High Rate of Return to Sport for Athletes Undergoing Articular Cartilage Restoration Procedures for the Knee

A Systematic Review of Contemporary Studies

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Background: Continued advancements in cartilage surgery and an accumulating body of evidence warrants a contemporary synthesis of return to sport (RTS) outcomes to provide updated prognostic data and to better understand treatment response.

Purpose: To perform an updated systematic review of RTS in athletes after knee cartilage restoration surgery.

Study Design: Systematic review; Level of evidence, 4.

Methods: PubMed, OVID/Medline, and Cochrane databases were queried in October 2023 for studies reporting any RTS outcome after knee cartilage restoration surgery. Meta-analyses with inverse-variance proportion and DerSimonian-Laird random-effects estimators were applied to quantify overall RTS. Comparative proportional subgroup meta-analyses with relative odds ratios (ORs) were constructed to quantify (1) the influence of the procedure on RTS and (2) RTS ability (lower vs same/greater level of play) based on procedure, competition level, and specific sport.

Results: A total of 52 studies (n = 2387) were included. The overall pooled RTS was 80.3% (95% CI, 73.3%-86.5%). Matrix-assisted chondrocyte implantation (MACI) (OR, 2.15) and osteochondral autograft transplantation system (OATS) (OR, 1.83) demonstrated the highest likelihoods of RTS at the same/greater level, while microfracture (MF) (OR, 0.78) was the only treatment demonstrating a higher likelihood of RTS at a lower level. The fastest mean RTS was observed after OATS (6.6 ± 2.6 months). Professional athletes demonstrated an OR of 1.01 for RTS at the same/greater level, whereas recreational/amateur athletes demonstrated an OR of 1.63; however, all professional athletes underwent MF, and recreational/amateur athletes who underwent MF demonstrated lower likelihoods of RTS (OR, 0.78), indicating a consistent association between MF and low RTS propensity. Basketball players demonstrated the lowest likelihood of RTS at the same/greater level (OR, 1.1), while American football and soccer were associated with high likelihoods of RTS (OR, 3 and 2.4, respectively) across all procedure types.

Conclusion: Cartilage restoration allows for high overall RTS, with OATS and MACI conferring the greatest propensity for RTS, while OATS allowed for the fastest RTS. Undergoing MF was associated with consistently poor RTS ability. This study identified several important associations between the level of RTS and clinically relevant factors when discussing RTS, with recreational/amateur athletes, soccer players, and American football players demonstrating a higher relative propensity to RTS.

Keywords: athlete; autograft; cartilage; cartilage restoration; chondrocyte; knee; osteochondral; sport

Articular cartilage lesions of the knee are an increasingly recognized source of pain and dysfunction in athletes and have an inherently high risk of progression to posttraumatic osteoarthritis, given the repetitive supraphysiologic loading of the knee experienced during sporting activity.[27,47,56,60] Several cartilage restoration procedures may be indicated for treatment depending on factors such as lesion size. Such procedures include microfracture (MF), osteochondral autograft transplantation (OAT), osteochondral allograft transplantation (OCA), autologous chondrocyte implantation (ACI), and other experimental approaches.[19,36,59,73] Although achieving the level of function necessary to perform sporting activity often requires cartilage restoration surgery, conflicting results exist regarding the rate and timing at which athletes may experience a successful return to sport (RTS) after these procedures.

Prior literature has demonstrated variable rates of RTS based on cartilage procedure, sport, age, and other factors,

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making the appropriate surgical treatment challenging to select on an individual basis.[31,38,41] One contributor to this variability may be the definition of RTS, often confounded by categorizing activity-related outcomes,[5,31] in addition to heterogeneous rehabilitation protocols.[65] Furthermore, favorable RTS rates have been published in select series across different populations, while others have reported a poor propensity for RTS.[35,49.75] As cartilage restoration procedures continue to be implicated in treating articular cartilage defects of the knee, it is essential to understand the treatment response to these surgeries and athletes' ability at different competition levels to RTS. Furthermore, while a growing body of literature examining outcomes data on RTS has accumulated since previously published reviews,[1,9,31,40] it is important to continually synthesize and reassess such data to evaluate whether these procedures are efficacious, provide prognostic information, and refine patient indications.

Additional peer-reviewed literature representing contemporary treatment outcomes has become available in the setting of continued technological and surgical advancements in recent years.[3,7,26,35] As such, it is critical to reassess the current state of cartilage restoration surgery in this population to better inform these patients and understand the efficacy of current treatments in this high-demand population. This study aimed to perform an updated systematic review and meta-analysis of the rate and timing of RTS in athletes after knee cartilage restoration surgery. The authors hypothesized that the overall RTS rate would be relatively high compared with previous historical estimates, given the recent advances in cartilage surgery.

METHODS

Article Search Process

This systematic review and meta-analysis was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) statement.[39] The following indexing databases were used to search the literature on RTS rates for athletes undergoing any cartilage restoration procedure in the knee: (1) Cochrane Database of Systematic Reviews, the Cochrane Central Register of Controlled Trials; (2) PubMed; and (3) OVID/MEDLINE. The query was performed in October 2023 using combinations of the following Boolean search and terms: "Cartilage," "Chondrocyte," "Chondral," "Osteochondral," "Articular," "Allograft," "Autograft," "Mosaicplasty," "OAT," "Microfracture," "ACI," "MACI," "Restoration," "Athlete," "Sport," "Athletic." This review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) before data collection (PROSPERO identification No. CRD42023483412).

Study Eligibility and Data Procurement

Studies published in English that addressed any aspect of RTS in athletes undergoing a primary cartilage restoration procedure of the knee were eligible for inclusion. The search was restricted to studies published between 2000 and 2023 to capture contemporary articles. The exclusion criteria were as follows: (1) editorials, abstracts, case reports, technical notes and surveys; (2) biomechanical or cadaveric studies; and (3) studies whose participants were not athletes. Athletes self-reported participation in a sport at the recreational, high school, college, semiprofessional, or professional levels. No restriction on the level of evidence was imparted; however, only level of evidence 5 was excluded.

All articles identified by the search were screened by 2 independent reviewers (K.N.K., M.M.). Sequential screening of all articles was performed, which included assessment of duplicates, screening of article title, evaluation of content within the abstract, and full-text review. References of identified articles were also explored and reconciled to minimize the risk of missing relevant literature. Furthermore, the article with longer follow-up was included when duplicate cohorts were identified. All data were recorded into a custom spreadsheet using a modified information extraction table.[20] Categories for data collection for each full article included (1) article information; (2) cartilage restoration method; (3) patient information; (4) lesion size and location; and (5) RTS information, including type of sport, ability to RTS, level of competition, and time to RTS.

Assessment of Methodological Quality

The Methodological Index for Nonrandomized Studies (MINORS) checklist[22] was used to evaluate the quality of

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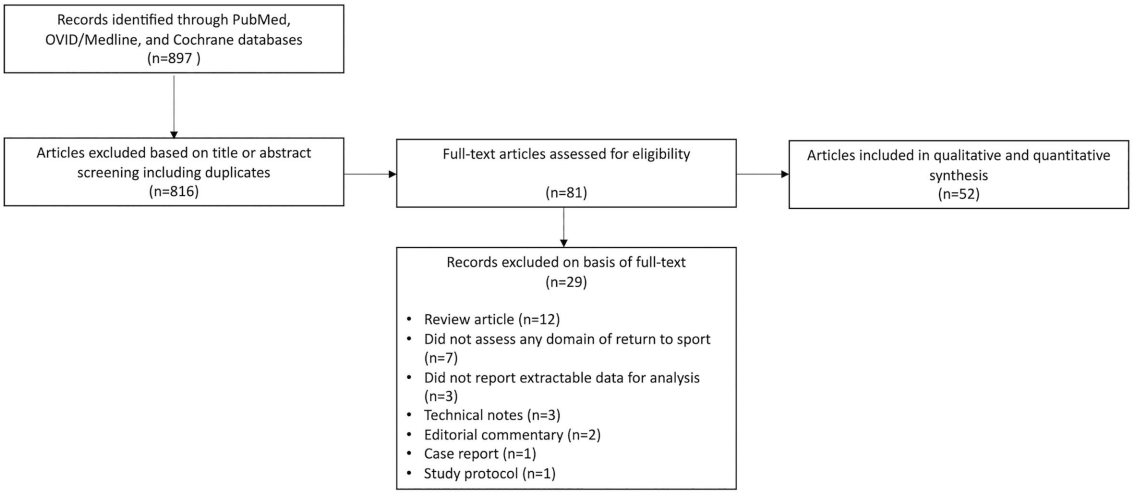

Figure 1. Article identification and selection process.

TABLE 1
Lesion Characteristics of Study Population[a]

Characteristic	Procedure Breakdown
Lesion Location, n (%)	
Femoral condyles, 1599 (77)	ACI: 397; OCA: 291; OAT: 291; MACI: 264; MFL: 197; other: 159
Trochlea, 202 (9.7)	ACI: 53; other: 51; MACI: 32; OAT: 39; OCA: 27
Patella, 178 (8.6)	ACI: 95; MACI: 47; OCA: 14; OAT: 13; other: 6; MF: 3
Multiple surfaces/bipolar, 70 (3.4)	OCA: 33; MF: 25; ACI: 8; other: 3; OAT: 1; MACI: 0
Tibial plateau, 28 (1.3)	Other: 11; MF: 8; OAT: 8; OCA: 1; ACI: 0; MACI: 0
Mean lesion size, cm^2	
Overall, 3.76 cm^2	OCA: 5.52; MACI: 3.99; ACI: 3.72; OAT: 2.94; MF: 2.94; other, 2.21

[a]ACI, autologous chondrocyte implantation; MACI, matrix-associated chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transplantation; OCA, osteochondral allograft transplantation; OR, odds ratio.

nonrandomized comparative studies, while the Cochrane Risk-of-Bias Version 2 tool was used to evaluate randomized controlled trials.[67] The MINORS checklist involves 12 items to assess quality, of which only 4 apply to comparative studies. The 4 additional criteria specific to comparative groups were used to assess the bias in articles when selecting cohorts. The maximum MINORS score is 16 for noncomparative studies and 24 for comparative studies.

Statistical Analysis

All statistical analyses were performed using the computing software R Version 3.6.1 and RStudio Version 1.2.5033 (R Foundation for Statistical Computing). A 2-tailed $P < .05$ was considered statistically significant.

A meta-analysis of proportions was used to provide quantitative study estimates of the rate of RTS after cartilage procedures. For all meta-analyses, a random-effects model using the DerSimonian-Laird method was implemented, and the pooled effect size was calculated as a weighted mean of the effects estimated in the studies, with weights representing the amount of information from each study. Imputation of constants to patient counts was performed when zero values were present, if necessary, which were later removed from quantitative syntheses to preserve estimate accuracies. For comparative proportional subgroup analyses, the relative odds of patients who returned to sport were stratified by the level at which RTS was achieved (lesser competition or functional level versus the same or greater competition or functional level) and also specific cartilage preservation surgery, specific sports, and specific competition levels (recreational, high school, college, or professional) were calculated. Odds ratios (ORs) were subsequently transformed into logarithmic syntax to stabilize variance and normalize the distribution of estimates for graphical depiction but also reported as ORs for ease of interpretation. The 95% CI was used to report all pooled statistics. Heterogeneity was assessed by the I^2 statistic using random-effects models and was regarded as insignificant when $I^2 = 0\%$, possibly unimportant when the I^2 value was <40%, moderate between 40% and 75%, and considerable[23] when >75%.

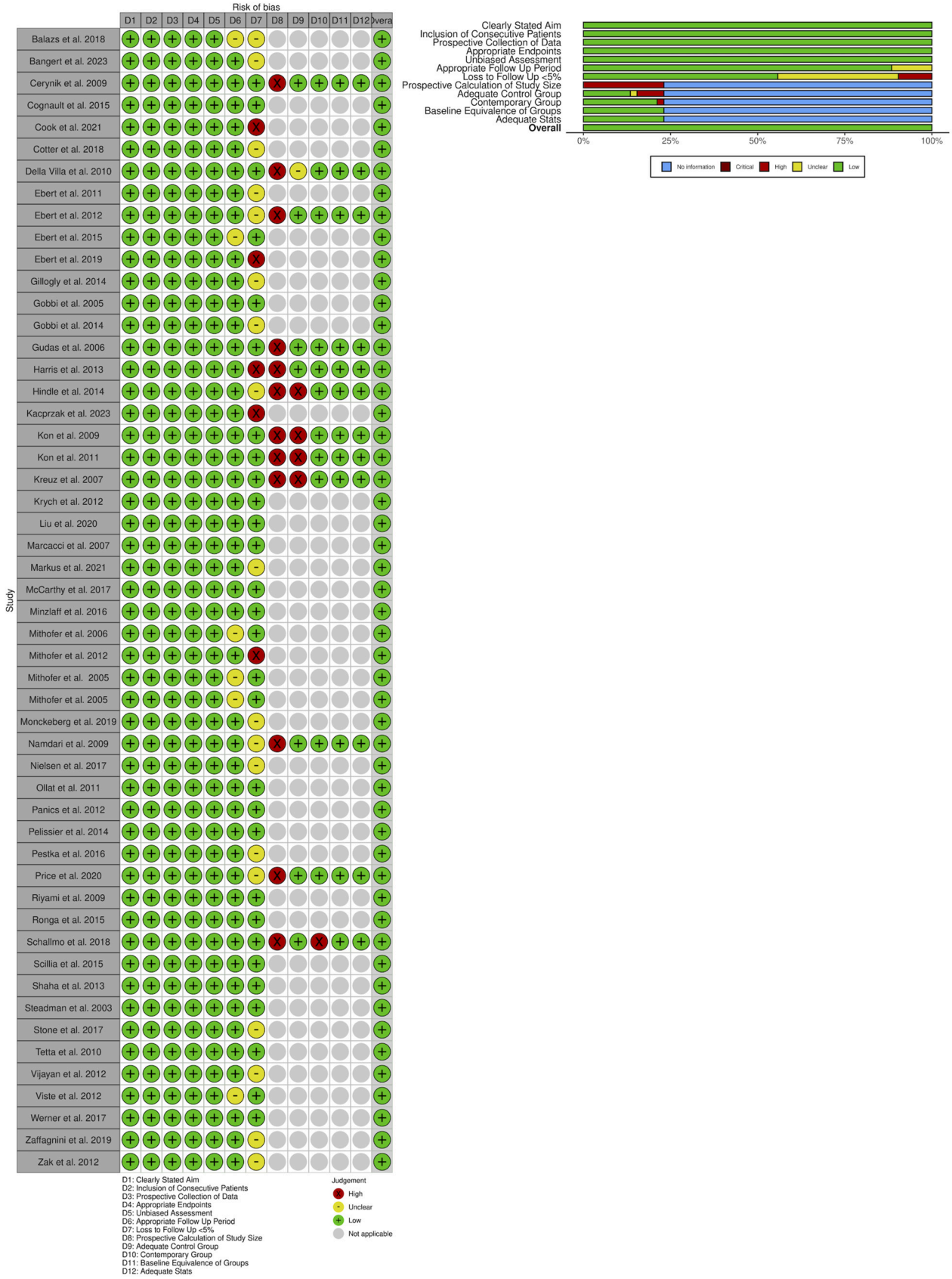

Figure 2. MINORS methodological bias assessments. (A) Top: The traffic light plot depicts the study-specific concern of bias in each respective domain. (B) Bottom: A summary plot depicting the proportion of bias in the study. MINORS, Methodological Index for Non-Randomized Studies.

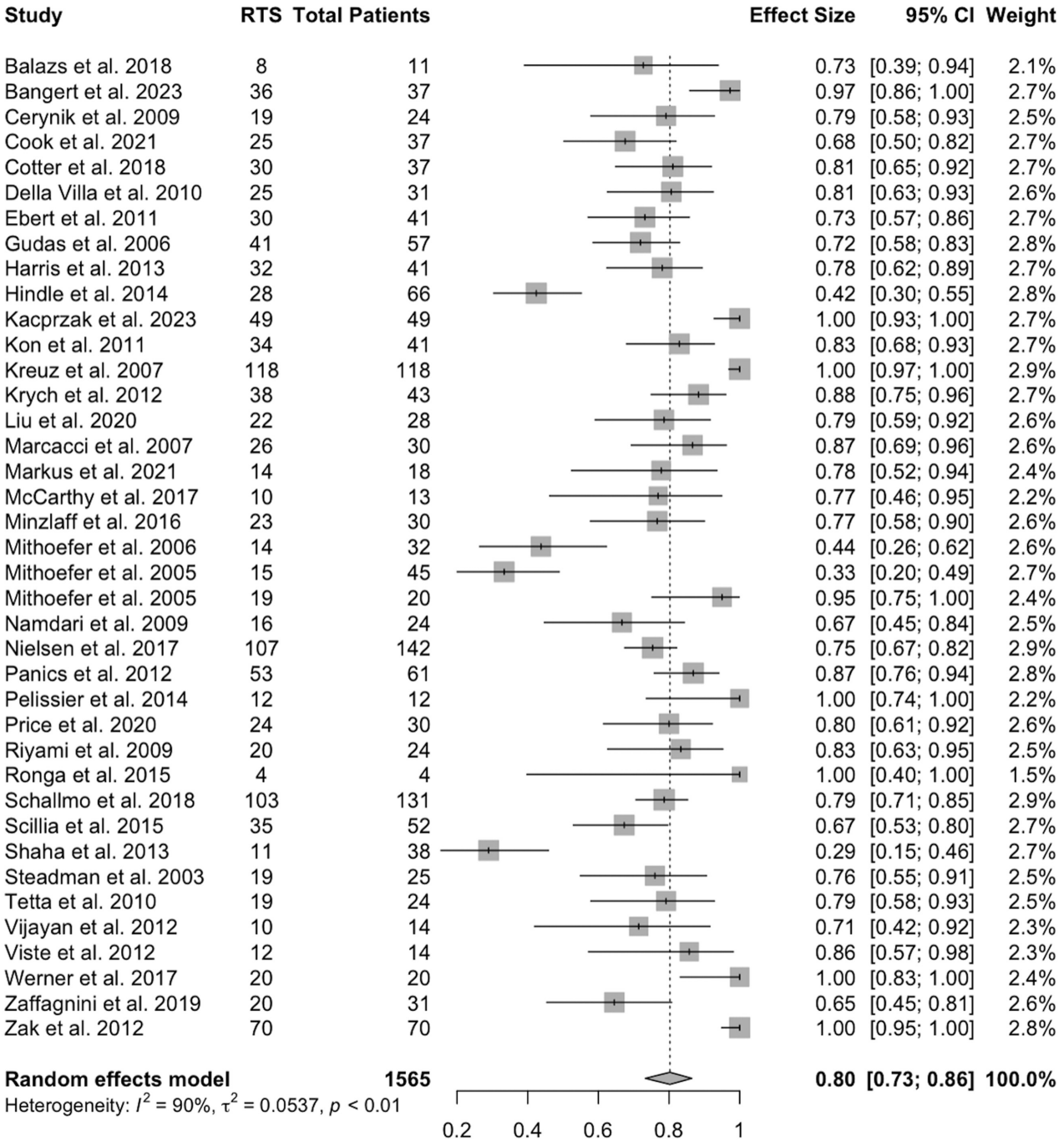

Figure 3. Meta-analysis of proportions for overall pooled RTS rate after all cartilage procedures. The effect size indicates the proportion of patients that RTS. Gray boxes represent the weighted contribution of each condition, with the horizontal black lines representing the 95% CI of the treatment estimate. Heterogeneity based on the definition in this study was rated as considerable (I^2 = 89.6%; P = .0001). RTS, return to sport.

RESULTS

A total of 52 studies comprising the outcomes of 2387 patients who underwent cartilage restoration surgery were identified who reported on 1 domain of RTS (Figure 1). Lesion characteristics are presented in Table 1. Because of variable reporting, not all studies were included in each quantitative analysis. Analysis of the MINORS bias assessment revealed that the included studies demonstrated predominately robust methodological foundations, except for calculating prospective study sizes (Figure 2).

TABLE 2
Proportion of Successful RTS Stratified by Cartilage Procedure[a]

Procedure	RTS Proportion, % (95% CI)
OAT	88.8 (79.4-96)
ACI	81.8 (62.5-95.6)
MF	78.1 (73.3-82.5)
OCA	77.2 (60.2-90.8)
Other	74.1 (46.5-94.4)
MACI	73 (60-84.4)

[a]ACI, autologous chondrocyte implantation; MACI; matrix-associated chondrocyte implantation; MF, microfracture; OAT; osteochondral autograft transplantation; OCA; osteochondral allograft transplantation; RTS, return to sport.

Overall RTS and Level of Return

An overall RTS proportion was reported in 39 studies comprising the outcomes of 1565 patients (Figure 3). These studies observed a pooled RTS rate of 80.3% (95% CI, 73.3%-86.5%). Across all studies, the RTS rate ranged between 29% and 100%. Only 4 of 39 studies reported an RTS rate of < 50%. A total of 17 (43.6%) studies reported an RTS rate ≥80%. RTS data stratified by level of return were reported in a manner amenable to quantitative analysis in 28 studies comprising 1076 patients.‖ Of these studies, 10 (35.7%) reported[8,15,19,26,28,32,34,66,74,76] overall positive outcomes, where most patients returned to a higher level of play, while 7 (25%) studies[2,4,17,18.21,69,72] reported overall negative outcomes, with most patients returning to a lower level of play. Eleven (39.3%) studies[7,16,33,35,37,42,43,44,48,54,75] reported neutral outcomes, where athletes returned to the same level of play. An RTS analysis without ACI can be found in the Appendix (available in the online version of this article), as ACI as a treatment may not be performed as frequently in contemporary cartilage restoration.

Cartilage Surgery

Overall RTS. A subgroup meta-analysis of the level of return stratified by cartilage procedure resulted in 5 surgical interventions encompassing outcomes of 1565 patients (Table 2; Figure 4). No significant difference in RTS rates among cartilage procedures was observed (P = .43). The mean (±SD) time for RTS was 9.2 ± 4 months,¶ and varied by procedure—ACI (13.1 ± 4 months), OCA (11.4 ± 4.3 months), MF (7.5 ± 1.6 months), other procedures (7.1 ± 1.6 months), and OAT system (OATS) (6.6 ± 2.6 months; Figure 5). No studies published data on the time for RTS after matrix-assisted chondrocyte implantation (MACI).

RTS Stratified by Level of Return. A subgroup meta-analysis of the level of return stratified by cartilage procedure was available for data encompassing outcomes of 1076 patients. Patients undergoing MACI or OATS experienced the highest relative likelihood of RTS (115% and 83% increased likelihood, respectively) at the same or greater level of competition postoperatively. Analysis of the association between cartilage surgery and the level of RTS indicated a significant, strong relationship (P = .002) between the procedure and the likelihood of RTS (Table 3; Figure 6).

TABLE 3
Transformed OR for RTS at the Same or Higher Level of Play Stratified by Cartilage Procedure[a]

Procedure	OR (95%CI) for Return to Same/Higher Level of Play
MACI	2.15 (1.39-3.33)
OAT	1.83 (1.14-2.94)
OCA	1.69 (1.23-2.31)
ACI	1.27 (1.04-1.56)
MF	0.78 (0.63-0.96)[b]

[a]ACI, autologous chondrocyte implantation; MACI, matrix-associated chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transplantation; OCA, osteochondral allograft transplantation; OR, odds ratio; RTS, return to sport.
[b]The OR indicates higher likelihood of returning to a lower level of play.

TABLE 4
Overall and Procedure-Stratified RTS Rates at the Same or Higher Level of Play[a]

Sport	OR (95% CI) for Return to Same/Higher Level of Play
Basketball	1.1 (0.91-1.33)
OAT	41 (2.48-677.9)
OCA	2.7 (1.45-5.05)
ACI	0.90 (0.61-1.34)[b]
MF	0.87 (0.67-1.11)[b]
American Football (MF)	3 (1.23-7.29)
Soccer (ACI)	2.36 (1.22-4.57)

[a]ACI, autologous chondrocyte implantation; MACI, matrix-associated chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transplantation; OCA, osteochondral allograft transplantation; OR, odds ratio.
[b]ORs indicate a higher relative likelihood of returning to a lower level of play.

Competition Level

Overall RTS. Three studies (89 patients)[4,21,48] reported an overall proportion of RTS in professional athletes. The overall proportion of professional athletes who returned to sport after cartilage surgery was 75.3% (67/89). Raw data were not available for overall RTS for recreational/amateur athletes.

‖References 2, 4, 7, 8, 15-19, 21, 26, 28, 32-35, 37, 42-44, 48, 54, 66, 69, 72, 74-76.
¶References 2, 4, 7, 8, 10, 19, 21, 24, 26, 28, 32, 33, 37, 44, 48, 50, 52, 54, 57, 58, 61-63, 66, 68.

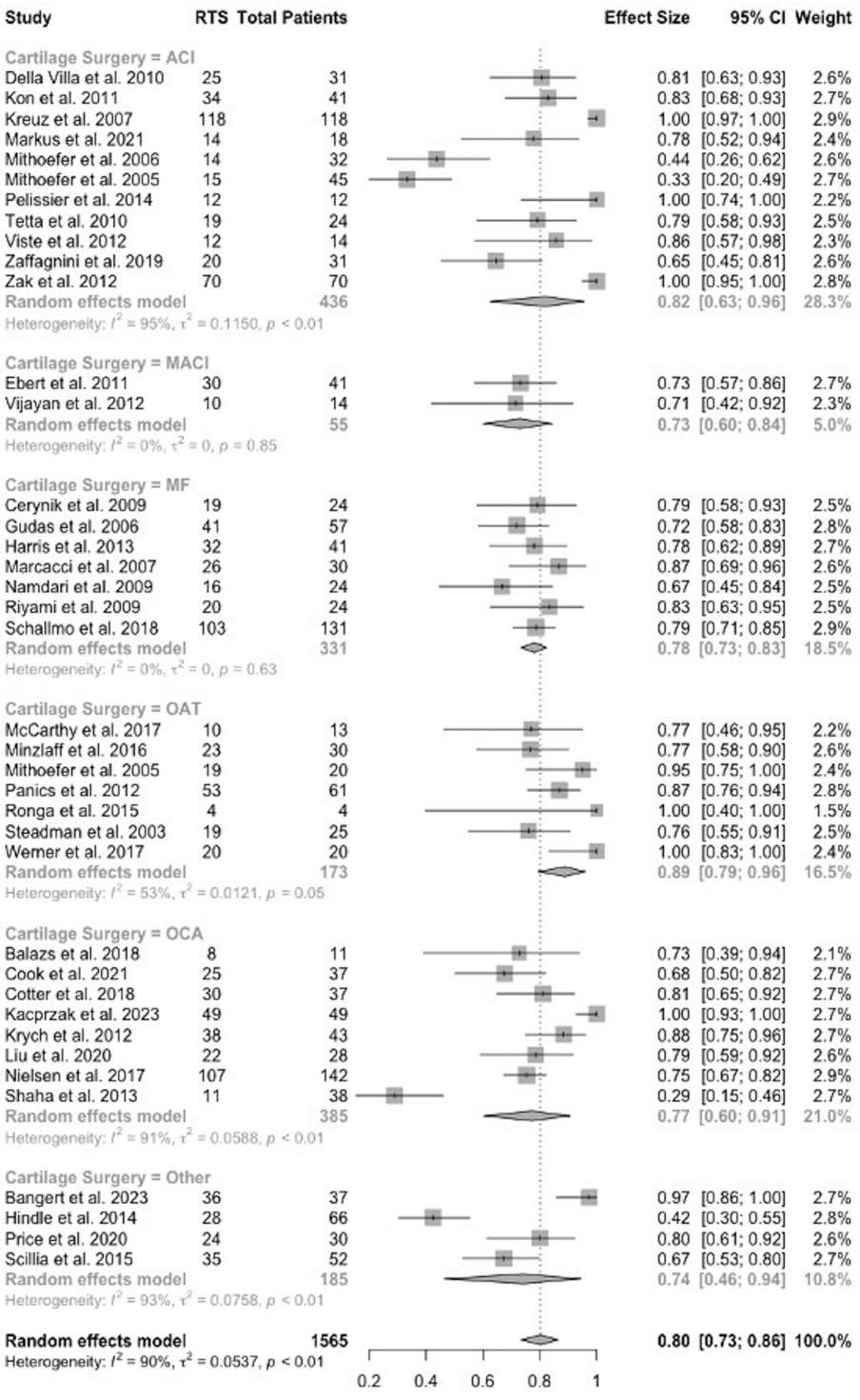

Figure 4. The RTS rate stratified by cartilage procedure. The effect size indicates the proportion of patients that RTS. Gray boxes represent the weighted contribution of each condition, with the horizontal black lines representing the 95% CI of the treatment estimate. Heterogeneity was considerable (I^2 = 89.6%; P = .0001). ACI, autologous chondrocyte implantation; MACI, matrix-induced autologous chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transfer; OCA, osteochondral allograft transplantation; RTS, return to sport.

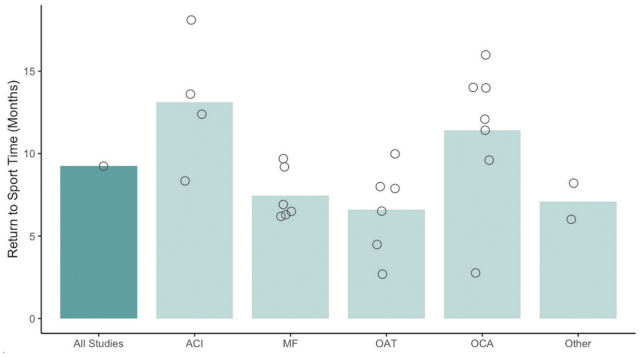

Figure 5. The histogram plot depicts the mean time to RTS in months and the distribution of RTS timing across studies stratified by cartilage procedure. Clear dots represent individual studies. ACI, autologous chondrocyte implantation (n = 4); MF, microfracture (n = 6); OAT, osteochondral autograft transfer (n = 6); OCA, osteochondral allograft transplantation (n = 7); other, other cartilage procedures (n = 2); RTS, return to sport.

RTS Stratified by Level of Return. A total of 7 studies (287 patients)[4,15,21,26,42,48,66] were available for this subanalysis (Figure 7). Also, 82 of 163 (50.3%) professional athletes who underwent any surgery type returned to the same or a higher level of play (OR, 1.01 [95% CI, 0.75-1.37])—all patients underwent MF. Recreational/amateur athletes exhibited varying outcomes based on surgery type. Overall, 77 of 124 (62%) athletes returned to the same or higher level (OR, 1.63 [95% CI, 1.14-2.34])—all patients underwent either MACI or MF. Recreational/amateur athletes who underwent MACI demonstrated a higher likelihood of RTS at the same or higher level (68.5%; OR, 2.15 [95% CI, 1.39-3.33]), while those who underwent MF demonstrated a decreased likelihood of RTS (OR, 0.78 [95% CI, 0.39-1.56]).

Type of Sport

Overall RTS. Fifteen studies[#] presented homogeneous population data (all athletes participated in the same sport) and overall RTS rates. The overall RTS rate for basketball players was 52.2% (128/245). Concerning individual procedures, the highest rate of RTS for basketball players was observed after OATS (20/20 [100%]), followed by OCA (39/48 [81%]), MF (108/146 [74%]), and ACI (20/31 [65%]). A single study on soccer players reported an RTS rate of 85% (35/41) after ACI.[24] The overall RTS rate for American football players was not reported.

RTS Stratified by Level of Return. Fifteen studies[#] reported RTS rates at the same or greater level across different sports and cartilage surgeries (Table 4). While certain procedures, such as OATS for basketball players, showed exceptionally high success rates, others, like ACI and MF in the same sport, had comparatively lower rates of returning to the same or higher level of competition. In contrast, football and soccer exhibited a higher overall likelihood of achieving this level of RTS overall (Figure 8).

[#]References 2, 4, 8, 18, 19, 21, 26, 28, 37, 43, 44, 48, 66, 74, 75.

DISCUSSION

The principle findings of the present study are as follows: (1) The overall RTS rate after cartilage restoration procedures was 80.3%, suggesting a high overall rate of RTS; (2) OATS and MACI conferred the highest overall RTS rates by procedure, while MF was associated with a consistently low RTS at the same or greater level of competition; (3) when considering level of competition, recreational/amateur athletes demonstrated a greater propensity for RTS than professional athletes; however, this was influenced by MF used in professional athletes; and (4) American football and soccer players exhibited uniformly high rates of RTS after cartilage restoration procedures, while basketball players experienced the highest RTS after undergoing OATS and OCA.

A high rate of RTS was observed after cartilage restoration surgery, suggesting that this consideration does not preclude athletes from proceeding with cartilage interventions. These data may be useful for patients and knee surgeons during shared decision-making and when considering if one of the above cartilage procedures may be efficacious in setting patient expectations. Krych et al[31] in 2017 performed a systematic review of sport function after cartilage procedures, reporting an overall RTS rate of 73% in 8 studies. Their study was limited in systematically averaging data for OCA patients due to a lack of reporting. In the present study, representing a larger number of more contemporary studies, the overall rate of RTS was 80.3%. It is plausible that the increased statistical power derived from an analysis of over 2300 patients may more accurately reflect RTS rates.

To our knowledge, no literature has investigated the specific association between cartilage procedure type and RTS at a specific level of function. Krych et al[31] reported that OATS conferred the highest RTS with a rate of 93% and MF the lowest at 57.6%. However, these authors did not include data on MACI or OCA. In the present study, the highest RTS rate was observed after OATS (88.8%), followed by ACI (81.8%), comparable to their results. Contemporary data collected in this study also allowed for quantifying RTS rates after OCA and MACI, which were found to be 77.2% and 73%, respectively. Interestingly, when considering the propensity to return to a specific level of function, MACI and OATS resulted in 115% and 83% increased odds of RTS at the same or higher level of competition, while MF was associated with a 22% *lower* likelihood of RTS at the same or higher level of competition. This suggests that MF is a potentially inferior treatment for athletes with focal chondral or osteochondral defects of the knee; however, other potential confounding factors may also contribute to poor outcomes in the MF population, which could be controlled for given the retrospective nature of this analysis. Regardless, given the

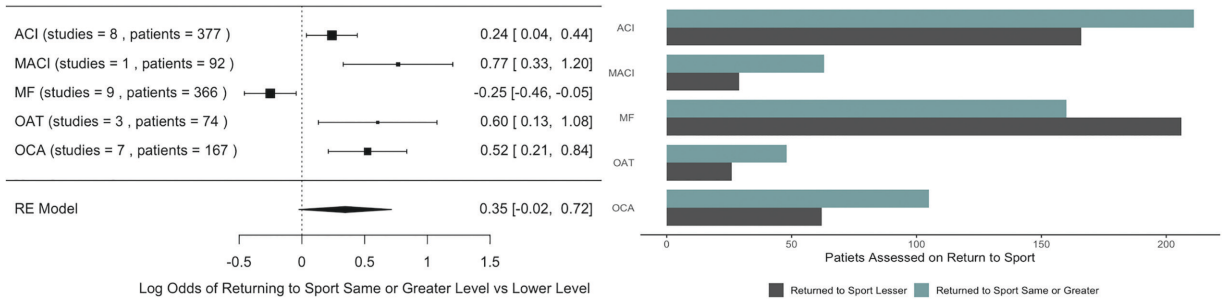

Figure 6. A forest plot depicting the log odds of RTS at the same or a greater level of play versus a lower level of play stratified by specific cartilage surgery (left) and the total number of patients composing each category (right). The right column of the forest plot depicts the log odds of each category with 95% CI. Black boxes represent the weighted contribution of each condition, with the horizontal black lines representing the 95% CI of the treatment estimate. Heterogeneity based on the definition in this study was rated as considerable (I^2 = 87.4%; $P < .0001$). ACI, autologous chondrocyte implantation; MACI, matrix-induced autologous chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transfer; OCA, osteochondral allograft transplantation; RTS, return to sport.

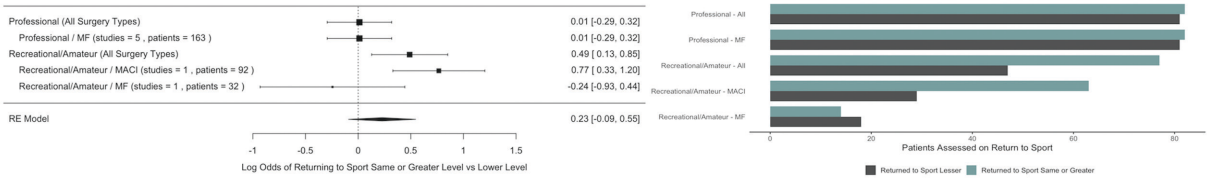

Figure 7. A forest plot depicting the log odds of professional and recreational/amateur athletes returning to sport at the same or a greater level of play versus a lower level stratified by specific cartilage surgery (left) and the total number of patients composing each category (right). The right column of the forest plot depicts the log odds of each category with 95% CI. Black boxes represent the weighted contribution of each condition, with the horizontal black lines representing the 95% CI of the treatment estimate. Heterogeneity based on the definition in this study was considered moderate (I^2 = 70.2%; P = .009). ACI, autologous chondrocyte implantation; MACI, matrix-induced autologous chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transfer; OCA, osteochondral allograft transplantation.

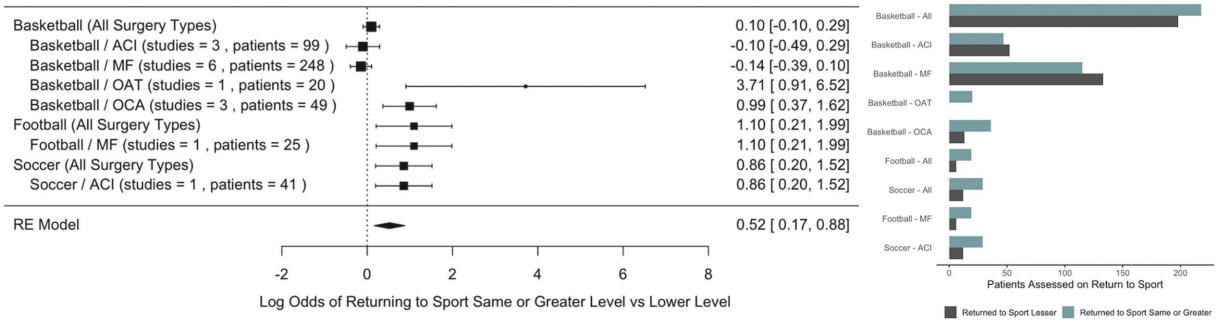

Figure 8. A forest plot depicting the log odds of RTS at the same or a greater level of play versus a lower level of play stratified by specific sport type (left) and the total number of patients composing each category (right). The right column of the forest plot depicts the log odds of each category with 95% CI. Black boxes represent the weighted contribution of each condition, with the horizontal black lines representing the 95% CI of the treatment estimate. Heterogeneity based on the definition in this study was considered moderate (I^2 = 43.7%; P = .13). ACI, autologous chondrocyte implantation; MACI, matrix-associated chondrocyte implantation; MF, microfracture; OAT, osteochondral autograft transplantation; OCA, osteochondral allograft transplantation; RTS, return to sport.

currently available data in the literature, the authors of this review recommend osteochondral grafting or cell-based therapy for athletes with chondral and osteochondral defects of the knee, as these procedures may confer a higher propensity for RTS.

Given the available data, recreational and amateur athletes were more likely to RTS at the same or higher level of competition than professional athletes. This analysis revealed a recurrent association between MF and RTS, with recreational/amateur athletes more likely to return to a lower level of competition after MF. Interestingly, all studies investigating RTS in professional athletes performed MF, potentially accounting for the limited RTS ability. Future studies are warranted to determine the propensity to RTS in professional athletes undergoing other cartilage restoration techniques such as OCA, OATS, and cell-based therapies, as these approaches may result in a more positive treatment response in this high-demand population.

Data on specific sports were amenable to review among basketball, American football, and soccer players. This specific subanalysis revealed the consistent ability of American football and soccer players to RTS, whereas basketball players only demonstrated RTS at the same or greater level if undergoing OATS or OCA (relative to MF or ACI). As such, MF has portended consistently inferior RTS ability in this review; however, it is unclear why treatment with ACI in this population was associated with a lower ability to RTS. One reason may be that basketball athletes play on hard-court surfaces, while American football and soccer players generally play on grass or turf fields. As the frictional property and compliance of surfaces have been implicated as important factors in injury development concerning cartilage, this may be one contributing factor.[25,64] Another potential explanation is that ACI is often used in more anatomically complex locations less amenable to an osteochondral plug with appropriate topographic characteristics, such as the patellofemoral joint; if associated with inferior outcomes, this may contribute to limited RTS within these cohorts.[51] Furthermore, as jumping athletes, basketball players impose repetitive supraphysiologic loads through their patellofemoral joints,[11,70] perhaps jeopardizing graft integrity and, therefore, experiencing inferior outcomes. Future studies are warranted to better understand whether this association exists.

Limitations

Several limitations should be considered when interpreting the results of the present study. First, the quality and granularity of the data are representative of the studies included, which were retrospective. Therefore, certain biases, if existing in individual studies, may influence the results and cannot be controlled for completely. Second, because of variable reporting, the granularity of certain subanalyses was limited. For example, it was necessary to combine patients who returned to the same or greater level of play and compare this cohort to those who returned to a lower level of play, given the limited data. Furthermore, specific subanalyses that may leverage important prognostic insights could not be performed. For example, RTS rates were not reported based on lesion location (ie, patellofemoral versus femoral condyles), based on lesion depth (surface versus deep), or by addition of concomitant procedures such as osteotomies, ligamentous reconstruction, or meniscal procedures. Third, limited sports types (basketball, American football, and soccer) could be studied, given the available data. Fourth, because of the retrospective nature of studies, inability to access original data, or failure of authors to report specific variables, some important factors, such as the number of plugs used for osteochondral grafts or cartilage lesion location, were variable or not reported. Finally, postoperative rehabilitation protocols and RTS criteria for supervised functional progression and timing of clearance often differ across institutions and individual providers, introducing heterogeneity in the definition of the primary RTS outcome.

CONCLUSION

Cartilage restoration procedures allow for a high rate of RTS postoperatively, with OATS and MACI conferring the greatest propensity for RTS, while OATS resulted in the fastest RTS. Undergoing MF was associated with recurrently poor RTS ability. This study identified several important associations between the RTS level and clinically important factors when discussing RTS, with recreational/amateur athletes, soccer players, and American football players demonstrating a high propensity to RTS at the same or greater preinjury level.

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