Arthritis Care & Research
Vol. 77, No. 4, April 2025, pp 475–483
DOI 10.1002/acr.25453

American College of Rheumatology
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Evaluating Criteria for Symptoms Suggestive of Early Osteoarthritis Over Two Years Post–Anterior Cruciate Ligament Reconstruction: Data From the New Zealand Anterior Cruciate Ligament Registry

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Objective. The objectives were to determine the prevalence of meeting criteria for symptoms suggestive of early osteoarthritis (OA) after anterior cruciate ligament reconstruction (ACLR) and to characterize the longitudinal changes in these symptoms during the first two years post-ACLR.

Methods. We analyzed data from 10,231 patients aged 14 to 40 years in the New Zealand ACL Registry who completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) at 6, 12, and 24 months post-ACLR. Symptoms suggestive of early OA were defined as scoring ≤85% on at least two of four KOOS subscales. Longitudinal patterns of change were categorized as persistent, resolution, new, inconsistent, or no symptoms across the three visits. Prevalence and odds ratios (ORs) of symptoms were compared across visits, sex, and age groups using generalized estimating equations, and longitudinal patterns of symptom change were analyzed using multinomial logistic regression.

Results. Prevalence of meeting criteria of symptoms suggestive of early OA was 68% at 6 months, 54% at 12 months, and 46% at 24 months post-ACLR. Longitudinally, 33% had persistent symptoms, 23% had no symptoms, 29% showed symptom resolution, 6% developed new symptoms, and 9% had inconsistent symptoms. Women consistently showed higher odds of symptoms (OR range 1.17–1.52). Older age groups demonstrated higher odds of symptoms, particularly at 6 months (OR range 1.64–2.45).

Conclusion. Symptoms suggestive of early OA are highly prevalent within two years post-ACLR, with one third of patients experiencing persistent symptoms. These findings indicate that symptoms are more likely to persist rather than newly develop, emphasizing the importance of early identification and targeted interventions.

INTRODUCTION

Knee osteoarthritis (OA) is a common and debilitating condition that frequently develops after anterior cruciate ligament reconstruction (ACLR).[1,2] Approximately one in three people will demonstrate radiographic knee OA within 10 years after an ACLR.[3] The onset of knee OA often manifests as subtle and insidious knee symptoms and functional deterioration in the absence of detectable joint space narrowing on radiographs.[4–6] Recent efforts have proposed an early OA classification criteria that operationally defines symptoms suggestive of early OA based on a combination of scores on the subscales of a patient-reported questionnaire.[7–10] Although these symptoms alone do not definitively indicate early OA, they represent an important aspect of potential early OA development that can be assessed using widely available patient-reported outcome measures. It is crucial to assess these symptoms because they may act as early markers of OA and significantly affect a patient's quality of life and ability to function. At six months after ACLR—when postsurgical pain should be classified as chronic pain[11,12]—one third of

Dr Harkey's work was supported by the National Institute of Arthritis and Musculoskeletal and Skin Diseases, NIH (grant K01-AR-081389).

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Additional supplementary information cited in this article can be found online in the Supporting Information section (https://acrjournals.onlinelibrary.wiley.com/doi/10.1002/acr.25453).

Author disclosures and graphical abstract are available at https://onlinelibrary.wiley.com/doi/10.1002/acr.25453.

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Submitted for publication January 15, 2024; accepted in revised form September 16, 2024.

SIGNIFICANCE & INNOVATION

- This study demonstrates a high prevalence of participants meeting a criteria of symptoms suggestive of early osteoarthritis (OA) within the first two years after anterior crucial ligament reconstruction (ACLR), using data from the New Zealand ACL Registry. The prevalence decreases from 68% at 6 months to 46% at 24 months, indicating a persistent issue despite some improvement over time.
- Our findings reveal that about one third of the patients persistently met a criteria of symptoms suggestive of early OA throughout the two years post-ACLR. This underscores the chronic nature of symptoms post-ACLR and the necessity for ongoing management.
- The research highlights significant sex- and age-related differences in the prevalence and persistence of symptoms suggestive of early OA, with women and older age groups being more susceptible.
- This study offers valuable insights into the patterns of symptom development and persistence post-ACLR, emphasizing the need for early identification of at-risk individuals and targeted interventions to optimize long-term joint health and prevent disability.

people exhibit significant symptoms that meet this classification criteria's definition of symptoms suggestive of early OA.[9] Although people commonly assume that symptoms at six months post-ACLR are attributable to the surgery and will continue to improve over time, it is unclear how a patient's symptom status on this criteria changes during the first two years after ACLR. Therefore, it is crucial to understand how a patient's status on this criteria for symptoms suggestive of early OA evolves during the first two years after ACLR to determine whether symptoms at six months typically resolve, persist, or fluctuate over this period.

A recent review compiled data across multiple cross-sectional and longitudinal studies to highlight that patient-reported outcomes often do not return to normative levels after ACLR,[13] even after rehabilitation. Prior studies typically use continuous Knee Injury and Osteoarthritis Outcome Score (KOOS) scores to understand overall group means over time,[13] which may obscure individual patient experiences. Using classification criteria may better identify the number of patients who meet a threshold for symptoms suggestive of early OA.[8] Recently, a study used the symptoms suggestive of early OA classification criteria to investigate the longitudinal change in meeting this symptom criteria from 6 to 12 months after ACLR.[14] This study found that 22% of participants persistently meet the criteria for symptoms suggestive of early OA at consecutive visits from roughly 6 to 12 months after ACLR, whereas only 9% of participants progressed from not meeting to meeting the symptom criteria across the two visits.[14] However, results from the aforementioned study have limited generalizability because they were from a single center and a relatively short-term follow-up period.[14] Larger-scale, population-based studies are needed to confirm the prevalence and change in meeting this symptom criteria in the first two years after ACLR. Studying longitudinal data in a national registry will delineate recovery patterns of this criteria for symptoms suggestive of early OA in a real-world sample.

Additionally, the large and robust data set in a population-based study will allow us to better understand how important factors may influence how patients change in meeting this criteria for symptoms suggestive of early OA after ACLR. Because factors such as sex and age can influence symptoms or the onset of OA after ACLR,[15–18] these represent important factors that may affect whether or not a patient may meet this symptom criteria across visits after ACLR. This information will be valuable for identifying people with symptoms suggestive of early OA after ACLR, who likely need additional interventions to alleviate pain and facilitate secondary prevention efforts to optimize long-term joint health after ACLR.[19–21]

Therefore, we aim to build upon prior research by using population-based New Zealand ACL Registry data. Specifically, we evaluated the performance of the criteria for symptoms suggestive of early OA by determining the prevalence at 6, 12, and 24 months after ACLR and characterized the longitudinal change in early OA symptom status across all visits. Given previous findings that factors such as sex and age can influence the onset of OA after ACLR,[15–18] we used regression models to analyze how meeting the criteria for symptoms suggestive of early OA differed across sex, age groups, visit time points, and their interactions. The initial Luyten classification criteria to define early OA use clinical examination findings and symptoms, as well as radiographs, to rule out someone with radiographic signs of OA.[8] We focused on their operational definition of symptoms similar to prior ACLR studies.[9,14,22] We have elected only to use symptoms because young patients during this time after ACLR generally lack radiographic evidence of OA,[23] and industry stakeholders have expressed major concerns about using clinical examination data for multicenter studies (eg, national registries, clinical trials) because of lack of reliability across sites and investigators.[24] We hypothesized that at least one third of people would present with symptoms suggestive of early OA at 6, 12, and 24 months post-ACLR and that a substantial proportion would experience persistent symptoms across each visit. We also expected a higher prevalence of symptoms suggestive of early OA in female patients compared with male patients, as well as older age groups compared with younger age groups.

PATIENTS AND METHODS

This study uses data from the New Zealand ACL Registry, an ongoing nationwide cohort study that prospectively collects outcomes in patients after ACLR across New Zealand.[25,26]

The registry began in 2014, and data submission has been mandatory for all surgeons performing ACLR in New Zealand since 2017. From 2014 to 2022, the registry captured 89% of all ACLR procedures performed nationally.[26] All patients provide informed consent for voluntary participation and use of their data for research and audit purposes. The registry has ethical approval as a quality assurance initiative endorsed by the New Zealand Ministry of Health. Patient demographic information was gathered through a preoperative form. The operating surgeon completed a surgical data form outlining the specifics of each reconstruction procedure. Patients were emailed, texted, or mailed to complete follow-up surveys assessing patient-reported outcomes at standard intervals of 6, 12, and 24 months after ACLR. Patients received up to three reminders to encourage survey completion.

Patients. We first selected participants from the New Zealand ACL Registry who were between 14 and 40 years of age based on a recent consensus statement on the secondary prevention of knee OA after ACL injury.[27] The upper limit of 40 years was chosen to minimize the inclusion of individuals with pre-existing OA, ensuring our focus on post-traumatic OA in a younger population. We then excluded participants who did not have KOOS data available from at least one of the visits at 6, 12, or 24 months post-ACLR. None of the patients were excluded based on operative findings. For a separate subset analysis, we also identified participants with complete KOOS data across all study visits to specifically examine within-participant patterns of change in meeting the criteria for symptoms suggestive of early OA from 6 to 12 to 24 months post-ACLR.

KOOS. The KOOS is a knee-specific patient-reported outcome measure designed to evaluate the effects of knee injuries across the lifespan.[28] The KOOS consists of five subscales: pain, symptoms, activities of daily living (ADL), sport, and quality of life (QoL). However, only the pain, symptoms, ADL, and QoL subscales are proposed to define symptoms suggestive of early OA status.[8] Each subscale includes items rated on a 5-point Likert scale from 0 (extreme problems) to 4 (no problems). Subscale scores are calculated and transformed to a 0 to 100 scale, with 0 representing severe knee problems and 100 no knee problems. The KOOS subscale scores are subsequently used to make a dichotomous determination of whether a patient meets the classification criteria for symptoms suggestive of early OA.[8]

Classification criteria for defining symptoms suggestive of early OA. We operationally defined the presence of symptoms suggestive of early OA using the symptoms portion of the 2018 Luyten early OA classification criteria.[8] As per the Luyten classification criteria, symptoms suggestive of early OA were identified when a participant scored ≤85% on a minimum of two of the four KOOS subscales: pain, symptoms, ADL, or QoL.[8] These classification criteria for symptoms suggestive of early OA have been employed in assessing participants after ACLR[9,14,22] and specifically in the New Zealand ACL Registry but only at 6 months after ACLR.[29] In the current study, symptoms suggestive of early OA were defined using this Luyten early OA classification criteria at 6, 12, and 24 months post-ACLR. We selected the Luyten criteria over similar Englund KOOS criteria for their greater sensitivity in detecting early OA symptoms (requiring fewer subscales to be below threshold) and their specific design for identifying initial early OA symptoms,[8,30] both of which align well with our goal of capturing a wider range of individuals with potential early OA symptoms in our post-ACLR population.[9] Additionally, we used the original subscale threshold values from the Luyten KOOS criteria rather than the threshold values corresponding to the patient acceptable symptom state because prior research indicated no significant differences in the prevalence and progression of symptoms suggestive of early OA between these two criteria.[14] It is important to note that our operational definition of "symptoms suggestive of early OA" represents only the patient-reported aspect of the full Luyten early OA classification criteria,[8] which also include clinical examination (ie, joint line tenderness or crepitus) and radiographic assessments (ie, Kellgren-Lawrence grade 0 or 1).

Determining longitudinal patterns of change in criteria of symptoms suggestive of early OA. One of the objectives of this study was to determine the longitudinal patterns in a participants' change in meeting a criteria of symptoms suggestive of early OA at 6, 12, and 24 months after ACLR. To define longitudinal change in meeting a criteria of symptoms suggestive of early OA across all three visits, we created a composite variable based on all potential combinations of a participant's symptom status at 6, 12, and 24 months after ACLR. We then summarized these combinations into five groups (Table 1): 1) no symptoms—not meeting the criteria for symptoms suggestive of early OA at any visit; 2) new symptoms—transitioning from not meeting the criteria to meeting the criteria at a later visit; 3) resolution of symptoms—transitioning from meeting the criteria to not meeting the criteria at a later visit; 4) inconsistent symptoms suggestive of early OA; or 5) persistent symptoms—meeting the criteria for symptoms suggestive of early OA at all visits. Table 1 provides a detailed explanation of how the groups are defined based on all possible combinations of meeting the criteria for symptoms suggestive of early OA across the 6-, 12-, and 24-month visits.

Operational definition of sex and age groups for analysis. We used variables to determine how additional factors affected the prevalence of meeting a criteria of symptoms suggestive of early OA after ACLR: 1) sex and 2) age group. Sex assigned at birth was dichotomized as male and female. Age at the time of surgery was stratified into the following age groups: a) ≤18 years, b) 18.1 to 22 years, c) 22.1 to 30 years, and d) 30.1 to 40 years. These age ranges were chosen to reflect

Table 1. Defining the groups for longitudinal change in early knee OA symptom across visits at 6, 12, and 24 months after ACLR*

Longitudinal pattern of symptoms suggestive of early OA	Symptoms suggestive of early OA across all visits (6, 12, or 24 months)
No symptoms suggestive of early OA	0, 0, 0
New early symptoms	0, 1, 1 or 0, 0, 1
Resolution of symptoms suggestive of early OA	1, 0, 0 or 1, 1, 0
Inconsistent symptoms suggestive of early OA	0, 1, 0 or 1, 0, 1
Persistent symptoms suggestive of early OA	1, 1, 1

* The three numbers indicate their longitudinal change in meeting a criteria of symptoms suggestive of early OA at 6, 12, and 24 months post-ACLR. 0, not meeting the criteria of symptoms suggestive of early OA; 1, meeting the criteria of symptoms suggestive of early OA. ACLR, anterior cruciate ligament reconstruction; OA, osteoarthritis.

distinct stages of life and activity levels: the ≤18 years group represents adolescents typically in high school, the 18.1 to 22 years group corresponds to young adults likely in college or early adulthood, and the 22.1 to 30 years and 30.1 to 40 years groups represent two phases of early adulthood, allowing for an even distribution and meaningful comparison of outcomes across different stages of adult life. This stratification helps in understanding how age-related factors influence recovery and symptom development post-ACLR.

Statistical analysis. *Prevalence and odds of symptoms suggestive of early OA.* We began our analysis by descriptively examining the prevalence of symptoms suggestive of early OA across each visit time point after ACLR. Subsequently, we employed a generalized estimating equation (GEE) model with an exchangeable correlation to determine how sex and age were related to the prevalence of these symptoms at 6, 12, and 24 months post-ACLR, as well as how they were associated with changes in meeting the criteria for early OA across visits. The outcome variable was defined as the presence/absence of symptoms suggestive of early OA. Predictor variables included sex, visit time points, and age, with male sex, 6 months, and the youngest age group as reference categories, respectively. The model included interaction terms for sex × visit and age × visit to examine how the effects of sex and age group on symptom prevalence and changes in early OA status varied across visits. Using a logit link function, we modeled the log odds of the presence of symptoms suggestive of early OA. This approach allowed us to calculate odds ratios (ORs) and 95% confidence intervals (95% CIs) for each predictor, as well as the ratios of longitudinal ORs. These ratios of longitudinal ORs indicate the differences in change in odds between the levels of sex and age group from 6 to 12 months and 12 to 24 months post-ACLR. We used contrast statements to assess these differences in changes of early OA status. This quantified how sex and age were associated with the likelihood of changing symptom status over time, expressed as ratios of longitudinal ORs. The analysis, performed using SAS software (SAS Institute Inc., Cary, NC), accounted for the correlated nature of repeated measures within participants and provided detailed insights into the associations among sex, age, and both the prevalence and longitudinal changes of symptoms suggestive of early OA at each time point. To ensure robust findings and evaluate the impact of missing data, we conducted the analysis using both the full sample and the subset with complete KOOS data at all three visits (6, 12, and 24 months).

Within-participant longitudinal pattern of change in symptoms suggestive of early OA. Using the subset of participants who had complete data across all time points, we analyzed the within-participant longitudinal patterns of change in symptoms suggestive of early OA after ACLR. We first conducted a descriptive examination to determine the prevalence of different within-participant longitudinal patterns: no symptoms (reference category), new symptoms, resolution of symptoms, inconsistent symptoms, and persistent symptoms. We then employed multinomial logistic regression to assess the associations of sex and age with these within-participant patterns of symptoms suggestive of early OA. Predictor variables included sex (referenced to male patients) and age group (categorized with "<18 years" as the reference). We used the generalized logit link function to model the log odds of each category of longitudinal pattern relative to the reference category (no symptoms). This approach allowed us to calculate ORs and 95% CIs for each predictor, providing insights into how sex and age group were associated with the odds of experiencing different within-participant longitudinal patterns of symptoms suggestive of early OA compared with having no symptoms over the 24-month period post-ACLR.

RESULTS

Prevalence and odds of symptoms suggestive of early OA. Of the 10,231 participants with KOOS data available at any visit post-ACLR, 3,693 had complete data across all three visits (6, 12, and 24 months). Table 2 highlights that participants with complete data were similar in age (26.7 vs 26.1 years) and time to surgery (8.4 vs 8.2 months) compared with the larger cohort but had a slightly higher proportion of female patients (52% vs 46%) and hamstring tendon autografts (69% vs 64%). Our analysis revealed a decreasing trend in the overall prevalence of symptoms suggestive of early OA over time post-ACLR (Table 3). At 6 months post-ACLR, 68% of patients met the criteria for symptoms suggestive of early OA. This prevalence decreased to 54% at 12 months and further reduced to 46% at 24 months post-ACLR. Despite this decreasing trend, the overall prevalence remains alarmingly high at 24 months. Notably, the results were consistent in the smaller subset analysis with

Table 2. Demographic and surgical characteristics of participants with data at all visits compared with those with data at any visit post-ACLR*

Variable	Participants with data at all visits (n = 3,693)	Participants with data at any visit (n = 10,231)
Age, mean ± SD, y	26.7 ± 7.2	26.1 ± 7.1
Months to surgery, mean ± SD	8.4 ± 17.6	8.2 ± 17.0
Sex, n (%)		
Female	1,916 (52)	4,722 (46)
Male	1,777 (48)	5,509 (54)
Autograft, n (%)		
Bone patellar tendon bone	967 (26)	2,249 (30)
Hamstrings tendon	2,540 (69)	4,807 (64)
Quadriceps tendon	94 (3)	267 (4)
Missing	92 (2)	201 (2)
Chondroplasty, n (%)		
No	3,545 (96)	9,800 (96)
Yes	148 (4)	431 (4)
Microfracture, n (%)		
No	3,609 (98)	9,984 (98)
Yes	84 (2)	247 (2)

* This table presents a comparison of demographic and surgical characteristics between participants who had complete data at all follow-up visits (n = 3,693) and those who had data at any visit (n = 10,231) after ACLR. The table includes mean ± SD for continuous variables (age and months to surgery) and frequencies (percentages) for categorical variables (sex, autograft type, chondroplasty, and microfracture). This comparison allows for an assessment of potential differences between the complete case cohort and the larger sample with any available data. ACLR, anterior cruciate ligament reconstruction.

complete data across all visits when compared with the larger group (Supplementary Table 1).

Table 3 presents detailed ORs and 95% CIs for all analyses of the prevalence of symptoms suggestive of early OA at each time point. To avoid redundancy, the specific statistics are not repeated in the text below. Compared with male patients, female patients consistently demonstrated higher odds of experiencing symptoms suggestive of early OA across all time points, with the difference being most pronounced at 6 months post-ACLR and slightly attenuated at 12 and 24 months. When examining the ratio of longitudinal ORs for changes in meeting the criteria for symptoms suggestive of early OA, female patients showed lower odds of change compared with male patients from 6 to 12 months post-ACLR, but no significant difference from 12 to 24 months (Table 4). These results were similar in the smaller subset with complete data across all visits (Supplementary Tables 1 and 2).

Age-related differences were also observed, with comparisons made relative to the reference group of ≤18 years (Table 3). At 6 months post-ACLR, all older age groups showed significantly higher odds of symptoms suggestive of early OA compared with the adolescent group (≤18 years). At 12 months, the differences persisted but were less pronounced, with significantly higher odds in the 22.1 to 30 years and 30.1 to 40 years groups, whereas the 18.1 to 22 years group showed nonsignificant elevated odds. By 24 months, only the 30.1 to 40 years group maintained significantly higher odds, whereas the younger adult groups did not show statistically significant differences compared with adolescents. Longitudinal analysis of changes in symptoms suggestive of early OA revealed that all older age groups had lower ratios of longitudinal odds of changing symptom status compared with the adolescent group, with this effect being more pronounced from 6 to 12 months than from 12 to 24 months post-ACLR (Table 4). These results were consistent in the smaller subset with complete data across all visits (Supplementary Tables 1 and 2).

Within-participant longitudinal pattern of change in symptoms suggestive of early OA. Descriptive analysis revealed the following distribution of longitudinal patterns of symptoms suggestive of early OA across all 3,693 participants (Table 5): no symptoms (23%, n = 859), new symptoms (6%, n = 226), resolution of symptoms (29%, n = 1,055), inconsistent symptoms

Table 3. Prevalence and ORs of symptoms suggestive of early OA at 6, 12, and 24 months post-ACLR stratified by sex and age group*

	6 months (n = 8,275)		12 months (n = 7,224)		24 months (n = 5,372)		Visit × group interaction
	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	*P* value
All (n = 10,231)	5,638 (68)		3,890 (54)		2,496 (46)		
Sex							
Male (n = 5,509)	2,789 (65)	REF	1,963 (52)	REF	1,222 (44)	REF	<0.0001
Female (n = 4,722)	2,849 (72)	1.52 (1.38–1.67)	1,927 (56)	1.19 (1.09–1.31)	1,274 (49)	1.17 (1.06–1.30)	
Age							
≤18 y (n = 1,581)	701 (55)	REF	474 (45)	REF	339 (43)	REF	<0.0001
18.1–22 y (n = 1,734)	888 (64)	1.64 (1.41–1.92)	582 (49)	1.27 (1.08–1.49)	394 (46)	1.13 (0.94–1.36)	
22.1–30 y (n = 3,796)	2,179 (72)	2.34 (2.05–2.68)	1,481 (55)	1.58 (1.37–1.82)	898 (45)	1.16 (0.99–1.36)	
30.1–40 years (n = 3,120)	1,870 (72)	2.45 (2.13–2.81)	1,353 (59)	1.86 (1.61–2.15)	865 (49)	1.33 (1.14–1.57)	

* This table presents the prevalence and ORs with 95% CIs for symptoms suggestive of early OA at 6, 12, and 24 months post-ACLR. Data are stratified by sex and age groups, with comparisons made to the reference categories (male patients and ≤18 years age group) at each time point. Significant interaction effects between visit time points and groups (sex and age) are noted with *P* values <0.0001. This table highlights the variations in early OA symptom prevalence and risk across different demographic groups over time. ACLR, anterior cruciate ligament reconstruction; OA, osteoarthritis; OR, odds ratio; REF, reference; 95% CI, 95% confidence interval.

Table 4. Ratio of longitudinal ORs of change in symptoms suggestive of early OA across visits post-ACLR, stratified by sex and age group*

	6 to 12 months ratio of longitudinal OR (95% CI)	12 to 24 months ratio of longitudinal OR (95% CI)
Sex		
Male	REF	REF
Female	0.79 (0.71–0.87)	0.98 (0.88–1.09)
Age		
≤18 y	REF	REF
18.1–22 y	0.77 (0.64–0.93)	0.89 (0.73–1.09)
22.1–30 y	0.67 (0.57–0.79)	0.73 (0.62–0.87)
30.1–40 y	0.76 (0.64–0.90)	0.72 (0.60–0.86)

* This table presents the group comparisons of longitudinal changes (6 to 12 months, and 12 months to 24 months) in meeting the criteria for symptoms suggestive of early OA after ACLR. Ratios of longitudinal ORs with 95% CIs are provided for comparisons among groups, using male patients and the ≤18 years age group as references. Data are stratified by sex and age groups, highlighting the differential risks of developing symptoms suggestive of early OA over time across demographic categories. Female patients showed lower odds of change in symptom status compared with male patients from 6 to 12 months, but no significant difference from 12 to 24 months. All older age groups demonstrated lower odds of change in symptom status compared with the adolescent group, with this effect being more pronounced from 6 to 12 months than from 12 to 24 months post-ACLR. ACLR, anterior cruciate ligament reconstruction; OA, osteoarthritis; OR, odds ratio; REF, reference; 95% CI, 95% confidence interval.

(9%, n = 342), and persistent symptoms (33%, n = 1,211). This distribution indicates that persistent symptoms are the most common and newly developed symptoms are the least common longitudinal patterns for meeting the criteria of symptoms suggestive of early OA symptoms across 6, 12, and 24 months post-ACLR. Supplementary Table 3 highlights the prevalence of the longitudinal pattern of change in symptoms suggestive of early OA across all eight potential combinations of symptom status across all visits.

Table 5 presents detailed ORs and 95% CIs for all analyses of the longitudinal patterns of symptoms suggestive of early OA. To avoid redundancy, the specific statistics are not repeated in the text below. Compared with male patients, female patients had significantly higher odds of experiencing resolution, inconsistent, and persistent symptoms relative to having no symptoms. The proportion of female patients with persistent symptoms (36%) was higher than that of male patients (30%). Interestingly, the odds of new symptom development relative to no symptoms were not significantly different between sexes.

Compared with adolescents (≤18 years), all other age groups had a greater chance of resolution and persistent symptoms instead of having no symptoms (Table 5). The proportion of participants with persistent symptoms increased with age, from 26% in the ≤18 years group to 37% in the 30.1 to 40 years group. Conversely, the proportion of participants with no symptoms decreased from 33% in the youngest age group to 20% in the oldest. Notably, the odds of incident symptoms relative to no symptoms were not significantly different across age groups.

Table 5. Longitudinal patterns of symptoms suggestive of early OA and corresponding ORs at 6, 12, and 24 months post-ACLR, stratified by sex and age group in patients with complete follow-up data*

	No Sx n (%)	New n (%)	Resolution n (%)	Inconsistent n (%)	Persistent n (%)	No Sx vs new OR (95% CI)	No Sx vs resolution OR (95% CI)	No Sx vs inconsistent OR (95% CI)	No Sx vs persistent OR (95% CI)
All (n = 3,693)	859 (23)	226 (6)	1,055 (29)	342 (9)	1,211 (33)				
Sex									
Male (n = 1,777)	469 (26)	126 (7)	487 (27)	167 (9)	528 (30)	REF	REF	REF	REF
Female (n = 1,916)	390 (20)	100 (5)	568 (30)	175 (9)	683 (36)	0.94 (0.70–1.27)	1.54 (1.28–1.85)	1.30 (1.01–1.68)	1.71 (1.43–2.05)
Age									
≤18 y (n = 521)	171 (33)	48 (9)	104 (20)	62 (12)	136 (26)	REF	REF	REF	REF
18.1–22 y (n = 575)	150 (26)	50 (9)	158 (27)	50 (9)	167 (29)	1.17 (0.74–1.85)	1.87 (1.34–2.61)	0.96 (0.62–1.49)	1.54 (1.12–2.11)
22.1–30 y (n = 1,336)	287 (21)	64 (5)	433 (32)	114 (9)	438 (33)	0.79 (0.52–1.20)	2.68 (2.01–3.58)	1.15 (0.80–1.66)	2.11 (1.61–2.78)
30.1–40 y (n = 1,261)	251 (20)	64 (5)	360 (29)	116 (9)	470 (37)	0.90 (0.58–1.37)	2.61 (1.94–3.51)	1.36 (0.94–1.96)	2.67 (2.02–3.52)

* This table presents the longitudinal patterns of symptoms suggestive of early OA at 6, 12, and 24 months post-ACLR for patients who have KOOS data available at all three time points. The data is stratified by sex and age groups, showing the prevalence of each symptom category (no symptoms, new, resolution, inconsistent, persistent). ORs with 95% CIs are provided for comparisons among groups, using "no symptoms" as the reference category. This table highlights the differences in symptom patterns and risk factors for early OA across different demographic groups, specifically for patients with complete follow-up data at all three visits. ACLR, anterior cruciate ligament reconstruction; KOOS, Knee Injury and Osteoarthritis Outcome Score; OA, osteoarthritis; OR, odds ratio; REF, reference; Sx, symptom(s); 95% CI, 95% confidence interval.

DISCUSSION

This study reveals a substantial prevalence of symptoms suggestive of early OA throughout the first two years after ACLR in 10,231 patients from the New Zealand ACL Registry. We observed a decreasing trend in prevalence from 68% at 6 months to 46% at 24 months post-ACLR, although the prevalence remains alarmingly high even 2 years after surgery. Longitudinal analysis showed 33% of participants persistently met the symptom criteria across all visits, whereas 23% never met the criteria. Significant sex- and age-related differences were observed. Female participants showed higher odds of experiencing symptoms across all time points, yet lower odds of changing symptom status from 6 to 12 months post-ACLR. Age-related differences were most pronounced at 6 months post-ACLR, with older groups demonstrating higher odds of meeting the criteria but lower odds of changing status over time compared with adolescents.

Although symptoms at 6 months post-ACLR are often attributed to postoperative recovery, our data show that these symptoms persist in a substantial proportion of patients through 24 months. This observation is important given that 6 months postsurgery is when postsurgical pain is typically reclassified as chronic.[11,12] The persistence of these symptoms in our study period raises questions about the nature of recovery after ACLR and highlights the need for continued monitoring and potential intervention beyond the immediate postoperative phase. Therefore, patients presenting with symptoms suggestive of early OA, especially those with persistent symptoms, constitute an important at-risk group that could benefit from targeted interventions to alleviate symptoms and potentially prevent progression to established OA.

Our results provide important insights into the prevalence of symptoms suggestive of early OA after ACLR, revealing the persistence of these symptoms over time. Our findings demonstrated that 68% of participants met the criteria for symptoms suggestive of early OA at 6 months post-ACLR, significantly higher than the previously reported 36% at 5 to 7 months.[9] This variation could be due to differences in average age (26.1 vs 20.0 years) and study populations,[9] with the previous study focused on high-volume orthopedic clinics in the United States, whereas the current used national registry data from New Zealand. Future research could explore regional or cultural adjustments to KOOS thresholds for more accurate assessment. Our results also extend previous work by highlighting the decreasing prevalence of symptoms at 12 (54%) and 24 (46%) months. This trend aligns with previous data indicating a decrease in unacceptable symptoms from 1 (43%) to 2 (33%) years post-ACLR.[31] Although the decline may reflect symptom resolution due to rehabilitation, it is concerning that 46% of participants still meet the criteria for symptoms suggestive of early OA at 24 months post-ACLR, indicating persistent issues with pain, function, and QoL.

Our longitudinal analysis provides insights into the natural history of symptom reporting over 2 years post-ACLR, revealing a low prevalence of new symptom development (6%) from 6 to 24 months post-ACLR. Instead, we observed that 33% of participants exhibited persistent symptoms across all visits, whereas 23% reported no symptoms and 29% experienced symptom resolution between visits. These findings indicate that symptoms are more likely to persist rather than newly develop within the first two years post-ACLR, emphasizing the importance of early identification and targeted interventions for those experiencing symptoms at six months postsurgery. Notably, we found that 57% of individuals with symptoms at 6 months continued to have symptoms at 24 months, compared with only 18% of those without symptoms at 6 months developing symptoms at 24 months (Supplementary Table 3). This persistence highlights the chronic nature of symptoms for many participants and underscores the importance of early identification and intervention at six months, when many patients are discharged from care. Although some individuals benefit from rehabilitation and natural recovery, a significant proportion continue to experience chronic symptoms, necessitating a proactive approach and additional therapeutic strategies to manage long-term outcomes effectively. Future studies should focus on understanding how these symptoms relate to the onset of symptomatic knee OA and developing targeted interventions for those at highest risk of persistent symptoms, potentially reducing the risk of long-term issues.[7,32]

Our analysis revealed significant sex-related differences in the prevalence and patterns of symptoms suggestive of early OA. Female patients consistently demonstrated higher odds of experiencing symptoms compared with male patients across all time points post-ACLR (Table 3). This aligns with prior evidence that women generally have worse patient-reported outcomes and higher rates of OA after ACLR.[6,15,16,33,34] Longitudinally, female patients showed higher odds of experiencing resolution, inconsistent, and persistent symptoms relative to having no symptoms. Notably, 36% of female patients exhibited persistent symptoms compared with 30% of male patients. However, our longitudinal GEE analysis revealed an intriguing paradox: Despite higher overall symptom prevalence, female patients had lower odds of changing symptom status from 6 to 12 months post-ACLR, with no significant difference between sexes from 12 to 24 months. This suggests that, although female patients may be more likely to experience symptoms, their symptom status tends to be more stable over time compared with male patients, particularly in the early postoperative period.

Age-related differences were also observed, with older age groups generally showing higher odds of symptoms suggestive of early OA (Table 3). These differences were most pronounced at 6 months post-ACLR, with all older age groups showing significantly higher odds than those ≤18 years. By 24 months, only the 30.1 to 40 years group maintained significantly higher odds. Longitudinally, we observed a clear trend of increasing persistent

symptoms with age, from 26% in the ≤18 years group to 37% in the 30.1 to 40 years group. Conversely, the proportion of participants with no symptoms decreased from 33% in the youngest age group to 20% in the oldest. These findings suggest that older individuals may require more intensive or prolonged rehabilitation strategies to mitigate the risk of persistent symptoms. However, it is important to note that at least one quarter of all age subgroups exhibited persistent symptoms, indicating that age alone does not determine long-term outcomes and that individualized approaches are necessary across all age groups. Our longitudinal GEE analysis further revealed that all older age groups had lower odds of changing symptom status compared with adolescents, particularly from 6 to 12 months post-ACLR. This suggests that, although older individuals are more likely to experience symptoms initially, their symptom status tends to be more stable over time.

This study has several limitations to consider. The use of registry data may introduce selection bias because male patients more commonly experienced missing KOOS data, resulting in a larger proportion of female patients (52%) with complete data at all visits compared with the broader cohort with any data (46%). The generalizability of our findings to other geographic regions is unclear, necessitating similar studies in different cohorts or population-based registries. Although the registry achieved >55% patient-reported outcome follow-up at 2 years post-ACLR,[26] incomplete follow-up data may affect the observed prevalence of symptoms suggestive of early OA at later visits. Continued longitudinal tracking is needed to determine long-term symptom trajectories and predict future symptomatic OA incidence. Additionally, the New Zealand ACL Registry is limited to operative information and patient-reported outcomes, lacking detailed data on concomitant injuries and other factors that could influence post-ACLR outcomes. Similar to prior studies in patients after ACLR,[9,14,22,29,35] our classification of symptoms suggestive of early OA is based solely on patient-reported outcomes using KOOS. However, the full Luyten classification criteria for early OA also include clinical examination and radiographic findings, which were not available in the New Zealand ACL Registry data. Future research should incorporate a multifaceted assessment, including clinical evaluation, structural imaging, biomechanics, and more detailed injury classifications (eg, meniscal involvement) to provide a comprehensive understanding of post-ACLR alterations.[27,32] We acknowledge that excluding patients with incomplete follow-up data for the within-participant longitudinal pattern analysis may introduce selection bias. However, supplementary tables indicate that there were no meaningful differences between this subset and the larger cohort with missing data. Future studies using statistical approaches to impute data could help include a broader sample and further validate our findings. Despite these limitations, this study characterizes symptoms suggestive of early OA in a real-world sample, providing valuable insights into the prevalence and patterns of these symptoms after ACLR.

Our study offers critical insights into the prevalence and change overtime in meeting a criteria for symptoms suggestive of early OA in a large cohort of participants post-ACLR. We found a high prevalence (46%–68%) of symptoms suggestive of early OA, with one third of participants showing persistent symptoms across all study visits. Female patients and older individuals were more likely to experience persistent symptoms suggestive of early OA. These results underscore the importance of improved care and secondary prevention of knee OA, including routine screening and targeted interventions post-ACLR. The study highlights the need for ongoing research and clinical efforts in symptom recovery and OA prevention, especially for those with persistent symptoms post-ACLR.

ACKNOWLEDGMENTS

This article was prepared with assistance from ChatGPT, a Large Language Model chatbot, which provided stylistic and grammatical guidance to enhance the writing quality. The authors thoroughly reviewed and revised the AI-generated content, ensuring it reflects their original research and insights accurately.

AUTHOR CONTRIBUTIONS

All authors contributed to at least one of the following manuscript preparation roles: conceptualization AND/OR methodology, software, investigation, formal analysis, data curation, visualization, and validation AND drafting or reviewing/editing the final draft. As corresponding author, Dr Harkey confirms that all authors have provided the final approval of the version to be published, and takes responsibility for the affirmations regarding article submission (eg, not under consideration by another journal), the integrity of the data presented, and the statements regarding compliance with institutional review board/Declaration of Helsinki requirements.

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