Effect of Workload After ACL Reconstruction on Rerupture Rates in NBA Players

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Background: Rupture of the anterior cruciate ligament (ACL) is a common and potentially career-altering injury sustained by players in the National Basketball Association (NBA). Strategies have been employed by the league to prevent reinjury of players after ACL reconstruction (ACLR), including minute restrictions and rest games; however, it remains unknown whether workload metrics after ACLR influence the risk for reinjury and revision surgery.

Purpose: To evaluate whether workload changes after return to play (RTP) from primary ACLR influences the risk of rerupture in NBA players.

Study Design: Case-control study; Level of evidence, 3.

Methods: We identified NBA players from 1975 to 2018 who underwent primary ACLR as well as those who required revision ACLR. Primary outcomes included workload measures such as games played, games started, and minutes per game. Secondary outcomes included in-game performance statistics. Statistical analysis was used to compare relative workload and performance 3 years before and 3 years after undergoing primary ACLR. Workload was also compared between the control group of NBA players who underwent primary ACLR and those who required revision ACLR.

Results: A total of 68 players who underwent primary ACLR were included, 8 of whom subsequently required revision ACLR. In their first season upon RTP, control players (primary ACLR) demonstrated a significant reduction in all workload metrics relative to the season before injury ($P < .001$), while the revision group demonstrated an unchanged to increased workload. In a comparison between the primary and revision groups during the first season after RTP, the primary group demonstrated significantly fewer games started (mean ± SD, 22.2 ± 3.0 vs 35.8 ± 8.3; $P = .039$) and minutes per game (20.5 ± 1.1 vs 27.0 ± 3.1; $P = .048$) than revision players. The primary ACLR group demonstrated reduced cumulative workload trends for the first 3 years after RTP relative to 3 years before injury, which was not demonstrated in the revision ACLR group, albeit statistically insignificant.

Conclusion: Our study found that after ACLR, a reduction in workload parameters relative to preinjury baseline was associated with players who did not sustain rerupture. Further study is required to determine if workload measures following RTP from primary ACLR should be individualized relative to preinjury baseline.

Keywords: ACL; anterior cruciate ligament; NBA; basketball; rerupture; ACL reconstruction

Rupture of the anterior cruciate ligament (ACL) is a common and potentially career-altering injury sustained by players in the National Basketball Association (NBA).[1,19] Owing to the frequent cutting and jumping required by basketball players, ACL injury and return to play (RTP) at a high level of performance are topics of great interest for athletes and coaches. A history of ACL reconstruction (ACLR) is a serious consideration that affects draft status, negotiation contracts, trades, RTP potential, and earnings of professional athletes.[24,26] These considerations lead players to exercise extreme caution in returning to sport prematurely, at fear of reinjury or underperformance.[20]

Historically, ACLR has a high success rate, with 98% of players returning to sport and 86% back to NBA level, typically within 1 season.[5] However, the risk of rerupture necessitating revision ACLR surgery occurs in 3.1% of NBA players.[5] A recent systematic review determined that safe return to sport after primary ACLR is 9 months after injury.[6] Despite the available studies, the in-game variables and workload parameters that pose risk for reinjury after primary ACLR are undetermined. NBA teams have employed strategies to prevent reinjury of players after ACLR, including minute restrictions and rest games. However, it remains unknown whether workload metrics after ACLR influence the risk for reinjury and revision surgery.

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The purpose of this study was to evaluate whether workload changes after RTP from primary ACLR influenced the risk of rerupture in NBA players. Primary outcomes included workload variables such as games played (GP), games started (GS), and minutes per game (MPG), spanning 3 years before primary ACLR through 3 years after RTP. Secondary outcomes include performance metrics from in-game seasonal statistics. We hypothesized that upon RTP from primary ACLR, decreased workload volume relative to preinjury baseline would be protective from ACL rerupture.

METHODS

Institutional review board approval was not required, given that all data were collected from publicly available sources and patient information/medical records were not accessed. We performed a retrospective case-control study in which we identified NBA players who sustained an ACL injury between 1975 and 2018. We identified these athletes with publicly available website searches, consistent with methods reported in similar studies.[3,8-10,13,16] Websites included a combination of team press releases, personal player profiles, and NBA.com and ESPN.com player profiles. We accepted terms such as "ACL injury," "ACL surgery," "ACL tear," and "ACL rupture" in our searches. Multiple websites were used to confirm date of injury, and statistical websites were cross-referenced to confirm absence of statistics during the time of injury. Players were excluded if they played <15 games during their career before injury, if they returned to play in the NBA for <25% of games over their first 2 seasons after surgery (20 games per season or 40 cumulative games), or if they did not RTP in the NBA after their injury (Figure 1). Players who returned to play in alternative leagues or overseas did not have game data from those leagues incorporated or analyzed alongside their NBA data; therefore, those seasons were excluded from analysis. Players who were identified as sustaining an ACL injury in the NBA were subsequently researched using aforementioned methods for their entire remaining career to determine if they sustained an ACL rerupture later in their career.

The comparison group comprised NBA players who returned to play after primary ACLR and did not sustain an ACL reinjury. The study group consisted of NBA players who returned to play after primary ACLR and did sustain a rerupture and required revision ACLR. This allowed comparison of all NBA players who returned to play after a primary ACLR to determine which factors contributed to the risk of rerupture in those who subsequently required revision surgery.

Outcome measures analyzed included workload metrics such as GP, GS, MPG, and total minutes (TM), all of which were collected before and after initial injury. Performance metrics, such as in-game statistics, were also attained. All data were captured using Basketball-Reference.com for each player's NBA career. Player workload was evaluated 3 years before injury as well as 3 years after injury to provide a more accurate and representative portfolio.[8] Players who sustained a reinjury within 3 years of RTP had workload and performance data collected for only the period before their reinjury.

Statistical Analysis

Pre- and postinjury player workload was compared between the study group of players sustaining an ACL rerupture and controls who did not sustain a reinjury. The relative workload of each group was also evaluated to determine if there was an increase or decrease in workload after RTP.

Continuous variables are presented using means and standard deviations or adjusted means and standard errors where appropriate. Frequency counts and percentages are displayed for categorical variables. Owing to the small sample of athletes in the revision ACLR group and nonnormal distributions, nonparametric tests were used for univariate comparisons between the groups. Wilcoxon rank-sum tests were used for 2-group comparisons of the continuous variables, while Fisher exact test was used for comparisons of categorical variables. Generalized estimating equations from PROC MIXED were used to compare the adjusted means, while controlling for time point and accounting for repeated measures. The adjusted means and standard errors for each workload variable by time point (pre- vs postindex injury) and group (ACLR vs revision ACLR) were analyzed, as well as the interaction between time point and group. The P values provided for the pairwise comparisons were obtained using the Tukey-Kramer adjustment to control the type I error rate. Statistical significance was determined if $P < .05$. All analyses were performed using SAS Version 9.4 (SAS Institute Inc).

RESULTS

Demographic Characteristics

A total of 68 NBA players who underwent primary ACLR and returned to play in the NBA were identified. Eight players (11.8%) were found to subsequently require revision ACLR, at a mean 5 seasons (range, 1-13 seasons) after

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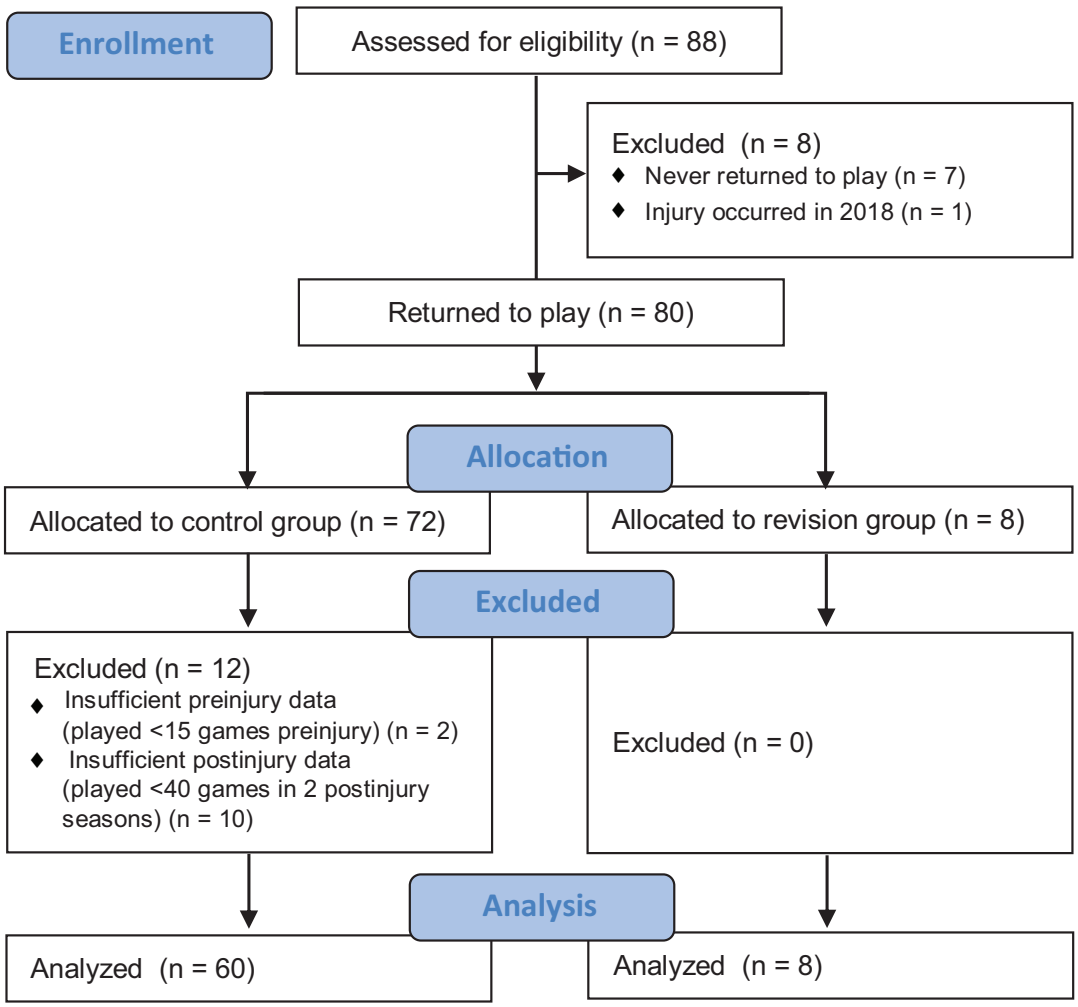

Figure 1. Flow diagram of National Basketball Association player inclusion per cohort.

RTP, with 3 of those players sustaining reinjury within the first 3 seasons after RTP. No significant differences were found in demographic variables between the revision and control groups (Table 1).

Workload Before Primary ACLR

Trends in player workloads before and after primary ACLR are presented in Tables 2 and 3. In the 3 years preceding primary ACLR, NBA players in the control group played in a significantly greater number of games than those in the revision ACLR group ($P = .019$) (Figures 2 and 3). There was no difference in GS, MPG, or TM between the groups ($P > .05$).

Relative Workload: Change Within-Group Analysis

In all workload metrics (GP, GS, MPG, and TM), control players had significantly reduced relative workload the season after RTP as compared with the season before injury (season 1/–1, $P < .001$) (Table 2). Conversely, revision players maintained or increased their workload as compared with preinjury baseline in all categories ($P > .05$). Table 3 illustrates the cumulative 3-season span post-ACLR relative to baseline 3 seasons pre-ACLR, demonstrating that control players significantly reduced their

TABLE 1
Demographic and Workload Characteristics at Primary ACLR[a]

	ACLR	Revision ACLR	*P* Value
Players	60 (88.2)	8 (11.8)	
Age, y	25.5 ± 3.3	23.4 ± 4.2	.146
Seasons	4.3 ± 2.8	5.5 ± 4.1	.525
Height, cm	199.9 ± 9.1	198.6 ± 10.7	.746
Weight, kg	99.3 ± 13.6	103.5 ± 15.5	.486
Body mass index, kg/m^2	24.4 ± 2.1	25.5 ± 2.5	.189
Starter	31 (52)	5 (63)	.713
Position			.689
Guard	27 (45)	4 (50)	
Forward/center	33 (55)	4 (50)	

[a]Values are presented as mean ± SD or No. (%). ACLR, anterior cruciate ligament reconstruction.

TABLE 2
Workload Trends by Season Before and After Primary ACLR[a]

Workload: Seasons[b]	ACLR	Revision ACLR	Effect	*P* Value
Games played				
–3	62.2 ± 2.93	56.6 ± 12.52	Group	.093
–2	62.67 ± 2.51	53.31 ± 8.69	Time	.509
–1	65.62 ± 2.26	40.75 ± 6.18	Group × time	.141
1	48.5 ± 2.94	48.13 ± 8.05	Season 1	.886
2	56.85 ± 2.89	51.25 ± 7.64	Season 2	.536
3	57.94 ± 3.25	59.5 ± 7.85	Season 3	.566
1/–1, *P* value	**<.001**	.54		
Games started				
–3	36.29 ± 4.93	60.67 ± 20.41	Group	.502
–2	31.84 ± 4.01	39.87 ± 12.61	Time	.26
–1	34.87 ± 3.66	30.88 ± 9.79	Group × time	.176
1	22.17 ± 3.02	35.84 ± 8.28	Season 1	**.039**
2	27.38 ± 3.85	18.75 ± 10.29	Season 2	.461
3	32.22 ± 4.37	32.88 ± 10.97	Season 3	.783
1/–1, *P* value	**<.001**	.65		
Minutes per game				
–3	22.71 ± 1.56	29.54 ± 5.75	Group	.223
–2	24.52 ± 1.33	27.95 ± 3.99	Time	.075
–1	24.89 ± 1.26	27.23 ± 3.45	Group × time	.064
1	20.5 ± 1.12	27.03 ± 3.05	Season 1	**.048**
2	20.4 ± 1.24	21.7 ± 3.36	Season 2	.863
3	21.34 ± 1.3	24.54 ± 3.42	Season 3	.729
1/–1, *P* value	**<.001**	.97		
Total minutes				
–3	1501.53 ± 131.6	2080.65 ± 502	Group	.86
–2	1574.64 ± 111.2	1404.86 ± 359.7	Time	.35
–1	1693.04 ± 102.52	1170.45 ± 280.8	Group × time	.09
1	1050.7 ± 97.1	1315.79 ± 265.8	Season 1	.327
2	1297.1 ± 112.5	1191.18 ± 301.4	Season 2	.768
3	1365.23 ± 124.8	1578.29 ± 319.4	Season 3	.839
1/–1, *P* value	**<.001**	.72		

[a]Values are presented as mean ± SD. Bold indicates significance ($P < .05$). Note that paired *t* tests were used for the tear group, while Wilcoxon signed-rank tests were used for the retear group owing to the extremely small sample size. ACLR, anterior cruciate ligament reconstruction.

[b]Negative and positive numbers indicate seasons before and after injury, respectively.

GP (–10.35 ± 3.15; $P = .009$). Other workload parameters, such as GS, MPG, and TM, demonstrated reducing trends that were not significant ($P > .05$ for all). Conversely, players in the revision ACLR group increased their workload (GP and TM) or maintained it (GS and MPG) relative to cumulative 3 seasons pre-ACLR baseline ($P > .05$). The divergent trends in relative workload between groups are illustrated for the first season (Figure 2) and first 3 seasons (Figure 3) after RTP relative to baseline.

Workload After RTP by Season: ACLR vs Revision ACLR

In the first season after RTP, players with a primary ACLR demonstrated a significantly reduced volume of GS (22.2 vs 35.8; $P = .039$) and MPG (20.5 vs 27.0; $P = .048$) but participated in a similar number of games (48.5 vs 48.1; $P = .886$) to players with a revision ACLR (Table 2). Both groups showed increasing trends (group × time, $P > .05$) across all workload parameters during seasons 2 and 3 after RTP, with no significant differences between groups ($P > .05$) (Table 2).

Relative Workload Trends

Table 2 illustrates that after RTP, players in the control and revision groups demonstrated increases in GP from season 1 to season 3. During this time, control players maintained consistent MPG, thus accounting for uptrending TM. Conversely, the revision ACLR group started its greatest number of games and averaged its greatest MPG the first season after RTP, followed in seasons 2 and 3 by fluctuating trends in GS, MPG, and TM. The trending changes of all workload parameters season by season, when compared between the primary ACLR and revision ACLR groups over time, were not statistically different (group × time, $P > .05$). Conversely, in terms of cumulative mean over each 3-year time span as illustrated in Table 3 (post- vs pre-ACLR), there was a significant reduction in GP by the control group (–10.35 ± 3.15; $P = .009$) but not the

TABLE 3
Workload Trends by Cumulative 3-Year Stretch Before and After Primary ACLR[a]

			P Value	
Workload: Time Point	ACLR (n = 60)	Revision ACLR (n = 8)	Group[b]	Group × Time[c]
Games played				
Pre-ACLR	63.76 ± 2.06	44.9 ± 5.94	**.019**	
Post-ACLR	53.41 ± 2.18	53.01 ± 5.75	.99	**.049**
Pre- vs post-ACLR (pairwise *P* value) [d]	−10.35 ± 3.15 (**.009**)	8.11 ± 8.67 (.79)		
Games started				
Pre-ACLR	32.41 ± 3.42	37.35 ± 9.53	.96	
Post-ACLR	24.43 ± 2.97	34.4 ± 8.1	.655	.613
Minutes per game				
Pre-ACLR	24.49 ± 1.29	26.5 ± 3.55	.951	
Post-ACLR	20.15 ± 1.15	26.3 ± 3.16	.269	.154
Total minutes				
Pre-ACLR	1545.17 ± 95.6	1319.9 ± 270.2	.861	
Post-ACLR	1100.1 ± 93.5	1408.36 ± 255.4	.67	.108
FGA				
Pre-ACLR	9.07 ± 0.63	9.95 ± 1.78	.97	
Post-ACLR	7.43 ± 0.57	9.27 ± 1.58	.698	.51
3pA				
Pre-ACLR	1.13 ± 0.19	2.31 ± 0.56	.199	
Post-ACLR	1.2 ± 0.2	2.0 ± 0.56	.546	.343
FTA				
Pre-ACLR	2.85 ± 0.23	3.1 ± 0.64	.982	
Post-ACLR	2.17 ± 0.19	2.87 ± 0.52	.583	.399

[a]Values are presented as adjusted mean ± SE. Bold indicates significance ($P < .05$). 3pA, 3-point field goals attempted; ACLR, anterior cruciate ligament reconstruction; FGA, field goals attempted; FTA, free throws attempted.
[b]Group *P* value: compares group effect broken down by time point.
[c]Group × time *P* value: compares changes over time between each group is compared between the two groups.
[d]Pairwise *P* value: compares the group × time interaction represents the pairwise comparison between pre- and postinjury within each group.

revision ACLR group (8.11 ± 8.67; $P = .79$). Figure 3 illustrates the significantly divergent trend in GP between groups during the pre- and post-ACLR cumulative 3-year time span ($P = .049$), as well as trends in GS, MPG, and TM.

Player Performance

No difference was found between the control and revision groups in player performance after return from ACLR (Table 3). Each group maintained consistent performance variables (field goals attempted, 3-point field goals attempted, free throws attempted) when compared with preinjury baselines.

DISCUSSION

Our study demonstrated an 11.8% incidence of rerupture after primary ACLR in NBA players. The main finding in our study was that NBA players who did not sustain a rerupture had significant reductions in workload after RTP, while players with revision ACLR maintained or increased workload from their baseline. Management of workload after ACLR may be an important consideration for the professional NBA athlete and warrants additional evaluation.

Prior studies estimated the ACL retear rate to be as low as 3.1% in NBA players[5]; however, our study found an almost 4-fold increase in the retear rate (11.8%). More high-powered epidemiologic studies are required to understand how injury characteristics of present-day NBA athletes are changing. Nevertheless, RTP rates for NBA players after ACL rupture remain high, and more information regarding player usage, workload, and reinjury risk is required to advance recommendations.[5,11] The risk of reinjury has been investigated in other sports, such as the National Football League (NFL), with regard to workload and RTP. Okoroha et al[22] aimed to assess the impact of the duration until RTP and the likelihood of revision surgery in NFL athletes. Their results suggested no significant correlation between the timing of RTP and reinjury or the timing of RTP and how soon after RTP reinjury occurred. Although they also compared athletes with primary versus revision ACLR, they did not stratify workload after RTP and were unable to comment on relative workload trends after RTP. Cinque et al[2] did investigate workload parameters and found no significant difference in GP and GS after RTP from primary ACL in NFL linemen as compared with matched controls. Their study concluded that there was no difference in career duration in their cohort versus controls. However, their study did not evaluate the influence of

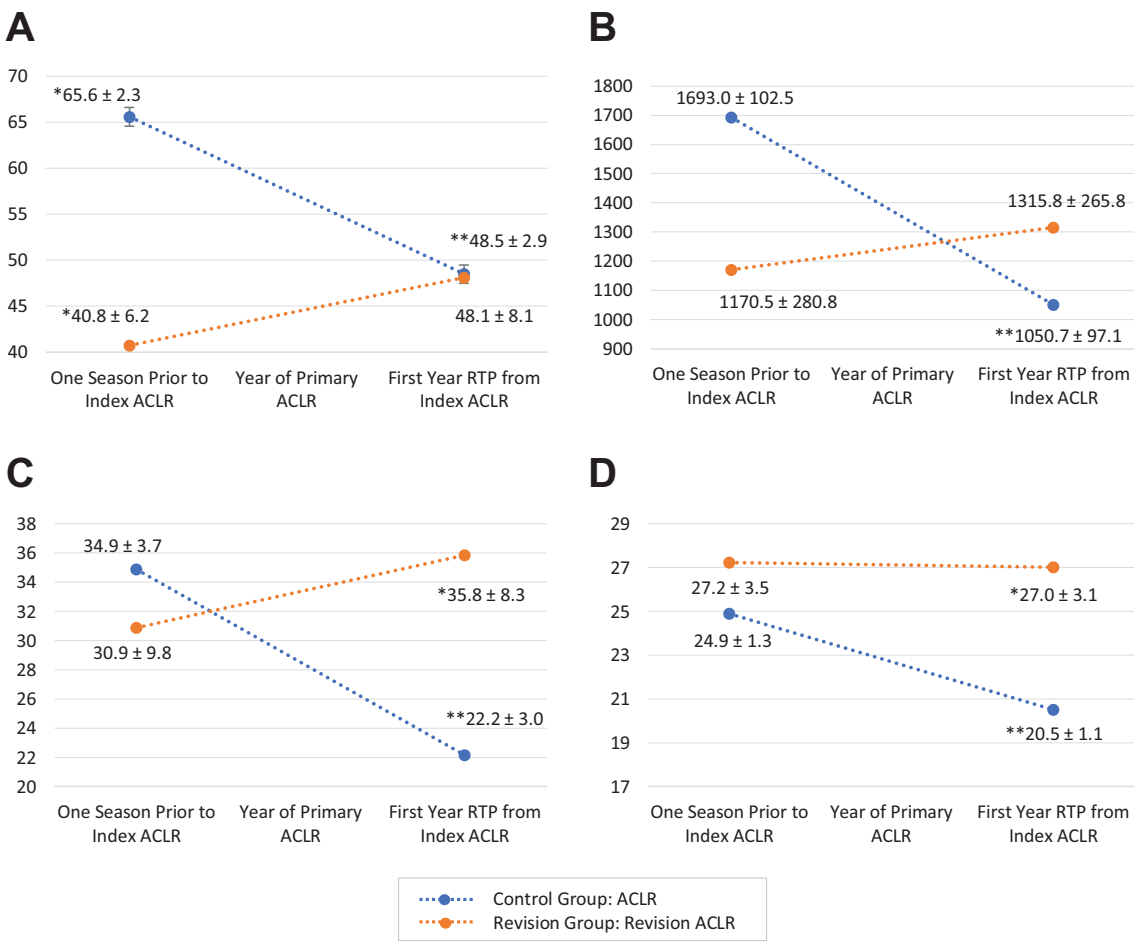

Figure 2. Workload trends 1 season after RTP relative to 1 season before ACLR for (A) games played, (B) total minutes, (C) games started, and (D) minutes per game. Control players (blue line) significantly decreased their workload after RTP, while players later sustaining a revision ACLR (orange line) maintained their baseline workload and demonstrated significantly greater minutes per game during their first season after RTP from primary ACLR. Values are presented as mean ± SD. A single asterisk (*) represents $P < .05$ between control and revision ACLR at 1 time point, while a double asterisk (**) represents $P < .05$ between 2 time points within a single group. ACLR, anterior cruciate ligament reconstruction; RTP, return to play.

workload on risk of reinjury or compare their cohort with reinjured players. Our results show that players who did not sustain a retear had significantly fewer GS and MPG as compared with players who did, upon returning from primary ACLR. These findings suggest that workload initially after return from primary ACLR warrants further investigation on the risk of sustaining a rerupture.

Risk factors for sustaining a general injury in the NBA have been studied, but the data on ACL injuries are limited with regard to workload. Lewis[12] showed that increased fatigue, game load, shorter stature, and increased number of years played in the NBA all led to increased general injury; however, without stratification of injury type or anatomic region, contributing factors to ACL injury were not determined. Harris et al[5] and Okoroha et al[23] investigated single-game usage and found that the quarter of a game in which an ACL injury occurred was evenly distributed among NBA players. Okoroha et al[23] furthered this discussion by showing that minutes played in a single NBA game were not correlated with sustaining an ACL injury. In evaluating workload after ACLR, studies have shown that NBA players average fewer GS, GP, and MPG,[11,21] albeit without assessing their risk of reinjury. While workload has been studied in relation to ACLR, these studies do not provide information on relative workload before and after ACLR and the risk of subsequent rerupture in professional basketball players.

Relative workload management after an injury has been studied in other sports. Keller and colleagues[8,9] investigated workload after RTP from Tommy John surgery in 2 cohorts of baseball pitchers: primary and revision surgery. In their investigations, they found no significant difference between the cohorts in workload during the first season after RTP from Tommy John surgery; however, the revision group did demonstrate an increased relative workload as compared with preinjury baseline upon RTP, which was not apparent in the primary group.[8] Using similar comparisons, our study found a significant decrease in relative

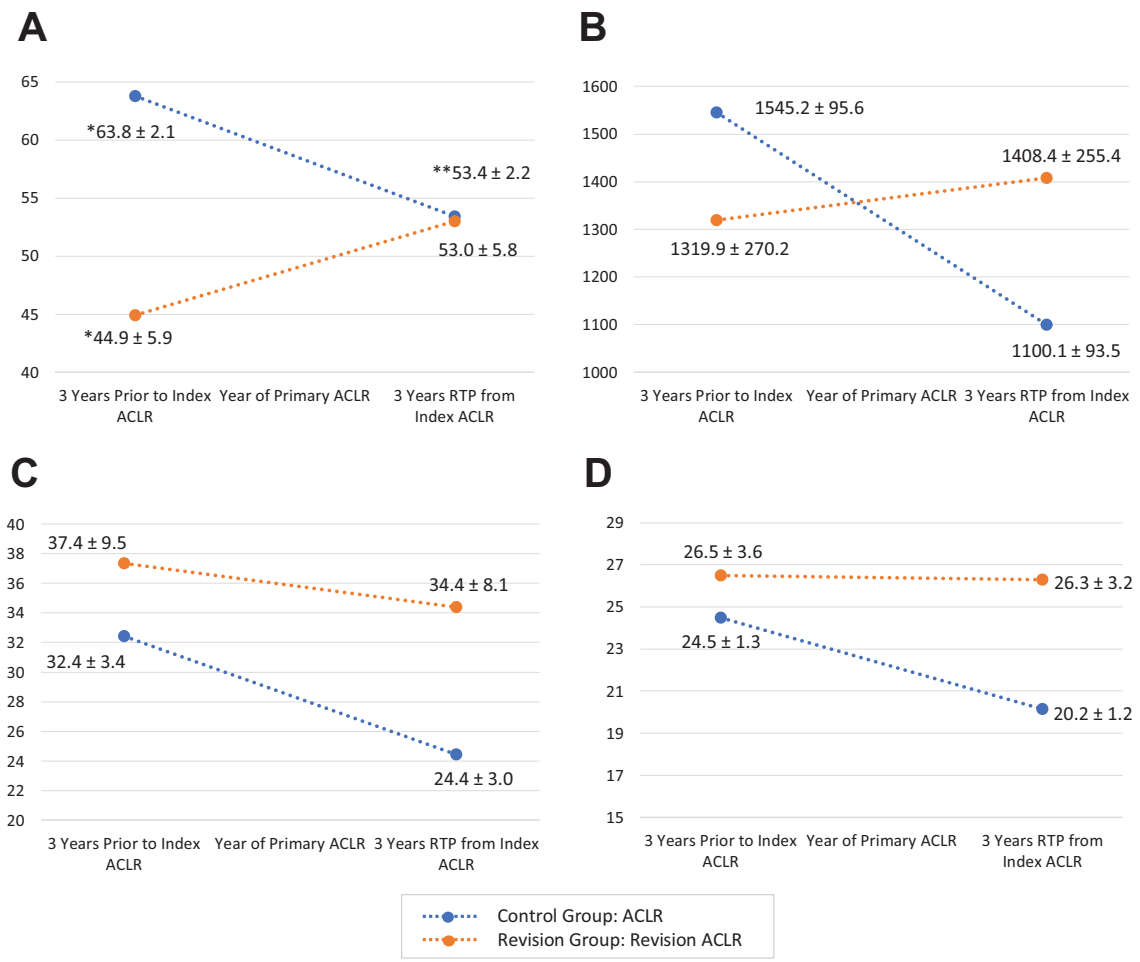

Figure 3. Cumulative workload trends for 3 seasons after RTP relative to 3 seasons before ACLR for (A) games played, (B) total minutes, (C) games started, and (D) minutes per game. Over a 3-year span after RTP as compared with a 3-year preinjury baseline, control players (blue line) played in significantly fewer games with a trend in reduced minutes per game, while players who later sustained a revision ACLR (orange line) maintained their baseline workload with a trend in increased games played. Values are presented as mean ± SD. A single asterisk (*) represents $P < .05$ between control and revision ACLR at 1 time point, while a double asterisk (**) represents $P < .05$ between 2 time points within a single group. ACLR, anterior cruciate ligament reconstruction; RTP, return to play.

workload (GS, MPG) in players who did not sustain a reinjury upon RTP, while players who subsequently required revision surgery were those who maintained or increased their preinjury baseline workload. These findings suggest that a player's relative workload after returning from ACLR may be of importance. Currently, NBA teams employ several strategies to limit player reinjury. These include minute restrictions in players returning from injury and "load management," which often entail examining a player's current load relative to his capacity. Biometric data, including minutes played, practice sessions, cardio work, sleep, and other factors, are entered into a computer program that determines when a player is reaching his capacity.[4] Reactive strength index is also a method used to gauge fatigue by having an athlete jump while using a force plate or inertia sensor.[17] Further study may be valuable in conjunction with this preliminary analysis to determine if preinjury baseline is a useful benchmark in reducing reinjury risk.

Performance in NBA players after RTP from ACLR has been evaluated in prior studies.[1,11,21] Nwachukwu et al[21] evaluated in-game performance during the first season after RTP from ACLR in NBA athletes. They found that the player efficiency rating (PER) significantly decreased as compared with baseline, while points, rebounds, assists, steals, and blocks insignificantly decreased. No significant differences existed by the second season after RTP. Kester et al[11] also demonstrated significant decreases in PER the first season after RTP from ACLR in NBA players versus matched controls. However, in the remaining years of their careers, decline in PER was not different between groups. These studies were contrary to the work of Busfield et al,[1] who reported insignificant reductions in PER and in-game statistics (points, rebounds, assists, etc) post-ACLR versus preinjury in their cohort as compared with controls, except for a significant reduction in field goal percentage. Similar to prior studies, our study found no significant differences in performance between post-ACLR and preinjury with regard

to in-game statistics. Furthermore, there were no significant differences between the control and revision ACLR groups over the 3-year span after RTP in our study. These results suggest that while NBA players who returned from primary ACLR without reinjury had decreased workload, this did not translate into decreased production or performance when compared with the study group.

Limitations

There are a number of limitations inherent to the retrospective case-control nature of this study. First, given the methods of data collection present in this study, confounding factors and player-specific biases, such as concomitant injuries and medical considerations, could not be accounted for, owing to the lack of medical records. This also includes factors that may be related to risk of rerupture, including graft type, graft fixation, repair techniques, sterilization techniques, and postoperative rehabilitation. However, this study was conducted in the same manner as previously reported literature on similar topics.[2,7-9,14,15,18,21-23,25] Furthermore, in an internet-based review method for evaluation of player statistics, we could not include data and statistics from basketball leagues outside of the NBA. However, none of the 8 players who sustained reinjury participated in leagues other than the NBA between their first and second injury, while 4 of the 8 played in alternate or overseas leagues after their revision ACLR. Additionally, while the small sample size is a limitation, it is a result of all presently available data. The present data may not be generalizable to basketball athletes at different levels, such as high school and college. Randomized controlled or prospective cohort trials would allow improved analysis given the low incidence of ACL reinjury in NBA athletes. Finally, although a number of statistically insignificant trends were demonstrated in our study, the small sample of NBA athletes with revision ACLR was limited by the data available in the NBA presently.

CONCLUSION

Results of the current study indicated that after ACLR, a reduction in workload parameters relative to preinjury baseline was associated with players who did not sustain rerupture. Further study is required to determine if workload volume after RTP from primary ACLR should be individualized relative to preinjury baseline.

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