the lateral femoral condyle (Figure 1). While pivoting during practice, she sustained an acute, full-thickness chondral injury (grade 4) to her lateral femoral condyle, near the cartilage abnormality identified on her preseason scan.

Preseason scans revealed at least 1 structural abnormality in all 24 asymptomatic knees. A particularly high prevalence of patellar and quadriceps tendinopathy, fat pad and BME, and articular cartilage changes was observed in the preseason scans (Table 2 and Appendix, Supplemental Digital Content 1, http://links.lww.com/JSM/A105). Prepatellar bursitis was seen in 15 of 24 knees (63%) with fat pad edema in 18 of 24 knees (75%). Patellar and quadriceps tendinopathy was demonstrated in 20 and 18 knees (83% and 75%), respectively. Bone marrow edema was observed in 18 knees (75%), 14 of which (78% of affected) involved the patellofemoral articulation. Chondral lesions were noted in 17 knees (71%), 15 of which (88% of affected) involved the patellar or trochlear cartilage (Figure 2). No complete ligament or meniscus tears were found in either the preseason or postseason scans, but 2 meniscal-capsular injuries were identified. Preseason meniscus signal change was observed in 12 of 24 knees (50%), with grade 1 and 2 signal seen in 8 and 4 knees, respectively. Preseason imaging also revealed small effusions in 2 knees (8%), evidence of Osgood–Schlatter disease in 2 knees (8%), and edema surrounding the iliotibial (IT) band in 11 knees (46%). Also noted were Baker’s cysts in 8 knees (33%) and cruciate ligament ganglion cysts in 2 knees (1 anterior cruciate ligament and 1 posterior cruciate ligament).

**TABLE 2.** Distribution of Preseason and Postseason Findings

<table>
<thead>
<tr>
<th>Structure/Pathology</th>
<th>Preseason, 24 Subjects (12/12)</th>
<th>Postseason, 21 Subjects (10/11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal, 0</td>
<td>Mild, 1</td>
</tr>
<tr>
<td>Prepatellar bursitis</td>
<td>5 (5/4)</td>
<td>12 (7/5)</td>
</tr>
<tr>
<td>Fat pad edema</td>
<td>6 (1/5)</td>
<td>10 (7/3)</td>
</tr>
<tr>
<td>Patellar tendinopathy</td>
<td>4 (1/3)</td>
<td>14 (7/7)</td>
</tr>
<tr>
<td>Quadriceps tendinopathy</td>
<td>6 (2/4)</td>
<td>14 (7/7)</td>
</tr>
<tr>
<td>BME</td>
<td>6 (2/4)</td>
<td>12 (7/5)</td>
</tr>
<tr>
<td>Patellofemoral BME</td>
<td>10 (3/7)</td>
<td>11 (8/3)</td>
</tr>
<tr>
<td>Tibiofemoral BME</td>
<td>16 (8/8)</td>
<td>5 (2/3)</td>
</tr>
<tr>
<td>Articular cartilage*</td>
<td>7 (4/3)</td>
<td>7 (4/3)</td>
</tr>
<tr>
<td>Patellofemoral</td>
<td>9 (6/3)</td>
<td>6 (2/4)</td>
</tr>
<tr>
<td>Tibiofemoral</td>
<td>16 (9/7)</td>
<td>6 (3/3)</td>
</tr>
<tr>
<td>Meniscus</td>
<td>12 (8/4)</td>
<td>8 (3/5)</td>
</tr>
<tr>
<td>Medial</td>
<td>13 (9/4)</td>
<td>7 (2/5)</td>
</tr>
<tr>
<td>Lateral</td>
<td>12 (11/11)</td>
<td>2 (1/1)</td>
</tr>
</tbody>
</table>

1 Twenty-four subjects (12 male and 12 female) completed preseason scans and 21 subjects (10 male and 11 female) completed postseason scans. Numbers in parentheses represent the gender breakdown (male/female) for each reported finding.

*For subjects with lesions in multiple locations, the highest grade lesion is listed.
All 21 subjects (10 male, 11 female) scanned after the season also had one or more findings on 3.0-T MRI. Postseason imaging continued to demonstrate high rates of “abnormal” findings. Prepatellar bursitis was seen in 16 of 21 knees (76%), fat pad edema in 17 knees (81%), patellar tendinopathy in 19 knees (90%), and quadriceps tendinopathy in 19 knees (90%). Bone marrow edema was evident in 18 knees (86%), 16 of which (89% of affected) involved the patellofemoral articulation. Chondral lesions were observed in 17 of 21 knees (81%) with patellofemoral chondral lesions in 15 of 21 knees (88% of affected knees). Intrasubstance (grade 1) or linear (grade 2) meniscus signal was found in a total of 13 (62%) of 21 knees (Table 2). Postseason scans revealed edema surrounding the IT band in 11 of 21 knees (51%). Of the 8 Baker’s cysts noted in the preseason scans, 2 knees were not reimaged in the postseason, 5 cysts remained essentially unchanged, and 1 cyst decreased in size.

Mean scores for the 21 subjects who completed both preseason and postseason scans are seen in Figure 3. No statistically significant change between preseason and postseason was observed for prepatellar bursitis, fat pad edema, and patellar and quadriceps tendinopathy. Patellofemoral compartment bone marrow edema increased after a season of play; however, this increase was not statistically significant ($P = 0.09$). The BME score summed over all compartments (BME SUM) was not significantly different ($P = 0.43$) in the preseason and postseason. The mean cartilage injury score for the patellofemoral compartment (Noyes PF) increased from preseason to postseason, but was not statistically significant ($P = 0.23$). A larger increase was observed in total cartilage injury score (Noyes Sum), which increased significantly from a preseason mean of 1.76 to a postseason mean of 2.48 ($P = 0.0009$). After a season of play, Noyes Sum increased in 13 of 21 subjects (62%), remained unchanged in 7 subjects (33%), and decreased in only 1 subject (5%).

A trend toward increasing meniscus signal in the postseason was observed (Figure 4) but was not statistically significant ($P = 0.016$). The meniscus score increased from a mean of 0.67 in the preseason to 0.95 in the postseason. The percentage of subjects with increased meniscus signal increased from 50% (12 of 24) to 62% (13 of 21) after a season of play (Table 2). Most signal change was observed in the medial meniscus (46% and 57% of subjects in the preseason and postseason, respectively). Signal change in the lateral meniscus was much less common (8% and 14% of subjects in preseason and postseason, respectively). No meniscal tears (grade 3) were seen in either preseason or postseason imaging (Table 2).
DISCUSSION

This study demonstrated a higher prevalence of pathologic MRI findings in the knees of high-level basketball players than previously reported. In previous MRI studies of basketball players performed in the preseason, Walczak et al.\textsuperscript{16} and Major and Helms\textsuperscript{15} reported patellar tendinopathy in 39% of professional and 24% of collegiate knees, respectively. Walczak et al.\textsuperscript{16} also reported the presence of quadriceps tendinopathy on MRI in 7% of 28 knees in National Basketball Association athletes. In this study, MRI changes consistent with patellar tendinopathy were seen in 83% and 90% of athletes in the preseason and postseason, respectively. High rates of quadriceps tendinopathy were also seen (75% preseason and 90% postseason). Interestingly, the degree of patellar and/or quadriceps tendinopathy improved by 1 grade in 2 male and 2 female subjects during the season (Appendix, Supplemental Digital Content 1, http://links.lww.com/JSM/A105); the reason for this observation is unclear, but may reflect higher intensity training during the off season by these 4 athletes. This study also found higher rates of prepatellar bursitis (63% preseason and 76% postseason) than the 7% previously reported in NBA players.\textsuperscript{16} In contrast, fewer joint effusions were seen in this study than previously reported for NBA players (8% vs 29%, respectively).\textsuperscript{16}

Bone marrow edema and cartilage findings were observed in most collegiate players, both in the preseason and the postseason. This study identified BME in 75% of players in the preseason and 86% at the end of the season. By comparison, Walczak et al.\textsuperscript{16} and Major and Helms\textsuperscript{15} reported a preseason prevalence of BME in 25% of professional and 41% of collegiate knees, respectively. In addition, previous studies have found a 41% to 50% prevalence of articular cartilage injuries in athletes.\textsuperscript{14–16} Our study also identified a high rate of chondral injuries of 71% preseason and 81% postseason. The articular cartilage and bony structures of the patellofemoral joint were especially affected. Postseason scans revealed marrow edema involving the patellofemoral articulation in 76% of subjects and articular cartilage injury of the patella or trochlea in 71% of subjects. Kaplan et al.\textsuperscript{14} and Walczak et al.\textsuperscript{16} also reported a high prevalence of

FIGURE 3. Comparison of mean scores for the 21 subjects with both preseason and postseason scans. Modified Noyes cartilage scores were summed in the patellofemoral compartment (= Noyes PF) and over all 3 compartments (patellofemoral + tibiofemoral = Noyes Sum). The asterisk (*) indicates a statistically significant increase in Noyes Sum from the preseason to postseason. PPB = prepatellar bursitis, FPE = fat pad edema, PT = patellar tendinopathy, QT = quadriceps tendinopathy.

FIGURE 4. Sagittal proton images of the medial compartment in a female player obtained during the preseason (A) and postseason (B). Preseason image (A) revealed grade 1 intra-substance signal in the posterior horn of the medial meniscus, which increased to a grade 2 linear signal in the postseason scan (B).
patellofemoral cartilage lesions, with patellar lesions noted in 35% and 44% and trochlear notch lesions noted in 25% and 26% of knees studied, respectively. These findings implicate the patellofemoral joint as a region of particularly high stress in basketball players. Patellofemoral biomechanics are strongly influenced by the applied loading, and patellar cartilage may have different mechanical properties than femoral cartilage, potentially increasing its susceptibility to fibrillation. These factors may play a role in the development of patellofemoral pathology as a result of the high loads generated during the repetitive, high-intensity running and jumping inherent in this sport.

Importantly, this study observed a high prevalence of signal change and irregularity in articular cartilage. Moreover, the Noyes Sum cartilage score, representing overall chondral injury throughout the knee, increased significantly after a season of play ($P = 0.0009$). Several studies have documented the short-term effects of exercise on articular cartilage, including in vivo cartilage deformation and changes in collagen structure, interstitial water content, and proteoglycan content. The long-term effects of exercise on cartilage are less well understood. In contrast to muscle and bone, cartilage has limited ability for repair after injury and is less adaptable to its mechanical environment. It is therefore plausible that high-intensity basketball may result in acute chondral changes, with potentially long-lasting effects. A 3.0-T MRI study of runners by Luke et al did not demonstrate any gross morphologic changes in articular cartilage after running a marathon. However, $T_2$ and $T_1\rho$ relaxation times were elevated, suggesting physiologic changes in cartilage that persisted for up to 3 months after running a marathon. In a recent 3.0-T MRI study of asymptomatic female collegiate athletes, Peers et al measured increased $T_1\rho$ relaxation times in the radial zone of the medial femoral condyle in basketball players compared with swimmers, suggesting decreased proteoglycan content consistent with degenerative change.

The current 3.0-T MRI study revealed meniscal signal abnormality in 50% of preseason knees and 62% of postseason knees. These results are similar to Walczak et al who reported degenerative changes in the menisci of 54% of asymptomatic NBA players with a tear in 1 player (3.6%). Major and Helms found no tears in 34 knees of college basketball players. In a 1.5-T MRI study of professional basketball players, Kaplan et al reported meniscal abnormalities (four grade 1, two grade 2, two grade 3) in 8 of 40 knees (20%), with 7 of these 8 lesions in the medial meniscus. Similarly in this study, most meniscal changes were localized to the medial meniscus (11 preseason and 12 postseason) as compared to the lateral meniscus (2 preseason and 3 postseason). A trend toward increasing meniscus signal was observed in the postseason. However, it was not statistically significant ($P = 0.016$) and may represent Type II statistical error because of inadequate number of subjects. A 3.0-T MRI study of marathon runners by Stehling et al revealed a 15% prevalence of grade 1 intrasubstance meniscal signal. Similar to the Luke et al study of articular cartilage in marathon runners, elevated $T_2$ and $T_1\rho$ relaxation times were measured in the menisci in postmarathon MRI. Although $T_2$ values decreased after 3 months, $T_1\rho$ values remained elevated, indicating more persistent changes in the meniscal matrix composition after a marathon.

The high prevalence of findings in this study is likely due to the use of 3.0-T MRI rather than 0.3-T to 1.5-T MRI. As has been reported previously, the increased SNR of 3.0-T may improve the diagnostic sensitivity, accuracy, and grading of cartilage abnormalities and other pathology. The limitations of this study include a small number of subjects and nonblinded reviewers. However, a high degree of concordance was noted between the 3 clinicians; of the few situations in which there was a discrepancy, it involved only 1 grade and was readily resolved by consensus. Another limitation of this study was the use of composite scoring systems for BME and cartilage and meniscus signals that did not incorporate the size of the lesion and were not validated. Validated MRI scoring systems, such as Magnetic resonance Observation of Cartilage Repair Tissue (MOCART) for cartilage repair and Whole-Organ Magnetic Resonance Imaging Score (WORMS) for knee osteoarthritis, were not applicable to our study data. Finally, comparing our results to studies of male NBA players may not be appropriate as half of our subjects were female. However, a similar prevalence of structural abnormalities was seen between male and female subjects, although a formal statistical comparison was not performed given the small number of subjects.

The high prevalence of asymptomatic MRI findings observed in this study reinforces the importance of treating the patient, not the MRI, and highlights the necessity for clinical correlation of MRI findings with patient symptoms and physical examination. Obtaining a preseason MRI as a baseline in high-risk athletes may be useful in determining whether an injury during the season represents a new finding on MRI and may help guide management of the injury. Further study is warranted to determine whether MRI findings in asymptomatic knees are associated with increased risk for future injury or degenerative change. In theory, morphologic defects of meniscus and cartilage visualized on clinical MRI sequences are likely preceded by early degeneration of the biological matrix, including effects on proteoglycan metabolism, collagen composition, and water content. Physiologic cartilage MRI sequences, such as $T_2$ mapping, $T_1\rho$, dGEMRIC, and sodium imaging, may be useful for detecting early changes in cartilage. Suggestions for future research include (1) longitudinal studies to determine the long-term effects of competitive basketball and (2) studies that use sequential postseason MRI to determine the time course for recovery of abnormal findings, which may provide insight into the amount of rest needed to prevent long-term injury.

REFERENCES