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Authors

Wright, Rick W
Huston, Laura J
Nwosu, Samuel K
et al.

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Rehabilitation Predictors of Clinical Outcome Following Revision ACL Reconstruction in the MARS Cohort

MARS Group*

Investigation performed at the Department of Orthopaedics, Washington University, St. Louis, Missouri, and the Department of Orthopaedic Surgery and Rehabilitation, Vanderbilt University, Nashville, Tennessee

Background: Revision anterior cruciate ligament (ACL) reconstruction has been documented to have worse outcomes than primary ACL reconstruction. The reasons remain varied and not completely understood.

Methods: Patients undergoing revision ACL reconstruction were prospectively enrolled. Data collected included baseline demographics, surgical technique and pathological condition, prescribed rehabilitation instructions, and a series of validated patient-reported outcome instruments. Patients were followed for 2 years and asked to complete a set of outcome instruments identical to those completed at baseline. Subsequent surgical procedures on the ipsilateral knee were recorded. Regression analysis was used to control for age, sex, activity level, baseline outcome scores, and the above-mentioned rehabilitation-related variables in order to assess the factors affecting clinical outcomes 2 years after revision ACL reconstruction.

Results: A total of 843 patients met the inclusion criteria and were successfully enrolled, and 82% (695) were followed for 2 years. Two rehabilitation-related factors were found to influence outcome. First, patients who were prescribed an ACL brace for their return to sports had a significantly better Knee injury and Osteoarthritis Outcome Score (KOOS) for sports and recreational activities at 2 years (odds ratio [OR] =1.50, 95% confidence interval [CI] = 1.07 to 2.11; p = 0.019). Second, patients prescribed an ACL brace for the postoperative rehabilitation period were 2.3 times more likely to have subsequent surgery by 2 years (OR = 2.26, 95% CI = 1.11 to 4.60; p = 0.024). The odds of a graft rerupture were not affected by any type of brace wear.

continued

*Members of the MARS (Multicenter ACL Revision Study) Group include Rick W. Wright, MD; Laura J. Huston, MS; Samuel K. Nwosu, MS; Christina R. Allen, MD; Allen F. Anderson, MD; Daniel E. Cooper, MD; Thomas M. DeBerardino, MD; Warren R. Dunn, MD, MPH; Amanda K. Haas, MA; Brett (Brick) A. Lantz, MD; Barton Mann, PhD; Kurt P. Spindler, MD; Michael J. Stuart, MD; John P. Albright, MD; Annunziato (Ned) Amendola, MD; Jack T. Andrish, MD; Christopher C. Annunziata, MD; Robert A. Arciero, MD; Bernard R. Bach Jr., MD; Champ L. Baker III, MD; Arthur R. Bartolozzi, MD; Keith M. Baumgarten, MD; Jeffery R. Bechler, MD; Jeffrey H. Berg, MD; Geoffrey A. Bernas, MD; Stephen F. Brockmeier, MD; Robert H. Brophy, MD; Charles A. Bush-Joseph, MD; J. Brad Butler V, MD; John D. Campbell, MD; James L. Carey, MD, MPH; James E. Carpenter, MD; Brian J. Cole, MD; Jonathan M. Cooper, DO; Charles L. Cox, MD, MPH; R. Alexander Creighton, MD; Diane L. Dahm, MD; Tal S. David, MD; David C. Flanigan, MD; Robert W. Frederick, MD; Theodore J. Ganley, MD; Elizabeth A. Garofoli; Charles J. Gatt Jr., MD; Steven R. Gecha, MD; James Robert Giffin, MD; Sharon L. Hame, MD; Jo A. Hannafin, MD, PhD; Christopher D. Harner, MD; Norman Lindsay Harris Jr., MD; Keith S. Hechtman, MD; Elliott B. Hershman, MD; Rudolf G. Hoellrich, MD; Timothy M. Hosea, MD; David C. Johnson, MD; Timothy S. Johnson, MD; Morgan H. Jones, MD; Christopher C. Kaeding, MD; Ganesh V. Kamath, MD; Thomas E. Klootwyk, MD; Bruce A. Levy, MD; C. Benjamin Ma, MD; G. Peter Maiers II, MD; Robert G. Marx, MD; Matthew J. Matava, MD; Gregory M. Mathien, MD; David R. McAllister, MD; Eric C. McCarty, MD; Robert G. McCormack, MD; Bruce S. Miller, MD, MS; Carl W. Nissen, MD; Daniel F. O'Neill, MD, EdD; Brett D. Owens, MD; Richard D. Parker, MD; Mark L. Purnell, MD; Arun J. Ramappa, MD; Michael A. Rauh, MD; Arthur C. Rettig, MD; Jon K. Sekiya, MD; Kevin G. Shea, MD; Orrin H. Sherman, MD; James R. Slauterbeck, MD; Matthew V. Smith, MD; Jeffrey T. Spang, MD; Steven J. Svoboda, MD; Timothy N. Taft, MD; Joachim J. Tenuta, MD; Edwin M. Tingstad, MD; Armando F. Vidal, MD; Darius G. Viskontas, MD; Richard A. White, MD; James S. Williams Jr., MD; Michelle L. Wolcott, MD; Brian R. Wolf, MD; and James J. York, MD.

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Conclusions: Rehabilitation-related factors that the physician can control at the time of an ACL reconstruction have the ability to influence clinical outcomes at 2 years. Weight-bearing and motion can be initiated immediately postoperatively. Bracing during the early postoperative period is not helpful. Use of a functional brace early in the postoperative period was associated with an increased risk of a reoperation. Use of a functional brace for a return to sports improved the KOOS on the sports/recreation subscale.

Level of Evidence: Prognostic Level I. See Instructions for Authors for a complete description of levels of evidence.

There is lack of consensus regarding the optimal postoperative rehabilitation elements that orthopaedic surgeons should prescribe following anterior cruciate ligament (ACL) reconstruction. In 2016, Budny et al. surveyed key professional groups of orthopaedic surgeons who performed ACL reconstructions (members of the American Orthopaedic Society for Sports Medicine and the Arthroscopy Association of North America) to better understand their preferences and trends[1]. When asked about postoperative rehabilitation factors, 69% (566) of 824 respondents stated that they preferred their patients to be fully weight-bearing immediately after surgery, 55% chose to use a range-of-motion brace locked in extension, 13% chose to use a rigid knee immobilizer, and 15% chose no immobilization for their postoperative care. In addition, functional bracing was preferred by 48% of the respondents, and 54% of those who used it preferred to have it in place for 6 to 12 months in the majority of the cases whereas 34% preferred a period of 1 to 2 years. Interestingly, these postoperative preferences did not change drastically from those in similar surveys performed in 1999[2] and 2006[3].

The literature on rehabilitation practices following primary ACL reconstruction is robust, with numerous Level-I and II studies evaluating and establishing appropriate approaches for postoperative rehabilitation protocols[4-28]. Unfortunately, the outcomes of revision ACL reconstruction are significantly worse than those of primary procedures, and many factors and variables may contribute to these disappointing results[1,4-6]. To our knowledge, rehabilitation practices after revision ACL reconstruction have not yet been evaluated. While some previous series of ACL reconstructions may have included some revisions, the studies typically have not delineated between primary and revision ACL reconstructions or excluded revision ACL reconstructions as part of the study design. We are not aware of any previously published studies of rehabilitation solely after revision ACL reconstructions.

The purpose of this study was to determine whether rehabilitation-related factors prescribed at the time of revision ACL reconstruction significantly influence 2-year outcomes as well as the prevalence of subsequent reoperations. Our hypothesis was that an immediate rather than a restricted passive/active range of motion and weight-bearing would result in improved outcomes without subsequent surgery. We also hypothesized that use of postoperative and functional return-to-sports braces would not improve sports-related function.

Materials and Methods

Study Design

The Multicenter ACL Revision Study (MARS) Group was formed to address the inferior outcomes typically seen following revision ACL reconstruction and to try to determine modifiable predictors of these worse outcomes[29-31]. The group was supported by the American Orthopaedic Society for Sports Medicine at both a board and a research committee level. Participation was offered to all members, and all of those who accepted participated in educational and study design meetings prior to patient enrollment. As previously described, the consortium is a group of 83 fellowship-trained sports surgeons working at 52 unique sites[32,33], which are a mix of 29 private-practice sites (56%) and 23 sites employing academic surgeons (44%). To be included in the study, a surgeon had to review and understand the surgeon questionnaire, obtain and maintain institutional review board approval, and complete a training session that included assessment of the surgeons' ability to agree on the type and severity of articular cartilage and meniscal injuries and input and review of the study design and patient inclusion criteria. Surgeons were allowed to perform the revision reconstruction as they desired. Allografts had to be obtained from a designated company (Musculoskeletal Transplant Foundation).

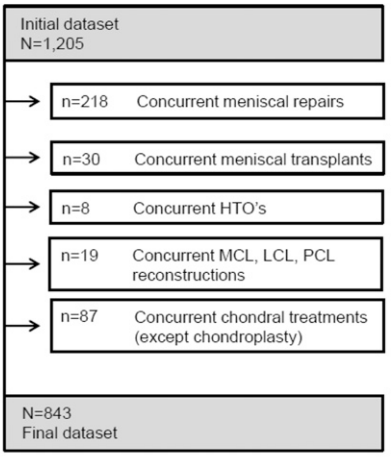
Study Population

After institutional review board approval from each site, 1,205 patients scheduled to undergo revision ACL reconstruction surgery following failure of an ACL reconstruction graft qualified for and agreed to participate in this study. The multicenter group began patient enrollment in 2006 and ended it in 2011. All patients between 12 and 65 years of age who were scheduled to be treated with a revision ACL reconstruction to address ACL deficiency by a participating MARS surgeon at a MARS site were eligible for inclusion. Participants needed to have a known ACL reconstruction graft failure as defined by a KT-1000 (MedMetric) arthrometer showing >5 mm of laxity, a positive Lachman and/or pivot-shift test, or magnetic resonance imaging (MRI) demonstrating graft failure. Exclusion criteria were a previous ACL reconstruction or knee infection, arthrofibrosis, or complex regional pain syndrome. Screening logs were not kept at all sites, so it was not possible to determine an accurate enrollment percentage. For this particular study, we excluded enrolled patients from the data analysis who underwent, at the time of the revision surgery, concomitant

procedures that would affect rehabilitation. These additional procedures included concurrent meniscal repairs, meniscal transplants, high tibial osteotomies, ligamentous reconstructions (of the medial collateral ligament, lateral collateral ligament, and/or posterior cruciate ligament), and certain chondral treatments (e.g., microfracture, abrasion arthroplasty, mosaicplasty, osteochondral autograft/allograft transplantation [OATS], and autologous chondrocyte implantation [ACI]). Figure 1 provides the study's enrollment flow diagram.

Data Sources and Measurement

Following informed consent, each patient filled out a 13-page questionnaire eliciting information about demographic characteristics, sports participation, mechanism of knee injury, and comorbidities. This questionnaire included a series of validated general and knee-specific outcome instruments: the Knee injury and Osteoarthritis Outcome Score (KOOS)[34], the International Knee Documentation Committee (IKDC) Subjective Knee Form[35,36], and the Marx activity rating scale[37]. MARS surgeons filled out a questionnaire on their impression of the etiology of the failure of the previous ACL reconstruction, the physical examination findings, the surgical technique utilized, and the meniscal and articular cartilage findings and their surgical management of these findings. Chondral damage was described using the modified Outerbridge system[38], with grade II or higher defined as a "worse grade" in this study. Meniscal injuries were classified by location and whether they were partial or complete tears. We recorded treatment as none, repair, resection, or other, which included trephination and transplants. At the time of surgery, the physicians answered "yes" or "no" to questions regarding their prescription of postoperative rehabilitation and brace use: i.e., whether they planned to restrict passive range of motion postoperatively, restrict active range of motion postoperatively, restrict postoperative full weight-bearing, prescribe a motion control brace (i.e., a knee immobilizer) postoperatively, prescribe an ACL derotation brace to be used in the postoperative rehabilitation period, and prescribe an ACL derotation brace to be used when the patient returned to sports. If any of these were answered "yes," the surgeon was instructed to fill in the number of days for which each prescription was to be followed (see Appendix).



Key: *HTO (high tibial osteotomy); MCL (medial collateral ligament); LCL (lateral collateral ligament); PCL (posterior cruciate ligament).*

Fig. 1

Flow diagram of study cohort.

TABLE I Baseline Cohort Characteristics

	Percentage (No.)*	Days†, If Yes
Sex		
Male	57% (482)	
Female	43% (361)	
Age† *(yr)*	27 (20, 36)	
Baseline Marx activity level (range, 0-16)†	11 (4, 16)	
Restriction of passive range of motion		
No	88% (745)	
Yes	11% (94)	14 (5, 28)
Blank	<1% (4)	
Restriction of active range of motion		
No	86% (722)	
Yes	14% (115)	16 (7, 30)
Blank	<1% (6)	
Restriction of postoperative full weight-bearing (without support)		
No	60% (507)	
Yes	39% (332)	21 (14, 28)
Blank	<1% (4)	
Prescription of motion control brace (i.e., knee immobilizer) postoperatively		
No	45% (380)	
Yes	55% (458)	24 (14, 42)
Blank	<1% (5)	
Prescription of ACL derotation brace for postoperative rehabilitation		
No	85% (715)	
Yes	15% (124)	180 (90, 365)
Blank	<1% (4)	
Prescription of ACL derotation brace for return to sports		
No	68% (573)	
Yes	30% (253)	365 (300, 365)
Blank	2% (17)	

*Except as indicated. †The values are given as the median (25th, 75th percentiles).

TABLE II Comparison of Demographic, Surgical, and Rehabilitation Characteristics As Well As Baseline Patient-Reported Outcome Measures Between Patients with Follow-up and Those Lost to Follow-up

	Patients with Follow-up* (N = 695)	Patients Lost to Follow-up* (N = 148)
Demographics		
Sex		
Male	379 (55%)	103 (70%)
Female	316 (45%)	45 (30%)
Age† *(yr)*	28.9 ± 10.5, 27 (20, 36)	28.0 ± 10, 25 (20, 34)
BMI† *(kg/m²)*	25.9 ± 4.6, 25.1 (22.5, 28.3)	26.9 ± 4.9, 26.5 (23.1, 30.5)
Smoking status		
Never	537 (77%)	107 (72%)
Quit	85 (12%)	24 (16%)
Current	63 (9%)	13 (9%)
Blank	10 (1%)	4 (3%)
Education level† *(yr of school)*	14.7 ± 2.9, 15 (12, 17)	14.3 ± 3.0, 14 (12, 16)
Surgical		
Time from last ACL reconstruction† *(yr)*	6.2 ± 6.0, 4.0 (1.5, 10.0)	4.5 ± 4.4, 3.0 (1.3, 6.5)
Graft type for revision		
Autograft	345 (50%)	78 (53%)
Allograft	329 (47%)	64 (43%)
Both	21 (3%)	6 (4%)
Graft source for revision		
Bone-patellar tendon-bone	354 (51%)	82 (55%)
Soft tissue	333 (48%)	63 (43%)
Other	8 (1%)	3 (2%)
Rehabilitation		
Restriction of passive range of motion		
No	612 (88%)	133 (90%)
Yes	79 (11%)	15 (10%)
Blank	4 (<1%)	0
Restriction of active range of motion		
No	597 (86%)	125 (84%)
Yes	93 (13%)	22 (15%)
Blank	5 (<1%)	1 (<1%)
Restriction of postoperative full weight-bearing (without support)		
No	417 (60%)	90 (61%)
Yes	275 (40%)	57 (39%)
Blank	3 (<1%)	1 (<1%)
Prescription of motion control brace (i.e., knee immobilizer) postoperatively		
No	320 (46%)	60 (41%)
Yes	371 (53%)	87 (59%)
Blank	4 (<1%)	1 (<1%)
Prescription of ACL derotation brace for postoperative rehabilitation		
No	595 (86%)	120 (81%)
Yes	96 (14%)	28 (19%)
Blank	4 (<1%)	0
Prescription of ACL derotation brace for return to sports		
No	482 (69%)	91 (62%)

continued

TABLE II (*continued*)

	Patients with Follow-up* (N = 695)	Patients Lost to Follow-up* (N = 148)
Yes	197 (28%)	56 (38%)
Blank	16 (2%)	1 (<1%)
Baseline patient reported outcomes†		
IKDC	52 ± 18, 52 (40, 63)	50 ± 19, 51 (32, 65)
KOOS		
Symptoms	67 ± 20, 68 (54, 82)	64 ± 21, 68 (50, 82)
Pain	72 ± 19, 75 (61, 86)	70 ± 22, 75 (56, 89)
Activities of daily living	81 ± 18, 87 (69, 96)	78 ± 22, 85 (68, 96)
Sports/recreation	47 ± 28, 45 (25, 65)	45 ± 27, 43 (25, 60)
Quality of life	34 ± 20, 31 (19, 44)	31 ± 22, 31 (13, 44)
Marx activity level	9 ± 6, 11 (4, 16)	9 ± 6, 10 (2, 14)

*The variables are reported as the number (percentage) except as indicated. †The variables are reported as the mean ± standard deviation, median (25th, 75th percentiles).

Patient Follow-up

The questionnaire used at baseline was also completed at 2 years postoperatively. Patients were asked, by mail or telephone, whether they had undergone surgery subsequent to the revision reconstruction, and operative reports of all subsequent surgical procedures were obtained. Subsequent graft failure was verified by MRI report and/or arthroscopic confirmation.

TABLE III Patient-Reported Outcomes and Prevalence of Subsequent Ipsilateral Knee Surgery at 2 Years

	Baseline	2-Year Follow-up
IKDC*	52 (39, 64)	78 (61, 87)
KOOS*		
Symptoms	68 (54, 82)	79 (68, 89)
Pain	75 (58, 86)	89 (75, 97)
Activities of daily living	87 (69, 96)	97 (88, 100)
Sports/recreation	45 (25, 65)	75 (55, 90)
Quality of life	31 (19, 44)	62 (44, 75)
Marx activity level (range, 0-16)*	11 (4, 16)	7 (2, 12)
Subsequent ipsilateral knee surgery†		
No		82% (694)
Yes		10% (88)
Unknown (unable to contact patient)		7% (61)

*The variables are reported as the median (25th, 75th percentiles). †Revision ACL reconstruction, arthroscopic procedure for meniscal and/or chondral pathology, implant removal, etc.). The variable is reported as the percentage (number).

Statistical Analysis

Continuous variables expressed as percentiles (i.e., 25th, 50th, and 75th) and categorical variables expressed as numbers and percentages were used to categorize our patient cohort. Independent predictors of outcome variables were identified via multivariable regression analyses. The primary outcome variables of interest were the 2-year outcome scores of the KOOS subscales and the IKDC, the Marx activity level, and the prevalence of subsequent surgery on the ipsilateral knee. The KOOS, IKDC, and Marx activity scores were all treated as continuous variables, whereas the prevalence of subsequent surgery was treated as binomial (yes/no). For the ordinal outcome variables (KOOS, IKDC, and Marx scores), a multivariable proportional odds model was fit because the data were not linear. A parametric model (e.g., linear regression) makes a linear assumption about the shape of the data that can lead to a model that does not reflect the true shape of the data. Hence, a proportional odds model fit the KOOS, IKDC, and Marx data more accurately. For the binary outcome variable (subsequent surgery), a multivariable logistic model was fit to the data. The covariates that we controlled for were age, sex, baseline activity level, baseline outcome scores, and the surgeon's rehabilitation prescription—i.e., restriction of postoperative passive range of motion (yes/no), active range of motion (yes/no), and full weight-bearing (yes/no) and prescription of a motion control brace (i.e., knee immobilizer) postoperatively (yes/no), an ACL derotation brace in the postoperative rehabilitation period (yes/no), and an ACL derotation brace for return to sports (yes/no). According to the number of levels, categorical variables were fit according to their degrees of freedom (i.e., $n - 1$). To stay within the allowable degrees of freedom, each continuous variable was tested for a nonlinear relationship, with a p value of <0.05 indicating significance. Statistical analysis was performed using open-source R statistical software (www.r-project.org; version 3.0.3).

Results

Patient Population

A total of 843 patients met the inclusion criteria and were successfully enrolled. Fifty-seven percent (482) were male, and the median age in the entire cohort was 27 years. Baseline characteristics of the cohort are summarized in Table I.

Two-Year Follow-up

At 2 years, the follow-up questionnaire was returned by 82% (695) of the 843 patients, and an answer to whether the patient had undergone any subsequent surgery was attained for 93% (782) of the 843 patients. Table II provides a comparison of demographic, surgical, and rehabilitation characteristics as well as baseline outcome measures between the patients who provided outcomes at 2 years and those who were lost to follow-up. We found a higher percentage of males in the group that did not return their 2-year follow-up questionnaires (70%) than in the cohort that did (55%). Body mass index (BMI) was also slightly higher in the group that was lost to follow-up. All other variables were fairly similar between groups.

IKDC and KOOS subscale outcomes all significantly improved ($p < 0.05$) by 2 years as compared with baseline (Table III). Conversely, the Marx activity levels were significantly lower at 2 years. Eleven percent (88) of the 782 patients reported at least 1 subsequent surgical procedure on the ipsilateral knee within the 2-year follow-up period.

Rehabilitation Predictors of 2-Year Outcomes

Two rehabilitation-related factors were found to influence 2-year outcomes. First, patients who were prescribed an ACL derotation brace for their return to sports had significantly better KOOS sports/recreation scores at 2 years (odds ratio [OR] = 1.50, 95% confidence interval [CI] = 1.07 to 2.11; $p = 0.019$) compared with patients who were not prescribed an ACL brace. In other words, the odds of having a higher KOOS sports/recreation score increased by 50% in patients who were prescribed a functional brace for sports (versus patients who were not prescribed one). Second, patients who were prescribed an ACL derotation brace to be used in the postoperative rehabilitation period were 2.3 times more likely to have subsequent surgery by 2 years (OR = 2.26, 95% CI = 1.11 to 4.60; $p = 0.024$). Lower baseline outcome scores and a lower baseline Marx activity rating significantly increased the odds of reporting worse clinical outcomes on the IKDC, all KOOS subscales, and the Marx activity rating) at 2 years. Conversely, whether or not a physician restricted a patient's passive or active range of motion postoperatively, restricted full weight-bearing without support, or prescribed a motion control brace postoperatively were all found to not be influential risk factors for 2-year outcomes in this revision cohort. In addition, 2-year activity levels were not influenced by whether a patient wore a brace.

Prevalence of Graft Failures with Brace Use

There were 25 confirmed graft failures over the 2-year follow-up period, for an overall graft failure rate of 3.2% (25 of 782). Of these 25 failures, 80% (20) occurred in subjects who had not been prescribed an ACL derotation brace for return to sports whereas 20% (5) occurred in subjects who had been prescribed an ACL derotation brace (intent-to-treat basis). As shown in Table I, 68% (573) of the 843 patients in the overall cohort were not prescribed an ACL functional brace for their return to sports, whereas 30% (253 of 843) were. As such, the expected frequency of graft failures among patients who were prescribed an ACL derotation brace for return to sports should have been 30%. However, although patients who were prescribed an ACL functional brace for their return to sports had a lower-than-expected frequency of graft failure (20% versus 30%), this difference was not significant ($p = 0.23$; chi-square = 1.414). Therefore, there was no difference between groups.

Discussion

As all sports surgeons know, postoperative rehabilitation can influence whether ACL reconstruction is a success or failure for the patient[2,3,7,8,39]. The best surgical procedure will fail if the rehabilitation is poorly or inappropriately performed. The protocol needs to protect the graft while regaining range of motion, strength, and proprioception. This needs to be accomplished in the most patient-friendly manner available to aid patient compliance. Many principles have been established as safe and improving outcomes in the primary ACL reconstruction setting. Whether or not these principles can be extended to the revision ACL reconstruction setting has not been established. A cohort study is way to analyze multiple variables given the challenge of accumulating a sufficient number of patients quickly enough to perform a randomized controlled study of revision ACL reconstruction.

This study enabled us to ask about and analyze a small number of important rehabilitation-related issues in the revision ACL reconstruction setting, including early versus delayed active and passive range of motion, immediate versus delayed weight-bearing, and rehabilitative and functional bracing. Range of motion has been analyzed in previous studies of primary ACL reconstructions[7,40]. Early initiation of extension and flexion has not been noted to be deleterious for the graft and may aid in obtaining a full range of motion. In this study, we confirmed that an early active and passive range of motion did not negatively impact outcome and can be allowed in the revision ACL reconstruction setting.

Early weight-bearing has been demonstrated to be safe and in fact decreases the risk of patellofemoral pain as evidenced by Level-I and II studies of primary ACL reconstruction[25,41]. In the current study, immediate weight-bearing did not have any negative impact on either reoperation rates or patient-reported outcomes.

At least 15 studies have analyzed rehabilitative bracing and motion control braces for rehabilitation after primary ACL reconstruction[8-10,12-14,16,20-22,24,27,39,42,43]. In aggregate, these studies did not support the use of these devices in the primary setting. In the current study, we analyzed this variable in the revision ACL reconstruction setting and found that use of these braces did not improve outcome. This allows surgeons to avoid their use in the absence of other surgical procedures that the surgeon believes

require utilization of a motion control brace (meniscal repair and collateral ligament repair or reconstruction), which can decrease cost and improve patient satisfaction. Some surgeons prescribe an ACL derotation device (or "ACL functional brace") during the postoperative rehabilitation period. There is little evidence regarding such utilization in any ACL reconstruction setting. Interestingly, in the current study, patients who were prescribed an ACL derotation brace in the rehabilitative phase were 2.3 times more likely to have subsequent surgery in the first 2 years of postoperative follow-up. It is not known why this may have occurred. Does the derotation brace have an inherent detrimental effect in this setting or does this finding reflect selection bias, confounding variables, or comorbidities? It appears counterintuitive to most clinicians. Two proposed mechanisms are (1) wearing a brace gave patients increased confidence and encouraged higher-level activity at an inappropriate time in their recovery and (2) these patients represented a cohort for which their surgeons thought the surgical reconstruction had not been as successful and needed additional protection and thus they were at a higher risk for outcomes requiring additional surgery.

Use of a functional ACL derotation brace for return to sports has been a controversial topic. Despite subjective hope that it might prevent future injury, evidence of a decreased likelihood of graft rupture or improved performance with their use has not been strong[5,18]. In the present study, prescribed use of a derotation brace for the return to sports was associated with a significant improvement in the score on the patient-reported KOOS sports/recreation subscale (OR = 1.50; p = 0.019) but had no effect on activity level or graft failure rates.

Strengths of this study include the fact that, to our knowledge, we analyzed the largest prospective cohort of revision ACL reconstructions ever reported. Its mix of private-practice and academic surgeons makes the results generalizable to the sports community. Our high rate of follow-up prevented attrition bias. Weaknesses include the lack of on-site follow-up. Not including graft choice in the model may be another important limitation. Also, as is a problem with rehabilitation studies in general, compliance with weight-bearing and brace wear during rehabilitation and return to sports was not known and could not be assessed in our study design. Individual prescribing practices and the indications used by the individual surgeons were not known. Some surgeons may only prescribe braces for patients who are absolutely committed to returning to sports.

Conclusions

There are rehabilitation-related factors that the physician can control at the time of an ACL revision that may have the ability to modify clinical outcomes at 2 years. Specifically, patients who were prescribed an ACL brace for return to sports had significantly better KOOS sports/recreation scores at 2 years and those who were prescribed an ACL brace for the postoperative rehabilitation period were 2.3 times more likely to have subsequent ipsilateral knee surgery by 2 years, independent of age and time of reinjury.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/F235). ■

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MARS Group

E-mail address for R.W. Wright: rwright@wustl.edu

ORCID iD for R.W. Wright: 0000-0003-4018-7132

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