Athletic Performance at the National Basketball Association Combine After Anterior Cruciate Ligament Reconstruction

Nima Mehran,*† MD, Phillip N. Williams,† MD, Robert A. Keller,‡ MD, Lafi S. Khalil,§ BS, Stephen J. Lombardo,† MD, and F. Daniel Kharrazi,† MD

Investigation performed at Kerlan-Jobe Orthopaedic Clinic, Los Angeles, California, USA

Background: Anterior cruciate ligament (ACL) injuries are significant injuries in elite-level basketball players. In-game statistical performance after ACL reconstruction has been demonstrated; however, few studies have reviewed functional performance in National Basketball Association (NBA)–caliber athletes after ACL reconstruction.

Purpose: To compare NBA Combine performance of athletes after ACL reconstruction with an age-, size-, and position-matched control group of players with no previous reported knee injury requiring surgery. We hypothesized that there is no difference between the 2 groups in functional performance.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 1092 NBA-caliber players who participated in the NBA Combine between 2000 and 2015 were reviewed. Twenty-one athletes were identified as having primary ACL reconstruction prior to participation in the combine. This study group was compared with an age-, size-, and position-matched control group in objective functional performance testing, including the shuttle run test, lane agility test, three-quarter court sprint, vertical jump (no step), and maximum vertical jump (running start).

Results: With regard to quickness and agility, both ACL-reconstructed athletes and controls scored an average of 11.5 seconds in the lane agility test and 3.1 seconds in the shuttle run test ($P = .745$ and .346, respectively). Speed and acceleration was measured by the three-quarter court sprint, in which both the study group and the control group averaged 3.3 seconds ($P = .516$). In the maximum vertical jump, which demonstrates an athlete's jumping ability with a running start, the ACL reconstruction group had an average height of 33.6 inches while the controls averaged 33.9 inches ($P = .548$). In the standing vertical jump, the ACL reconstruction group averaged 28.2 inches while the control group averaged 29.2 inches ($P = .067$).

Conclusion: In athletes who are able to return to sport and compete at a high level such as the NBA Combine, there is no significant difference in any combine performance test between players who have had primary ACL reconstruction compared with an age-, size-, and position-matched control group.

Clinical Relevance: Athletes with previous ACL reconstruction who are able to return to high-level professional basketball have equivalent performance measures with regard to speed, quickness, and jumping ability as those athletes who have not undergone knee surgery.

Keywords: ACL reconstruction; NBA; basketball; functional performance

Anterior cruciate ligament (ACL) ruptures have been one of the most devastating injuries in elite athletes for decades. For some athletes, it can be career ending; for others, it can delay their progress and create a sense of insecurity regarding their future in athletics. Regardless of the sport, after an ACL injury and reconstruction, elite athletes question whether they will return with the same speed, agility, and jumping ability.

Many studies have demonstrated return-to-play rates after ACL reconstruction in professional sports.[1,3,5,8,14,19] Studies have reported that the return-to-play rate in the National Basketball Association (NBA) after ACL

*Address correspondence to Nima Mehran, MD, Kerlan-Jobe Orthopaedic Clinic, 6801 Park Terrace Drive, Los Angeles, CA 90045, USA (email: Mehran1119@gmail.com).

†Kerlan-Jobe Orthopaedic Clinic, Los Angeles, California, USA.

‡Henry Ford Hospital, Detroit, Michigan, USA.

§Wayne State University School of Medicine, Detroit, Michigan, USA.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

The Orthopaedic Journal of Sports Medicine, 4(5), 2325967116648083
DOI: 10.1177/2325967116648083
© The Author(s) 2016

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (http://creativecommons.org/licenses/by-nc-nd/3.0/), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For reprints and permission queries, please visit SAGE's Web site at http://www.sagepub.com/journalsPermissions.nav.

reconstruction is between 78% and 86%.[2,8] Similar studies have shown a return-to-play rate of 88% in Major League Baseball (MLB)[7] and between 63% and 92% in the National Football League (NFL).[1,3,6,19] Of the players who returned to their sport, Erickson et al[6] demonstrated no significant difference in player performance after ACL reconstruction compared with prereconstruction in NFL quarterbacks. However, Carey et al[3] showed a significant drop in NFL players' performance post–ACL reconstruction compared with preinjury performance. In the NBA, Busfield et al[2] reported that after return from ACL reconstruction, 44% of players had a greater than 1-point drop in player efficiency rating compared with preinjury statistics. However, these data were not statistically significant when compared with a control group.

Many of these previous studies demonstrated that there is a high likelihood of return to play at a professional level after ACL reconstruction. However, literature is limited in evaluating an athlete's functional performance in terms of speed, agility, and jumping ability after an ACL reconstruction. Generally, the majority of studies evaluate performance in terms of statistical performance on return.[2,6,8] If a study can demonstrate that the foundation of athletic ability (speed, quickness, and jumping) does not change after ACL reconstruction, injured athletes may be reassured and have more confidence in their post–ACL reconstruction rehabilitation and performance. Keller et al[10] reported that there was no difference in combine testing performance when comparing NFL-caliber athletes after ACL reconstruction to an age-, size-, and position-matched cohort of healthy controls. However, to our knowledge there are no data reviewing NBA Combine performance of athletes post–ACL reconstruction compared with an age-, size-, and position-matched control group.

The purpose of this study was to evaluate the functional performance of NBA Combine athletes post–ACL reconstruction compared with an age-, size-, and position-matched control group. The authors believe that there will be no difference between athletes with previous ACL reconstruction and the control group in terms of speed, quickness, agility, and jumping ability.

METHODS

This was a retrospective case-control study that was approved by our institutional review board. A cohort of 1092 professional-level basketball players who participated in the NBA Combine between 2000 and 2015 were reviewed to identify players who underwent a primary ACL reconstruction prior to the NBA Combine. Of note, athletes who participate in the NBA Combine are invited to participate based on their previous performance during collegiate or international basketball play. Additionally, some athletes decline to attend due to injuries that prevent them from participation. A total of 26 players with a history of ACL reconstruction prior to participation in the NBA Combine were identified. One player had a rerupture of his ACL graft and had a revision ACL reconstruction prior to the combine and therefore was excluded. Four players invited to compete withdrew from competition due to their injury and surgery occurring too close to the combine. Thus, 21 players met our inclusion criteria of having an ACL reconstruction prior to participating in the NBA Combine. Players who underwent ACL reconstruction were identified through a web-based search system that included personal player websites, university team websites, press releases, and university player biography pages. Identifying players with previous ACL reconstruction was similar to the methods used in previous studies.[4,6,11-13,16] In identifying the study group athletes, ACL surgery, ACL repair, and ACL reconstruction were all considered acceptable references.

All combine data were obtained from the NBA official combine results at http://stats.nba.com/draftcombine. Age, height, weight, body mass index (BMI), position, and years between ACL reconstruction and performance at the combine were recorded for each player. The athletic performance parameters recorded for each athlete included shuttle run, lane agility drill, three-quarter court sprint, standing vertical jump, and maximum vertical jump. The shuttle run measures how fast a player is able to change direction. The lane agility drill determines how fast a player moves while forward sprinting, back pedaling and side-to-side shuffling to navigate around cones placed around the key. Both these drills are a measurement of quickness and agility while changing direction. The three-quarter court sprint gauges a player's longitudinal speed and acceleration. Finally, the vertical jump testing evaluates a player's jumping ability without (no step) and with (maximum) a running start.

To compare NBA Combine performance of ACL-reconstructed players, a blinded control group was created that was matched by age, size (height, weight, and BMI), and position. The only exclusion criteria were any evidence of previous knee injury requiring surgery and references of an "undisclosed knee injury." Our method of creating a control group was similar to that reported in previous studies.[3,4,11,12] Subsequently, a de-identified database was created of the remaining players who participated in the NBA Scouting Combine between 2000 and 2015. Players were then matched to the respective ACL reconstruction cases via year of combine performance, listed position at combine, age at combine, height, and weight. For each control player, we recorded their listed playing position, age, height, weight, and BMI. Athletic performance data that were recorded for each player included shuttle run, lane agility drill, three-quarter court sprint, standing vertical jump, and maximum vertical jump.

Statistical Analysis

Statistical analysis compared demographic and performance measures between patients with previous ACL reconstruction and controls and also compared the same between players with a reconstruction in high school to players with reconstruction in college. All continuous data are described as means and standard deviations and are compared between groups using a Wilcoxon-Mann-Whitney test, which is the nonparametric equivalent to the Student *t* test and was chosen due to the small group sizes.

TABLE 1
Comparison of Cases and Controls, Including Demographics and Performance Test Results[a]

Variable	All (N = 42)	Controls (n = 21)	ACL Reconstruction (n = 21)	*P*
Age, y	21.5 ± 1.5	21.3 ± 1.5	21.8 ± 1.4	.383
Height, in	77.8 ± 2.0	77.9 ± 2.1	77.7 ± 2.0	.635
Weight, lbs	228.4 ± 23.5	228.7 ± 23.9	228.1 ± 23.7	.990
Year, n (%)				NA
2000	2 (5)	1 (5)	1 (5)	
2002	2 (5)	1 (5)	1 (5)	
2003	6 (14)	3 (14)	3 (14)	
2005	2 (5)	1 (5)	1 (5)	
2006	2 (5)	1 (5)	1 (5)	
2007	6 (14)	3 (14)	3 (14)	
2008	2 (5)	1 (5)	1 (5)	
2009	4 (10)	2 (10)	2 (10)	
2010	4 (10)	2 (10)	2 (10)	
2012	4 (10)	2 (10)	2 (10)	
2013	2 (5)	1 (5)	1 (5)	
2014	2 (5)	1 (5)	1 (5)	
2015	4 (10)	2 (10)	2 (10)	
Position (binary), n (%)[b]				
Back court	25 (60)	13 (62)	12 (57)	>.999
Front court	17 (40)	8 (38)	9 (43)	
Position, n (%)				
Guard	13 (31)	7 (33)	6 (29)	>.999
Forward	25 (60)	12 (57)	13 (62)	
Center	4 (10)	2 (10)	2 (10)	
Lane agility, s	11.5 ± 0.5	11.5 ± 0.6	11.5 ± 0.5	.745
Shuttle run, s	3.1 ± 0.2	3.1 ± 0.1	3.1 ± 0.3	.346
Three-quarter court sprint, s	3.3 ± 0.1	3.3 ± 0.1	3.3 ± 0.1	.516
Standing vertical jump, in	28.7 ± 2.7	29.2 ± 2.9	28.2 ± 2.4	.067
Maximum vertical jump, in	33.7 ± 2.7	33.9 ± 2.8	33.6 ± 2.6	.548

[a]Data are provided as mean ± SD unless noted otherwise. ACL, anterior cruciate ligament; NA, not applicable.
[b]Back court = grouped player positions of point guards, shooting guards, and small forwards; front court = grouped player positions of power forward and centers.

Categorical data are described as counts and column percentages and are compared between groups using the Fisher exact test, the nonparametric equivalent of the chi-square test, which was chosen due to small expected cell counts. Spearman correlation coefficients were used to assess the relationship between age and the performance measures for all players separately. Also, within the cases, correlation coefficients were computed for the years since surgery with the performance measures. Statistical significance was set at $P < .05$. All analyses were performed using SAS 9.4 (SAS Institute Inc).

RESULTS

According to our review, 25 of 1092 NBA-caliber athletes invited to participate at the 2000 through 2015 NBA Combines had a prior primary ACL reconstruction. This resulted in an incidence of 2.38% of players invited to the NBA Combine who underwent prior primary ACL reconstruction. However, only 21 players met our inclusion criteria as 4 players withdrew from competition since their surgery precluded them from participating. These players were naturally excluded from all combine performance data. Table 1 reports the characteristics of both players with ACL reconstruction and the control group. There were no statistically significant differences between cases and controls in terms of age (21.8 vs 21.3 years, $P = .38$), height (77.7 vs 77.9 inches, $P = .64$), weight (228.1 vs 228.7 pounds, $P = .99$), or position. The average time between ACL reconstruction and combine performance was 2 years, with a range of 1 to 5 years.

The combine performance results were nearly identical when comparing players with previous ACL reconstruction to control players with no statistically significant difference in any functional performance categories. With regard to quickness and agility, both ACL-reconstructed athletes and controls scored an average of 11.5 seconds in the lane agility test and 3.1 seconds in the shuttle run test ($P = .745$ and .346, respectively). Speed and acceleration were measured by the three-quarter court sprint, in which both the study and control groups averaged 3.3 seconds ($P = .516$). In the maximum vertical jump, the ACL reconstruction group had an average height of 33.6 inches while the controls averaged 33.9 inches ($P = .548$). However, there was a trend seen in the standing vertical jump with the ACL reconstruction group averaging 28.2 inches while the control group

TABLE 2
Correlations With Years Between NBA Combine and Injury (ACL Reconstruction Only)[a]

Variable	Correlation Coefficient (*r*)	*P*[b]
Lane agility (n = 21)	0.063	.786
Shuttle run (n = 4)	0.738	.262
Three-quarter court sprint (n = 21)	–0.023	.921
Standing vertical jump (n = 21)	–0.149	.520
Maximum vertical jump (n = 21)	–0.044	.850

[a]ACL, anterior cruciate ligament; NBA, National Basketball Association.
[b]There were no statistically significant correlations.

TABLE 3
Correlation With Age

Variable	Correlation Coefficient (*r*)	*P*[a]
Lane agility (n = 42)	0.015	.923
Shuttle run (n = 8)	–0.464	.247
Three-quarter court sprint (n = 42)	0.019	.906
Standing vertical jump (n = 42)	–0.288	.065
Maximum vertical jump (n = 42)	–0.260	.097

[a]There were no statistically significant correlations.

averaged 29.2 inches ($P = .067$), although this did not reach statistical significance.

In evaluating the correlation between the number of years between combine and ACL reconstruction and performance there were no significant relationships determined in any performance test, including lane agility ($P = .79$), shuttle run ($P = .26$), three-quarter court sprint ($P = .92$), standing vertical jump ($P = .52$), and maximum vertical jump ($P = .85$) (Table 2). Additionally, there were no significant relationships between combine performance and age in any of the performance tests: lane agility ($P = .92$), shuttle run ($P = .25$), three-quarter court sprint ($P = .91$), standing vertical jump ($P = .065$), and maximum vertical jump ($P = .097$) (Table 3). Finally, when separating players into athletes who had ACL reconstructions performed in high school (n = 6) and athletes who had ACL reconstructions performed in college (n = 15), there was no statistical difference in any of the combine performance testing: lane agility ($P = .84$), shuttle run ($P > .99$), three-quarter court sprint ($P = .42$), standing vertical jump ($P = .82$), and maximum vertical jump ($P = .62$) (Table 4).

DISCUSSION

Professional-level basketball players who underwent prior ACL reconstruction and maintained an elite level of play postreconstruction to be invited to the NBA Combine performed similarly to age-, size-, and position-matched controls in measurements of speed, agility, quickness, and jumping ability. Studies evaluating return to play after ACL reconstruction are valuable for their prognostic value; however, quantifying a player's skill level is often overlooked in the literature. This is unfortunate because players may have concerns regarding their athletic performance level and confidence in their knee once they return to the court. An important component of on-court success in elite-level basketball is predicated on an athlete's ability to consistently perform at an elite level in functional movements specific to basketball. Thus, we examined lane agility, shuttle run, three-quarter sprint, standing vertical jump, and maximum vertical jump. To our knowledge, this is the first study to evaluate functional performance of high-level basketball players who have undergone ACL reconstruction.

Although functional performance after ACL reconstruction in the NBA has not been previously studied, there have been investigations into other aspects of NBA performance. Busfield et al[2] analyzed player efficiency ratings (PERs) in a cohort of 27 NBA players after ACL reconstruction and found that of the 78% that returned to play, 15% had an increase in their PER, 19% were within 1 point of their preinjury PER, and 44% had a greater than 1-point decrease in their PER. It is important to note that this change in PER was not statistically significant. Furthermore, there were no statistically significant differences between the injured group and comparison group in terms of other player statistics (number of games played, field goal percentage, turnovers per game), but there was a negative trend in ACL-reconstructed patients.

In another study, Harris et al[8] found that 86% of NBA players returned after ACL reconstruction. Even though performance in reconstructed players declined significantly after returning, there were no differences from controls. Namdari et al[17] retrospectively studied female professional basketball players. Eighteen Women's National Basketball Association (WNBA) athletes who underwent ACL reconstruction between 1998 and 2008 were compared with matched controls. Seventy-eight percent of athletes were able to return to play. Interestingly, shooting percentage and steals per minute of play were the only performance measures that significantly decreased postoperatively. These results differ from studies on NBA players and suggest further investigation on WNBA players after ACL reconstruction is warranted.

The literature consistently shows that NBA-caliber athletes can expect a high rate of return to basketball and subsequently equivalent production if they undergo an ACL reconstruction.[2,8] Yet, what is not clear from the literature is the reason for their postoperative success. By focusing on functional performance, our study helps to provide a framework for understanding the basis of athleticism in elite basketball players. The only indicator of functional performance to show a trend toward a difference, albeit nonsignificant, was the standing vertical jump. In a study comparing functional ability of knees reconstructed either with traditional single-bundle (SB) ACL reconstruction or with double-bundle (DB) ACL reconstruction, Ventura et al[21] assessed vertical jump in 80 patients (40 SB vs 40 DB). They found that jumping performance decreased at 6 months after surgery and increased at 1- and 2-year follow-up

TABLE 4
Comparisons of Demographics and Performance Tests Between Athletes With ACL Reconstruction in College and High School[a]

Variable	All (N = 21)	ACL Reconstruction		P^b
		In College (n = 15)	In High School (n = 6)	
Age, y	21.8 ± 1.4	22.4 ± 0.9	20.2 ± 1.2	**.006**
Height, in	77.7 ± 2.0	77.2 ± 2.0	78.8 ± 1.7	.144
Weight, lbs	228.1 ± 23.7	226.1 ± 20.8	233.1 ± 31.4	.969
Position (binary), n (%)[c]				
Back court	12 (57)	8 (53)	4 (67)	.659
Front court	9 (43)	7 (47)	2 (33)	
Position, n (%)				
Guard	6 (29)	5 (33)	1 (17)	.802
Forward	13 (62)	9 (60)	4 (67)	
Center	2 (10)	1 (7)	1 (17)	
Lane agility, s	11.5 ± 0.5	11.5 ± 0.5	11.4 ± 0.6	.847
Shuttle run, s	3.1 ± 0.3	3.2 ± 0.3	3.1 ± 0.3	>.999
Three-quarter court sprint, s	3.3 ± 0.1	3.3 ± 0.1	3.4 ± 0.1	.423
Standing vertical jump, in	28.2 ± 2.4	28.0 ± 1.9	28.5 ± 3.5	.817
Maximum vertical jump, in	33.6 ± 2.6	33.4 ± 2.8	34.1 ± 2.0	.618

[a]Data are presented as mean ± SD unless noted otherwise. Age at the time of the combine was the only statistically significant difference between the 2 groups. In other words, players who had an anterior cruciate ligament (ACL) reconstruction in high school performed similarly to those who had an ACL reconstruction in college.

[b]*P* value in boldface indicates statistically significant difference between groups.

[c]Back court = grouped player positions of point guards, shooting guards, and small forwards; front court = grouped player positions of power forward and centers.

compared with preoperative values. Restoration of jumping ability in both groups was ultimately achieved 2 years after ACL reconstruction. Regardless of reconstruction technique, the initial reduction in performance may be attributable partially to rehabilitation protocols and quadriceps atrophy, which is a known phenomenon due to inactivity and arthrogenic muscle inhibition.[18] In a study by Urbach et al,[20] voluntary activation of the quadriceps muscle in ACL-injured patients significantly improved after ACL reconstruction, yet they were not able to achieve the levels of the matched control subjects 2 years after surgery. Muscle strength and activation were not directly measured in our study; however, the difference in standing vertical jump does appear to be supported by findings from other investigators. Regardless of this minor difference, all other measures of athletic performance that we tracked were not affected.

Another distinctive finding from this study was that there was no correlation between years between the injury and participation in the combine (see Table 2). Once fully recovered from their ACL reconstruction, players were still able to perform at the same level as controls regardless of the postoperative time interval. It is important to mention that these elite athletes have greater access to exceptional medical care and physical rehabilitation than the average citizen. Myer et al[15] caution that athletes can demonstrate measurable functional deficits after ACL reconstruction that are independent of time from surgery. They compared athletes who had been cleared to return to sport after ACL reconstruction with controls using the single-legged vertical hop test and found significant deficits that persisted in the postoperative group. These findings may also further explain the minor difference we found in the standing vertical jump of ACL-reconstructed athletes. Finally, we found no correlation in combine performance whether the ACL reconstruction occurred before or during college (Table 4). This is an important finding because others have shown that athletes who have ACL reconstruction prior to college have a greater rate of reinjury. In a retrospective review of National Collegiate Athletic Association (NCAA) Division I athletes at a single public university, Kamath et al[9] found that precollegiate ACL reconstruction was associated with a 37.1% rate of repeat ACL injuries to the graft or contralateral knee versus a 13% rate of repeat injuries in the intracollegiate reconstruction group. This study, however, included multiple sports besides basketball so our population most likely has a different reinjury rate.

The retrospective design of this study is one of its limitations. We recognize that there are flaws and possible inaccuracies in retrospectively reviewing information based on publicly available data. We did not have access to medical charts and therefore specific details of the nature of the injury, concomitant pathology, reconstructive technique, surgeon, and postoperative course were not available. Importantly, there is a clear selection bias in this study; our ACL cohort represents a highly selective group since these were the players who performed at a high enough level post–ACL reconstruction to be invited to participate in the NBA Combine. It is likely that players who had ACL reconstruction and were not invited to the combine would have had worse functional performance than the matched control group. Another possibility is that the ACL reconstruction

group may have actually surpassed the control group prior to their injury. Additionally, the combine only captures one moment in a player's career. Changes in functional performance may manifest over time. Finally, this study did not evaluate draft position or in-game performance, both of which may be areas of interest for future research.

CONCLUSION

Functional performance during NBA Combine athletic activity does not appear to be affected by ACL reconstruction. The findings from this study further reassure these elite athletes that if they are able to return to high-level basketball, their speed, agility, quickness, and jumping ability should not decline at 2 years after ACL reconstruction. Prospective studies with matched controls could provide meaningful data on changes in functional performance in this cohort over longer follow-up.

REFERENCES

1. Bradley JP, Klimkiewicz JJ, Rytel MJ, Powell JW. Anterior cruciate ligament injuries in the National Football League: epidemiology and current treatment trends among team physicians. *Arthroscopy*. 2002; 18:502-509.
2. Busfield BT, Kharrazi FD, Starkey C, Lombardo SJ, Seegmiller J. Performance outcomes of anterior cruciate ligament reconstruction in the National Basketball Association. *Arthroscopy*. 2009;25: 825-830.
3. Carey JL, Huffman GR, Parekh SG, Sennett BJ. Outcomes of anterior cruciate ligament injuries to running backs and wide receivers in the National Football League. *Am J Sports Med*. 2006;34:1911-1917.
4. Erickson BJ, Gupta AK, Harris JD, et al. Rate of return to pitching and performance after Tommy John surgery in Major League Baseball pitchers. *Am J Sports Med*. 2014;42:536-543.
5. Erickson BJ, Harris JD, Fillingham YA, et al. Anterior cruciate ligament reconstruction practice patterns by NFL and NCAA football team physicians. *Arthroscopy*. 2014;30:731-738.
6. Erickson BJ, Harris JD, Heninger JR, et al. Performance and return-to-sport after ACL reconstruction in NFL quarterbacks. *Orthopedics*. 2014;37:e728-e734.
7. Fabricant PD, Chin CS, Conte S, Coleman SH, Pearle AD, Dines JS. Return to play after anterior cruciate ligament reconstruction in Major League Baseball athletes. *Arthroscopy*. 2015;31:896-900.
8. Harris JD, Erickson BJ, Bach BR Jr, et al. Return-to-sport and performance after anterior cruciate ligament reconstruction in National Basketball Association players. *Sports Health*. 2013;5:562-568.
9. Kamath GV, Murphy T, Creighton RA, Viradia N, Taft TN, Spang JT. Anterior cruciate ligament injury, return to play, and reinjury in the elite collegiate athlete: analysis of an NCAA Division I cohort. *Am J Sports Med*. 2014;42:1638-1643.
10. Keller RA, Mehran N, Austin W, Marshall NE, Bastin K, Moutzouros V. Athletic performance at the NFL scouting combine after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2015;43:3022-3026.
11. Keller RA, Steffes MJ, Zhuo D, Bey MJ, Moutzouros V. The effects of medial ulnar collateral ligament reconstruction on Major League pitching performance. *J Shoulder Elbow Surg*. 2014;23:1591-1598.
12. Makhni EC, Lee RW, Morrow ZS, Gualtieri AP, Gorroochurn P, Ahmad CS. Performance, return to competition, and reinjury after Tommy John Surgery in Major League Baseball pitchers: a review of 147 cases. *Am J Sports Med*. 2014;42:1323-1332.
13. Marshall NE, Keller RA, Lynch JR, Bey MJ, Moutzouros V. Pitching performance and longevity after revision ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sports Med*. 2015;43:1051-1056.
14. McCullough KA, Phelps KD, Spindler KP, et al. Return to high school- and college-level football after anterior cruciate ligament reconstruction: a Multicenter Orthopaedic Outcomes Network (MOON) cohort study. *Am J Sports Med*. 2012;40:2523-2529.
15. Myer GD, Martin L Jr, Ford KR, et al. No association of time from surgery with functional deficits in athletes after anterior cruciate ligament reconstruction: evidence for objective return-to-sport criteria. *Am J Sports Med*. 2012;40:2256-2263.
16. Namdari S, Baldwin K, Anakwenze O, Park MJ, Huffman GR, Sennett BJ. Results and performance after microfracture in National Basketball Association athletes. *Am J Sports Med*. 2009;37:943-948.
17. Namdari S, Scott K, Milby A, Baldwin K, Lee GC. Athletic performance after ACL reconstruction in the Women's National Basketball Association. *Phys Sportsmed*. 2011;39:36-41.
18. Palmieri-Smith RM, Thomas AC, Wojtys EM. Maximizing quadriceps strength after ACL reconstruction. *Clin Sports Med*. 2008;27:405-424, vii-ix.
19. Shah VM, Andrews JR, Fleisig GS, McMichael CS, Lemak LJ. Return to play after anterior cruciate ligament reconstruction in National Football League athletes. *Am J Sports Med*. 2010;38:2233-2239.
20. Urbach D, Nebelung W, Becker R, Awiszus F. Effects of reconstruction of the anterior cruciate ligament on voluntary activation of quadriceps femoris a prospective twitch interpolation study. *J Bone Joint Surg Br*. 2001;83:1104-1110.
21. Ventura A, Iori S, Legnani C, Terzaghi C, Borgo E, Albisetti W. Single-bundle versus double-bundle anterior cruciate ligament reconstruction: assessment with vertical jump test. *Arthroscopy*. 2013;29:1201-1210.