

# Full-Thickness Knee Articular Cartilage Defects in National Football League Combine Athletes Undergoing Magnetic Resonance Imaging: Prevalence, Location, and Association With Previous Surgery

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**Purpose:** To better define the prevalence and location of full-thickness articular cartilage lesions in elite football players undergoing knee magnetic resonance imaging (MRI) at the National Football League (NFL) Invitational Combine and assess the association of these lesions with previous knee surgery. **Methods:** We performed a retrospective review of all participants in the NFL Combine undergoing a knee MRI scan from 2005 to 2009. Each MRI scan was reviewed for evidence of articular cartilage disease. History of previous knee surgery including anterior cruciate ligament reconstruction, meniscal procedures, and articular cartilage surgery was recorded for each athlete. Knees with a history of previous articular cartilage restoration surgery were excluded from the analysis. **Results:** A total of 704 knee MRI scans were included in the analysis. Full-thickness articular cartilage lesions were associated with a history of any previous knee surgery ( $P < .001$ ) and, specifically, previous meniscectomy ( $P < .001$ ) but not with anterior cruciate ligament reconstruction ( $P = .7$ ). Full-thickness lesions were present in 27% of knees with a previous meniscectomy compared with 12% of knees without any previous meniscal surgery. Full-thickness lesions in the lateral compartment were associated with previous lateral meniscectomy ( $P < .001$ ); a similar relation was seen for medial meniscus tears in the medial compartment ( $P = .01$ ). **Conclusions:** Full-thickness articular cartilage lesions of the knee were present in 17.3% of elite American football players at the NFL Combine undergoing MRI. The lateral compartment appears to be at greater risk for full-thickness cartilage loss. Previous knee surgery, particularly meniscectomy, is associated with these lesions. **Level of Evidence:** Level IV, therapeutic case series.

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Elite American football players are at a high risk of knee injury, including articular cartilage injury. Among players at the National Football League (NFL) Invitational Combine, where collegiate players are eval-

uated for their potential to participate at the professional level, over 50% reported a history of previous knee injury and over 25% had undergone previous knee surgery.<sup>1,2</sup> Articular cartilage lesions are common in patients undergoing knee arthroscopy after athletic injury,<sup>3-7</sup> and previous studies have shown a high rate of articular cartilage injuries in athletes undergoing magnetic resonance imaging (MRI).<sup>8-12</sup>

Treatment options for symptomatic full-thickness articular cartilage lesions in the knee continue to evolve, but treatment of these lesions remains particularly challenging in the elite athlete. Brophy et al.<sup>13</sup> recently reported a series of 118 NFL players with knee articular cartilage injuries over a 15-year period. In this series 46% of players underwent surgical treat-

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ment. This study also surveyed NFL team physicians and reported that microfracture was the most common treatment approach to these lesions. Despite improving treatment options, the ability to return to high-level sports after treatment of articular cartilage lesions is variable, with few long-term data.<sup>14-16</sup>

Although a recent study reported on the prevalence of knee articular cartilage lesions at the NFL Combine among athletes undergoing MRI,<sup>17</sup> the incidence and natural history of articular cartilage lesions remain unclear, particularly in elite athletic populations such as collegiate and professional American football players. Risk factors for such lesions have not been well described or studied. The purpose of this study was to better define the prevalence and location of full-thickness articular cartilage lesions in elite American football players undergoing knee MRI. In particular, the study was designed to test the hypothesis that previous knee surgery, particularly previous meniscal surgery and/or anterior cruciate ligament (ACL) reconstruction, is associated with these lesions.

## METHODS

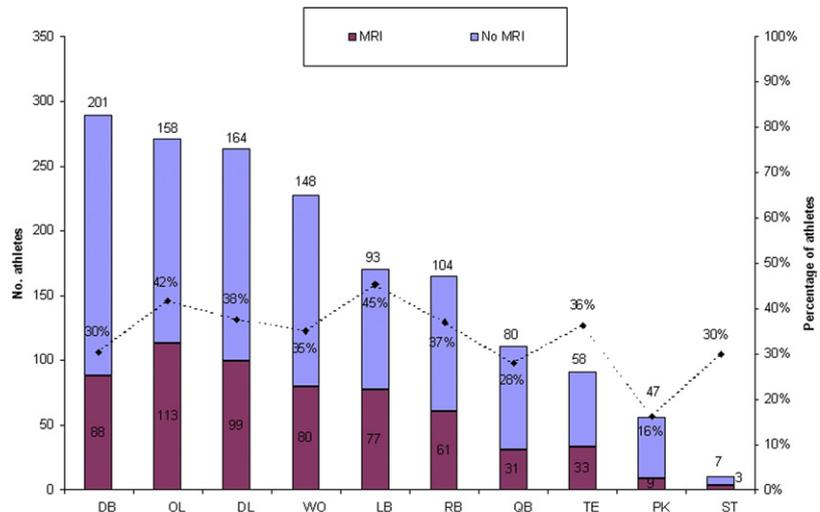
We obtained institutional review board approval before conducting this study. We performed a retrospective review of all NFL Combine participants undergoing knee MRI from 2005 to 2009. During this period, 594 players with 723 knee MRI scans were identified among a total of 1,654 players. At the NFL Combine, each athlete's medical history is discerned from direct interview as well as from information provided by his college's athletic training staff. Each player undergoes 6 separate comprehensive knee examinations by team orthopaedists from each of the 32 NFL teams. In general, these orthopaedists are fellowship trained in sports medicine. A series of knee radiographs is performed on all athletes with a history of knee injury, surgery, those noted to have relevant physical examination findings (effusion and so on), or pain. This series includes a posterior-anterior weight-bearing radiograph with the knee flexed to 40° (Rosenberg view), a non-weight-bearing lateral radiograph at 30°, and a bilateral Merchant view of the patellofemoral joint. A knee MRI scan is generally performed in players at highest risk for intra-articular pathology. This includes players with a history of major knee injury; prior meniscal, ligamentous, or articular cartilage surgery; abnormalities noted on plain radiographs and/or physical examination; or those athletes with current knee symptoms. Knee MRI scans were performed by standard protocols at 1.0 or

1.5 T without intra-articular gadolinium. Most participants at the NFL Combine are currently asymptomatic and are competing at a high level.

Clinical data for all patients undergoing knee MRI scans were obtained from NFL Combine documentation. Demographic data recorded included age, position, height, and weight. Body mass index (BMI) was calculated from these data. Players were grouped by position (Fig 1). Any history of previous knee injury or surgery, any current symptoms, and all physical examination abnormalities were documented. Details of previous surgery were recorded, including partial medial/lateral meniscectomy, medial/lateral meniscal repair, ligament reconstruction, and treatment of articular cartilage lesions. When full details of operative treatment were not available, MRI findings were used to supplement details. For example, a history of unspecified partial meniscectomy with evidence of decreased meniscal size on MRI was recorded as a partial meniscectomy of the surgically altered meniscus (medial or lateral). Two players had histories of unspecified meniscal tears that were not able to be further defined from history or MRI. These players were included in the analysis, with the exception of compartment-specific variable analysis. Players with bilateral knee MRI scans are included in the analysis twice (as 2 separate knees). The MRI findings of 19 players with a history of previous treatment to restore a full-thickness articular cartilage defect were excluded from the analysis. Among players with previous treatment of full-thickness lesions, 10 had undergone microfracture; 8, osteochondral autograft transfer/mosaicplasty; and 1, autologous chondrocyte implantation. Of the 19 players, 3 had a history of ACL reconstruction. These lesions were located most commonly in the lateral femoral condyle ( $n = 8$ ) or medial femoral condyle ( $n = 5$ ). The remaining 704 knee MRI scans were the focus of the study.

The MRI scans were reviewed for evidence of articular cartilage disease and osteochondral lesions by fellowship-trained musculoskeletal radiologists. Articular cartilage disease was classified as absent, partial-thickness articular cartilage loss, or full-thickness articular cartilage loss. The MRI scans of full-thickness cartilage lesions and lesions whose classification was unclear based on the radiologist's report were reviewed by 2 of the authors (one orthopaedic attending surgeon and one orthopaedic resident surgeon). Athletes with generalized, nonfocal cartilage loss consistent with osteoarthritis were not considered to have full-thickness lesions. Full-thickness cartilage lesions were further characterized by location and size. Location was classified based on

**FIGURE 1.** Number and percentage of athletes with knee MRI by position: defensive secondary (DB), running back (RB), offensive lineman (OL), defensive lineman (DL), linebacker (LB), quarterback (QB), tight end (TE), wide receiver (WR), and kicker (K).



the anatomic location (i.e., patella, trochlea, medial or lateral femoral condyle, or medial or lateral tibial plateau).

The relation between potential risk factors and the presence of full-thickness articular cartilage lesions was analyzed by  $\chi^2$  analysis.  $P < .05$  was considered significant. Statistical analysis was performed with SPSS software (SPSS, Chicago, IL).

## RESULTS

During the study period, a total of 594 players (723 knees) underwent knee MRI (Table 1). The mean BMI among the cohort was 31.8, with 59% of players having a BMI greater than 30. Linemen and linebackers were most likely to have a knee MRI scan (Fig 1). Only 17 knees (2.4%) had current symptoms or abnormal physical examination findings, which manifested most commonly as a knee effusion or recent injury.

### Surgical History

Previous knee surgery was reported in 423 (59%) of the 723 knees, with 65 (9.0%) of the knees having

**TABLE 1.** Demographics of Athletes Undergoing Knee MRI (N = 594)

	Data
Age (yr)	22.7 $\pm$ 0.9 (range, 20.5-26.2)
BMI	31.8 $\pm$ 4.6 (range, 22.3-44.9)
Side (right)	36.5% (217)
Side (left)	41.8% (248)
Bilateral	21.7% (129)

undergone more than 1 surgery (Fig 2). Meniscus tears were twice as common in the lateral meniscus as the medial meniscus. Lateral meniscus tears were treated with partial meniscectomy in 171 knees (92.4%), including 2 patients requiring partial meniscectomy after previous repair, and meniscal repair in 14 knees (7.6%). Medial meniscus tears were treated with partial meniscectomy in 80 knees (90.9%), including 2 patients requiring partial meniscectomy after previous repair, and meniscal repair in 8 knees (9.1%).

ACL reconstruction was reported in 137 knees (19%). A history of ACL revision was reported in 7 knees (1%). Among the 130 knees with primary ACL reconstructions, 54 (42%) had a history of a meniscal tear, including 25 knees with lateral meniscus tears, 18 knees with medial meniscus tears, and 11 with both medial and lateral meniscus tears.

Of the 723 knees, 87 (12%) had previous surgery that did not involve treatment of meniscal or ACL injuries. These included 25 isolated arthroscopic chondroplasties, 15 isolated loose body removals, 14 diagnostic arthroscopies, 10 procedures to address full-thickness chondral/osteochondral lesions, 6 procedures involving treatment of an osteochondritis dissecans lesion (including open reduction-internal fixation, debridement, and drilling), and 17 other miscellaneous procedures. The MRI findings of 19 players who underwent previous articular cartilage repair surgery were excluded from the analysis, resulting in a total of 704 knee MRI scans.

### MRI Findings

Articular cartilage abnormalities were seen in 432 (61%) of the 704 knees. A total of 152 full-

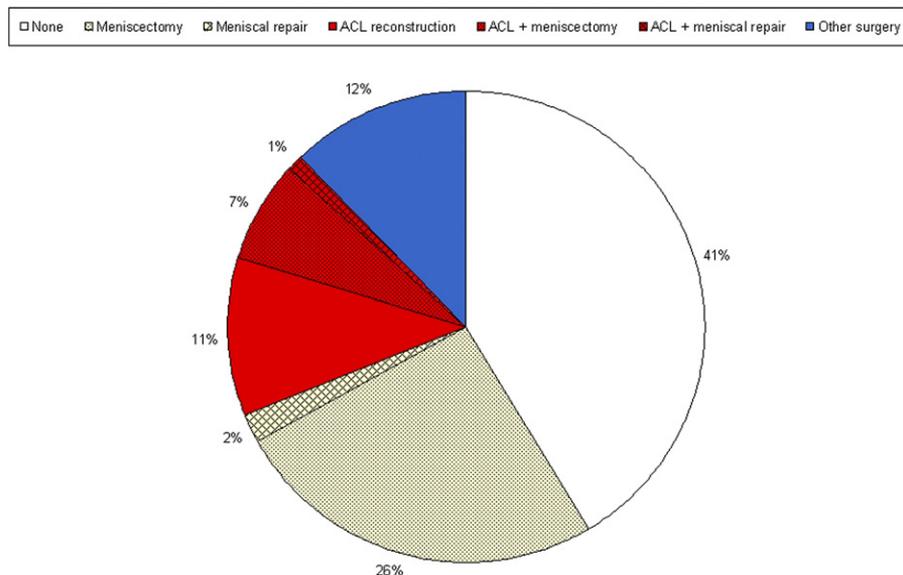


FIGURE 2. Previous surgical history of knees undergoing MRI.

thickness cartilage defects were present in 122 knees (17%). Full-thickness lesions were most common in the lateral compartment and, specifically, the lateral femoral condyle (Table 2). In 16 knees, 2 full-thickness lesions were in the same compartment, with 15 (94%) of these occurring in the lateral compartment, accounting for over half of all lesions of the lateral tibial plateau. Full-thickness defects were present in multiple compartments in 10 knees (1.4%). The mean size of the full-thickness defects was 104 mm<sup>2</sup>. Mild chondromalacia was present in an additional 310 knees (44%); no evidence of cartilage abnormality was seen in 272 knees (39%). Evidence of osteochondral lesions was found in 29 knees (4.1%). These lesions were most common in the medial femoral condyle and trochlea.

### Factors Associated With Full-Thickness Articular Cartilage Lesions

Univariate analysis found previous surgery to be significantly associated with full-thickness articular

TABLE 2. Intra-Articular Location of Full-Thickness Articular Cartilage Lesions

Location	No. of Lesions	%
Lateral femoral condyle	59	39
Lateral tibial plateau	29	19
Patella	22	14
Trochlea	21	14
Medial femoral condyle	20	13
Medial tibial plateau	1	1

cartilage lesions ( $P < .001$ ). Full-thickness cartilage lesions were present in 96 knees (24%) with a history of previous surgery compared with 26 knees (8.7%) without previous surgery (Table 3). Full-thickness lesions were significantly more likely in players with a history of partial meniscectomy (27% v 12%). Players with a history of previous meniscal repair, including athletes who had a meniscectomy after failed meniscus repair, had a 16% incidence of full-thickness lesions, which was not significantly different from those without previous meniscal surgery. The incidence dropped to 11% after successful meniscal repair. Knees with full-thickness cartilage defects were more likely to have partial meniscectomy surgery compared with the other knees evaluated by MRI at the NFL Combine (Fig 3). ACL reconstruction was not associated with full-thickness articular cartilage loss ( $P = .7$ ).

Lateral meniscus surgery was associated with full-thickness lateral compartment disease, being present in 25% of players with previous lateral meniscus surgery and 5.0% of players without it ( $P < .001$ ) (Table 4). Successful lateral meniscal repairs had a 14.0% rate of full-thickness lateral disease. There was a trend toward more lateral compartment cartilage disease in players who underwent ACL reconstruction ( $P = .071$ ).

Medial meniscus tears were also significantly associated with full-thickness medial compartment disease ( $P = .01$ ), with rates of full-thickness medial compartment disease of 7.1% and 2.3% in those with

**TABLE 3.** Association Between Previous Knee Surgery and Full-Thickness Articular Cartilage Defects

	Negative	Positive	P Value
Surgery	8.7% (26/300)	24% (96/404)	< .001
Meniscus surgery	12% (56/454)	26% (66/250)	< .001
Partial meniscectomy*		28% (62/225)	< .001
Meniscal repair*		17% (4/24)	.6
ACL reconstruction	17% (97/570)	19% (25/134)	.7
Primary		17% (22/127)	.9
No meniscal surgery		16% (12/75)	.8
Meniscal surgery		19% (10/52)	.7
Revision		43% (3/7)	.07

\*Excludes 1 patient with partial lateral meniscectomy and medial meniscal repair, without full-thickness lesion.

meniscal tears and those without them, respectively (Table 5). None of the 6 successful medial meniscal repairs had full-thickness cartilage loss (Table 5). ACL reconstruction was not associated with full-thickness medial compartment disease.

A history of previous loose body removal ( $P = .005$ ) and a history of chondroplasty ( $P = .041$ ) were both significantly associated with an increased likelihood of full-thickness cartilage lesions.

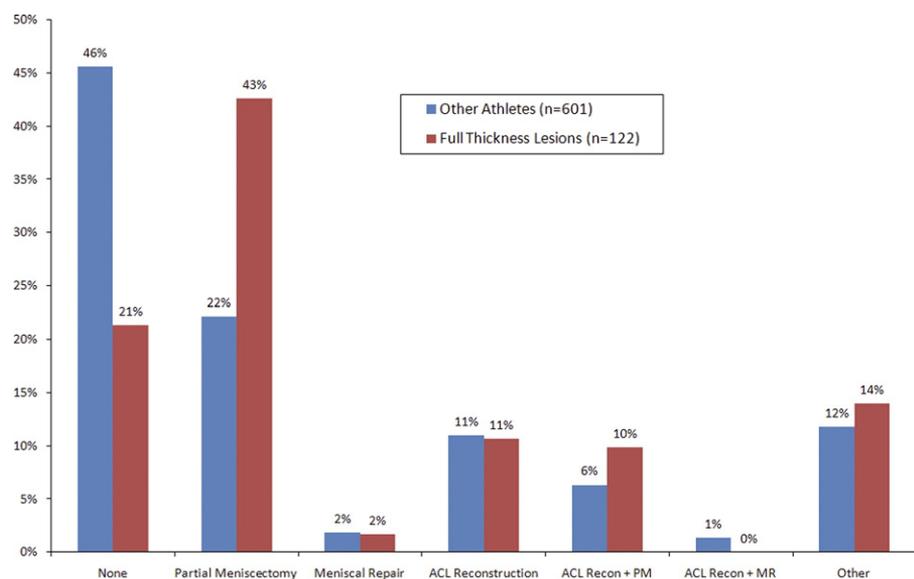
In our cohort full-thickness cartilage lesions were not associated with a BMI greater than 30 or player position. These lesions were most common in tight ends (22%), defensive linemen (19%), and wide receivers (18%) and were least common in offensive linemen (13%) and running backs (13%).

**TABLE 4.** Association of Previous Knee Surgery With Full-Thickness Cartilage Lesions in Lateral Compartment

	Negative	Positive	P Value
Meniscal surgery	5.0% (26/523)	25% (44/179)	< .001
Partial lateral meniscectomy		25% (41/163)	< .001
Lateral meniscus repair		19% (3/16)	.02
Healed lateral meniscus repair		14% (2/14)	.1
ACL reconstruction	9.0% (51/570)	14% (19/134)	.07
No lateral meniscal surgery		13% (12/96)	.3
Lateral meniscal surgery		18% (7/38)	.05

## DISCUSSION

Our study investigated characteristics of articular cartilage degenerative disease in a large group of primarily asymptomatic elite football players undergoing MRI at the NFL Combine. This setting offers a unique opportunity to investigate a large cohort of individuals with a similar athletic history, thorough history and physical examination, and uniform imaging studies. Changes in the articular cartilage were found in 3 of 5 athletes with MRI of the knee, and almost 1 in 5 had full-thickness cartilage lesions. Even if one assumes a zero rate of full-thickness cartilage loss in the athletes who did not undergo knee MRI, the prevalence of focal full-thickness articular carti-

**FIGURE 3.** Comparison of previous knee surgery between all athletes at the NFL Combine and athletes with full-thickness cartilage lesions of the knee. (MR, meniscal repair; PM, partial meniscectomy; Recon, reconstruction.)

**TABLE 5.** Association of Previous Knee Surgery With Full-Thickness Cartilage Lesions in Medial Compartment

	Negative	Positive	P Value
Meniscal surgery	2.3% (14/617)	7.1% (6/85)	.01
Partial meniscectomy		6.6% (5/76)	.03
Meniscal repair		11% (1/9)	.1
Healed meniscal repair		0% (0/6)	.7
ACL reconstruction	2.8% (16/570)	3.0% (4/134)	.9
No medial meniscal surgery		1.9% (2/104)	.6
Medial meniscal surgery		6.7% (2/30)	.2

lage defects is at least 8.5% (141 of 1,654). Previous knee surgery is associated with full-thickness cartilage lesions, as is previous partial meniscectomy. Interestingly, prior ACL reconstruction was not associated with a higher incidence of full-thickness cartilage lesions. A history of partial meniscectomy in the lateral compartment is associated with a higher rate of full-thickness chondral lesions than a history of partial meniscectomy in the medial compartment (25% and 7%, respectively).

Our study focused on full-thickness articular cartilage lesions rather than including less severe chondromalacia for several reasons. MRI has been shown to be highly sensitive in the detection of focal cartilage defects but may less reliably detect lesser stages of disease.<sup>18</sup> Symptomatic partial-thickness defects are generally managed conservatively or with arthroscopic debridement, whereas full-thickness defects may be treated with more aggressive intervention to restore articular cartilage.<sup>13,16</sup>

The prevalence of articular cartilage disease in asymptomatic individuals is not well defined. Laprade et al.<sup>19</sup> reported cartilage lesions in 5.6% of 54 asymptomatic patients. Three studies investigating asymptomatic college and professional basketball players documented rates of articular cartilage abnormalities of 41% to 56%.<sup>8,10,12</sup> Full-thickness defects were present in 7.5% to 8.8% of knees. As mentioned previously, extrapolation of our findings to the entire group of athletes at the NFL Combine suggests a rate of at least 8.5%, which is similar to these values.

Hirshorn et al.<sup>17</sup> previously reported on the prevalence of chondral injuries at the NFL Combine. Although their study period overlapped with ours, they reported a higher incidence of full-thickness chondrosis in 38.2% of athletes undergoing MRI. There are a number of potential underlying causes for this discrep-

ancy. First, Hirshorn et al. appear to have reviewed the MRI readings but not the actual films themselves. We excluded a significant number of athletes who had comments in the radiologist's report such as "full-thickness fissure" or "focal defect" who did not have a full-thickness cartilage defect when we reviewed the actual MRI scan. Second, we did not include patients with moderate osteoarthritis, that is, nonfocal change on MRI or loss of joint space on radiography, who did not have full-thickness cartilage loss, which may be the primary reason that we did not find an association between articular cartilage defects and BMI whereas Hirshorn et al. reported a higher incidence of chondral injury in athletes with a BMI over 30.5. Finally, we did not classify osteochondritis dissecans lesions and previously treated chondral lesions as full-thickness lesions.

Several studies have reported on the rates of articular cartilage disease in athletes and nonathletes undergoing knee surgery. Brophy et al.<sup>13</sup> previously reported on a cohort of 118 NFL players with articular cartilage injuries over a 15-year period. The incidence of articular cartilage injury in professional football players was estimated at 11.4 per 100,000 games. Cartilage lesions were most common in defensive linemen, linebackers, and offensive linemen. These lesions were located in the femoral condyles in over half of cases. Our study population differs significantly from this prior cohort because it includes asymptomatic as well as symptomatic athletes.

Maffulli et al.<sup>5</sup> reported articular cartilage lesions in 43% of individuals undergoing ACL reconstruction, including full-thickness lesions in 9.3%. Riyami and Rolf<sup>6</sup> reported a 5.1% prevalence of full-thickness tibiofemoral cartilage defects in a group of professional athletes undergoing knee arthroscopy. Large studies of individuals undergoing knee arthroscopy have reported rates of articular cartilage lesions that range from 40% to 63%.<sup>3-7</sup> In patients aged under 40 years, full-thickness cartilage defects have been reported in 3% to 5% of knees.<sup>4,6,7</sup>

When broken down by compartment, previous meniscectomy was associated with a greater incidence of full-thickness lesions both medially and laterally. Full-thickness articular cartilage lesions were most common in the lateral compartment. The rate of full-thickness articular cartilage lesions after partial meniscectomy in the lateral compartment (25%) was higher than the rate found for the medial compartment (6.6%). This suggests that the lateral compartment may be more vulnerable to chondral damage after partial meniscectomy than the medial compartment.

The association between previous meniscal surgery and articular cartilage defects does not necessarily imply causation. The initial injury to the meniscus in itself is a harbinger of change in the joint, given that Biswal et al.<sup>20</sup> previously showed that meniscal tears were significantly associated with progression of cartilage disease on MRI. However, it is important to recognize that athletes who have injured their meniscus and required surgery are at risk for articular cartilage lesions. Future studies should investigate ways to mitigate that risk.

Meniscus repairs were not associated with a significantly higher rate of full-thickness articular cartilage defects. However, statistical comparisons of athletes with meniscal repair are limited by the small numbers of athletes undergoing this treatment during the study period. More research is needed to determine the long-term effect of meniscal repair on the risk of articular cartilage damage in this population. Knees with a meniscus tear amenable to repair may be a distinct cohort from knees with tears that are not amenable to repair, which could make it difficult to separate the effect of treatment from the natural history of the injury itself.

ACL reconstruction was not associated with full-thickness articular cartilage disease. This may be because of the elevated baseline rate of full-thickness lesions in this high-risk group of athletes. Even after we excluded all knees with meniscus tears, the rate of full-thickness disease of 16% in knees that had undergone ACL reconstruction did not differ significantly from the rate of 12% in knees without ACL reconstruction. Unfortunately, we do not have data on the time interval from ACL reconstruction, which could confound this analysis because patients are known to have an increased rate of osteoarthritis over time after ACL surgery.<sup>21,22</sup> However, there was a trend toward more athletes with a history of revision ACL reconstruction being more likely to have full-thickness cartilage lesions than those undergoing only a single ACL reconstruction (43% v 17%). In our study further characterization is limited by the presence of only 7 patients with revision ACL reconstruction in this cohort. The rate of grade 3 or 4 Outerbridge cartilage lesions in primary and revision ACL reconstruction has been reported by the MOON (Multicenter Orthopedic Outcomes Network) and MARS (Multicenter ACL Revision Study) study groups to be approximately 28% and 64%, respectively.<sup>23,24</sup> Unfortunately, we do not have detailed data on the time interval from ACL reconstruction or objective documentation of the condition of the ACL graft. Because

there were no athletes in this cohort with failed ACL grafts at the time of the examination, we can state conclusively that all of the knees were ligamentously stable. We are unable to comment on any differences between graft types (i.e., patellar tendon or hamstring autograft or allograft) and the risk for articular cartilage disease. In a case-control study looking at the effect of previous knee surgery on athletes' careers in the NFL, those with a history of meniscectomy had shorter careers than well-matched controls, whereas there was no difference between athletes with a history of ACL reconstruction and control subjects.<sup>25</sup> This may be explained, at least in part, by the current findings that full-thickness articular cartilage disease is more prevalent in athletes with a history of meniscectomy compared with ACL reconstruction.

Unfortunately, our study may not be adequately powered to detect the small difference in full-thickness disease in this population. Shelbourne and Gray<sup>26</sup> reported a 21.6% rate of grade 3 or 4 chondral lesions at the time of ACL reconstruction. However, in the absence of a meniscal tear, only 10.3% of knees had such chondral lesions compared with 34.5% with meniscal tears. At 5- to 15-year follow-up in this cohort, 3% of knees without a meniscal tear had radiographic evidence of osteoarthritis compared with 19% with a meniscal tear.

We showed the lateral femoral condyle to be the most common location for full-thickness lesions. The lateral femoral condyle was also the most common location for treated articular cartilage disease. Previous studies of treated articular cartilage lesions have shown the medial femoral condyle (35% to 89%) to be the most common location.<sup>27-32</sup> The reason for this difference is unclear, although the impact of partial lateral meniscectomy may be partly to blame. There was a much higher rate of full-thickness lesions after meniscectomy in the lateral compartment (25%) compared with the medial compartment (6.6%). Another possible explanation is that lateral femoral condyle defects may be less likely to cause symptoms at least initially. An additional possible explanation is that our study includes a younger, more athletic cohort with a greater incidence of traumatic lesions whereas previous cohorts in the literature may have included older patients with more degenerative lesions. However, very little is known regarding asymptomatic articular cartilage lesions.

A BMI greater than 30 was not found to be associated with full-thickness cartilage lesions. A higher BMI has been shown to result in a poorer outcome after knee surgery. Mithoefer et al.<sup>33</sup> showed that a

BMI greater than 30 was associated with a worse outcome after microfracture surgery. Scheller et al.<sup>34</sup> found a similar association to be present after partial lateral meniscectomy. It should be noted that previous studies have shown that BMI is a poor marker for percent body fat among elite football players because of their large muscle mass.<sup>35,36</sup> In our study a BMI greater than 30 was present in over 60% of players.

Because not all players had MRI scans performed at the NFL Combine, we were unable to determine the true overall prevalence of full-thickness articular cartilage lesions among these players. It is not possible to predict how these findings would change if all of the athletes at the Combine underwent knee MRI. Other weaknesses of our study include its retrospective nature. Surgical details were limited to documentation or player reporting. When possible, these findings were corroborated with MRI findings. The lack of data on the status of the articular cartilage at the time of previous surgery is another confounding factor.

## CONCLUSIONS

Full-thickness articular cartilage lesions of the knee were present in 17.3% of athletes at the NFL Combine undergoing MRI. The lateral compartment appears to be at greater risk for full-thickness cartilage injury. Previous knee injury requiring surgery, particularly meniscectomy, is associated with a higher risk for these lesions.

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