Epidemiology of knee injury and anterior cruciate ligament (ACL) reconstruction in Alberta

by

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Abstract

Current trends of knee injuries and anterior cruciate ligament reconstruction (ACLR), as well as incidence of and factors associated with primary and recurrent ACLR in Alberta, are not well understood. This thesis aims to fill this knowledge gap by using administrative data from Alberta's Ministry of Health. Data covering the period from 2002/03 to 2018/19 were obtained. Multiple databases (ambulatory care, inpatient, physician claims, and population registry) were linked for analysis. Furthermore, this thesis synthesizes literature on facilitators and barriers to implement ACL injury prevention programs.

There was a decline in knee injury-related emergency department (ED) visits in the province over the 17-year study period. Males experienced a significant decline in the knee injury-related ED visits, while the proportion of ED visits remained almost constant among females. Sprain and strain of joints and ligaments and internal derangement of the knee comprised more than 90% of knee injury-related ED visits.

Between 2002/03 and 2018/19, age-standardized annual incidence of primary ACLR among those aged 10 years and older increased from 44.7 to 54.9 per 100,000 people among males. Among females, it increased from 32.9 to 47.5 per 100,000 people. Although overall incidence was higher among males, the average annual growth rate was higher among females compared to males, contributing to a narrowing gender gap in annual ACLR incidence in Alberta. Revision ACLR incidence increased from 1.9 to 5.4 per 100,000 people among males and 1.8 to 5.0 per 100,000 people among females.

Among ACL injuries diagnosed in the ED between 2010/11 and 2015/16, less than half (45%) underwent ACLR within three years of follow-up. Whereas nearly two-third (64.5%) underwent ACLR among those who were diagnosed in a non-emergency setting. Living in rural areas or poorer income quintile neighbourhoods was associated with lower chances of ACLR compared to living in the highest income quintile neighbourhoods, after adjusting for age, gender, season of ACL injury diagnosis, place of diagnosis, and other covariates. Females showed a higher chance of ACLR compared to male counterparts. Females under 20 years old had a higher chance of ACLR compared to older females, as well as all male age categories. Chances of ACLR peaked before 20 years in females and peaked before 30 years in males. Average time from first diagnosis to ACLR was found to be almost a year among those diagnosed in the ED and more than eight months among those diagnosed in a non-ED setting. Of the total ACLR with an initial ACL injury diagnosis made in ED, just above one-third (35.6%) underwent surgery within five months from diagnosis. The remaining two-third operated on five months or more after diagnosis, were considered “delayed surgeries.”

Among those with a history of primary ACLR between 2010/11 and 2015/16, ipsilateral revision was found in 3.9% (95% CI: 3.5-4.3) and a contralateral ACLR was found in 3.6% (95% CI: 3.2-3.9) with an average follow-up period of 5.7 years. Patients aged 10-19 years had substantially higher chances of revision (7.7%) and contralateral ACLR (6.2%) compared to other groups. Having primary ACLR in winter (HR: 1.6, 95% CI: 1.2-2.2) compared to summer, and/or having allograft (HR: 1.5, 95% CI: 1.0-2.3) compared to autograft, were associated with increased risk of revision ACLR.

A systematic review on facilitators and barriers found that people (coaches and athletes) are the most critical elements of Injury Prevention Program (IPP) implementation. The IPPs need to focus on capacity enhancement and motivation of coaches and athletes. Further, IPPs that need minimal additional resources (budget, and human resources) are more likely to be adopted. Secondary factors include the program's adaptability, collaborative design, cost, and timing of implementation, as well as duration of the program per session. Furthermore, the inner setting (availability of supportive resources and people, enabling environment), outer setting (policy environment, media role, favourable evidence) and process of program implementation (frequent supervision, feedback, and support) were also very important.

Preface

I (YRP) am primarily responsible for all aspects of the research included in this thesis and I am the lead author for all chapters. I was involved in the conceptualization of the studies. I conducted all analyses and prepared all initial drafts for the seven chapters of this thesis.

This thesis involves use of administrative data received from Ministry of Health, Government of Alberta. This project received research ethics approval from the University of Alberta's Research Ethics Board, under the project name "Epidemiology of knee injury and anterior cruciate ligament reconstruction in Alberta (2002-2018) in Alberta, Canada," No. Pro00090820, June 22, 2020.

Don Voaklander (DCV) is the supervisory author for Chapters 2, 3, 4, 5 and 6. DCV provided guidance on concept formation and interpretation of results; he also critically reviewed the initial draft chapters of this thesis and contributed to edits. Mark Sommerfeldt (MS) was a co-supervisor and a coauthor for Chapters 2, 3, 4, 5 and 6. He provided guidance on concept formation, critically reviewed all thesis chapters, and provided feedback contributing to revisions therein.

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-Yuba Raj Paudel

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List of abbreviations

ACL	anterior cruciate ligament
ACLR	anterior cruciate ligament reconstruction
AKIC	acute knee injury clinic
CCI	Canadian classification of health intervention
CFIR	consolidated framework for implementation research
DAD	discharge abstract database
ED	emergency department
GP	general practitioners
HR	hazard ratio
ICD-10	international classification of disease, 10th version
IPP	injury prevention program
KLIPP	knee ligament injury prevention program
MCL	medial collateral ligament
MRI	magnetic resonance imaging
NACRS	national ambulatory care reporting system
NMT	neuro-muscular training
PCL	posterior cruciate ligament
PEP	prevent injury and enhance performance program
SR	sports and recreational

1. Introduction

1.1 Knee injuries and their burden

Sports participation peaks during adolescence and declines in adulthood (1). In Canada, a significant proportion of youth and adults participate in ice hockey, skiing, football, and snowboarding (2). Recent patterns in sports and recreational (SR) activities participation shows soccer and basketball are becoming the most popular sports among Canadian youth (3). While participation in sports and physical activity is beneficial for health and wellness (4), it is also associated with increased risk of injury, resulting in hospitalization and restriction of physical activity (5).

Knee injury is one of the common injuries among SR-related injuries. A population-based study conducted in Alberta in late 1990s showed that most of the sports-related injuries in Alberta were to the knee (20%) and ankle (14%) (6). Nearly one-third of the reported injuries (31%) were related to ligament injuries (6). SR-related injury rates in Alberta were reported to be higher than in Ontario and Quebec (6).

Knee injury is associated with multiple short- and long-term consequences. Short-term effects include decreased quality of life, reduced strength, and poor balance (7). Studies have shown that a current or previous injury is a barrier to participation in physical activity (8), and SR activities (9), with significant consequences in personal and professional life (10, 11). Longer term effects of knee injuries include early onset osteoarthritis (12, 13).

The societal impacts of knee injuries are also enormous (4). Anterior cruciate ligament (ACL) injury, one of the most common knee ligament injuries, has the one of the highest direct costs for treatment and rehabilitation among sports-related injuries (11, 14). The consequences are multiplied when we consider societal cost due to absenteeism, and long-term health consequences (14).

1.2 ACL injury and its burden

ACL rupture is the most common ligament injury in the knee, particularly among younger athletes (15, 16). Incidence rates of ACL injury in the general population are reported to be between 8.1 to 36.9 per 100,000 person years (17).

Females have a higher incidence of ACL injury (per athletic exposure) compared to males (18, 19). A recent systematic review and metanalysis found that one in 29 female athletes and one in 50 male athletes experienced an ACL injury over 25 years of follow-up (20). Females have 1.5 times incidence proportion and a 1.7 times higher incidence rate than males (20).The injury rate rapidly grows during adolescence and early adulthood and declines with adulthood (17). Athletes between 15-25 years of age sustain nearly half of all ACL injuries (18, 21).

ACL injuries present a significant burden to individuals, families and the health care system. Individuals face lost wages, reduced productivity, and disability (22). In addition to missed participation in sports and recreational activities, injured individuals experience substantial physical and psychological impairment (23), increased chances of being overweight/obese, and reduced function of the knee and lower knee related quality of life 3-10 years after injury (24). A historical cohort study conducted among 100 youths who sustained knee injuries in Calgary, Canada suggested that youth with history of knee injury were more likely to have higher abdominal and overall adiposity, lower physical activity, and less aerobic fitness in comparison to non-injured controls (25). Physical fitness and higher adiposity are strong determinants of multiple chronic conditions, including diabetes (26), obesity, and high risk of mortality (27). Further, lower physical fitness in adolescents was associated with risk factors for lower cognitive function and cardiometabolic disease (28).

ACL injury exerts a significant burden on the health system today and will continue to do so in the future. More than 130,000 ACL reconstructions are performed annually in the United States (29). Evidence suggests that 1.7% to 7.7% of those who undergo primary ACL reconstruction (ACLR) will need revision ACLR (30, 31). Besides activity limitation, and immediate costs to the health care system, ACL injury is associated with increased risk of osteoarthritis (13, 32). ACL injuries contribute to an estimated 30,000 to 38,000 additional cases of symptomatic knee osteoarthritis in the United States per year (22). A population-based matched cohort study conducted in Ontario, Canada showed an increased risk of arthroplasty – an outcome of chronic osteoarthritis – among patients who had a history of ACL reconstruction compared with the general population (33). A metanalysis of studies comparing ACL injured knees with contra-lateral un-injured knees showed a 3.89-times increase in risk of any kind of osteoarthritis after 10 years of follow-up in an ACL injured knee, regardless of management type (34).

Multiple studies have investigated the prevalence of meniscal damage in the ACL-deficient knee (16, 35–37). In nearly 50% of ACL tear cases, meniscal tears occur along with the ACL injury (38). Among isolated ACL injury cases, the medial meniscus acts as a secondary stabilizer in the ACL-deficient knee (39). However, recurrent instability episodes can degrade the medial meniscus over time and may also lead to displaced or “bucket handle” meniscal tears (39, 40).

1.3 Management of ACL injury

A complete knee examination can identify an ACL injury with a sensitivity of more than 82% and specificity of over 94% (41). The three commonly used clinical methods for the diagnosis of ACL injury are Lachman tests, anterior drawer tests, and pivot shift tests. The Lachman test is considered the most accurate clinical test (42). A magnetic resonance imaging (MRI) scan is the primary tool used to diagnose an ACL tear in the United States (43).

After ACL injury, referral to orthopedic surgeon depends on the activity level of the patients, and patient preference. Patients, who have recurrent instability episodes, have simultaneous meniscus damage or collateral ligament damage need to be referred to a surgeon. In the past, surgery was not generally recommended for skeletally immature individuals (42). Bracing, rehabilitation, and sports restriction was the suggestion for such athletes. However, advances in surgical techniques have made it easier to perform surgery in these children without impacting growth (44). Generally, surgery is recommended for patients who want to return to pre-injury level of sports activities, especially for those who participate in organized competition or those involved in physically demanding occupations (45, 46). Furthermore, patients with signs of recurring instability need ACLR to restore stability and protect the meniscus and cartilage tissue from damage (45).

Autografts and allografts can be used based on a surgeon's preferences; however, some studies show higher failure rate of allograft compared to autograft (47, 48). Patients aged 10-19 years had the highest failure rate (48). Higher activity (post-operative) and use of allograft was found to have a much higher risk of graft failure than autograft (47). Lower success rate of allograft surgery may be associated with preparation and preservation techniques and use on a younger population (49, 50).

Some patients may prefer conservative management for an ACL injury. A systematic review and metanalysis showed that neither patient reported outcomes, knee functional outcomes nor incidence of radiographic osteoarthritis differed between an ACLR group and a conservative management group (51). Authors suggest trialing non-operative management before reconstruction, although younger and active patients might benefit from reconstruction.

There is a lack of consensus on optimal timing and approach (surgical or non-surgical) for management of ACL injury (37, 39 ,52). Evidence suggests that patients who undergo ACLR longer than three months after injury are significantly more likely to suffer meniscus tears (39).The American Academy of Orthopedic Surgeons has recommended that the ACL needs to be reconstructed within five months of initial injury, or when indicated (53). Some studies have used six months as a cutoff time from injury to ACLR to observe the difference in likelihood of medial meniscus damage (16, 37).

Furthermore, which patients will benefit most from surgical reconstruction is also poorly understood. A study showed that females were more likely to benefit from early ACL reconstruction compared to males (37). A matched cohort study comparing meniscal repair alone with ACL reconstruction and meniscal repair showed that ACL reconstruction was protective against further meniscal damage (54).

After ACLR, patients need to follow an extensive rehabilitation plan that involves 10 to 12 weeks of strength-building activities. The types of rehabilitation activity need to be customized for each patient. A graduated rehabilitation program focussing on regaining full knee extension (straightening), bearing weight, maintaining an active range of motion, and strengthening muscles can be started after surgery. Progressive rehabilitation for the first three months includes: "range-of-motion exercises, patellar mobilization, endurance training, and closed-chain strengthening exercises" (42). Other activities such as straight-line jogging, plyometrics, and sport-specific exercises are added after four to six months (42).

1.4 Post-operative health care utilization

Primary ACLR is recommended to treat symptomatic instability caused by ACL injury to prevent further damage of other internal structures of the knee among high-risk individuals. Allografts and autografts are used for ACLR; however, evidence regarding success of allograft and autografts is mixed (49, 55, 56).

A metanalysis has showed ACLR failure rate from 4.3% to 12.7% (57). A follow-up study using a Danish ACL registry by tracking about 85% of the ACLR cases showed that 4.1% of ACLR cases need revision ACLR after five years of follow-up (58). The study showed that patients below the age of 20 years at the time of ACLR had a 2.5 times higher risk of revision compared to patients above the age of 20 years. Use of allograft tissue for the revision was associated with twice the risk of re-revision than autograft. The most common cause of graft failure was new trauma (38%) and poor femoral tunnel positioning (20%), though nearly a quarter of grafts (24%) failed with no known cause. Other possible risk factors for graft failure include returning to activity too soon (56), graft size (59), graft fixation, and positioning (60).

Schilaty et al. followed up with 1041 patients who had their ACL reconstructed between 1990 and 2000 (61). Follow-up until December 2015 showed that 6% had experienced a second ACL tear and the highest prevalence of a subsequent ACL tear was among the 17-35-year age group. Incidence rates of second ACL tears were steady among males aged 15-45 years.

Females below the age of 20 showed a highest incidence. Risk of a second ACL tear was higher among those who had their ACL reconstruction using allograft compared to patellar tendon autograft or hamstring autograft (61). Of those who had a subsequent ACL injury, more than two-thirds (66.7%) involved the contra-lateral side (61). An Ontario-based study from Canada followed up with 827 patients who had their first revision ACLR between 2004 and 2010 and found that 4.4% needed a re-revision over a mean follow-up period of 4.8 ± 2.2 years, and 3.4% needed contra-lateral ACLR (30). Another population study among patients who had ACLR between 2003 and 2008 from Ontario, Canada found a revision rate of 2.6%, with a mean follow-up period of nearly three years on the ipsilateral knee (62). Furthermore, the rate of primary ACLR in the contra-lateral knee was 4.6% with a mean follow-up period of nearly three years. Pullen et al. conducted a retrospective study using administrative data from a military health system in the United States and found that 3.6% of the ACLR group needed revision surgery (63). In addition to ACL revision, patients use health care services for pain management, infection control, or others.

1.5 Health care system in Alberta for the management of ACL injuries

Health care services in Alberta are managed by five health regions under Alberta Health Services. Health services are delivered through hospitals, community health centres, continuing care facilities, public health programs and home care (64). Many sport- and recreation-related knee injuries are investigated and treated in the emergency department (ED) of hospitals. Patients alternatively present to primary care providers, seek home-based care, or present to physiotherapists or sports physicians (65).

Alberta currently has a referral system in which general practitioners (GPs),surgeons, and other physicians refer patients to orthopedic specialists (66). Before referral, health care providers recommend physiotherapy, walking aids, pain relief medication, and weight loss programs to mitigate the impact of ACL injury. If these approaches are insufficient or the health care provider wishes to seek an additional opinion, the patient will be referred to a specialist. Many practitioners in Alberta send knee patients to specific acute knee injury clinics, which are multidisciplinary centers where patients receive a continuum of care, from pre-consultation to post-surgical follow-up (66).

Early diagnosis and timely management are critical to the initiation of appropriate rehabilitation activities. The literature suggests that the Canadian health care system is not efficient in dealing with musculoskeletal conditions such as knee injuries (67), and Alberta is no exception (40). Many patients in Alberta with ACL injury who present to the emergency room are discharged without a diagnosis. A retrospective study among adolescents with ACL injury in Edmonton, Alberta showed that average waiting time for MRI from injury was nearly 3 months, and median time for surgery was 11.4, months which is much longer than the recommended timing of less than five months for ACLR (40). A study using chart audit of 666 acute knee injuries showed that 65% of MRI requests were inappropriate (68). This shows that while MRI resources are being wasted, needy patients also must wait a long time for diagnosis.

Some studies suggest inadequate training among primary care physicians to deal with certain musculoskeletal conditions, including severe knee injuries (67, 69). Furthermore, shortages of physicians, specialists, and medical facilities in Canada limit the health care system's ability to provide timely care for acute injuries such as knee injuries (67). Due to lack of diagnosis and timely management, many patients are likely to experience several instability episodes during this period.

A study conducted in Calgary, Alberta showed that providing training and mobilizing non-physician experts such as athletic therapists can create a "more effective, efficient and accessible clinical care pathway for evaluation and management of acute knee injuries with the assistance of technology and interdisciplinary team of physicians and non-physicians" (70). Interdisciplinary approaches and a competency-based curriculum targeting non-physicians were used. The model was found to reduce wait times, improve patient satisfaction, and contribute to cost savings for health care systems (67).

1.6 Injury prevention

Prevention of ACL injury is the most effective approach to protect knee health. Approximately 75% of ACL injuries occur without direct contact (71), and research suggests that some risk factors for injury may be modifiable (72, 73). Several prevention programs have been developed and are shown to be effective to reduce ACL injury (74, 75). It is suggested that an ACL prevention program should include at least 10 minutes of neuromuscular training exercise three times a week (74). A metanalysis of ACL prevention protocols concluded that plyometrics (i.e., repetitive rapid loading and contraction of a targeted muscle group), strength training, and balance exercises accompanied by regular feedback about proper landing techniques are the most effective approaches for ACL injury prevention among females (75).

A cohort study involving education, stretching, neuromuscular training, and proprioceptive performance among 1,041 female soccer players compared with 1905 age and skill-matched controls showed that the intervention reduced ACL injury by 88% in the first year, and the result was reproduced after two years of follow-up, showing 74% reduction in the intervention group compared to controls (76).

Use of functional knee braces has been found to reduce strain on ACL during drop-landing activities (77). The knee braces were found to alter the muscle firing pattern during the dynamic activities among high-risk individuals. Integrating neuromuscular training provided to young athletes has been shown to be a cost-effective approach for preventing ACL injury (78). A recent cluster randomized controlled clinical trial among female basketball, soccer, and volleyball players – high risk sports for ACL injury – showed that a neuromuscular training program focusing on trunk and lower extremity was effective to reduce knee injuries, and ACL injuries specifically (79). The training program included “anterior hopping, lateral hopping, trunk flexion, trunk extension, trunk rotation, hip extension, lunges, and plyometrics.”

A effective ACL injury prevention program should be based on determined risk factors for injury with the application of program design principles to minimize risk (80). A recent review showed that some of the tested programs (sports metrics that involved 60 to 90 minutes of exercise three times per week for six weeks pre-season) were effective to prevent

ACL injury (81). Prevent Injury and Enhance Performance Program (PEP), which involves a 20 minute warm-up in-season using running, flexibility, strength, plyometrics, and agility, and Knee Ligament Injury Prevention Program (KLIPP), which includes a 20-min warm-up twice a week in-season involving plyometrics and agility exercises, were shown to be effective in preventing ACL injury (81).

1.7 Thesis rationale

Previous studies on ACL injury have mainly focused on surgical approaches, graft types, and patterns of physician practice. Fewer studies have been conducted to investigate epidemiology of knee injury, ACL injury, or post-operative health care utilization patterns, including revision of ACL reconstruction in a population-based setting (82). Moreover, there are very few studies in Canada that have investigated the epidemiology of ACLR and revision. In Alberta, there is a limited data on epidemiology of knee injuries presenting to emergency departments or ACLRs (83).

Understanding the epidemiology of acute knee injuries in Alberta will be helpful in planning health care delivery and resource allocation (83). Acute knee injury clinics established in Calgary and Edmonton are facing difficulties in anticipating patient numbers and resources required to meet their needs. Similarly, estimating the number of ACLRs and ACL revisions (by age, sex, year, season) that will be required in the region will help waitlist management, resource planning, and allocation. Ultimately the goal is that injured patients requiring ACLR can have surgery within an acceptable timeframe (less than five months from injury) (83). Additionally, investigating factors related to surgical delay as well as postoperative health care utilization can contribute to improving health system efficiency and client satisfaction.

By identifying the distribution and risk factors of knee injuries, the current study may contribute to the prevention of knee injuries that occur due to modifiable risk factors. The true risk to young people, especially females, of suffering knee injury while being involved in competitive sports may have been underappreciated by parents and related organizations (83, 84). In this light, information, education, and communication about ACL injury can be targeted to at-risk individuals, as has been done in the field of youth concussion (83, 85). However, data on the epidemiology of the injury in Alberta are needed to move forward on these tasks (83).

We adopted a continuum of care approach to investigate incidence and correlates of ACLR (Fig. 1). Although it was not possible to study all possible clinical pathways, including conservative treatment due to data and time limitations, we investigated epidemiological trends of surgical management of ACL injury. We analyzed trends of ACLR, proportion of ACL patients with diagnosed ACL injury undergoing ACLR, and investigated the proportion of patients with primary ACLR who required post-operative reconstruction, e.g., ipsilateral ACL revision or contralateral primary ACLR.

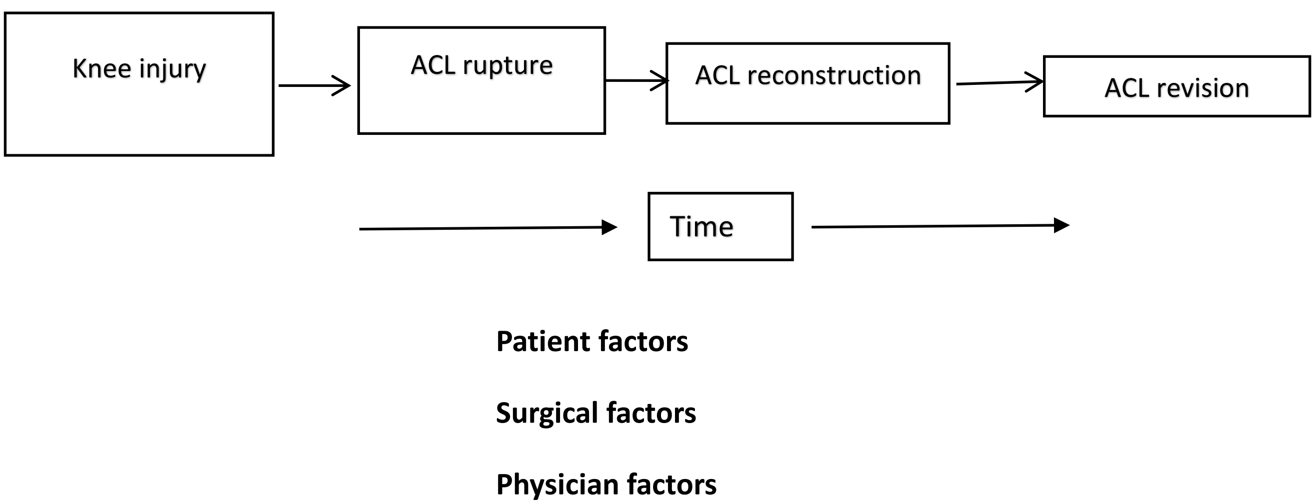

Figure 1.1 Conceptual framework for study on incidence and risk factors for primary and revision ACLR

1.8 Theoretical framework for the thesis

This thesis aims to integrate epidemiology and implementation science. While the epidemiology component of the thesis will inform researchers and policymakers about trend and risk factors for primary and revision ACL reconstruction, the implementation science component will inform readers about the potential barriers and facilitators to implement an ACL injury prevention program.

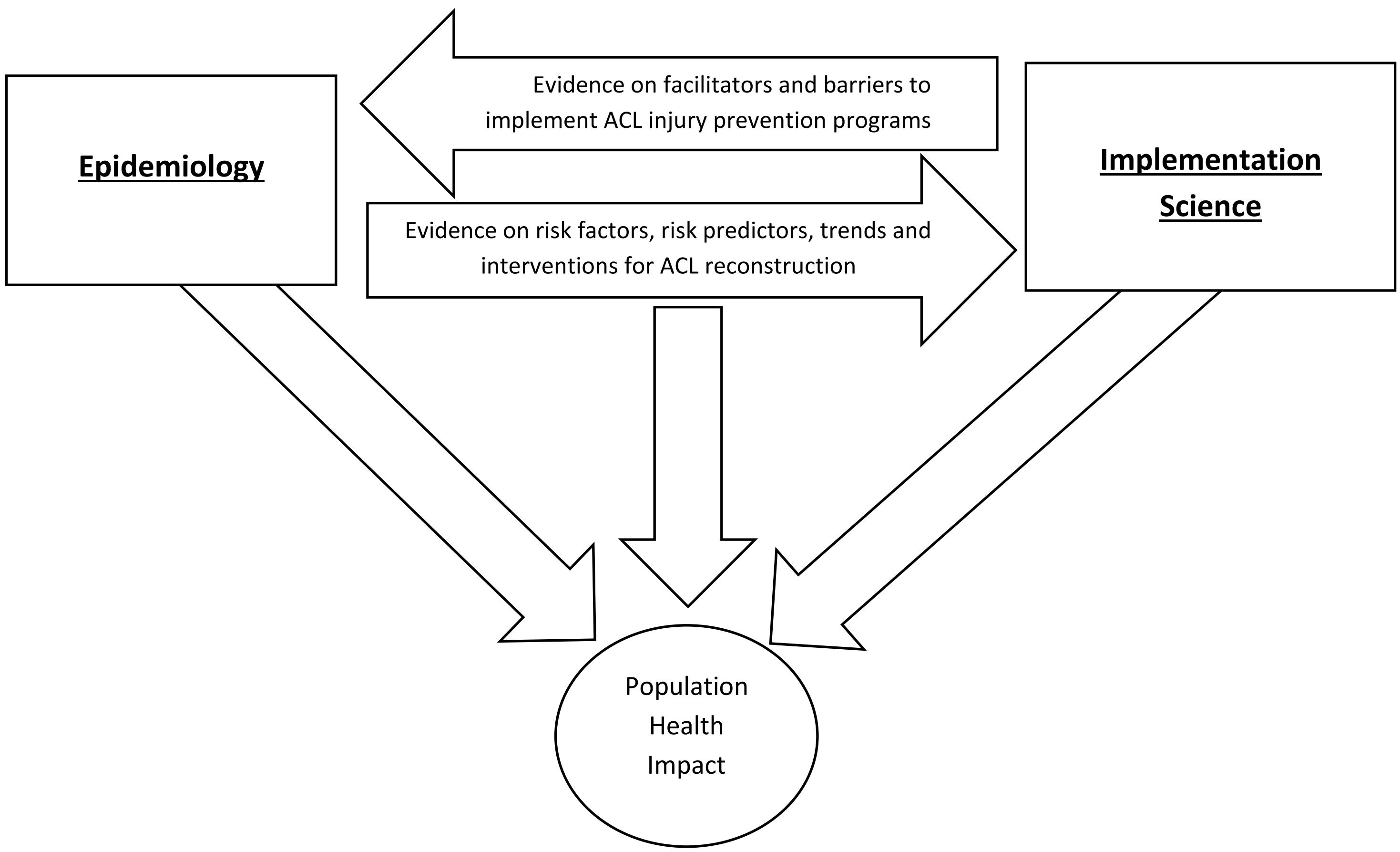

Figure 1.2 Interrelationship between epidemiology and implementation science for improved knee health (Adapted from Neta et al. (86))

Historically, epidemiology was intertwined with efforts to reduce deaths and control disease. John Snow's ghost map did not only help to identify the distribution and cause of the disease, but also was linked with the actions for controlling the cholera epidemic (e.g., removal of the town water pump handle) and reducing the number of deaths (86, 87).

Over the years, epidemiology has advanced as a discipline. However, in its current practice, epidemiology has been criticized for overemphasizing methods and failing to provide knowledge needed for effective public health practice (88). While continuing to refine methods to identify causes for the disease and injuries, there is also a need to push forward for translation of our findings. Therefore, epidemiologists need to reflect upon and revisit the unidimensional approach currently being taken.

Recently, there is a renewed call among epidemiologists to pay attention to translational component of their work or to adopt a consequentialist approach (86,89). While etiological research is the foundation and unique role of epidemiology, the role of control of disease/injury should not be forgotten (89). Galea et al. (89) raise a strong argument for recalibration of epidemiology by redefining its purposes, i.e. to attain optimum health and to reduce disease at the population level using robust methods as tools to achieve these goals.

While engaging in solution-focused epidemiology, there is a need to revisit contemporary approaches by paying greater attention to dissemination of existing evidence without compromising the quality of epidemiological work, including objectivity and scientific rigour (90, 91).

1.9 Specific aims

The current study has the following specific aims:

- Study 1. Epidemiology of knee injuries in Alberta
    - Aim 1.1 To investigate the epidemiology of knee injuries presenting to EDs between 2002/03 and 2018/19 by year, gender and age groups, and sports
- Study 2. Epidemiology of ACLR in Alberta
    - Aim 2.1 To investigate epidemiological trends of primary ACLR and ACL revision between 2002/03 and 2018/19 by year, gender, and age groups
- Study 3. Cumulative incidence and correlates of ACLR among ACL injuries
    - Aim 3.1 To estimate incidence of ACLR among ACL injuries
    - Aim 3.2 To estimate interval between ACL injury diagnosis and ACLR
    - Aim 3.3 To investigate correlates of ACLRs among ACL injuries
- Study 4. Post-operative health care utilization among primary ACLR patients
    - Aim 4.1 To estimate incidence of and factors associated with ipsilateral ACL revision among primary ACLR cases
    - Aim 4.2 To estimate incidence of and factors associated with contralateral primary ACLR among primary ACLR cases
- Study 5. Systematic review on strategies/facilitators and barriers to implementation of ACL injury reduction/prevention program among female athletes
    - Aim 5.1: To conduct an up-to date synthesis of literature to find potential facilitators and barriers to ACL injury prevention program among female athletes.

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2. Epidemiological trends of knee injuries presenting to emergency departments in Alberta

2.1 Introduction

Participation in sports and recreational activities is a strong risk factor for knee joint injury (1). More than one-third (36.6%) of all sports injuries occur in the knee (2) , and a quarter of all knee injuries occur during sporting activities (3). A study among children below the age of 19 years in British Columbia, Canada revealed cycling, soccer, basketball, ice hockey, snowboarding, and skating were the most common cause of ED visit among sports-related (SR) injuries (4). A study from Alberta showed that more than 270,000 SR-related injuries occur each year in Alberta (5), of which more than one-third were related to the knee and ankle.

Knee injury during SR activities can result in external and internal lesions (6). External knee lesions include minor knee distortions, acute and chronic lesions of joint cartilage, and dislocation of the patella. Internal lesions, which account for nearly half of the injuries (44.5%), include injuries to the cruciate ligaments and meniscus (6). Of the total internal knee injuries, the ACL is involved in 45.4% of cases (6).

Growing evidence suggest that knee and ankle injuries at a young age are associated with increased risk of osteoarthritis in adulthood (7–9). Additionally, nearly one in 10 athletes drop out of sports due to sport-related injuries(10), resulting in reduced physical activity, leading to poor health outcomes. Therefore, sports injury prevention has gained a renewed attention in order to reduce injury incidence enabling communities to reap the full benefits of increased sports participation.

Knowledge on distribution and risk factors of knee injuries is important to policy makers, sports medicine physicians and orthopedic surgeons. However, few published data are available describing the type and frequency of knee injuries in Alberta, Canada. Some of the previously conducted studies focus only on sports-related injuries and some focus on specific sports and age groups (11 to 13). The current study aims to study knee injury epidemiology across the age continuum in both sexes. Although there is a worldwide effort to elucidate the mechanisms of knee injury during sports to prevent knee trauma, there still is a lack of adequate knowledge on epidemiology and pattern of knee injury. Identification of high-risk sports, high-risk populations and high-risk areas can inform prevention strategies. While policy makers can use such information for resource allocation and planning of targeted injury prevention programs, clinicians can use it for patient education.

2.2 Methods

Study design

A descriptive epidemiological study was conducted using administrative databases available from Alberta's Ministry of Health. All ED visits associated with knee injuries between 2002/03 and 2018/19 reported in National Ambulatory Care Reporting System (NACRS) were included. NACRS includes data on ED visits, same day procedures and visit to urgent care centers. Those with missing demographics were excluded (n=320).

Measures

Outcome measures for this study were ED visits due to knee injury, which were identified using International Classification of Disease,10th version, with Canadian Enhancements (ICD-10-CA) codes for the dislocation or sprain of joints and ligaments of the knee, and fracture of the patella. These injuries include open wound on the knee, crush injury to the knee, and traumatic amputation at the knee. The ICD-10 codes used to identify knee injury-related visits are shown below (Table 2.1).

Table 2.1 ICD-10 codes for knee injuries

ICD 10 code	Description
S800	Knee contusion
S820	Fracture of patella
S810	Open wound of knee
S870	Crushing injury of knee
S880	Traumatic amputation at knee level

S830-S839	Dislocation, sprain, and strain of joints and ligaments of knee
M230-M239	Internal derangement of knee

Covariates

Age was categorized into groups of 10 years, 10-19 years, 20-29 years, 30-39 years, 40-49 years, and 50 years and above. Sex was categorized into males and females. The seasons of the ED visits were divided into spring (March, April, May), summer (June, July, August), fall (September, October, November) and winter (December, January, February). We investigated type of ligaments injured, mechanism of injury, and place of injury. Similarly, we calculated the proportion of knee injuries associated with major sports.

Statistical analysis

The proportion of ED visits was calculated using the number of knee injury-related ED visits as the numerator. The population of specific age and sex groupings reported in the closest census was used as the denominator and was expressed as a number of ED visits per 100,000 people. Time trends for knee injury-related ED visits were plotted for both sexes (overall) and by age categories. Poisson regression was fitted to test the significant differences in the ED visit trends between males and females, and age groups using the GENMOD procedure in SAS. We reported mechanism of knee injury, place of knee injury, season of knee injury, sports associated as a percentage of total knee injuries for specific year. We conducted a sensitivity analysis by comparing aggregate number of knee injury visits to acute knee injury clinics (AKIC) into the NACRS data. Proportion of AKIC visit by sex was divided by historical trend in NACRS data, which showed that 60% of knee injury-related visits were among males. This study received ethical approval from the University of Alberta Human Research Committee (Pro00090820).

2.3 Trend and distribution of knee injuries

An estimated total of 221,161 knee injuries presented to the ED in Alberta hospitals. The average age of those presenting to ED due to knee injury was 34.8 years (SD: 18.1 years). More than half (55.2%) of the visitors were males. The ED visit rate peaked in 2007/08 (390 per 100,000 people) and again in 2013/14 (390 visits per 100,000 people).

Majority of the knee injury-related ED visits (90%) were associated with dislocation and sprain or strain of ligaments and joints of the knee and their chronic effects (internal derangement of knee) (Figure 2.1). About 10% of ED visits were associated with external injury to the knee and patella fracture.

Analysis of knee injury-related ED visits by sex showed that the trend of ED visits among males decreased at a faster pace compared to females in the province (Figure 2.2), showing a statistically significant difference in trend between males and females ($p<0.0001$). There was a sharp decline in the ED visit among males in 2009/10 and 2014/15 with an overall 30% decline from 444.0 to 313.0 per 100,000 people between 2002/03 and 2018/19. The ED visit rates among females has remained almost constant over the last 17 years with variations in between. There was a gradual increase from 2002/2003 until 2008/09, with a decline in 2009/10, followed by a gradual increase until 2013/14 and a decline thereafter. While there was a big difference on the proportion of ED visits by sex in 2002/03, the sex difference has reached approximately at equal level in 2018/19 (313 and 310 /100,000 people) among males and females respectively.

Most of the age categories in males showed a decline in knee injury-related ED visits (Figure 2.3), and there was a significantly different trend among age groups ($p<0.0001$). The highest decline in knee injury-related ED visits was observed in the 20-29-year-old age group (41%), followed by 10-19-year-old (25%) and 30-39-year-old (25%) groups. The highest rate of ED visit was among 10-19-year-olds (564.4/100,000 people) and 20-29-year-old age groups (443.1/100,000 people).

Among females also, a significantly different trend among age groups ($p<0.0001$) was observed. However, there was a slightly different trend on ED visits among females (Figure 2.4) compared to males. While other age groups showed a decline in the ED visits, females aged 10-19 years (2% increase) and 50 years and above (27.5% increase) showed an increase in knee injury-related ED visits. Females aged 10-19 years had markedly higher ED visit rates compared to other age categories throughout the study period (564.3/100,000 people), equivalent to males aged 10-19 years (564.4/100,000 people) in 2018/19.

It was found that majority of patients who underwent ACLR received ACL injury diagnosis in non-ED settings (Table 2.2). Overall, approximately 1 in 5 knee injury-related visits were associated with ACL injury.

Diagnosis of another knee ligament and meniscus tear among those visiting the ED was also explored (Table 2.3). The most common ligament tear behind ACL tear was medial collateral ligament (MCL), followed by meniscus tear. However, one should note that more than half of the knee injuries received no specific diagnosis in the ED and were diagnosed as "sprain and strain of other and unspecified part of the knee."

Just less than one-third of the knee injuries (approximately 30%) were related with SR activity (Table 2.4). A slightly higher proportion (approximately 35%) were related with fall. About 5-8% were associated with motor-vehicle accidents and a similar proportion were associated with getting struck.

Data on place of injury was available for about a quarter of knee injury-related ED visits. Of the total available records on place of injuries, approximately half of the injuries occurred at the sports and athletic area (Table 2.5). About 10-17% of the visits were due to injury at home and the proportion of injuries that occurred in a home setting has shown a slight increase in recent years. Over the study period, the proportion of ED visits due to knee injuries occurring at industrial and construction areas has declined. A significant proportion of knee injuries had an unspecified place of knee injury.

Investigation of associated sports showed that of the total sports-related knee injuries occurring during skiing/snowboarding, hockey, soccer, football/rugby, and basketball were associated with nearly 60% of ED visits (Table 2.6). While the number of ED visits associated with skiing/snowboarding and hockey remained almost constant over time, ED visits associated with soccer and basketball during the period increased.

A similar proportion of ED visits are reported in the four seasons in Alberta. A slightly higher proportion of ED visits occurred in spring, winter, and summer in comparison to fall (Table 2.7).

2.4 Discussion

The most important finding in the current analysis is the declining trend of knee injury-related ED visits (18% lower in 2018/19 compared to 2002/03). Our findings are consistent with the findings from a school-based survey among high school students from Alberta, which reported a 30% decline in the sports-related injury rate (all kinds of injury) in 2019 compared to 2004 (13). The authors attributed declining sports participation in their study group as one of the possible reasons. The declining sports participation in recent years in the younger population might have resulted in an overall decline in knee injury-related ED visits. Furthermore, some of the decline in knee injury-related ED visits may be due to implementation of injury prevention programs in the province (13). A sport injury prevention and research center located at the University of Calgary has initiated school- and community-based sports injury prevention programs and best practices, including neuromuscular training warm-ups in physical education classes and team sports are increasingly being adopted (13-15). Also, the decrease in knee injury-related ED visits coincides with establishment of acute knee injury clinics in the province's two major metropolitan cities, Calgary and Edmonton. It was reported that the annual number of knee injury-related visits range from 1,600 to 2,300 annually in Calgary AKIC from 2014 onwards (personal communication, April 2022), which are not currently being reported to national/provincial data repositories. Therefore, the observed decline in knee injury-related ED visits in recent years may also be due in part to the underreporting of patient visits data from AKIC to the NACRS database. Including the minimum number of knee injury visits in fiscal years 2014/15 onwards (n=1600 visits, of whom 60% are by males, based on historical data), we still found that there is a decrease in knee injury-related visits.

Other important finding from this study is the narrowing gender gap in ED presentation due to knee injuries. There was a larger decline among males compared to females. As a result, the wide gender gap in knee injury-related ED visits has narrowed down to an equivalent level. Despite declines in sports participation in males, and underreporting from AKIC visits, the proportion of ED visits among females has remained at the same level as it was before the establishment of AKIC. Previous studies have also reported that adolescent females are at a higher risk of knee sprains and strains compared to males (16-18). A recent ecological study covering data of skiers and snowboarders in western Canada also reported that the proportion of females injured increased from 39.8% in 2012-13 to 43.6% in 2017/18 (12). The narrowing of the gender gap in knee injury-related ED visits indicate increasing sports participation among females and a tendency to remain active among adult females in recent years. Incorporating the AKIC data into the NACRS data (minimum number of 1600 visits, of whom 60% are by males, based on historical data), we found that while proportion of knee injury-related visits by females slightly increased, whereas it showed a significant decline among males.

There was a variation by age category and sex on the change in proportion of knee injury-related visits. In males, all age categories experienced a decline except those aged 50 years and above, who showed a slight increase. In females, those aged 10-19 years and 50 years and above experienced an increase in knee injury-related ED visits, especially among females aged 50-60 years. Similar findings were reported from the United States data by Gage et al. based on data from the United States (1), who reported an increase in knee injury-related ED visits in those aged 50-64 years and 65 years and above. Increasing sports participation and other factors, such as skeletal immaturity and variability in development, may have contributed to high injury rates among those aged 10-19 years (19). An increasing tendency to remain active during adulthood may have resulted in an increase in knee injuries among adults. In light of these findings, knee injury prevention programs need to focus on those aged 10-19 years and those aged 50 years and above.

Sports and athletics account for almost half of the total knee injuries and this proportion has remained constant over the study period. Although overall sports participation has declined in recent years compared to the early years of this study (13, 19), the participation rate in higher-risk sports for knee injuries such as basketball and soccer has not declined (13,19) . Various extrinsic and intrinsic risk factors are associated with knee injuries during sporting activities (20). Extrinsic factors include playing surface, equipment, shoes, weather conditions, and the interaction of these factors. Intrinsic factors include age, sex, physical and anatomical factors of the athlete, experience, fatigue/sleep deprivation, and others (19, 20). Since many of these intrinsic and extrinsic factors are modifiable, strategies to prevent sports-related knee injuries need to identify and address these factors.

Among sports-related injuries, skiing/snowboarding, ice hockey, soccer, football/rugby, basketball and skating occupied more than 60% of the total sports-related knee injury ED visits. In the current analysis, skiing and ice hockey were responsible for more than a quarter of total knee injury-related ED visits. Skiing and hockey are popular winter sports in Alberta, and therefore have a high participation rate (5, 21) which may be one of the reasons for the higher number of ED visits associated with these sports. An ecological study from Western Canada among alpine skiers showed more than half of the injuries were to the lower limbs, with knee injuries accounting for 30% of total injuries (12). On the other hand, football, basketball, soccer are strongly associated with sprains/strains in comparison to skiing and ice hockey (22). We also found that ED visits associated with soccer and basketball are on the rise in Alberta, most likely reflecting increasing popularity of these sports. Therefore, prevention programs need to focus on sports that have a high participation rate as well as those having high knee injury rates.

Implications

As seen from the declining trend of knee injury-related ED visits, one of the objectives of AKIC is to divert acute knee injury patients away from the ED, which seems to be partially working. However, data sharing with national/provincial repositories need to be a priority to get the entire picture. Data sharing and linkage will enable us to understand whether referral to AKIC has reduced time to diagnosis, and time to surgery, among other variables. Sports with the most injuries (skiing/snowboarding, hockey, soccer, football/rugby, basketball, and skating) need to be prioritized for surveillance and future research about knee injury prevention strategies. Adolescents and adults of both sexes need to be targeted for injury prevention programs with a special focus on the female population, due to its higher risk of knee injuries compared to males.

Strengths and Limitations

Knee injury epidemiology was investigated using ED visit data in Alberta, thus reducing the chances of recall bias. However, our study only captures the profile of knee injuries that presented at the ED. Additionally, we do not have information on the number of people involved in different activities/sports, limiting our ability to make inferences regarding risk level of the activity/sport. The higher proportion of injuries in a specific sport may either be due to the high risk of injury, high participation rate, or both.

2.5 Conclusion

Over the last 17 years, the incidence of knee injury-related ED visits has declined, more so for males than females. Nearly one-third of knee injury-related ED visits were associated with sports participation. Knee injury prevention programs and safety awareness programs need to focus on young (10-19 years old) and adult (50 years old and above) populations, as well as those involved in skiing/snowboarding, hockey, football/rugby, basketball, soccer, and skating.

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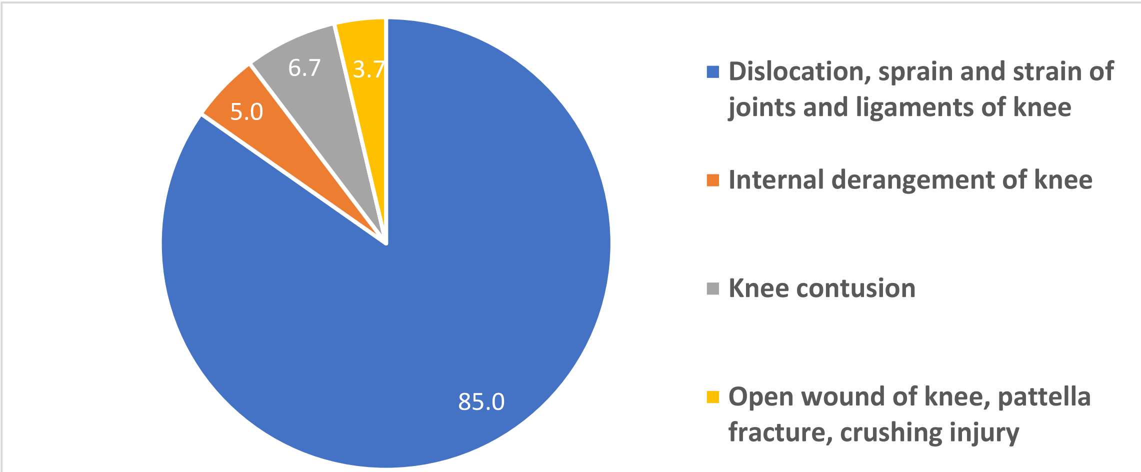

Figure 2.1 Type of knee injury by affected structure

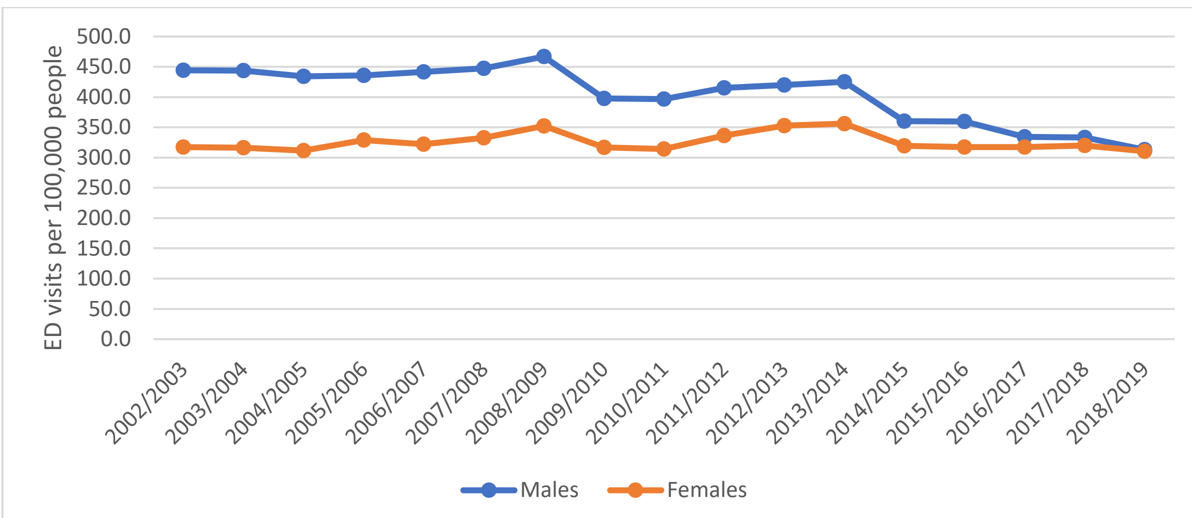

Figure 2.2 Incidence trends of knee injury-related ED visits per 100,000 people by gender

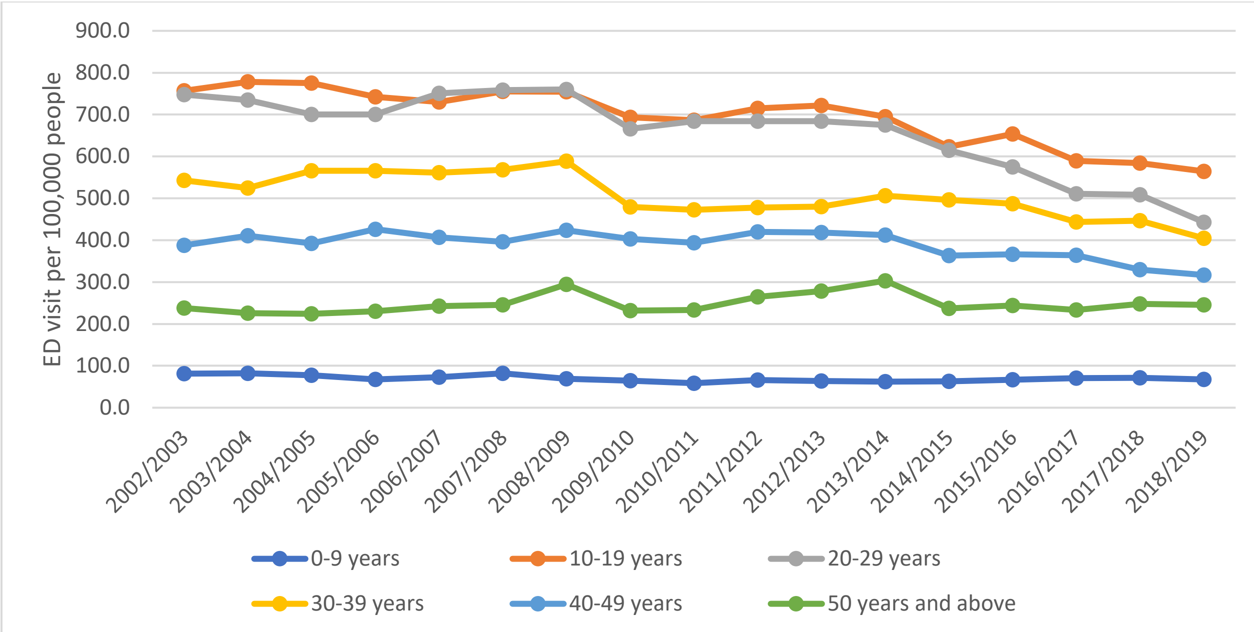

Figure 2.3 ED visits per 100,000 people among males

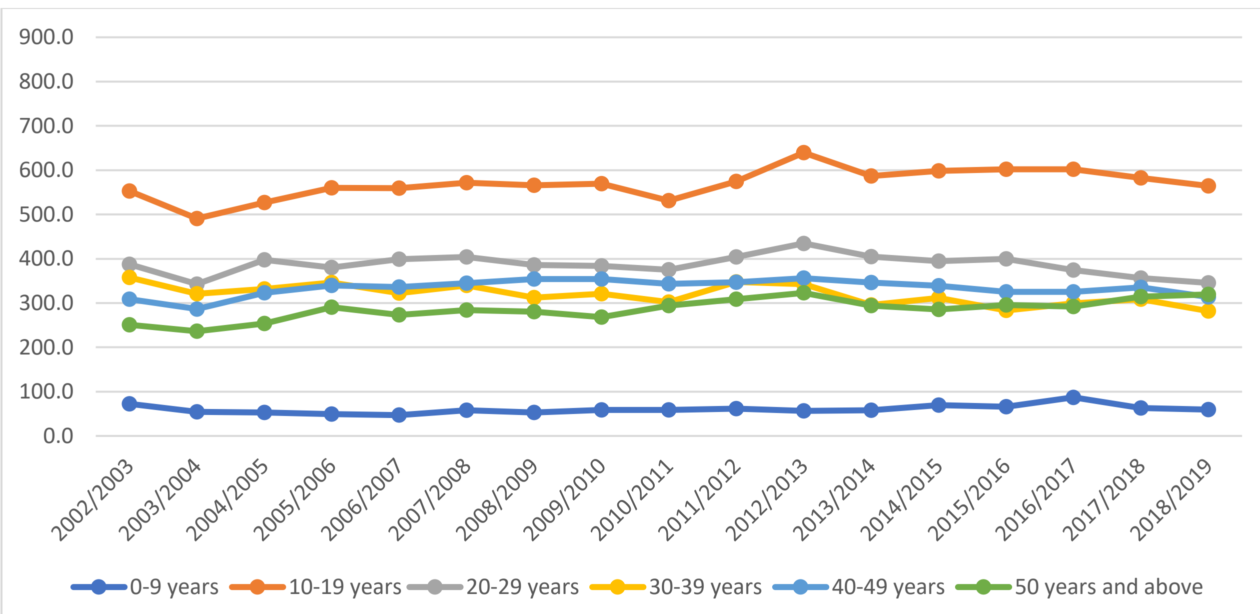

Figure 2.4 Incidence trends of knee injury-related ED visits by age category among females

Table 2.2 Proportion of ACL injuries diagnosed in ED and non-ED clinical settings by gender

	Diagnosed in the ED			Diagnosed in ambulatory setting (ED and non-ED)			
Year	Females (%)	Males (%)	Total (%)	Females (%)	Males (%)	Total (%)	Total knee injuries
2002/2003	1.6	2.4	4.0	8.9	12.3	21.2	11327
2003/2004	1.5	2.5	4.0	8.5	12.4	20.8	11303
2004/2005	1.4	2.8	4.2	8.1	11.8	19.9	12271
2005/2006	1.7	2.9	4.7	7.8	10.6	18.4	12576
2006/2007	2.0	3.1	5.1	7.9	11.1	19.0	12565
2007/2008	1.6	3.1	4.7	8.5	12.5	21.1	12840
2008/2009	1.9	3.9	5.8	9.0	13.5	22.5	13473
2009/2010	2.3	3.1	5.4	9.9	12.9	22.8	13017
2010/2011	2.2	3.9	6.1	8.4	12.3	20.7	12964
2011/2012	2.4	3.4	5.9	8.2	11.9	20.2	13698
2012/2013	2.4	3.4	5.8	8.4	12.0	20.4	14089
2013/2014	2.0	2.9	5.0	8.3	11.8	20.1	14243
2014/2015	2.1	2.9	5.0	8.9	11.7	20.6	13819
2015/2016	2.2	2.9	5.1	9.4	12.7	22.0	13766
2016/2017	2.1	2.6	4.7	9.6	11.6	21.2	13248
2017/2018	2.2	3.0	5.2	10.0	11.7	21.7	13283

2018/2019	1.8	2.4	4.2	8.6	10.8	19.5	12679

Table 2.3 Proportion of knee injuries by ligament type among those diagnosed in the ED

Year	Unspecified part of knee (%)	Medial collateral ligament (%)	Meniscus tear (%)	Lateral collateral ligament (%)	Posterior cruciate ligament (%)	Other cruciate ligaments (%)	Multiple parts of knee (%)	Total knee injuries
2002/2003	47.6	15.5	7.8	0.34	0.17	0.88	0.87	11327
2003/2004	47.5	15.5	7.1	0.40	0.28	0.91	0.72	11303
2004/2005	53.0	16.7	6.7	0.55	0.26	0.89	0.83	12271
2005/2006	56.0	17.1	6.9	0.34	0.29	0.66	0.96	12576
2006/2007	54.8	17.6	6.3	0.24	0.29	0.73	1.05	12565
2007/2008	58.0	15.7	6.1	0.25	0.26	0.58	1.07	12840
2008/2009	60.4	16.3	5.9	0.24	0.37	0.63	1.20	13473
2009/2010	58.6	15.8	6.0	0.22	0.34	0.55	1.16	13017
2010/2011	59.2	15.7	5.4	0.27	0.31	0.49	1.13	12964
2011/2012	63.8	16.4	5.2	0.25	0.28	0.59	1.32	13698
2012/2013	65.3	16.5	6.1	0.26	0.31	0.57	1.20	14089
2013/2014	66.8	16.7	5.6	0.22	0.19	0.41	1.08	14243
2014/2015	63.6	16.2	5.5	0.22	0.25	0.39	1.27	13819
2015/2016	64.3	16.1	5.1	0.15	0.28	0.50	0.97	13766
2016/2017	63.1	14.7	4.7	0.12	0.26	0.49	1.05	13248
2017/2018	63.2	15.3	3.9	0.25	0.26	0.47	0.87	13283

2018/2019	60.2	14.3	4.0	0.16	0.29	0.42	0.73	12679

Table 2.4 Proportion of knee injury by mechanism of injury

Year	Sports and recreation-related*	Fall-related	Motor vehicle-related	Struck	Total knee injuries
2002/2003	28.7	27.7	7.0	5.8	11,327
2003/2004	28.4	28.7	8.0	5.8	11,303
2004/2005	27.2	29.8	6.8	5.7	12,271
2005/2006	26.7	28.1	7.5	6.1	12,576
2006/2007	24.7	29.1	7.9	5.5	12,565
2007/2008	24.0	28.7	7.3	5.5	12,840
2008/2009	22.7	29.6	7.6	5.3	13,473
2009/2010	24.0	29.8	6.7	5.3	13,017
2010/2011	28.9	31.0	6.6	5.9	12,964
2011/2012	28.0	31.1	6.1	5.9	13,698
2012/2013	30.4	32.1	6.3	5.8	14,089
2013/2014	30.8	32.5	5.9	5.5	14,243
2014/2015	31.8	31.7	6.4	5.7	13,819
2015/2016	33.7	31.0	5.9	6.0	13,766
2016/2017	30.8	33.5	5.6	6.0	13,248
2017/2018	31.2	34.6	5.7	5.7	13,283

2018/2019	30.8	35.7	5.4	5.8	12,679

***Sports and recreation sub-codes not available before 2010**

Table 2.5 Proportion of knee injuries by place of injury

Year	Sports and athletics area	Home	Industrial and construction area	Trade and service area	Residential institution	School, other institution, and public administrative areas	Street and Highway	Farm	Unspecified place	Total
2002/2003	49.3	12.8	11.1	7.3	0.9	4.8	2.7	1.4	9.8	4470
2003/2004	48.5	11.0	12.0	6.5	1.0	5.3	3.5	1.6	10.7	4364
2004/2005	48.1	11.3	9.9	9.0	0.8	5.2	3.7	1.6	10.4	4707
2005/2006	48.0	10.1	10.7	10.0	1.1	5.5	3.5	1.4	9.8	4559
2006/2007	47.5	11.3	9.6	9.7	1.2	4.9	3.1	1.1	11.7	4701
2007/2008	47.8	11.2	9.4	9.2	0.9	6.1	2.6	0.8	11.9	4466
2008/2009	45.9	12.3	8.2	8.0	1.3	6.2	3.3	1.0	13.9	4582
2009/2010	48.6	12.2	6.9	8.4	0.9	6.1	3.1	1.0	12.9	4503
2010/2011	48.6	12.4	6.2	8.0	1.4	5.3	3.4	0.9	13.8	4803
2011/2012	47.7	13.4	5.8	8.9	1.3	5.6	2.9	1.2	13.3	5004

2012/2013	50.0	12.4	5.2	8.6	1.0	5.3	3.9	1.0	12.6	5187
2013/2014	48.5	13.5	5.6	9.0	1.1	6.3	3.3	0.9	11.8	4965
2014/2015	48.4	12.9	5.8	9.5	1.3	6.3	2.8	0.8	12.2	4692
2015/2016	54.6	14.1	4.0	9.8	1.2	0.0	2.5	0.8	13.1	4396
2016/2017	50.4	16.9	3.4	10.4	1.6	0.0	3.2	1.1	13.0	3538
2017/2018	50.6	15.4	4.9	10.0	1.3	0.0	3.0	1.1	13.7	3515
2018/2019	50.4	16.6	4.1	9.6	1.8	0.0	3.3	1.1	13.0	3457

Table 2.6 Proportion of knee injuries by sport

Year	Skiing/ snowboarding	Hockey	Soccer	Football/Rugby	Basketball	Skating	Cycling	Equipment-related	Baseball	Animal-related sports	Swimming	Total*
2010/2011	16.2	10.2	8.0	5.1	3.6	5.0	3.1	2.7	2.7	1.9	0.3	3747
2011/2012	16.0	10.5	8.1	4.4	3.1	6.0	3.5	3.0	2.2	1.8	0.4	3834
2012/2013	20.0	10.8	9.9	4.9	4.5	5.2	2.8	2.6	2.3	1.8	0.5	4288
2013/2014	16.5	11.0	10.6	5.9	6.2	5.7	3.2	2.5	3.6	1.9	0.5	4388
2014/2015	15.6	10.7	12.6	5.9	5.5	5.7	3.4	3.4	3.0	2.0	0.5	4400
2015/2016	15.4	10.6	11.4	6.6	5.5	5.7	2.9	3.8	3.9	1.7	0.6	4638
2016/2017	15.1	9.9	11.7	7.3	6.1	5.6	3.0	3.9	4.3	2.0	0.6	4079
2017/2018	16.4	10.5	10.5	6.5	6.2	5.0	3.4	3.6	3.3	1.5	0.6	4146
2018/2019	16.3	10.2	11.2	6.4	6.8	5.3	2.8	3.8	3.5	1.6	0.5	3911

**Total indicates total sport- and recreational-related injuries recorded in the database*

Table 2.7 Proportion of knee injuries by season of injury from 2002/03 to 2018/19

Year	Spring	Summer	Fall	Winter	Total knee injuries
2002/2003	26.8	24.8	22.8	25.7	11,327
2003/2004	26.0	25.8	22.6	25.7	11,303
2004/2005	25.1	25.5	23.4	26.1	12,271
2005/2006	25.8	25.5	24.7	24.0	12,576
2006/2007	24.9	25.4	23.8	25.8	12,565
2007/2008	25.3	25.2	24.4	25.1	12,840
2008/2009	25.4	25.5	24.3	24.8	13,473
2009/2010	26.7	26.0	22.7	24.6	13,017
2010/2011	25.4	25.5	22.8	26.2	12,964
2011/2012	26.4	25.0	22.9	25.7	13,698
2012/2013	26.6	23.7	23.7	26.1	14,089
2013/2014	25.9	24.9	23.9	25.2	14,243
2014/2015	25.8	26.4	23.3	24.6	13,819
2015/2016	25.6	25.1	24.2	25.1	13,766
2016/2017	26.8	25.9	23.0	24.3	13,248
2017/2018	27.0	25.2	23.7	24.2	13,283
2018/2019	26.1	24.2	24.4	25.3	12,679

3. Epidemiological trends of anterior cruciate ligament reconstruction in Alberta, Canada [1,2]

3.1 Introduction

ACL rupture is a commonly reported injury among younger athletes (1, 2). Over a period of 25 years, one in 29 female athletes and one in 50 male athletes are reported to experience an ACL injury (3). In a general population, the incidence rate of ACL injury is reported to be between 8.1 to 36.9 per 100,000 person years (4).

Anterior cruciate ligament reconstruction (ACLR) is a cost-effective treatment for ACL injury (5, 6). Surgical reconstruction is generally recommended for patients who want to return to usual activity, especially for those in organized sports or those in physically demanding occupations (7, 8). Furthermore, patients with signs of recurring instability are often offered ACLR to restore stability and protect meniscus and cartilage tissue (7). Timely diagnosis and optimal management of ACL injury can prevent intra-articular injuries by reducing chances of instability episodes (9).

Increasing number of studies show that ACLR incidence is increasing in other jurisdictions (10,11). However, limited data are available in Alberta examining the trend of primary and revision ACLR. Limited data from elsewhere show a seasonal pattern of ACL injury (12); however, data on seasonal patterns of ACLR in Alberta are currently unavailable. Therefore, our objective in this paper was to estimate trends of ACLR from 2002/03 to 2018/19 by age, sex, outpatient/inpatient setting, and season. Knowledge of the disease burden is important for proper allocation of scarce resources. More importantly, identification of most at-risk groups can help to design and implement targeted strategies for prevention programs.

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[1] This chapter has been published as : Paudel YR, Sommerfeldt M, Voaklander D. Increasing incidence of anterior cruciate ligament reconstruction: a 17-year population-based study. Knee Surgery, Sports Traumatology, Arthroscopy. 2022 Aug 10:1-8.

[2] An abstract based on this paper was presented in Annual meeting of Canadian Orthopedic Association held in June 2022 in Quebec Canada

3.2 Materials and methods

Study design

A descriptive epidemiological study was carried out using administrative databases available from Alberta's Ministry of Health. We identified primary ACLRs and revisions conducted between 2002/03 to 2018/19 using a physician claims database. We linked the physician claims database with the NACRS and the inpatient discharge abstract database (DAD) to identify reconstruction settings. This study received ethical approval from the University of Alberta Human Research Committee (Pro00090820).

Exclusion criteria

Primary and revision ACLR conducted between 2002/03 and 2018/19 in Alberta were identified. We excluded early (less than 14 days) repair of ACL. Non-Albertans and those with missing demographic data were excluded. Patients below the age of 10 years were excluded due to sparse ACLR data in this age group. Duplicate records of ACLR conducted on a person on the same date were excluded. Records of more than two primary ACLRs on a person were excluded from analysis. The number of patients excluded for different reasons is shown in Fig. 3.1.

Measures

The outcome measures for this study were primary ACLR and revision ACLR. We assessed the distribution of ACLR by age, sex, setting of surgery, and season of surgery. Age groups were categorized into 10-19 years, 20-29 years, 30-39 years, 40-49 years, 50-59 years, and 60 years and above. Sex was categorized into males and females. Surgery setting was classified into outpatients and inpatients. Season of ACLR was divided into spring, summer, fall, and winter.

Statistical analysis

Age-standardized ACLR rates were calculated for the entire population by sex, using the 2011 Canadian population as a standard population. The average annual growth rate of primary

ACLR was compared between males and females by age group. Poisson regression was fitted to test the significant differences in the incidence trends between males and females, and age groups using the GENMOD procedure in SAS. The proportion of ACLRs was calculated using the number of primary/ revisions ACLRs in each fiscal year as the numerator. The population of specific age and sex groupings reported in the closest census was used as the denominator (Appendix table 3A.1).

3.3 Results

Primary ACLRs

From 2002/03 until 2018/19 there were a total of 28,401 primary ACLRs performed in Alberta in patients aged 10 years and older (Appendix Table 3A.2). Of them 27,124 (95.5%) were initial primary ACLR and 1,274 (4.5%) were contralateral primary ACLRs. Of the total primary ACLRs, 56% were performed on males and 44% on females.

The annual number of primary ACLRs increased from 1,137 in 2002/03 to 1,894 in 2018/19 (Appendix Table 3.2). The annual age standardized incidence increased from 40.6 per 100,000 people in 2002/03 population to 51.2 per 100,000 people in 2018/19, an increase of 26% over the study period with an annual growth rate of 1.3% (Fig. 3.2).

Among males, ACLR incidence increased from 44.7 per 100,000 people to 54.9 per 100,000 people (Fig 3.3). Among females, it increased from 32.9 per 100,000 to 47.5 per 100,000 people. However, there was no significantly different trend between males and females (p=0.44).

There was a significantly different trend among age-groups in both males (p=0.002) and females (p=0.012) . The highest incidence was reported among males in the 20-29-year age group (Fig. 3.3). The peak incidence among males was reported in 2015/16 among the 20-29-year age group (147.2/100,000 people). Females had the highest incidence among 10-19-year age group (Fig. 3.4). The peak incidence among females was reported in 2017/18

(108.8/100,000 people) among in the 10-19-year age group. ACLR rates were highest among 10-19-year-old females compared to male counterparts throughout the study period.

Annual growth rates of primary ACLR were higher among adolescents (10-19 years old), and older age categories (40-49 years old and 50 years old and above), compared to middle age groups among both males and females (Fig. 3.5). The incidence rate of primary ACLR increased from 3.9 to 12/100,000 people among females aged 50 years old and above, with an annual growth rate of 9.1% per year. Similarly, the rate increased from 50.1 to 102.0/100000 population among females aged 10-19 years of age. Among males, the highest annual growth rate was reported among those 10-19 years old (4.3%), followed by those 50 years old and above (3.7%) and 40-49 years old (2.6%).

There was a strong trend toward outpatient (same-day) surgery over the course of the study (Fig. 3.6). The proportion of primary ACLR conducted in an outpatient setting/same-day surgery increased from 72% in 2002/03 to 97% in 2018/19 (Fig. 3.6). The highest increase in proportion of surgeries conducted in an outpatient setting compared to previous years was observed in 2007/08 (7%) and 2014/15 (12%).

Generally, a lower proportion of ACLRs were conducted in summer compared to other seasons (Fig. 3.7). Similar proportions of primary ACLRs were performed in spring, fall, and winter seasons. In 2018/19, of the 1894 primary ACLRs, 27% were conducted in spring, 26% in fall, and 26% in winter, whereas 21% were conducted in summer (Fig. 3.7).

Revision ACLRs

A total of 2,085 ACLR revisions were reported in this period. Of them, 1,094 (52.5%) were among males and 991 (47.5%) were among females. The annual number of revised ACLRs increased from 53 in 2002/03 to 195 in 2018/19. The annual incidence of ACLR revision increased from 2.1 per 100,000 people to 5.5 per 100,000 people, an increase of 168% over the study period. Age standardized annual rates of revision ACLRs increased from 1.9 per 100,000 to 5.4 per 100,000 among males (Fig. 3.8). For females, age standardized annual rates of ACLR increased from 1.8 per 100,000 to 5.0 per 100,000 people (Fig. 3.8).

Of the 2,085 revisions, 1940 (93.1%) were first revisions and 145 (6.9%) were either repeat revisions or revisions on a contralateral knee. First revisions were reported in (n=1,940, 6.8%) of total primary ACLR (n=28,401) conducted between 2002/03 and 2018/19. However, some of the revision cases observed during the study period may be among individuals who underwent primary ACLR before 2002/03.

3.4 Discussion

The most important finding from our study was that the annual incidence of primary ACLR was on an increasing trend in Alberta with an average annual growth rate of 1.3%. The annual age standardized incidence increased by 26% over the study period. This finding is consistent with findings from studies conducted in other settings (10, 11). The increase in ACLR may be partly due to growing incidence of ACL injury due to increased sports participation or intention to remain active among a wider age range of population. It may also be driven by improved surgical technique and increased comfort with the ACLR procedure.

The next important finding from this study was that adolescents (10-19 years old) and adults (50 years old and above) showed a higher annual increase compared to other age categories. Specially, females aged 10-19 years and 50-59 years reported the highest annual increase compared to other age categories. Research from the United States and Australia also showed an increasing ACLR trend in adolescents (11, 13, 14). Tepolt et al., using data from 45 hospitals in the US, reported a 2.8 times increase in ACLR in the pediatric population, especially in 11-18-year-olds, compared to total orthopedic operations in the same population over a 10-year period between 2004 and 2014 (14). Studies from the United States and Sweden have shown that female adolescents have a higher ACL injury risk compared to males involved in soccer, basketball, and softball (15, 16). The higher annual increase among adolescent females may be due to increased popularity of multidirectional sports, such as soccer and basketball.

Additionally, current preferred practice among surgeons is to recommend surgical reconstruction among the active pediatric population with complete ACL tears, since technical advances have improved outcomes in skeletally immature patients (17, 18). Further, new evidence showing superior outcomes of ACLR over non-operative management with minimal growth disturbance (19, 20), and adolescents reaching skeletal maturity earlier than previously thought may also play a role (21). Increases among the adult population (50 years old and above) may be due to efforts to stay active during adulthood, or increased comfort and satisfaction with ACLR (22) due to advances in surgical technique and instruments.

The timing and intricacies of surgical reconstruction among skeletally immature patients is still a contentious issue. It is suggested that early surgical intervention is an appropriate strategy compared to delayed reconstruction or non-operative management (18, 23, 24). However, high risk of re-rupture and some concern for growth disturbance resulting in leg length discrepancy remains prominent (25-27), despite technological advances.

In addition to impacts on immediate physical and psycho-social health, ACL injury among adolescents increases risk of early onset osteoarthritis (28). The odds of total knee replacement in adults with ACL injury is seven times higher in comparison to those without ACL injury (29), and the risk increases with early-onset osteoarthritis. A systematic review and metanalysis revealed that only 65% of athletes with an ACL injury returned to their pre-injury level of sport (7). Remaining inactive after an ACL injury increases the chances of adiposity (30). The chances of returning to pre-injury activity level may be much lower in the general population. The chances of returning to pre-injury level of activity is nearly half among females compared to males (31). Therefore, the growing incidence of ACL injury in the young population is worrying because the future burden of degenerative disease will be heavily borne by today's younger cohorts. Additionally, it adds strain to the health system now and in the future (32).

Current analysis reveals that the incidence of ACLR peaked in males and females in different age groups. Among males, ACLR incidence was the highest among 20-29-year-olds throughout the study period. Among females, peak incidence rate was observed between 10-19-year-olds for most of the study period. While the population of adolescent females was less than adolescent males in the province, the absolute number of ACLRs performed in adolescent females (10-19 years old) was greater than in adolescent males for most years. This finding might reflect higher risk of ACL injury among adolescent females compared to males. A recent metanalysis found adolescent girls were at about 1.5 times greater risk of ACL injury compared to males, with females showing four times greater risk for basketball compared to males (33). It could also be due to female adolescents attaining skeletal maturity two years earlier than male adolescents (34).

However, overall ACLR incidence was higher in males (57.9/100,000 people) compared to females (49.4 per 100,000 people) in 2018/19. Overall, incidence of ACLR was reported higher in males compared to females in other settings as well (10). Males reported the highest incidence between 20-29 years of age (113.9 per 100,000 people). The higher proportion among males may be due to a higher proportion of males remaining active compared to females and may also be due to participation bias, with males more likely to be participating in higher-risk sports than females (12).

Consistent with findings from an Australian study (11), we found a greater increase in annual incidence of revision ACLR compared to primary ACLR. One of the reasons for higher revision ACLR may be due to the growing number of ACLRs being performed in younger age groups (10-19 years old), who are more likely to return to pre-injury activity levels earlier compared to older age groups (35). Additionally, graft selection, tunnel placement (36), or other factors may also have played a role.

Growing evidence shows that implementing neuromuscular training programs can effectively reduce ACL injury. A meta-analysis of metanalyses showed that injury prevention programs can reduce ACL injury by 50% in all athletes and non-contact ACL injuries by 67% among female athletes (37). Translating this evidence from RCTs and metanalyses to large-scale implementation is the current challenge for stakeholders (38, 39). Identifying context-specific barriers and facilitators so as to design best strategies to facilitate widespread adoption and sustainable implementation are now needed (40,41). The benefits of the growing number of females participating in sports will truly be reaped in terms of long-term health outcomes if such injury prevention programs can be implemented on a mass scale on a routine basis.

Consistent with recent trends in other settings (42), there was a significant drop in the proportion of ACLR conducted in inpatient settings with a simultaneous increase in proportion of ACLRs conducted in outpatient setting. Advances in surgical and anesthesia techniques and equipment have made ACLR a simple surgical procedure that can be successfully performed in an outpatient setting.

Strength and limitations

To our knowledge, this is the first study from Alberta to examine the epidemiology of primary and revision ACLR using population-based administrative data. However, the study has some limitations. Since we do not have data on the number of patients undergoing non-surgical management, the incidence of ACL injury is higher than incidence of ACLR. However, the growing ACLR incidence might reflect growing ACL injury incidence. Physician billing codes may change over time or may have been miscoded or missed to entry. However, our incidence proportions are comparable to reports from other jurisdictions in Canada (43) and elsewhere (10, 11). Further, we verified our primary ACLR records from physician billing codes with NACRS and inpatient databases associated with ligament reconstruction, and we found a match of 96%. Therefore, we assume physician billing codes are a reliable source for ACLR data.

3.5 Conclusions

The incidence of primary ACLR is increasing in Alberta, especially in adolescents, which most likely reflects a growing incidence of ACL injury in the province. Since ACL injury at a young age increases the risk of early-onset osteoarthritis and consequently increases the risk of total knee replacement at a young age, implementing ACL injury prevention programs with a special focus on adolescent population is critical.

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Tables and Figures

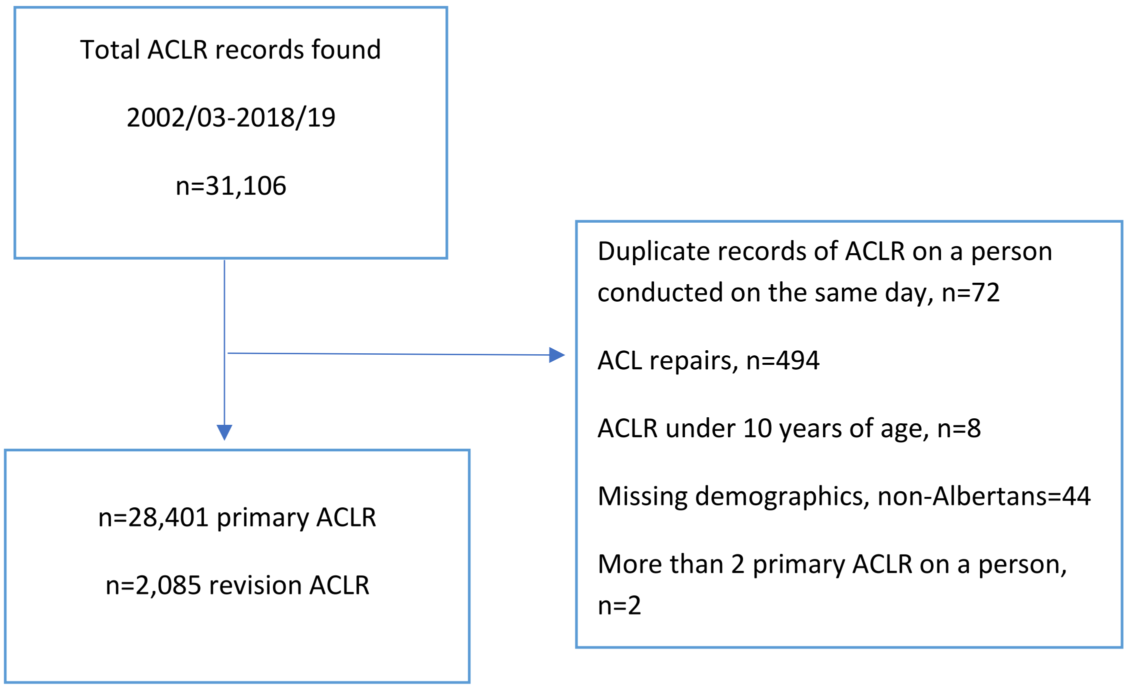

Figure 3.1 Sample selection flow chart

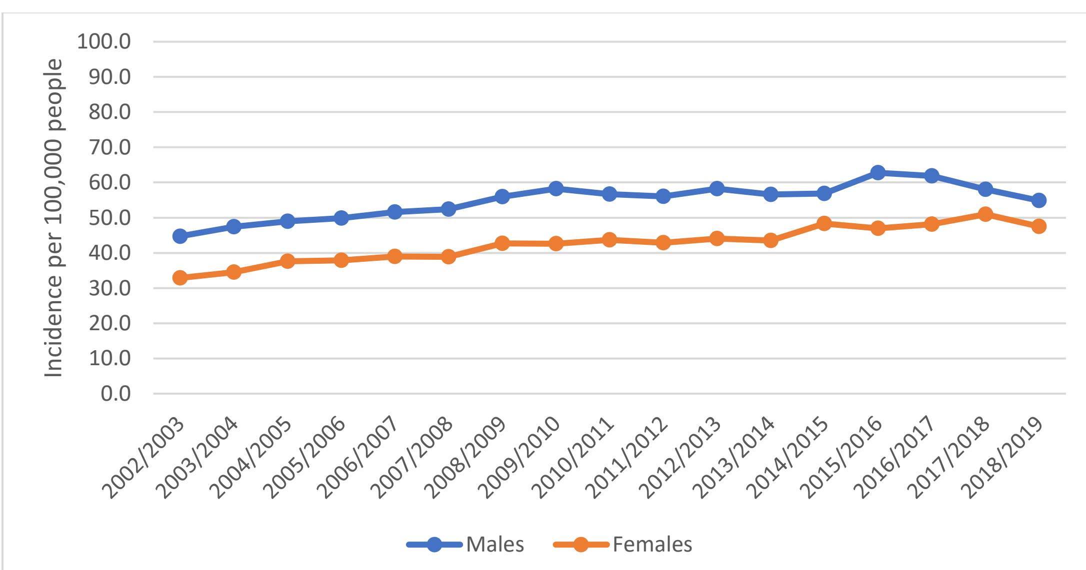

Figure 3.2 Annual age standardized incidence of primary ACLR per 100,000 people among males and females aged 10 years and above (Standard population: 2011 Canada population)

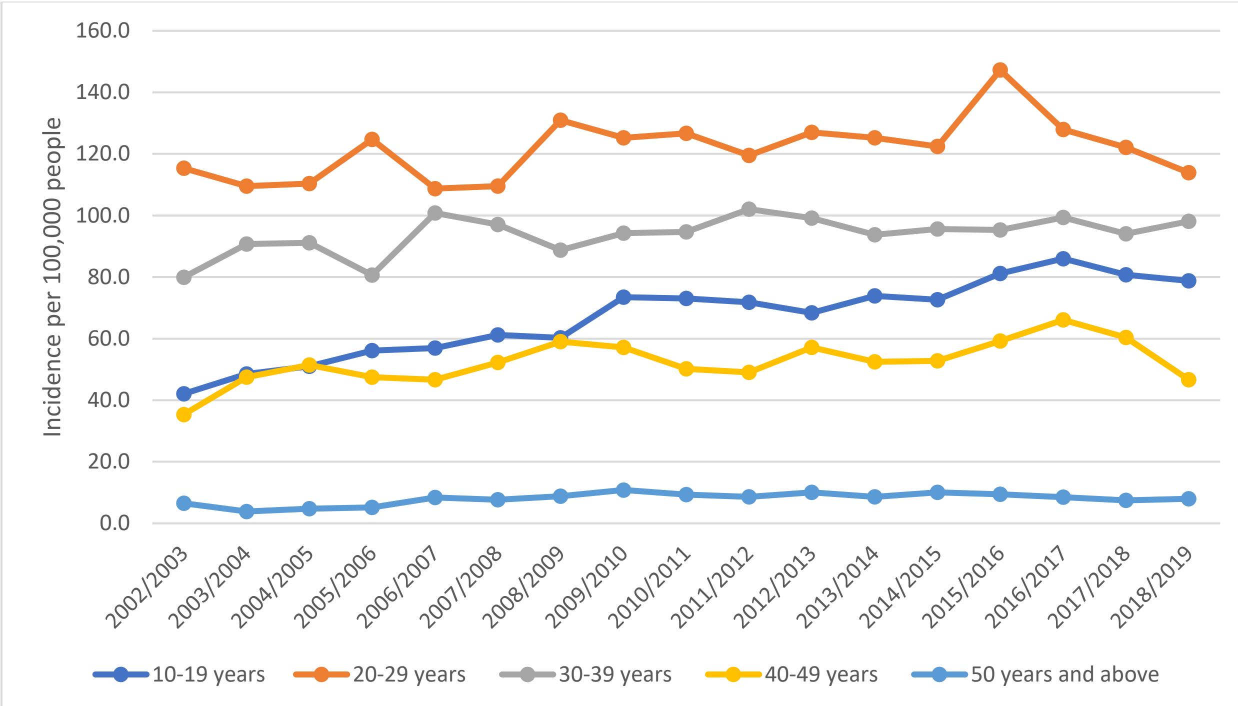

Figure 3.3 Incidence trend of primary ACLR per 100,000 people by age groups in males

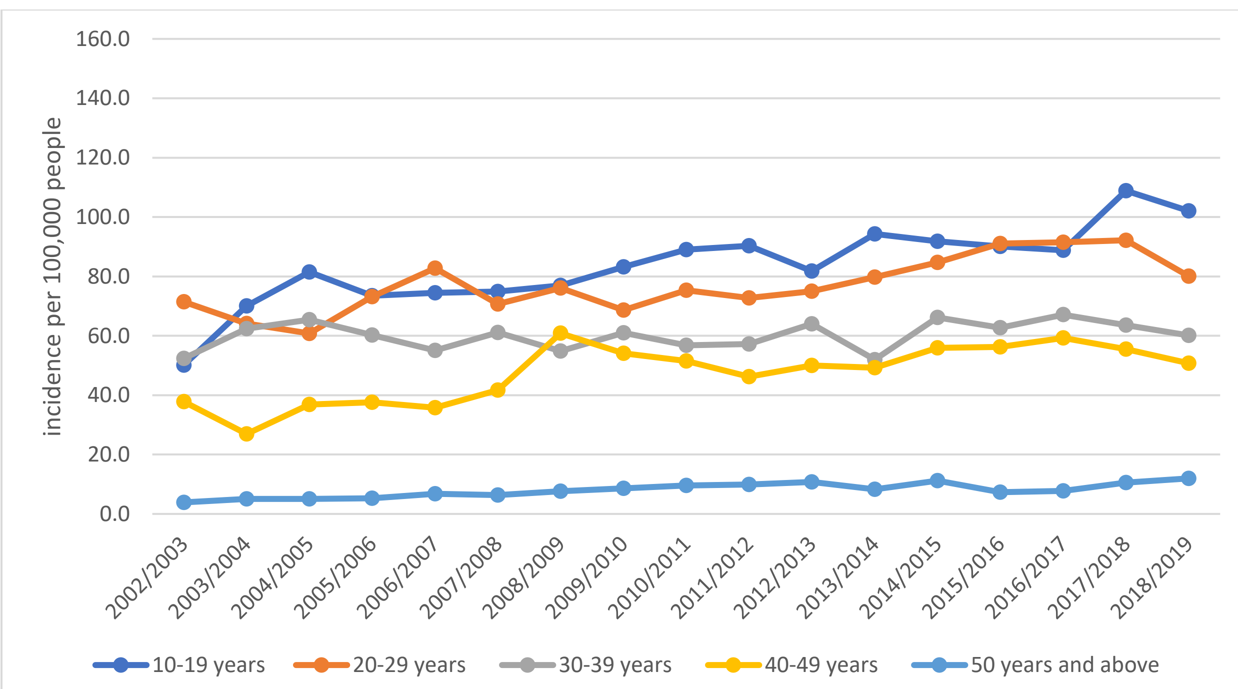

Figure 3.4 Incidence trend of primary ACLR per 100,000 people by age group in females

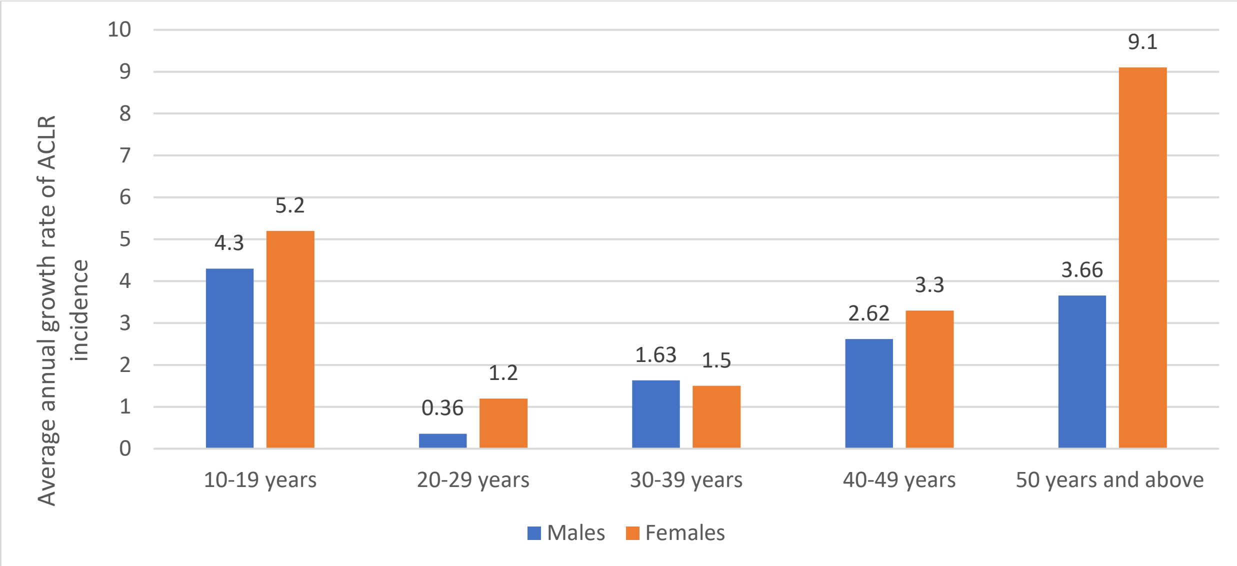

Figure 3.5 Annual growth rate in Primary ACLR by age group and sex

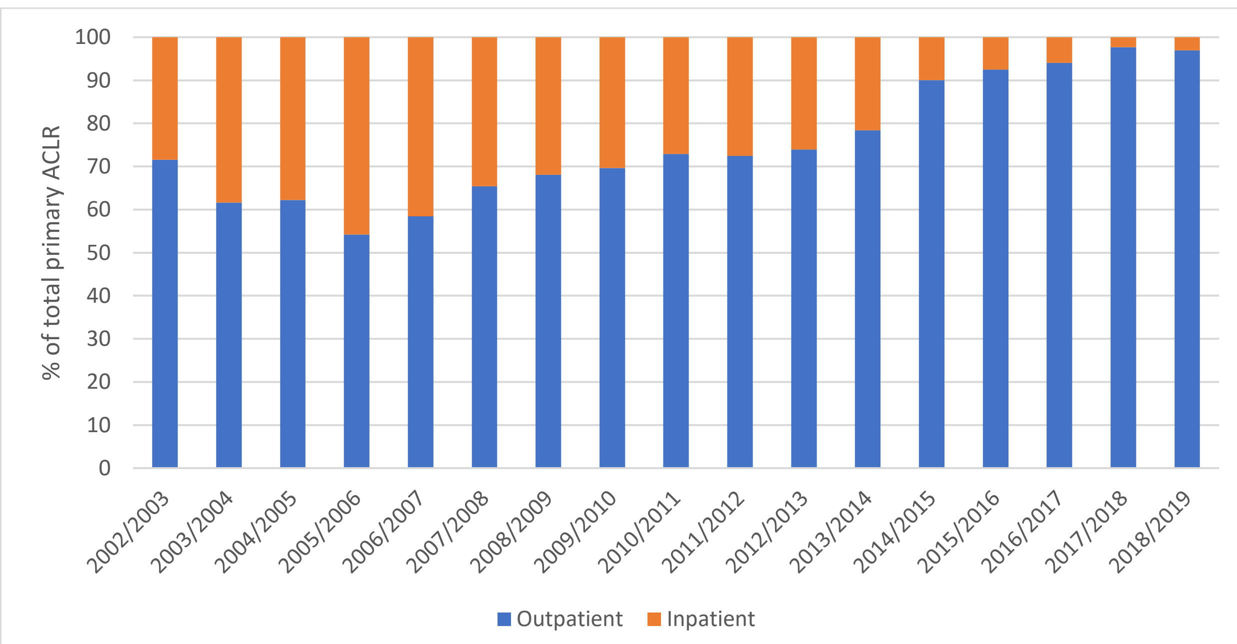

Figure 3.6 Trend of surgery settings for primary ACLR

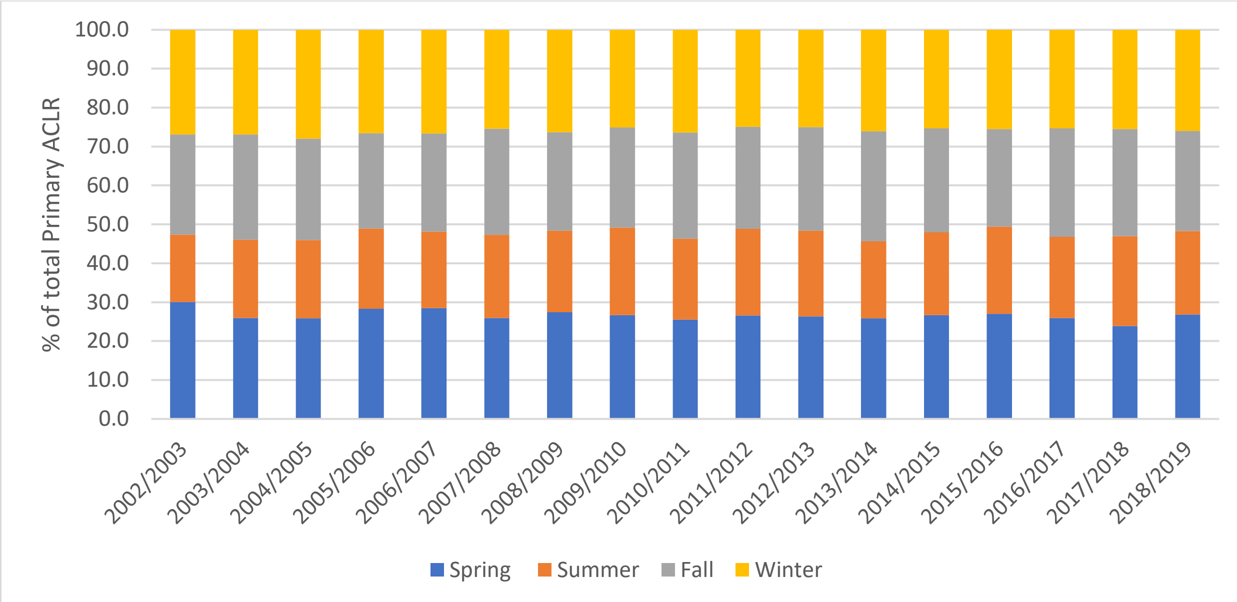

Figure 3.7 Trend of seasons for primary ACLR

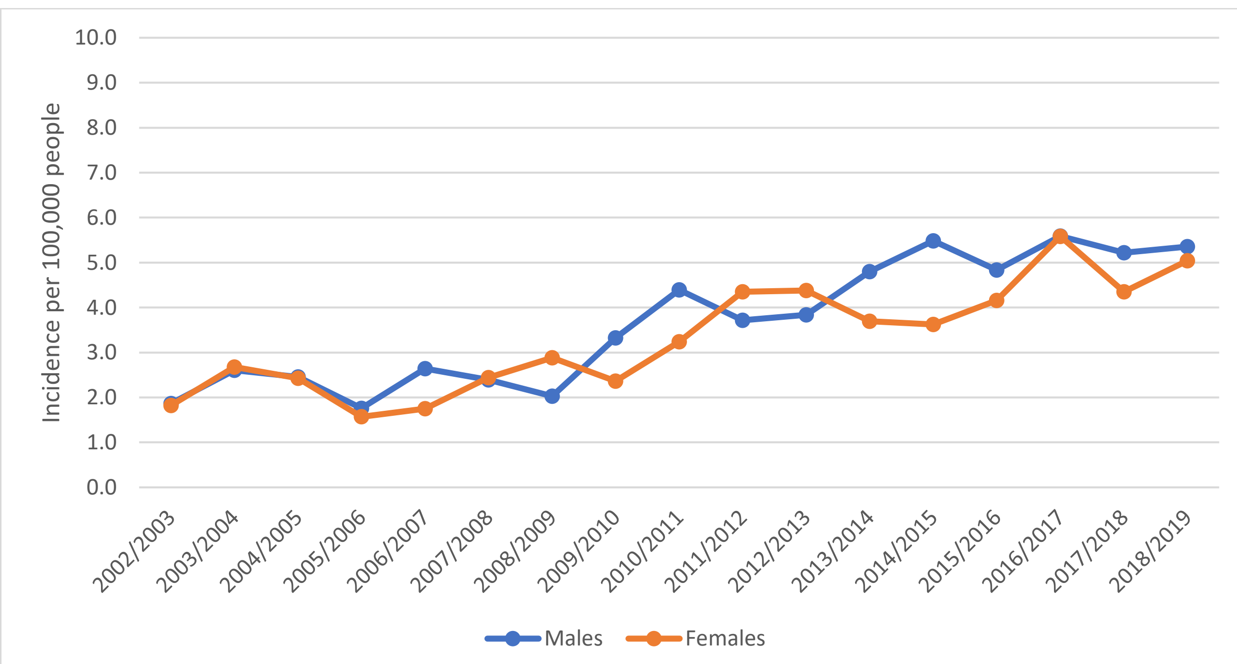

Figure 3.8 Annual age standardized incidence of revision ACLR per 100,000 people among males and females aged 10 years and above (Standard population: 2011 Canada population)

Table 3A.1: Alberta population for censuses conducted in 2001, 2006, 2011, and 2016 by age category and sex (Source: Statistics Canada, Census of Population. Available from https://www12.statcan.gc.ca/census-recensement/pc-eng.cfm)

Year	**2001**		
Age category	Male	Female	Total
0-9 years	202,140	192,785	394,925
10-19 years	228,145	217,500	445,645
20-29 years	216,750	209,840	426,590
30-39 years	235,175	236,560	471,735
40-49 years	251,635	246,180	497,815
50 years and above	352,765	385,360	738,125
Year	**2006**		
Age category	Male	Female	Total
0-9 years	208,440	198,270	406,710
10-19 years	236,985	225,730	462,715
20-29 years	250,125	241,780	491,905
30-39 years	238,095	234,060	472,155
40-49 years	271,935	271,090	543,025
50 years and above	441,230	472,620	913,850
Year	**2011**		
Age category	Male	Female	Total
0-9 years	237,670	226,205	463,875
10-19 years	235,475	223,645	459,120
20-29 years	277,835	269,370	547,205
30-39 years	270,405	264,120	534,525
40-49 years	271,205	267,940	539,145
50 years and above	535,220	566,165	1,101,385
Year	**2016**		
Age category	Male	Female	Total
0-9 years	275,515	261,725	537,240
10-19 years	247,680	234,275	481,955
20-29 years	290,700	282,070	572,770
30-39 years	321,205	317,470	638,675
40-49 years	278,405	271,840	550,245
50 years and above	625,900	660,395	1,286,295

Table 3A.2. Total number of ACLRs performed in Alberta in different year by sex

Fiscal Year	Male	Female	Total
2002/2003	646	491	1,137
2003/2004	751	556	1,307
2004/2005	775	608	1,383
2005/2006	789	611	1,400
2006/2007	811	626	1,437
2007/2008	826	626	1,452
2008/2009	953	728	1,681
2009/2010	989	726	1,715
2010/2011	966	744	1,710
2011/2012	956	729	1,685
2012/2013	991	749	1,740
2013/2014	1,048	800	1,848
2014/2015	1,053	890	1,943
2015/2016	1,159	868	2,027
2016/2017	1,141	891	2,032
2017/2018	1,072	938	2,010
2018/2019	1,021	873	1,894
Total	15,947	12,454	28,401

4. Cumulative incidence of and factors associated with anterior cruciate ligament reconstruction among ACL injuries in Alberta [3]

4.1 Introduction

ACL injury and subsequent ACLR are common in orthopedic care (1). ACL injury is often associated with injury to the meniscus, ligaments and chondral injuries (2). However, exposure to instability episodes following ACL injury can lead to secondary injury to knee ligaments and cartilages. Therefore, timely diagnosis and appropriate management of ACL injury is critical to prevent meniscal/chondral lesions and to reduce the chances of osteoarthritis (3).

ACL rupture is managed either by surgical reconstruction or by non-operative rehabilitation, such as activity limitation or physiotherapy (4, 5). Timing of, and procedure for optimal treatment of ACL injury is contentious (6). Furthermore, who might benefit most from non-surgical management and who might benefit from ACLR is also not very well understood (4). A study suggested that patients with limited activity needs, and those without subjective instability symptoms might benefit from conservative treatment (physiotherapy) alone (7). Research continues to optimize the ACLR procedure, and improve post-operative care and rehabilitation protocols (8).

In clinical practice, the incidence of surgical reconstruction is increasing. In the US, an estimated 130,000 ACLR (43.5 per 100,000 person years) occurred in 2006 (9). However, less is known about utilization of ACLR in Alberta, Canada. A retrospective study among adolescents with ACLR in Alberta showed that the interval between ACL injury and ACLR was nearly 12 months (10). However, it is not known if a similar interval exists for a broader population as well or if the time to ACLR has changed over time. Therefore, our objectives in this paper were multifold: First, to estimate the cumulative incidence of ACLR among ACL injuries; second, to estimate average time from first ACL injury diagnosis to ACLR; and third, to identify factors

[3] A poster titled "Factors associated with anterior cruciate ligament (ACL) reconstruction among ACL injuries in Alberta, Canada" based on this paper was presented at ISAKOS Congress. Nov 28, 2021.

associated with ACLR. The findings will inform policymakers about the wait times to ACLR from injury diagnosis and the sub-populations who are less likely to use ACLR or choose non-operative management.

4.2 Methods

Study design

A retrospective cohort study was conducted using administrative data from Alberta Health covering a period of 2010/11 to 2018/19. We identified first visit due to ACL injury (all diagnosis fields were considered) and followed for three years to identify ACLR. If there was more than one record of ACL injury diagnosis on a person, we selected the earliest diagnosis date. The first primary ACLR on an individual was defined as an outcome measure.

Data

Administrative databases available from Alberta Ministry of Health were used and deterministically linked using a unique identifier. We used the NACRS database to identify emergency visits and same-day procedures. We used the DAD to identify diagnosis and ACLR conducted in an inpatient setting. We also used a practitioner claims database to identify diagnosis and to identify whether it was a primary ACLR or a revision ACLR. We linked with the Alberta Health Care Plan registry to identify patients who died or moved out of the province within three years from the date of diagnosis. We used 2011 National Household Survey data used to define neighbourhood income quintile and urban/rural classification.

Inclusion/exclusion criteria

ACL tears diagnosed between April 1, 2010 and March 31, 2016 were identified and followed up for three years from the first diagnosis date of ACL injury. To avoid the possibility of missing the first date of ACL injury diagnosis among patients in the earlier years, all ACL injury diagnosis made between 2002/03 until 2018/19 were included and the first diagnosis date on a person was selected for analysis. Therefore, we excluded anyone with an ACL injury diagnosis prior to 2010/11. Those with reconstruction dates earlier than injury diagnosis dates were excluded. Participants less than 10 years old were excluded. Non-Albertans and those with missing demographic information were excluded. Those with ACL injury on or after April 1, 2016, or those who died or moved out of the province within three years of injury were censored.

Cohort

All patients in NACRS and DAD database with a recorded first-time diagnosis of an ACL injury (ICD-10: S83500: Sprain and strain of ACL of knee, rupture S83501: Other sprain and strain of ACL of knee, distortion engaging the cruciate ligament in the knee and M2361: Other spontaneous disruption of ligament(s) of knee) were identified. All sprains and strains of cruciate ligament of knee (ICD 9 code: 844.2) and old disruption of cruciate ligament of knee (ICD 9 code: 717.83) from the practitioner claims database were included.

Outcome

Canadian Classification of Health Intervention (CCI) codes for ACLR were combined with practitioner billing codes to confirm the procedures performed. CCI code with three initial letters "1VL" among those with ACL injuries were classified as ACLR. Similarly, billing codes were used to identify primary ACLR (93.45A), primary ACLR with meniscal repair (93.45D) and primary ACLR with meniscectomy (93.45C). Similarly, billing codes for revision ACLR included: 93.45E (revision ACL), 93.45F (revision ACL with meniscus repair) and 93.45J (revision ACL with meniscectomy).

Covariates

Patient-related variables were age, sex, income quintile, and place of residence. Age was categorized into six categories: 10-19 years old, 20-29 years old, 30-39 years old, 40-49 years old, 50-59 years old and 60 years and above. Sex was categorized into male and female groups. Urban-rural location was determined by the numeral '0' in the second position of the 3 letter FSA postal code. SES quintile was obtained by linking the three-letter postal codes with 2011 National Household Survey data to derive neighbourhood income quintiles. The season of injury was defined as spring (March, April, May), summer (June, July, August) and fall (September, October, November) and winter (December, January, February). Two time periods – 2010-2014 and 2015-2016 – were derived to assess the early effects of establishment of acute knee injury clinics versus late effects.

Statistical analysis

Continuous variables were expressed as mean (SD) and categorical variables were presented as proportion. We calculated a cumulative proportion of patients who underwent ACLR within first six months, within one year and within three years of the first diagnosis of ACL injury in the ED. Among participants with ACLR, we investigated intervals between the first date of ACL injury diagnosis and the date of first ACLR. We divided ACLR groups into two categories: Those who had ACLR within five months of diagnosis (timely surgery); and those who had ACLR more than five months after diagnosis (delayed surgery). We chose five months as a cut-off time because the American Academy of Orthopedic Surgeons suggests to have an ACLR within five months of ACL injury, when indicated(11). We calculated mean (SD) days to ACLR separately for timely surgery group and delayed surgery group. Analysis on cumulative incidence of ACLR and time to ACLR was done separately for those with an ACL injury diagnosis in the ED and non-ED. Those with an apparent same-day diagnosis and ACLR diagnosed in a non-ED setting were excluded in this analysis.

We used a Cox's proportional hazard regression model to identify factors associated with ACLR (versus no reconstruction), adjusting for socio-demographic variables and season of injury diagnosis. Censoring was done at the time of death or departure from the province, at the time of ACLR or end of follow-up (March 31, 2019), whichever came first. We tested for multicollinearity among predictor variables before running the regression model. We also tested for interaction of age category and sex, age category and season of injury, and sex and season. Analysis was carried out in SAS software version 9.4 (SAS Institute, North Carolina, United States).

4.3 Results

Sample characteristics

A total of 16,477 participants with a diagnosis of ACL injury between 2010/11 and 2015/16 were included in this analysis. Mean age of the participants was 33.3 years (SD:13.5). Males represented 57.9% of the cohort and 14.7% were from rural areas (Table 4.1). More than two-thirds (67.3%) were of middle- or higher-income quintile. Higher proportion of injuries were diagnosed in spring (27.4%) and winter (25.6%) than in summer (23.2%) and fall (24.2%). Over half of ACL injuries were diagnosed in a non-emergency setting either in physician clinics or inpatients setting (60%). Data on sports and recreation (SR) code was available for just over one-fifth of the participants (20.6%) at the time of first ACL injury diagnosis. Of those with data on SR subcode, skiing, soccer, ice hockey, skating, and basketball were the top five sports . Similarly, data on place of injury was available only among (19.0 %) of the total ACL injuries, of which more than three quarters (77%) occurred in the sports and athletic area.

Cumulative incidence of ACLR

Of the total ACL injuries, 56.6%; (95% CI: 55.8%-57.3%) had ACL reconstruction within three years of diagnosis. Cumulative incidence among those with a diagnosis in the ED was 44.9% and among those with a diagnosis in non-ED setting was 64.5% (Table 4.2). There was a variation in proportion of ACLR among males and females by age category. Proportion of ACLR peaked in 10-19-year-olds among females and dropped with an increase in age. Among males it peaked among those aged 20-29 years and dropped afterwards (Table 4.3). There was a higher chance of ACLR among younger age groups compared to those aged 40 years and above (Fig. 4.1 and 4.2).

Time from injury diagnosis to ACLR

Among those with a diagnosis in the ED, after excluding those with apparently same date of surgery as the date of diagnosis, average time to ACLR from the date of diagnosis in these patients (n=1,115) was 366 days (SD=459 days) (Table 4.4). Just over one third (35.6%, n=397) of the patients receiving diagnosis in ED received ACLR within five months from the date of diagnosis (timely surgery). Similarly, after excluding participants with ACLR on the apparent same day of diagnosis, among those diagnosed in non-ED setting (n=6,009), average time to ACLR was 244 days (SD 330 days). More than half of these patients who received diagnosis in a non-ED setting (n=3,044, 50.6%) received ACLR within five months from the date of diagnosis (timely surgery).

Factors associated with ACLR

Bivariate analysis showed a strong association of age categories, sex, neighbourhood income quintile, urban/rural place of residence, season of injury, place of injury diagnosis, and year of injury with the odds of ACLR (Table 4.5). So, we included the variables showing significant association into the multivariable Cox's proportional hazard regression model.

Cox's proportional hazard regression analysis revealed that patients' age at injury and place of injury diagnosis were strongly associated with time to ACLR compared to other factors. Patients aged 10-19 years (hazard ratio (HR):3.0, 95% CI:2.7-3.3), 20-29 years (HR:2.9, 95% CI:2.7-3.2), 30-39 years (HR:2.6, 95% CI:2.4-2.9), and 40-49 years (HR:1.9, 95% CI:1.7-2.1) were significantly more likely to have ACLR in comparison to those aged 50-59 years old Similarly, females showed slightly higher chances of ACLR compared to males (HR:1.1, 95% CI:1.06-1.15). In comparison to those in the poorest income quintile neighbourhoods, those in the higher income quintile had a significantly higher chance of ACLR. Similarly, patients from urban areas had significantly higher chances of ACLR compared to patients from rural areas. Having an ACL injury diagnosed in fall was associated with higher chances of ACLR compared to those with ACL injury diagnosed in summer.

Those who received ACL injury diagnosis in a non-emergency setting had 1.3 times the chances of ACLR compared to those having ACL injury diagnosed in an emergency setting (HR:1.34, 95% CI:1.28-1.40). Furthermore, results showed that there were significantly higher chances of ACLR among patients diagnosed with ACL injury in recent years compared to the reference year (2010/11).

A sensitivity analysis was carried out to investigate time to ACLR among those with diagnosis of sprains and strains of knee and leg (844), sprain of cruciate ligament of knee, and internal derangement of knee (717.0-717.9) from the physician claims database among those who had a history of ACLR. Among those with above diagnosis and available data on time to reconstruction, we found that average time to ACLR was 184 days (SD-210 days) among those diagnosed in non-ED setting and had ACLR done on a different date to date of diagnosis. Among those with a diagnosis in the ED setting, average time to ACLR was 278 days (SD- 219 days).

4.4 Discussion

Our results show that more than half of the ACL injury diagnosed between 2010/11 and 2015/16 underwent ACL reconstruction within three years of injury diagnosis. Our three-year cumulative incidence is lower than reported in a study from Belgium with a similar age and gender profile of the cohort (12). The authors reported 74% of their cohort with ACL injury underwent ACLR. However, our ACLR incidence is higher than a Swedish nationwide cohort study which showed a 30% cumulative incidence with a minimum follow-up of one year among patients with cruciate ligament injuries (6). They included all cruciate ligament injuries, while we only included ACL injuries. Our study, along with the previous studies (6,12,13), are based on a general population, so the findings cannot be compared with studies conducted in athlete populations. In addition to the above factors, activity level of the population and surgical pattern among others determine the percentage of surgically treated patients.

Patients who received an ACL injury diagnosis in non-emergency settings had 1.3 times higher chance of ACLR compared to patients diagnosed in the ED. It is possible that most of the patients who received ACL injury diagnosis outside of the ED (physician clinics, acute knee injury clinics) were diagnosed by orthopedic surgeons or personnel trained in orthopedic care, reducing the chances of misdiagnosis. Seil et al. (12), in a cohort of 346 patients with an MRI-confirmed ACL injury, reported a similar proportion of ACLR (74%). Among patients who received diagnosis in non-emergency setting, we found that nearly 65% underwent ACLR. It is well known that it has been persistently difficult to diagnose ACL injury in EDs for many emergency physicians (14). A French study found that of the 27 ACL injury diagnosis established by sports medicine specialist, emergency physicians were able to diagnose only 7 injuries (25%) (15). Similar findings were reported in UK-based studies by Arastu et al. (16) and Parwaiz et al. (14), who found that the correct diagnosis was made in 28.2% and 14.4% of cases, respectively, at initial consultation. Therefore, one possible reason for low ACLR rate in patients with a diagnosis in the ED is misdiagnosis of ACLR.

Our results show that the proportion of ACLR ranged from 29% among adults aged 50-59 years old and about 67% among those 20-29 years of age. A United States-based study among the adult population (mean age=47 years) with three years of follow-up reported a cumulative incidence of 22.6% (13). Our study also showed that among patients aged 50 years and above, just above one-third (33.4%) underwent ACLR within three years. Furthermore, we found that the proportion of ACLR peaked among those aged 20-29 years in males (74.3%), whereas it peaked in those aged 10-19 years among females (80.4%). Seil et al. reported that ACL injury peaks before 21 years in females and peaks before the age of 30 in males (12). Overall, the chance of ACLR was slightly higher among females compared to males (OR:1.06, 95% CI:1.01-1.10). This finding is consistent with Nordenval's nation-wide study (6). Younger patients are more likely to be involved in strenuous sports and prefer to return to pre-injury activity level than older patients (12), which may be one of the reasons clinicians would commonly offer ACLR to younger patients instead of conservative management.

We found that average Time to ACLR from ACL injury diagnosis was almost a year from the date of first diagnosis in the ED and about 8 months among those diagnosed in a non-ED setting. A retrospective study among adolescents who underwent ACLR in two Alberta hospitals showed that mean time from injury to ACLR was nearly 12 months, or 342 days (SD: 248 days), and mean time from MRI diagnosis to ACLR was nearly 9 months, or 265 days (SD: 260 days) (10). It is to be noted that the previous study (10) was conducted among an adolescent population (10-16 years old at the time of injury) whereas our study cohort included a wide age group ranging from 10-90 years. A study from New Zealand also showed a mean time from injury to ACLR was 11 months (17). These findings suggest that many Alberta patients with ACL injury have to wait longer than recommended time for ACLR. It is suggested that patients typically present to the health care providers within 24 hours of ACL injury (17), therefore it is unlikely that delays in ACLR are affected by delayed presentation to the health system. Since each week of delay from injury to ACLR significantly increases the chances of medial meniscus tear, medial femoral condyle damage, and mild or higher grade radiographic osteoarthritis of the medial compartment, identifying and mitigating factors that cause delay in time to ACLR should be a priority (3). Longer wait time among those with diagnosis made in the ED may be due to less patient education due to workload in the ED or due to lack of a definitive diagnosis.

Current results show that the interval between diagnosis and ACLR had not improved until 2019 compared to ACLR conducted between 2005-2011, and the wait times were higher if ACL injury was diagnosed in the ED (10). Longer wait time-to-imaging in Canada compared to other countries is well known (18). Previous work has shown that average time to MRI diagnosis from injury is nearly three months in Alberta (10). Irrespective of the reason for delay, an ACL-deficient knee is vulnerable to injuries to menisci and articular surfaces (19), and chondral damage (20). Exposure to instability episodes can cause new meniscal tears and make existing meniscal tears complex and less likely to be repaired (20); it can also worsen meniscal tears, especially the medial bucket handle tear (10). These findings warrant a multipronged approach to improve efficiency and effectiveness of knee injury management in Alberta. First, the number of well-trained orthopedic care providers needs to be increased. Second, emergency physicians and family physicians need to be oriented to improve diagnostic accuracy of ACL injury to enhance diagnosis at initial consultation. Third, given significant delay between injury and ACLR, it is necessary to educate and encourage patients to limit activity until a confirmed diagnosis or ACLR is done to prevent further knee damage. Fourth, acute knee injury patients might need to be diverted from the ED to other non-ED settings, such as acute knee injury clinics, for accurate diagnosis and timely care.

Patients living in rural areas and patients from the lowest-income neighbourhoods were also significantly less likely to undergo ACLR. Urban/rural and socioeconomic disparity with respect to ACLR utilization has been reported elsewhere too. Furthermore, it was interesting to note that patients who had their ACL injury diagnosed in spring and fall were significantly more likely to undergo ACLR compared to patients who had their injury diagnosed in summer. Qualitative research is needed to understand why certain populations underutilize ACLR.

Strengths and Limitations

This is one of the few studies examining incidence and factors associated with ACLR among ACL injuries. We used multiple databases to confirm ACLR (NACRS, DAD, claims database). However, our study has some limitations. ACLR cases reported here are only those with the ACL injury diagnosis. Many patients do not receive ACL injury diagnosis. Therefore, the true incidence of ACL injury and ACLR may be higher than reported here during the study period. We included only the first primary ACLR on a person as the outcome measure. Due to lack of information on knee sidedness, the time between ACL injury diagnosis and ACLR may have been mismatched for some patients with an ACL injury in both legs. However, since we used the participants with a history of single ACLR and used the first date of ACL injury diagnosis, the results may not have been hugely impacted.

For assessment of time to ACLR from the date of ACL injury diagnosis, we excluded a significant number of patients who received ACLR on the same date as their ACL injury diagnosis, with the first diagnosis made in non-ED setting. Since an increasing number of ACL injuries are diagnosed in acute knee injury clinics, we suspect that majority of these patients received ACL injury diagnosis in AKIC and were referred to physician clinics/hospital for ACLR. It was reported that data from AKIC are not submitted to the provincial and national databases until now (personal communication), therefore, we would not know the exact date when ACL injury was diagnosed first. Inclusion of ACL injuries diagnosed outside of ED would have resulted in inaccurate estimates of time to ACLR.

4.5 Conclusion

More than half of ACL injuries had ACL reconstruction within three years of injury diagnosis. The average time to ACLR was almost a year from the date of diagnosis at ED and over 8 months among diagnoses made in a non-ED setting. Patients living in rural areas, those living in poorer income neighbourhoods and those receiving diagnosis in EDs had a lower chance of ACLR. Strategies to improve timely utilization of ACLR needs to focus on patient education as well as on health system strengthening.

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Table 4.1 Individual and injury-related characteristics of the study participants

Variables		n	%
Age Category			
	10 -19 years	2,992	18.2
	20-29 years	4,451	27.0
	30-39 years	3,820	23.2
	40-49 years	2,950	17.9
	50-59 years	1,680	10.2
	60 and above	584	3.5
Sex			
	Female	6,930	42.1
	Male	9,547	57.9
Neighborhood Income Quintile			
	Q1 (Poorest quintile)	2,765	16.8
	Q2	2,621	15.9
	Q3	3,563	21.6
	Q4	3,661	22.2
	Q5 (Richest quintile)	3,867	23.5
Place of residence			
	Urban	14,052	85.3
	Rural	2,425	14.7
Injury diagnosis season			
	Spring	4,508	27.4
	Summer	3,817	23.2
	Fall	3,927	23.8
	Winter	4,225	25.6
Place of diagnosis			
	Non-emergency setting	9,816	59.6
	Emergency department	6,661	40.4
Year of injury diagnosis			
	2010/11-2013/14	11,061	67.1
	2014/15-2015/16	5,416	32.9

Table 4.2 Proportion of ACLR by individual and injury characteristics within three years of follow-up

Variables			
Age Category	**No reconstruction**	**Reconstruction**	**p value**
10 -19 years	1022 (34.2)	1970(65.8)	<0.0001
20-29 years	1481 (33.3)	2970 (66.7)	
30-39 years	1421 (37.2)	2399 (62.8)	
40-49 years	1487 (50.4)	1463 (49.6)	
50-59 years	1196 (71.2)	484 (28.8)	
60 and above	548 (93.8)	36 (6.2)	
Sex			
Female	2928 (42.3)	4002 (57.7)	0.006
Male	4227 (44.3)	5320 (55.7)	
Neighborhood Income Quintile			
Q1 (Poorest quintile)	1407 (50.9)	1358 (49.1)	<0.0001
Q2	1227 (46.8)	1394 (53.2)	
Q3	1487 (41.7)	2076 (58.3)	
Q4	1516 (41.4)	2145 (58.6)	
Q5 (Richest quintile)	1518 (39.3)	2349 (60.7)	
Place of residence			
Urban	5897 (42.0)	8155 (58.0)	<0.0001
Rural	1258 (51.9)	1167 (48.1)	
Injury Season			
Spring	1968 (43.7)	2540 (56.3)	0.01
Summer	1669 (43.7)	2148 (56.3)	
Fall	1623 (41.3)	2304 (58.7)	
Winter	1895 (44.9)	2330 (55.1)	
Place of diagnosis			
Non-emergency setting	3487 (35.5)	6329 (64.5)	<0.0001
Emergency department	3668 (55.1)	2993 (44.9)	
Year of injury diagnosis			
2010/11-2013/14	4834 (43.7)	6227 (56.3)	0.0009
2014/15-2015/16	2321 (42.8)	3095 (57.2)	

Table 4.3. Gender differences in chances of ACLR

Gender	10 -19 years	20-29 years	30-39 years	40-49 years	50-59 years	60 years and above
Males (n=9,547)	923 (59.2)	1871 (65.7)	1494 (63.0)	774 (48.5)	238 (26.7)	20 (7.1)
Females (n=6,930)	1047 (73.0)	1099 (68.5)	905 (62.5)	689 (50.9)	246 (31.2)	16 (5.3)

Table 4.4. Time to ACLR from date of diagnosis by place of diagnosis

Place of first diagnosis	N	Mean	Std Dev	Median	Lower Quartile	Upper Quartile
ED setting	1115	366	459	219	108	412
Non-ED setting	6009	244	330	149	76	273

*n=2,198 who were found to have ACLR on the day of ACL injury diagnosis were excluded in this analysis

Table 4.5 Cox's proportional hazard regression showing association of ACLR with background characteristics

Variables	Unadjusted Hazard ratio	95% Confidence limits		Adjusted Hazard Ratio	95% Confidence limits		p value
Age category							
10 -19 years	3.10	2.80	3.40	3.00	2.71	3.31	<.0001
20-29 years	2.99	2.72	3.30	2.92	2.65	3.21	<.0001
30-39 years	2.68	2.43	2.96	2.59	2.35	2.86	<.0001
40-49 years	1.98	1.79	2.20	1.93	1.74	2.14	<.0001
50-59 years	**Ref**			**Ref**			
60 years and above	0.18	0.13	0.26	0.18	0.13	0.26	
Sex							
Female	1.06	1.02	1.11	1.10	1.06	1.15	<.0001
Male	**ref**			**Ref**			
Neighborhood Income Quintile							
Q1 (Poorest quintile)	**Ref**						
Q2	1.12	1.04	1.21	1.11	1.03	1.20	0.006
Q3	1.27	1.18	1.36	1.14	1.05	1.23	0.001
Q4	1.29	1.21	1.39	1.21	1.12	1.30	<.0001
Q5 (Richest quintile)	1.37	1.28	1.46	1.23	1.14	1.33	<.0001
Place of residence							
Urban	1.31	1.23	1.39	1.12	1.04	1.21	0.003
Rural	**Ref**			**Ref**			
Injury diagnosis season							
Summer	**Ref**						
Spring	1.01	0.95	1.07	1.01	0.95	1.07	0.79
Fall	1.08	1.02	1.15	1.07	1.01	1.13	0.031
Winter	0.98	0.93	1.04	0.98	0.93	1.05	0.6
Place of diagnosis							
Non-emergency setting	1.45	1.39	1.52	1.34	1.28	1.40	<.0001
Emergency department	**Ref**			**Ref**			
Year of injury diagnosis							
2010/2011-2013/14	**Ref**			**Ref**			
2014/15-2015/16	1.08	1.03	1.13	1.06	1.01	1.10	0.012

5. Incidence and risk factors for revision and contralateral ACLR in Alberta, Canada: a population-based retrospective cohort study[4]

5.1 Introduction

ACLR is a common and cost-effective procedure for restoring functional stability of the knee after a rupture of the ACL (1). However, there is a variation in graft choice, surgical technique, and location, as well as rehabilitation practices, after ACLR (2). Timely ACLR can prevent further damage to the meniscus and other knee ligaments (3).

Multiple studies have investigated revision ACLR rate and associated risk factors (4-9). Commonly reported risk factors are age, graft type, body mass index (BMI), smoking status, and concomitant ligament injuries. Previously reported revision rates ranged from 2.6% to 8.4%. Furthermore, the variables included in multivariable models greatly differ across studies with only a few studies including a combination of patient-related, surgery-related, and provider-related variables. Additionally, few studies have investigated the rate and factors associated with primary ACLR in the contralateral knee (6, 10, 11).

The purpose of this study was to investigate the incidence and factors associated with ipsilateral ACLR revision and contralateral primary ACLR among individuals with a primary ACLR between the fiscal years 2010/11 and 2015/2016. This population-based study will provide a reference for monitoring trends of subsequent ACLR and may be helpful for future quality assessment projects in Canada. In addition, it may inform clinicians on factors that may help to improve patient outcomes.

[4] A paper based on this chapter is currently under review in Clinical Journal of Sports Medicine.

5.2 Methods

Study design

A retrospective cohort study was conducted with a minimum of three years of patient follow-up.

Setting

Alberta has a population of more than 4.4 million, with a publicly funded health care system that guarantees universal access to hospital and medical services to all Albertans. There are no user fees for physician services and most diagnostic services. Alberta has acute knee injury clinics in Edmonton and Calgary. In Calgary, the Acute Knee Injury Clinic (AKIC) program was started in 2008 as a pilot and it was launched full time in 2010 (personal communication). Similarly, the AKIC was started in Edmonton in 2013 (personal communication). Alberta knee clinics offer specialized diagnostic and treatment services for knee injuries with a shorter wait time than in a general hospital setting. This study was approved by the University of Alberta Human Research Committee (Pro00090820).

Data

Administrative data from the fiscal years 2010/11 until 2018/19 were used to identify ACLRs performed during the study period. Databases available from Alberta Ministry of Health were linked deterministically using a unique identifier. Population registry has demographic and geographic information on all individuals registered with the Alberta Health Care Insurance program. The ambulatory care database includes data on ED visits and same-day procedures i.e day surgery. The discharge abstract database has information on all inpatient cases from hospitals, including free-standing rehabilitation hospitals. The practitioners' claims database has information on processed claims on fee-for-service claims from all medical practitioners within Alberta Health.

Primary Outcome

Practitioner billing codes for primary ACLR (primary ACL-93.45A), primary ACLR with meniscal repair (93.45D), and primary ACLR with meniscectomy (93.45C) were used to identify cases of primary ACLR. There was no variable to determine laterality, hence, if there were two records for primary ACLR for the same person on two different dates, then the second primary ACLR was considered as the contralateral primary ACLR. Similarly, billing codes for revision ACLR are as follows: 93.45E (revision ACL), 93.45F (revision ACL with meniscus repair) and 93.45J (revision ACL with meniscectomy) were used to identify ACL revision. Canadian Classification of Health Intervention (CCI) codes for ACLR were combined with practitioner billing codes to confirm the procedures performed. The CCI codes for ACLR were accessed from a previous study (6), available in Appendix 5A.1.

Demographic and clinical variables

Demographic data available in-patient registers were used. Patient-related variables were age, sex, income quintile, place of residence, and Charlson Comorbidity Index (12). Age was divided into six categories: 10-19 years old, 20-29 years old, 30-39 years old, 40-49 years old and 50-59 years old. Sex was categorized into males and females. Urban-rural residence status was obtained by looking at the initial three-letter forward sortation areas (FSA) in postal code. An FSA with a zero in the middle would indicate a rural residence (13). Socio economic status (SES) quintile was obtained by linking the postal codes with 2011 National Household Survey data to derive neighbourhood income quintiles. The comorbidity index was created using the Charlson - Deyo procedure for using administrative hospital discharge data (12). Two categories, no morbidity and index >=1, were created. Surgery related variables included graft type, season of surgery, outpatient/inpatient surgery setting, and concomitant meniscus procedure during primary ACLR. Graft type was categorized into three categories: autograft, allograft, synthetic and combined techniques. Season of surgery was defined as spring (March, April, May), summer (June, July, August) and fall (September, October, November) and winter (December, January, February). Surgery years were divided into two categories: 2010-2014 (representing early years of establishment of AKIC) and 2015-16 (later years of establishment of AKIC). 2015 was chosen as a cut-off year since there was a big increase in the proportion of ACLR conducted in outpatient settings in 2015 compared to 2014. Setting of surgery had two categories: outpatient surgery versus inpatient surgery. Presence of concomitant meniscus procedure was divided into three categories: ACLR only, ACLR with meniscectomy, and ACLR with meniscus repair. Provider-related variables include surgeon volume in the last 365 days of initial primary ACLR and average annual hospital volume over six years. Surgeon volume one year prior to the index operation was calculated and five categories were formed as suggested by Wasserstein et al.: 0, 1-12, 13-50. 51-100, >100 (6). Annual hospital volume was categorized into 3 categories: 1-24(V1) , 25-99(V2), and >100(V3), with some adjustment to classification suggested in a previous work (14).

Eligibility criteria

All Albertans undergoing primary ACLRs over 6 years (between 2010/11 and 2015/16) were included in the analysis. Patients below the age of 10 years and above 60 years were excluded, since ACL injury is less common in these age groups. Non-Albertans were excluded because of unavailability of demographic and follow-up data. If the index ACLR was recorded as ACL revision, then patients were excluded from the analysis. ACL repairs (93.45B) were excluded. Primary ACLRs that occurred after April 1, 2016 were excluded in the Cox proportional hazard model to allow a minimum of three years of follow-up period for all ACL reconstructions. Patients having posterior cruciate ligament tears were excluded. When estimating proportion of ACL revision and its associated factors, we excluded all records from individuals having contralateral knee reconstructions since there was no information on sidedness of the knee. To improve the specificity of outcome assessment, all primary reconstructions performed before April 2010 and subsequent contralateral reconstructions, and revision ACL records for those patients were excluded.

Statistical analysis

Outcomes were assessed until March 31, 2019. Survival analysis using the Kaplan-Meier approach was used to estimate event-free survival for both ipsilateral ACL revision and contralateral primary reconstruction. Censoring was done for death, emigration, occurrence of event of interest, or end of follow up period (March 31, 2019), whichever was earlier. Time of follow-up (expressed as years) was calculated by subtracting the date of primary ACLR from revision date or date of contralateral primary ACLR. Event rates were calculated for age categories and sex with an average length of follow-up of 5.7 years, and expressed as an event rate per 1000 person years. The Cox's proportional hazard regression model was used to identify factors associated with ipsilateral ACL revision and contralateral ACLR.

5.3 Results

Cohort characteristics

A total of 17,793 ACLR conducted between 2010/11 and 2018/19 that had a CCI code available in the NACRS or DAD databases were found. After exclusions based on a pre-determined criterion (Fig. 5A3 and Fig. 5A4), our analysis included a total of 9636 initial primary ACLRs performed in either knee and 9292 ACLR performed in a single knee over six years between April 2010 and March 2016 in Alberta (Table 5.1). The annual volume of primary ACL reconstructions meeting our inclusion criteria increased from 1528 in 2010/11 to 1712 in 2015/16. Over half of the participants (56%) were males. The mean age of the participants was 30 years (SD 10.9) and over half of the participants (57%) were between 20-39 years of age (Table 5.1). The cohort was mostly healthy, with 99.3% of the participants having a Charlson comorbidity index of 0. About 12% of the participants were from rural areas. Most participants (80%) underwent same-day surgery. Of the total number of primary ACL reconstructions performed annually, slightly lower proportions were performed in the summer season (21.5%) compared to spring, fall, and winter seasons (25-27%). Nearly 73% of primary ACLRs were performed in hospitals that conducted over 100 ACLRs annually. We followed up our cohort for a minimum of three years and a maximum of nine years, with an average follow-up period of 5.7 years.

5.3.1 Ipsilateral revision ACLR

Of the 9292 participants with an initial primary ACLR in a single knee, n=359 (3.9%, 95% CI: 3.5-4.3) underwent ipsilateral ACL revision over a mean revision period of three years (SD 1.8) (Table 5.1). The Kaplan-Meier estimate of failure-free survival for revision ACLR was 94.6% (Fig 5A.1). The event rate for revision ACL was 13.5 per 1000 person years, and 7.5 per 1000 person years among those 10-19 and 20-29 years of age, respectively (Appendix 5A.2). Similarly, the event rate was 7.4 per 1000 person years in females and 6.3 per 1000 person years in males (Appendix 5A.2).

Cox's proportional hazard regression analysis revealed that age at the time of initial primary ACLR was strongly associated with the risk of revision (Table 5.2). Participants aged 10-19 years showed 3.5 times higher risk (hazard ratio (HR)=3.5; 95% CI-2.6-4.8) compared to the 30-39-year-old age group (Table 5.2). Similarly, those aged 20-29 years old were at nearly double (HR=1.9; 95% CI-1.4-2.7) higher risk than the 30-39-year-oldage group (Figure 5.1). Participants aged 50-59 years showed lower risk compared to 30-39-year-olds (HR=0.4; 95% CI:0.2-1.0). Place of residence or income quintile did not show association with risk of ACL revision.

Among the surgery-related factors, outpatient/inpatient surgery setting, season of primary surgery, and graft type showed association with revision surgery. Having an initial surgery in an inpatient setting was associated with a 1.3 times higher chance of revision surgery (HR=1.3; 95% CI:1.0-1.7) compared to surgeries conducted in an outpatient setting/same day surgery (Table 5.2). Similarly, initial surgery in the winter season (HR=1.6; 95% CI:1.2-2.2) was associated with increased risk of ACL revision compared to those having surgery in the summer season (Fig. 5.2). Allograft was associated with higher risk of revision surgery compared to patients having an initial reconstruction using autograft (HR=1.5; 95% CI:1.0-2.3). Provider-related factors, such as surgeon volume in the previous year and annual hospital volume, did not show a statistically significant association.

5.3.2 Contralateral primary ACLRs

Of the 9676 initial primary ACLRs in either knee, n=344 (3.6%; 95% CI: 3.2-3.9) underwent presumed contralateral primary ACLR over a mean reconstruction period of 3.0 years (SD 2.1) (Table 5.1). The Kaplan-Meier estimate of failure-free survival for contralateral ACLR was 94.7% (Fig. 5A.2). The event rate for contralateral primary ACLR was 10.9 per 1000 person years, and 6.8 per 1000 person years among those 10-19 and 20-29 years of age, respectively (Appendix Table 5A.2). Similarly, the event rate was 7.1 per 1000 person years in females and 5.6 per 1000 person years in males. Females represented 50% of contralateral ACLR cases compared with 44% of the primary ACLR cases.

Cox proportional hazard regression analysis revealed that age at the time of initial primary ACLR was the only patient-related factor associated with the risk of contralateral ACLR, with participants 10-19 years having more than double (HR=2.4; 95% CI-1.8-3.3) higher risk compared to the 30-39-year age group (Table 5.2). Similarly, those aged 20-29 years were at 1.6 times (HR=1.6; 95% CI-1.2-2.2) higher risk than the 30-39-year age group (Fig.5.3). The participants undergoing contralateral ACLR were five years younger (mean age=25.2 (SD-9.8) years) than the cohort (mean age=30.0 years (SD-10.9). Place of residence or income quintile did not show association with contralateral ACLR.

No provider-related factors were associated with the risk of contralateral ACLR. Having an initial primary ACLR in an inpatient setting was associated with higher risk of contralateral ACLR (HR= 1.5; 95% CI 1.1-1.9) compared to outpatient/same-day surgery (Fig.5.4).

5.4 Discussion

The most important finding in our study is that age is a significant risk factor for both revision ACLR and contralateral ACLR. Secondary findings were that patient-related factors, including sex, place of residence, neighbourhood income quintile, Charlson comorbidity index, surgery-related factors (such as concomitant meniscus procedure), and provider-related factors. Surgeon volume and average annual hospital volume were not found to be associated with subsequent ACLR surgery in this cohort. Finally, having ACLR in the winter was associated with an increased risk of revision ACLR, a finding that has not previously been shown in the literature.

Age was strongly associated with the risk of revision ACLR, and contralateral primary ACLR, a finding consistently reported in published literature (7, 15, 16). Participants aged 10-19 years and 20-29 years were 3.5 times and 1.9 times higher risk than participants aged 30-39 years, respectively. Younger participants may have higher pre-operative activity levels, tend to return to normal activity earlier and are less compliant with their rehabilitation plans (4). We also found that older patients aged 50-59 years had a lower risk of revision ACLR than patients aged 30-39 years. Altogether, these findings suggest that young patients might benefit from patient education and rehabilitation plans to avoid early return to normal activity levels.

The revision ACLR rate (3.9%) and the contralateral primary ACLR rate (3.6%) in our cohort fall within the range reported in published literature (4, 6, 15). Our revision rates and contralateral primary ACLR rate are greater than reported in some studies with two years or shorter follow-up (10, 16, 17). Longitudinal cohort studies with five years or longer follow-ups (4, 18-20), report higher subsequent ACLR rates than in our study. In a US-based longitudinal follow-up study with six years of follow-up, Hettrich et al. found an ipsilateral revision rate of 7.7% and contralateral ACLR rate of 6.4% (18). Higher median age of the participants (29 years versus 23 years) and a shorter follow-up period (5.6 years versus six years) than in Hettrich et al.'s study might be some of the reasons for the lower rate in our study. Another study from Italy with 10 years of follow-up among patients undergoing hamstring autograft reported ipsilateral revision ACLR of 3.4% and contralateral ACLR of 7.8% (19). Another Australia-based longitudinal follow-up study with five years follow-up reported both ipsilateral graft rupture and contralateral ACL rupture rate of 6% (20). It is to be noted that studies showing lower reconstruction rates than ours (9, 16, 17) used a similar approach to ours using administrative data to investigate the incidence of subsequent reconstruction among patients with a history of primary ACLR. Whereas, studies showing higher subsequent reconstruction rate from the US, Australia, and Italy (18–20) used a combination of follow-up patient interviews and medical chart review to collect information about graft rupture. Therefore, it can be assumed that real incidence of ipsilateral graft rupture and contralateral ACL rupture may be higher than the incidence of subsequent reconstruction. Some studies in highly active professional athletes report revision rates and contralateral ACL rupture rates much higher than in our general population-based study (21).

We found similar rates for revision and contralateral ACLR. Studies with six years or longer follow-up have shown that contralateral ACL rupture occurs later than ipsilateral graft rupture (18, 19). Of the total contralateral reconstructions within six years, Hettrich et al. reported that 40% occurred within two years of follow-up and 60% occurred after two years of follow-up (18). Whereas 63% of graft rupture on the ipsilateral knee occurred within two years of follow-up. In a 10-year follow-up study, Grassi et al. reported double the rate of contralateral ACLR compared to ipsilateral revision ACLR (19). Another study among professional football players also reported that mean time to ipsilateral graft rupture (23.5 months) was shorter than contralateral ACL rupture (31.5 months) (22). Therefore, ipsilateral revision ACLR and contralateral ACLR rates are similar within five years of follow-up and risk of contralateral ACL rupture increases thereafter.

We found that use of allograft in the index ACLR was associated with higher risk of undergoing ACLR compared to use of autograft. This finding is consistent with the published literature (6, 23). Previous studies have reported that early return to sports and use of allograft in combination further increase the risk of revision ACLR, especially in young patients (24, 25). Since the mean age of our cohort was 30 years, early return to activity might have increased the chances of graft failure among those who had an allograft. Due to lack of data on time to return to sports and type of autografts, we could not investigate the risk of subsequent ACLR by these variables.

Also of note was the association with surgery in the winter being a risk factor for revision ACLR. To our knowledge, this is also the first time that association with season of surgery has been reported. We hypothesize that patients having primary ACLR in winter may be more likely to return to normal activity as soon as the spring/summer season arrives compared to patients having surgery in summer or fall. Research has shown that physical activity in Canada is higher in summer compared to spring and winter, due to shorter days and extreme weather conditions, especially in winter (26, 27). However, this needs further investigation to fully understand why the season of primary ACLR is associated with a risk of revision ACLR.

Having index surgery in an inpatient setting was associated with increased risk of revision ACLR, as well as contralateral primary ACLR. In our cohort, although mean age was similar among inpatients and outpatients (30 years old), inpatients comprised only 9% of the total ACLR in later years (2015 and 2016) compared to 25% of total ACLR between 2010 and 2014. This abrupt change in clinical practice led to the inpatient sample in this analysis to have a longer follow up period (6.2 years) from the date of primary ACLR compared to outpatients (5.5 years). Another reason for protective role of outpatient setting may be due to improved procedure over time with advanced techniques and equipment, meaning the outpatients of later dates may have benefited more. A systematic review and meta-analysis revealed that having ACLR in an outpatient setting was associated with better outcomes in pain management, patient satisfaction, and knee function (28). Whether these short-term outcomes translate to lower graft failure or revision rates needs further research. In our sample, higher proportion of those who had primary ACLR in an inpatient setting did not have an ACL injury diagnosed in the ED, compared to those having ACLR in outpatients. Not having a timely diagnosis of ACL injury may have led to exposure to further instability episodes and cartilage/meniscus damage before waiting for a knee procedure. The current analysis showed a stronger association of inpatient setting with risk of contralateral primary ACLR (Hazard ratio 1.5; 95% CI: 1.1-1.9) compared to risk of revision ACLR (Hazard ratio 1.3; 95% CI: 1.0-1.7). Further research is needed to understand why inpatient setting is associated with higher risk of subsequent ACLR.

Strengths and limitations

Using population-based data we present the epidemiology of contralateral primary ACLR and revision ACLR in Alberta for the first time. We have an average follow-up period of 5.7 years, one of the longest follow-up periods used in similar studies. However, our study has some limitations. ACLR conducted through workers' compensation board (WCB) claims are not included, since these claims are directly submitted to WCB by physicians (29). Many patients who have failed ACLR may choose not to perform revision ACLR or to have another ACLR in the next knee, which might underestimate true graft failure rate or contralateral ACL tear. Our findings might have reflected only selected patients who seek further medical care after graft failure/ACL rupture. Residual confounding due to unmeasured confounders is possible since we relied on administrative data. Additionally, our findings rely on accuracy of billing practices and electronic records. However, previous studies have established the validity of administrative data in Alberta, including physician claims to analyze service utilization patterns (30). Lack of information on sidedness of the knee made it impossible to understand whether the knee reconstruction is on the left knee or right knee. Similarly, we did not have data to investigate risk of subsequent ACLR by type of autograft used. Furthermore, we do not have the number of people involved in different sports so as to calculate time spent in different sports/activity and to calculate the failure rate by sports/activity.

5.5 Conclusion

In this retrospective cohort study with an average follow up of 5.7 years, we found similar rates of ipsilateral revision ACLR and contralateral primary ACLR. Participants aged 10-19 years and 20-29 years reported an increased risk of revision ACLR as well as contralateral ACLR compared to those aged 30-39 years. Having primary ACLR in an inpatient setting was associated with 1.3 times higher risk of revision ACLR and 1.5 times higher risk of contralateral ACLR. Having allograft compared to autograft was associated with 1.5 times higher risk of revision ACLR. Having the initial primary ACLR winter season showed 1.5 times higher risk of revision ACLR compared to summer. Overall, findings from this study and previously published data suggest the reported rates of subsequent ACLR depend on method of assessment, age of the patients, length of follow up, activity level of the participants, and graft type among others. Future cohort studies are needed to provide an accurate estimation of graft rupture and contralateral ACL rupture, as well as to disentangle the relationship between surgery setting and season with risk of subsequent ACLR.

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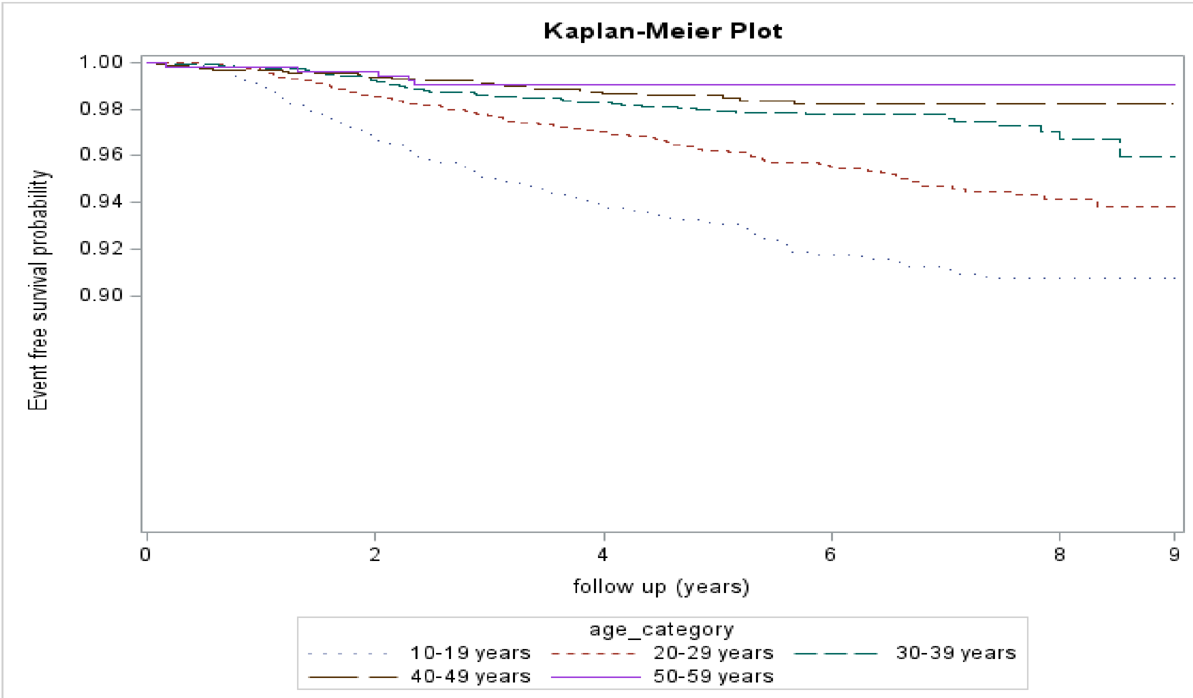

Figure 5.1 Kaplan-Meier survival curve for ipsilateralision ACLR by age category

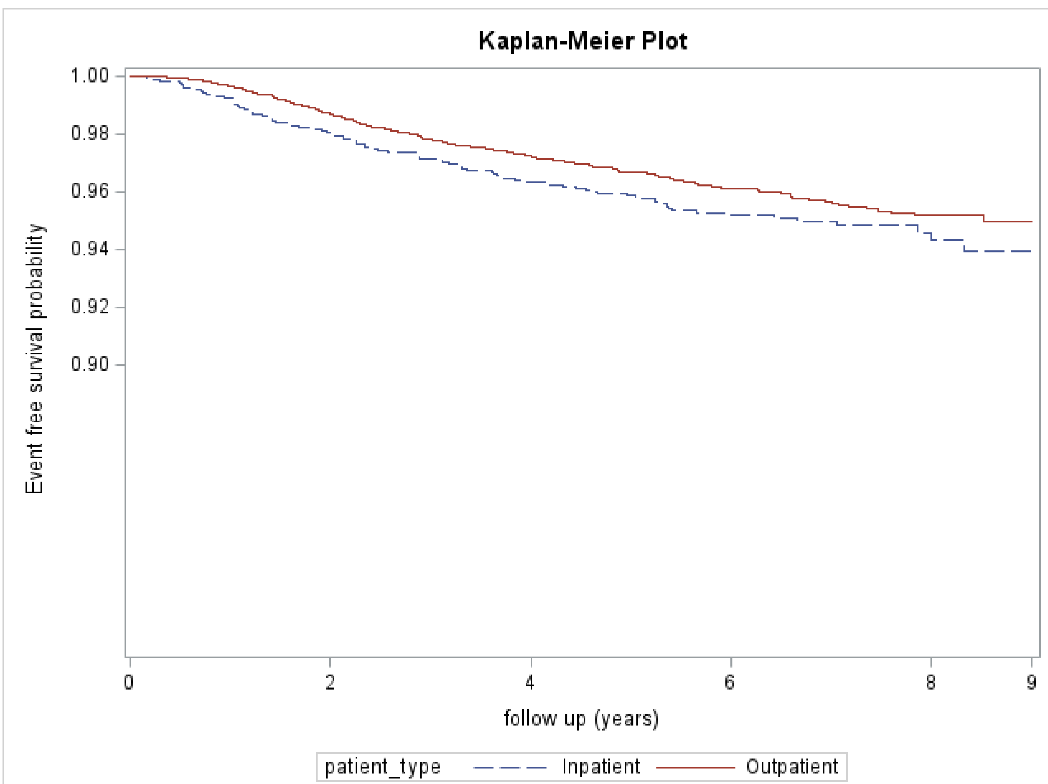

Figure 5.2 Kaplan-Meier survival curve for ipsilateral revision ACLR by outpatient/inpatient setting

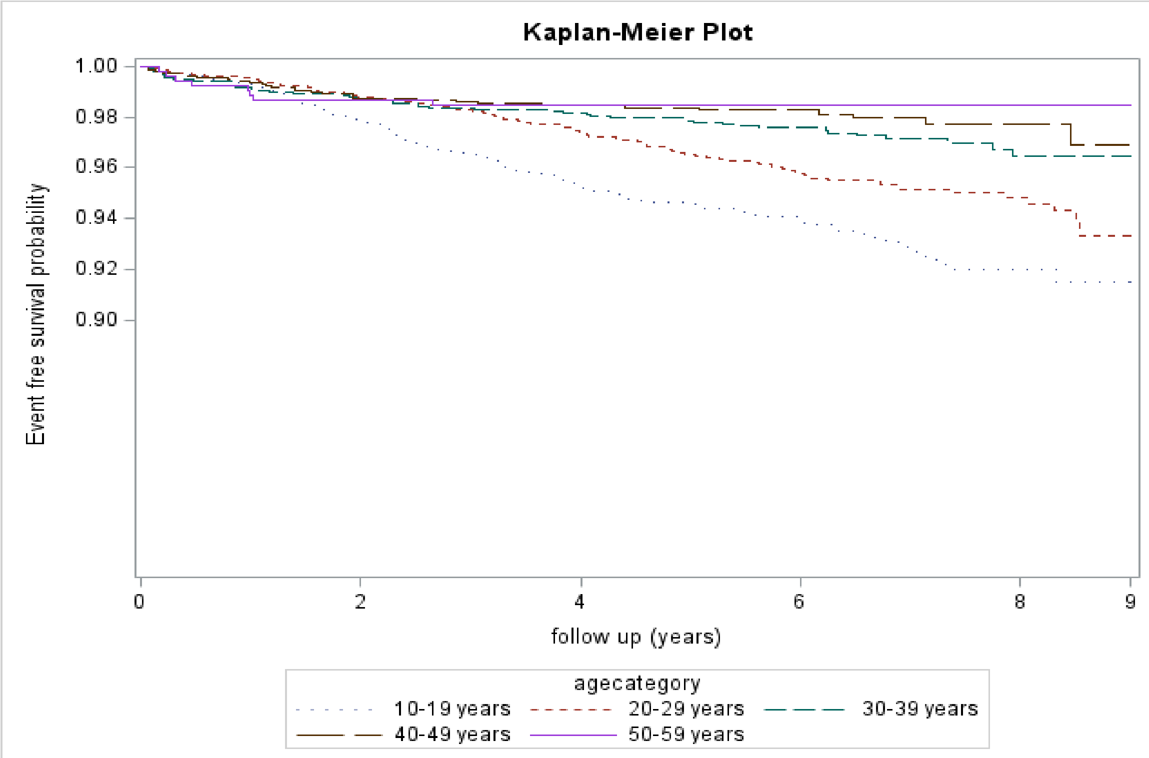

Figure 5.3 Kaplan-Meier survival curve for contralateral ACLR by age category

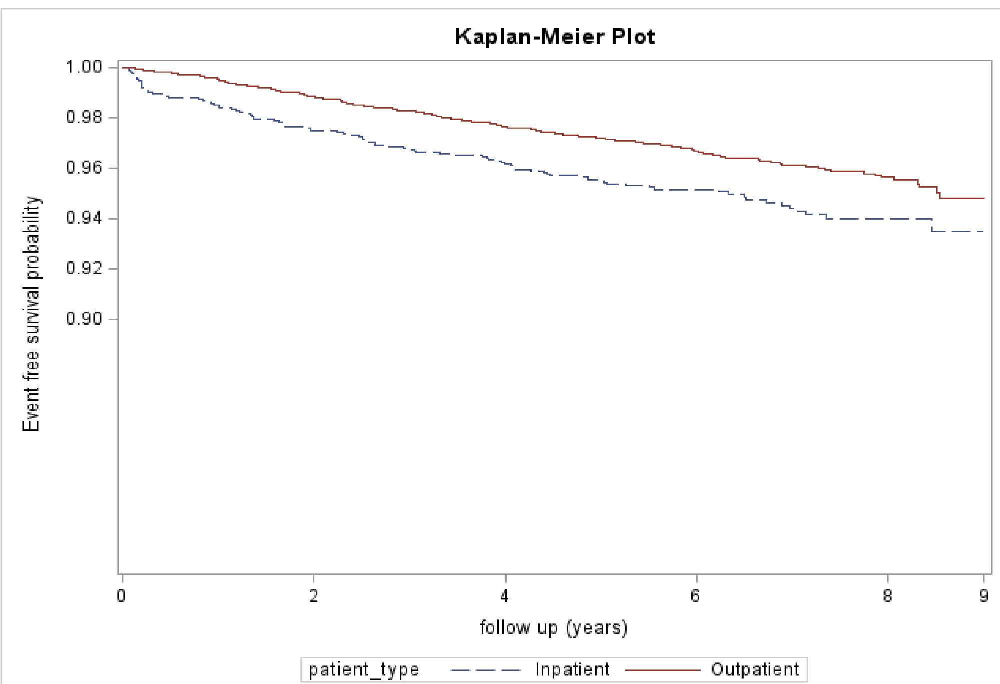

Figure 5.4 Kaplan-Meier survival curve for contralateral ACLR by inpatient/outpatient setting

Table 5.1. Characteristics of the cohort

Variables	Ipsilateral revision ACLR				Contralateral Primary ACLR			
Patient-related factors	Initial cohort (n=9,292)		Revision ACLR (n=359, 3.9%)		Initial cohort (n=9,636)		Contralateral ACLR (n= 344, 3.6%)	
Age category	n	%	n	%	n	%	n	%
10 to 19 yrs	1,955	21.0	150	7.7	2,084	21.6	129	6.2
20 to 29 yrs	2,955	31.8	127	4.3	3,074	31.9	119	3.9
30 to 39 yrs	2,351	25.3	54	2.3	2,410	25.0	59	2.4
40 to 49 yrs	1,502	16.2	23	1.5	1,531	15.9	29	1.9
50 to 59 yrs	529	5.7	5	0.9	537	5.6	8	1.5
Gender								
Females	4,055	43.6	170	4.2	4,227	43.9	172	4.1
Males	5,237	56.4	189	3.6	5,409	56.1	172	3.2
Charleson Index								
0	9,224	99.3	357	3.9	9,566	99.3	342	3.6
>=1	68	0.7	2	2.9	70	0.7	2	2.9
Income Quintile								
Q1 (poorest)	1,319	14.2	50	3.8	1,367	14.2	48	3.5
Q2	1,373	14.8	53	3.9	1,419	14.7	46	3.2
Q3	2,081	22.4	82	3.9	2,159	22.4	78	3.6
Q4	2,148	23.1	77	3.6	2,224	23.1	76	3.4
Q5 (richest)	2,371	25.5	97	4.1	2,467	25.6	96	3.9
Place of residence								
Urban	8,159	87.8	324	4.0	8,458	87.8	299	3.5
Rural	1,133	12.2	35	3.1	1,178	12.2	45	3.8
Surgery-related factors								
Surgery years								
2011-2014	5,998	64.6	260	4.3	6,253	64.9	255	4.1
2015-2016	3,294	35.5	99	3.0	3,383	35.1	89	2.6

Setting of surgery								
Outpatient/same day surgery	7,495	80.7	271	3.6	7,741	80.3	246	3.2
Inpatient	1,797	19.3	88	4.9	1,895	19.7	98	5.2
Season of surgery								
Spring	2,460	26.5	82	3.3	2,539	26.4	79	3.1
Summer	1,991	21.4	69	3.5	2,075	21.5	84	4.0
Fall	2,494	26.8	99	4.0	2,587	26.8	93	3.6
Winter	2,347	25.3	109	4.6	2,435	25.3	88	3.6
Graft type								
Autograft	8,379	90.2	325	3.9	8,691	90.2	312	3.6
Allograft	594	6.4	28	4.7	618	6.4	25	4.0
Combined, synthetic, unspecified	319	3.4	6	1.9	326	3.4	7	2.1
Concomitant procedure								
Primary ACL reconstruction only	1,736	18.7	70	4.0	1,818	18.9	82	4.5
Primary ACL reconstruction with meniscus repair	5,419	58.3	186	3.4	5,601	58.1	182	3.2
Primary ACL reconstruction with menisectomy	2,137	23.0	103	4.8	2,217	23.0	80	3.6
Provider-related factors								
Hospital volume (Annual)								
Low (1-24)	205	2.2	8	3.9	211	2.2	6	2.8
Medium (24-99)	2,324	25.0	76	3.3	2,397	24.9	73	3.0
High(>=100)	6,763	72.8	275	4.1	7,028	72.9	265	3.8
Surgeon volume (previous year)								

0	58	0.6	0	0.0	62	0.6	4	6.5
1 to 12	938	10.1	44	4.7	971	10.1	33	3.4
13-50	3,305	35.6	117	3.5	3,414	35.4	109	3.2
51-100	1,440	15.5	53	3.7	1,491	15.5	51	3.4
>100	3,551	38.2	145	4.1	3,698	38.4	147	4.0

Table 5.2. Cox proportional hazard model for ACL revision and contralateral primary ACLR

Variables	Ipsilateral revision ACLR				Contralateral Primary ACLR			
Age category	Hazard ratio	95% CI		P value	Hazard ratio	95% CI		P value
10 to 19 yrs	3.5	2.6	4.8	<.0001	2.4	1.8	3.3	<.0001
20 to 29 yrs	1.9	1.4	2.7	<.0001	1.6	1.2	2.2	0.003
30 to 39 yrs	Ref				Ref			
40 to 49 yrs	0.7	0.4	1.1	0.090	0.7	0.5	1.2	0.180
50 to 59 yrs	0.4	0.2	1.0	0.049	0.6	0.3	1.2	0.127
Gender								
Females	Ref							
Males	0.9	0.7	1.1	0.461	0.8	0.7	1.0	0.116
Charlson Index								
0	0.9	0.2	3.7	0.911	1.0	0.2	3.8	0.938
>=1	Ref							
Income Quintile								
Q1 (poorest)	Ref							
Q2	1.0	0.7	1.4	0.868	0.9	0.6	1.4	0.690
Q3	0.9	0.6	1.4	0.659	1.1	0.8	1.7	0.520
Q4	0.8	0.5	1.2	0.302	1.0	0.7	1.6	0.829
Q5 (richest)	1.0	0.7	1.4	0.826	1.2	0.8	1.9	0.327
Place of residence								

Urban	Ref							
Rural	0.7	0.5	1.1	0.091	1.3	0.8	1.9	0.278
Surgery-related factors								
Surgery years								
2011-2014	Ref				Ref			
2015-2016	1.1	0.9	1.4	0.429	1.1	0.8	1.4	0.526
Setting of surgery								
Outpatient/same day surgery	Ref							
Inpatient	1.3	1.0	1.7	0.046	1.5	1.1	1.9	0.003
Season of initial surgery								
Spring	1.1	0.8	1.5	0.576	0.8	0.6	1.2	0.288
Summer					Ref			
Fall	1.4	1.0	1.9	0.054	1.0	0.8	1.4	0.833
Winter	1.6	1.2	2.2	0.003	1.0	0.8	1.4	0.756
Graft type								
Autograft	Ref							
Allograft	1.5	1.0	2.3	0.039	1.3	0.9	2.0	0.178
Combined, synthetic, unspecified	0.5	0.2	1.1	0.099	0.6	0.3	1.3	0.234
Concomitant procedure								
Primary ACL reconstruction only	Ref				Ref			
Primary ACL reconstruction with meniscus repair	1.0	0.8	1.3	0.986	0.8	0.6	1.1	0.145

Primary ACL reconstruction with menisectomy	1.1	0.8	1.5	0.455	0.7	0.5	1.0	0.066
Provider-related factors								
Hospital volume (Annual)								
Low (1-24)	Ref				Ref			
Medium (24-99)	0.8	0.4	1.6	0.479	1.1	0.4	2.5	0.899
High(>=100)	0.9	0.4	1.8	0.683	1.1	0.5	2.7	0.780
Surgeon volume (previous year)								
0	0.0	0.0	0.0	0.960	1.2	0.4	3.5	0.706
1 to 12	1.2	0.8	1.8	0.388	0.7	0.5	1.2	0.188
13-50	1.0	0.7	1.3	0.961	0.8	0.6	1.1	0.227
51-100	0.9	0.6	1.2	0.439	0.8	0.6	1.1	0.146
>100	Ref				Ref			

Appendix 5.1: Canadian Classification of Health Intervention (CCI) procedural codes for ACLR (Wasserstein et al., 2013)

Autograft

1VL80LAXXA","1VL80UYXXA", "1VL80DAXXA","1VL80FYXXA",

"1VL80LAKDA","1VL80UYKDA","1VL80DAKDA","1VL80FYKDA",

"1VL80LANWA","1VL80UYNWA","1VL80DANWA","1VL80FYNWA",

"1VL80LAFHA","1VL80UYFHA","1VL80DAFHA","1VL80FYFHA"

Allograft

'1VL80LAXXK' '1VL80UYXXK' '1VL80DAXXK' '1VL80FYXXK'

'1VL80LAKDK' '1VL80UYKDK' '1VL80DAKDK' '1VL80FYKDK'

'1VL80LANWK' '1VL80UYNWK' '1VL80DANWK' '1VL80FYNWK'

'1VL80LAFHK' '1VL80UYFHK' '1VL80DAFHK' '1VL80FYFHK'

Synthetic graft

"1VL80LAXXN","1VL80UYXXN","1VL80DAXXN","1VL80FYXXN",

"1VL80LAKDN","1VL80UYKDN","1VL80DAKDN","1VL80FYKDN",

"1VL80LANWN","1VL80UYNWN","1VL80DANWN","1VL80FYNWN",

"1VL80LAFHK","1VL80UYFHN", "1VL80DAFHN","1VL80FYFHN"

Combined graft

"1VL80LAXXQ","1VL80UYXXQ","1VL80DAXXQ","1VL80FYXXQ",

"1VL80LAKDQ","1VL80UYKDQ","1VL80DAKDQ","1VL80FYKDQ",

"1VL80LANWQ","1VL80UYNWQ","1VL80DANWQ","1VL80FYNWQ",

"1VL80LAFHQ","1VL80UYFHQ", "1VL80DAFHQ","1VL80FYFHQ"

Technique not specified

'1VL80LAFH','1VL80UYFH','1VL80DAFH','1VL80FYFH',

'1VL80LA','1VL80DA','1VL80DA','1VLFYKK','1VL78DAKK'

Appendix 5.2: Incidence rate for revision ACLR and contralateral ACLR by age category and sex

Ipsilateral revision ACLR			
Age category	Sample size	Number of events	Event rate per 1000 person years
10 to 19 yrs	1955	150	13.5
20 to 29 yrs	2955	127	7.5
30 to 39 yrs	2351	54	4.0
40 to 49 yrs	1502	23	2.7
50 to 59 yrs	529	5	1.7
Sex			
Females	4055	170	7.4
Males	5237	189	6.3
Contralateral primary ACLR			
Age category	Sample size	Number of events	Event rate per 1000 person years
10 to 19 yrs	2084	129	10.9
20 to 29 yrs	3074	119	6.8
30 to 39 yrs	2410	59	4.3
40 to 49 yrs	1531	29	3.3
50 to 59 yrs	537	8	2.6
Sex			
Females	4227	172	7.1
Males	5409	172	5.6

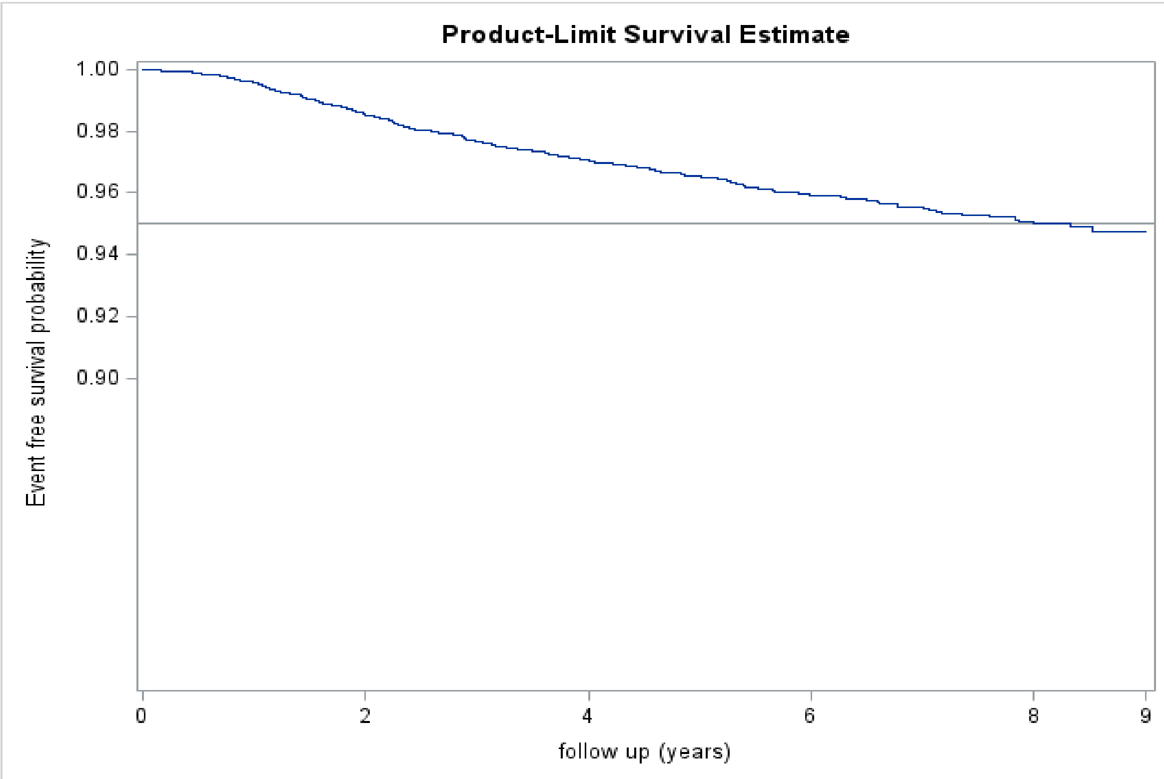

Figure 5A1. Kaplan-Meier survival curve for revision

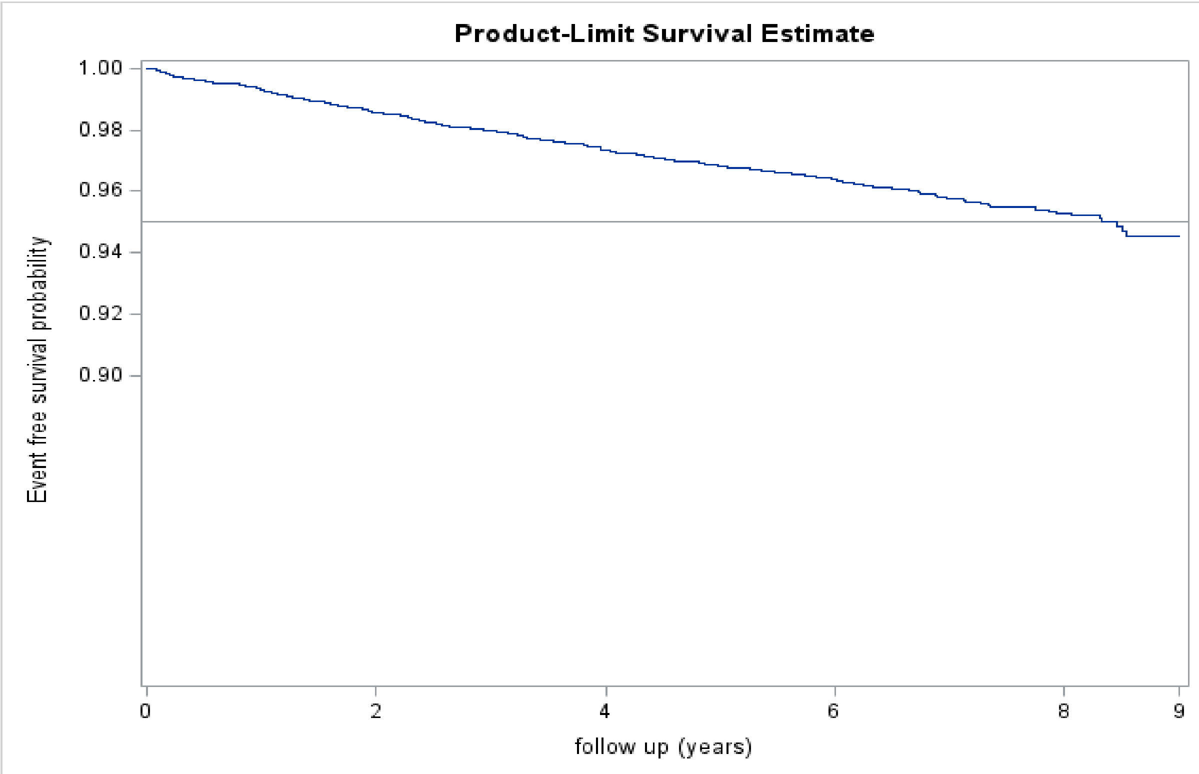

Figure 5A2. Kaplan-Meier survival curve for contralateral ACLR

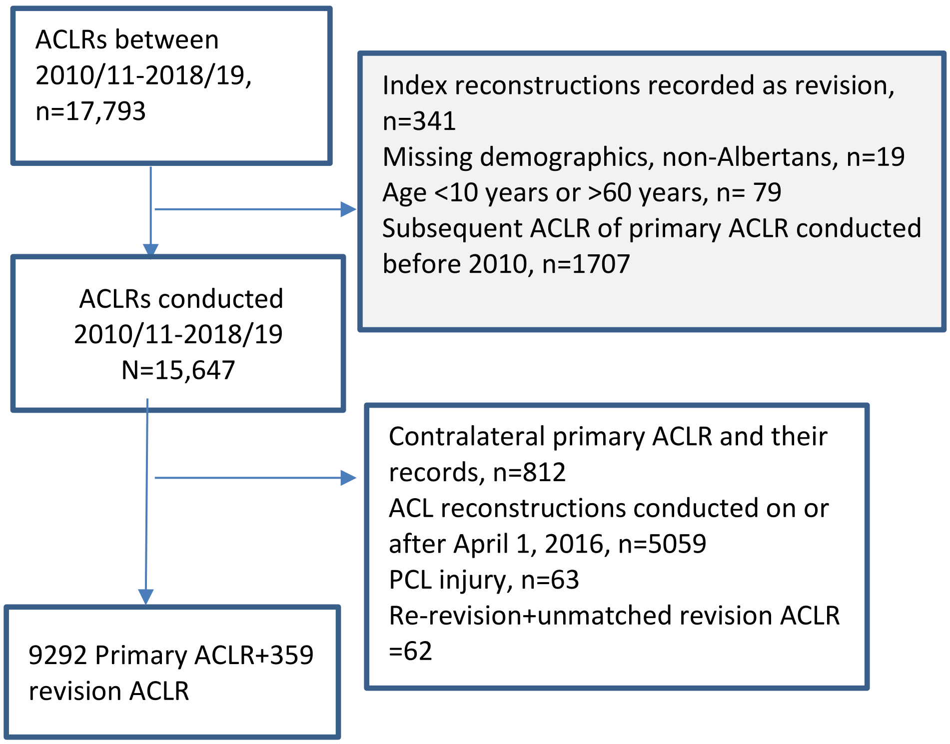

Figure 5A3. Sample selection flow chart (revision ACLR)

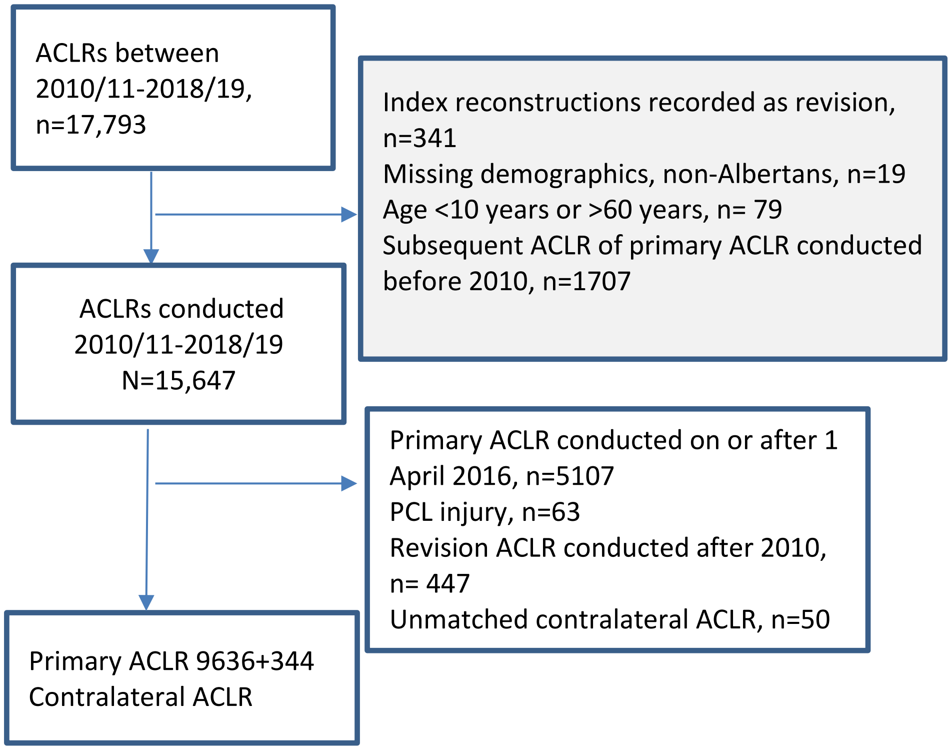

Figure 5A4. Sample selection flow chart (Contralateral primary ACLR)

6. A systematic review on potential facilitators and barriers to implementation of ACL injury prevention program among female athletes[5]

6.1 Introduction

Owing to the short-term and long-term consequences of ACL injury, various ACL injury prevention programs have been proposed. ACL injury prevention programs (IPPs) are found to be effective in preventing non-contact ACL injuries, especially in female athletes (1). A metanalysis of metanalyses on this topic concluded that ACL IPPs are effective in females (2) . However, there is not enough evidence to suggest effectiveness of ACL IPPs in males (2).

Females have been targeted in knee IPPs because of a two- to nine-fold higher injury rate than males (3-7). The higher injury rate and an increase in female participation in sports in the last 30 years has resulted in an increased volume of sport-related injuries in females (8). One study has shown that non-modifiable factors such as anatomical, biomechanical differences (femoral notch size, q angle, ACL dimensions, knee laxity), and hormonal factors are the cause of increased risk for ACL injury (9). Others have looked at modifiable risk factors, including poor jumping/landing techniques, and "neuromuscular recruitment patterns" as being the reasons for the gender discrepancy in injury risk (10-12).

Since a large scale implementation of IPPs have the potential to narrow the gender difference in ACL injury incidence (9), it is necessary to identify the facilitators and challenges/barriers to implementation of ACL IPPs. Only a few studies have been conducted to identify field-level implementation issues (13). Despite the proven efficacy of ACL IPPs, ACL injury rates have not decreased in the United States (14, 15), mainly because of the low participation of high school female athletes in neuromuscular training programs (13-20%), particularly in rural areas (16). It has been reported that coaches' attitudes and perceptions were often not favourable to IPPs (16). Lack of "buy-in," non-compliance to programs, either

[5] This paper was presented in mini-oral session of Canadian Injury Prevention Conference held in Vancouver Canada from 02-04 November 2022.

due to athlete related or coach related reasons (17, 18), and lack of continuity (19) are some of the challenges to the implementation of IPPs.

The specific barriers to program implementation can be grouped into four main categories: time, environment, personnel, and organization (19). Bogardus et al. recently conducted a systematic review on implementation barriers to ACL IPPs (20). They identified five main barriers for implementation: "time, motivation, skill requirement for program facilitators, compliance, and cost" (20). Since, ACL IPPs have been shown to be effective among females and considering the fact that females have different motivating factors (21), different learning styles and different neuromuscular adaptations (22) compared to males, strategies adopted for male athletes may not apply to females. Further, Bogardus et al.'s literature search strategy was not comprehensive as they only searched the PUBMED database and the Cochrane library and did not include grey literature, which may lead to publication bias (20). Moreover, Bogardus et al.'s systematic review focused only on barriers. In this systematic review, we studied potential facilitators as well so that the these can be replicated in other settings. In addition, we used findings from both experimental and cross-sectional studies that have information on potential facilitators and barriers in a comprehensive review of the literature. Therefore, this systematic review was conducted to synthesize updated knowledge on potential facilitators and barriers to implementation of ACL IPPs among female athletes with a robust search strategy using a conceptual framework applicable to implementation climate.

6.1.1 Conceptual Framework

The Consolidated Framework for Implementation Research (CFIR), a model derived from implementation science was used to guide analysis, synthesis, and presentation of data. We believe that CFIR framework provides a better conceptual framework to increase the relevance of our findings to inform implementation (23) compared to an ecological framework. The adapted version of CFIR framework is given in the figure below (Fig. 6.1). The five elements of CFIR framework are: Characteristics of the people involved, process of implementation, characteristics of intervention/program, internal environment, and external environment. CFIR has been widely used in recent days to identify system-level facilitators and barriers to guide adaptation. Some examples of its recent applications include formative evaluation of a colorectal cancer screening program in the United States (24) and a weight management program (25). More recently, CFIR has been used in studies focused in sports injury prevention (26), and in redesigning a national level recreation initiative (27).

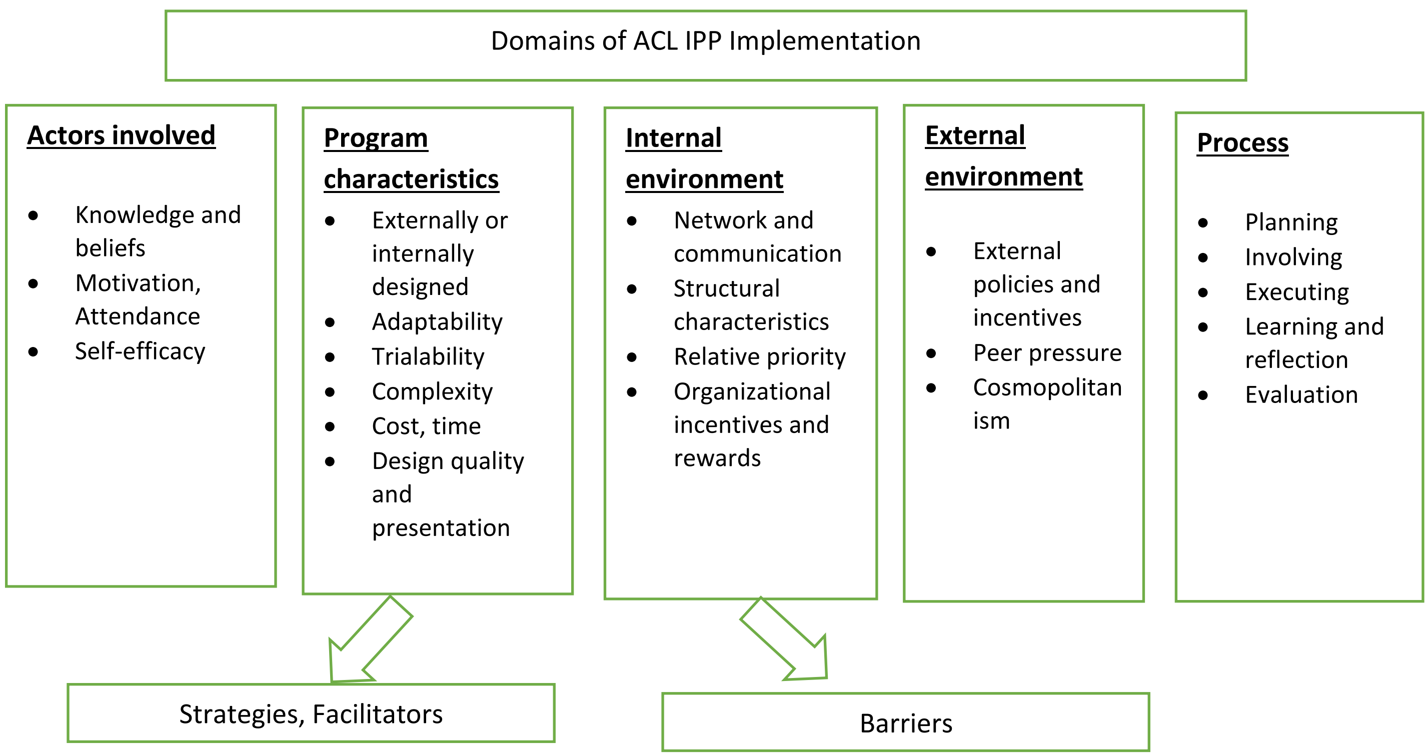

Figure 6.1 Consolidated Framework for Implementation Research to identify facilitators and barriers to ACL IPPs (Adapted from Briggs et al., 2020)(28)

6.2 Methods

6.2.1 Search strategy

A search was executed by an expert searcher/librarian (SC) on the following databases: PROSPERO, OVID Medline, OVID EMBASE, OVID ERIC, OVID PsycInfo, Cochrane Library (CDSR), EBSCO CINAHL, SCOPUS, SPORTDiscus, and Proquest Dissertations and Theses Global, using controlled vocabulary (e.g., MeSH, Emtree, etc.) and key words representing the concepts "anterior cruciate ligaments" and "prevention programs." Studies related to males only were excluded. Studies published in the English language were included. Results (2019) were exported to the Covidence systematic review management system. Duplicates (976) were removed. Detailed search strategies are available in Appendix 1.

6.2.2 Study selection

Two authors, Yuba Raj Paudel (YRP) and Nabil Khan (NK), independently reviewed the study abstracts and titles first. Among the selected studies, a full text review was conducted to select the studies for evaluation. Experimental studies were selected if they had ACL injury as an outcome and had reported at least one barrier or facilitator while implementing a prevention program. We selected experimental studies aiming to reduce ACL injuries or aiming to improve the implementation of IPPs. Similarly, cross-sectional studies investigating the facilitators/barriers to implementation of ACL IPPs were included. Study selection flow chart is shown below (Fig. 6.2).

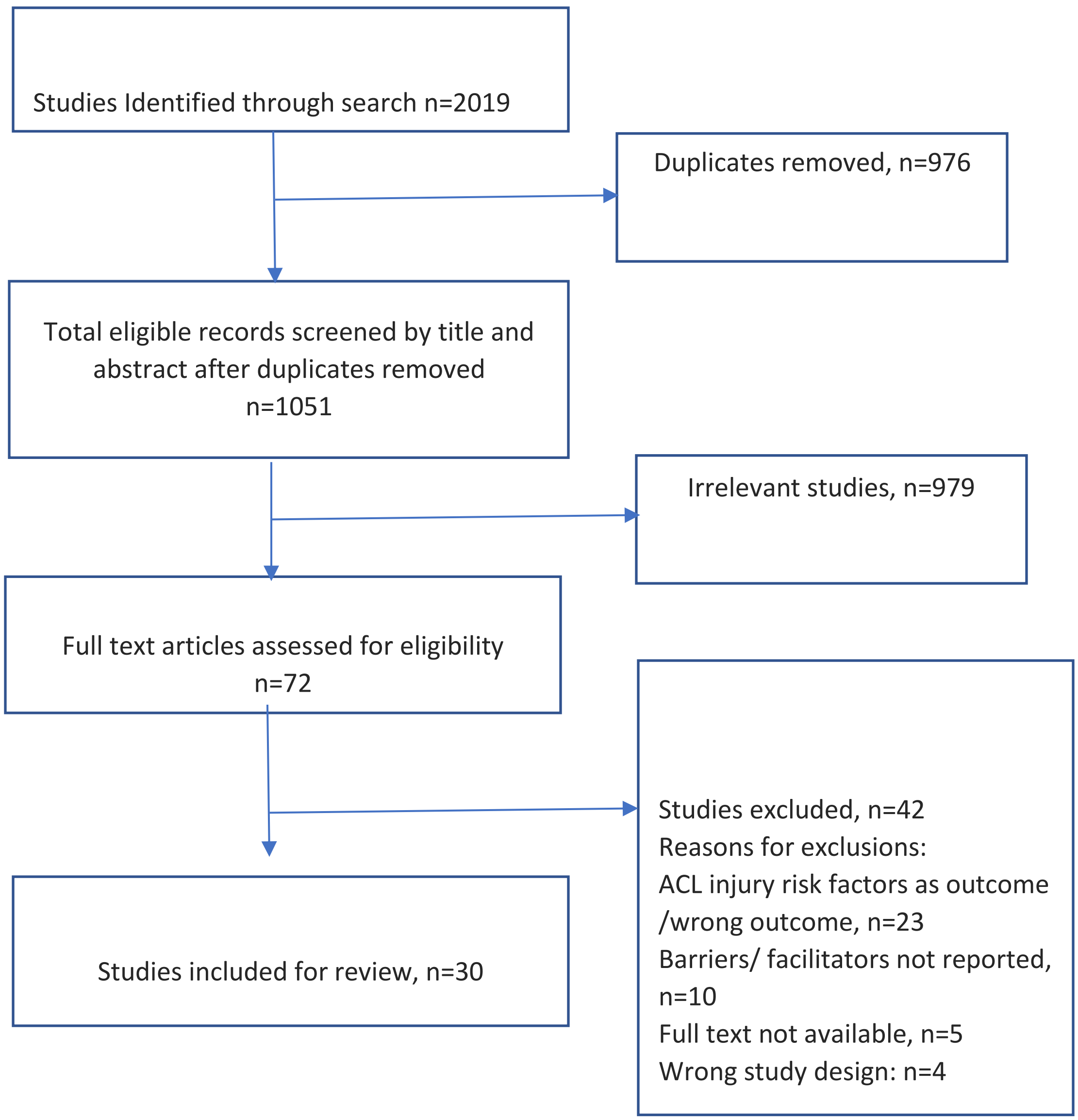

Figure 6.2 Study selection flow chart

6.2.3 Data extraction

Three authors, YRP, Bonaventure Oguaju (BO), and Olivia Antos (OA), extracted all data and were reviewed by Mark Sommerfeldt (MS) and Don Voaklander (DV). We extracted information on separate data extraction sheets for cross-sectional studies and experimental studies. The information extracted from experimental studies included the number and type of participants, description of the intervention, mode of delivery, place of delivery, driver of the program, whether the program was found to be effective to reduce ACL injuries, and facilitators and barriers reported. Similarly, information extracted from cross-sectional studies included: sample size, type of respondent, survey method, response rate, percentage mentioning use of IPP, facilitators and barriers.

6.2.4 Data synthesis

Data synthesis was done using a thematic synthesis approach. Thematic analysis is commonly used in qualitative research; however, it has been also used in systematic reviews (29, 30). The barriers and facilitators were deductively grouped into five main categories based on the CFIR framework. A theme for facilitator or barrier to program implementation was considered for reporting if it was directly or indirectly mentioned in at least two included studies.

6.2.5 Quality appraisal of selected studies

The PEDRO scoring checklist (31) was used for assessing quality of experimental studies and AXIS criteria was used for assessing quality of survey/cross-sectional studies (32). According to PEDRO scale studies, scoring 8 or above can be classified as high-quality studies, studies scoring 5-7 as medium-quality studies, and those scoring less than 5 as low-quality studies. No numerical cutoff was available to assess quality of cross-sectional studies using AXIS criteria (28, 32). Based on the approach adopted by Briggs et al., we looked for missingness to report four or fewer key elements to determine high quality (28).

6.3 Results

Characteristics of included studies

A total of 19 experimental studies and 11 cross-sectional studies were included in this review. Of the 19 experimental studies included in our review, seven studies were from the United States, and eight studies were from Scandinavian countries (Sweden and Norway). Six studies were blinded either to assessors or coaches and 13 studies were not blinded. Fourteen studies were found to be effective to reduce ACL injuries. Eight studies involved soccer players/coaches, and other studies included handball (n=4), football (n=3), basketball, hockey, and volleyball players. Similarly, we included 11 cross-sectional studies total in this review. Most of the respondents were coaches/trainers of athletic teams. Data in cross-sectional studies were mostly collected through web-based or online surveys.

Assessment of quality of included studies

Of the 19 experimental studies included in the review, 10 were of moderate quality (i.e., Pedro score 5-7) and 9 were of low quality. Among the 11 cross-sectional studies, three were of high quality (33–35), i.e., reported 16 or more out of 20 items. Remaining studies reported 12-15 items. The following section reports findings on facilitators and barriers categorized according to five domains of CFIR framework.

6.3.1 People-related factors

Facilitators

Several experimental studies showed that coaching was the most important factor to ensure implementation of IPPs (Table 16). Coaches who were highly motivated and who believed that IPPs reduce injury among (36)**,** and those who were autonomous to decide modality of implementation were found to be more likely to implement IPPs (37, 38).

Cross-sectional studies reported that coaches' attitude, motivation, and experience were the most influential factors for adoption and implementation of injury prevention (21, 33, 39–41). A coach's positive attitude, motivation, and belief that implementing an IPP can impact chances of injury (33, 34, 39, 42), and enhance athletic performance (33) were facilitators to program implementation. Joy et al. found that coaches with longer coaching experience were more likely to adopt/implement the IPP (35). Further, coaches' acceptance of change regarding IPP, self-education and personal playing experience were associated with successful IPP (35). Martinez et al. reported that coaches' belief that IPP would improve health and quality of life of athletes was associated with high (21).

Additionally, coaches impacted by ACL injury, either personally or in a team environment, were more likely to implement an IPP. One study showed that coaches who have been affected by an ACL occurrence within the athletic population, who are aware of ACL injuries and who believe the ACL injury can be reduced by injury prevention training were more likely to utilize ACL (41). Similarly, coaches involved in girls' sports were more likely to be affected by ACL injury, and those holding coaching credentials were more likely to seek out prevention and implement an ACL IPP (41). Similarly, Terrel found that coaches receiving some formal training on proper resistance, plyometric training principles were more likely to prioritize strength training in the offseason (43). Further, coaches' personal playing experience was positively associated with implementation of an IPP (35).

Use of an IPP was also associated with athlete motivation, attendance, and characteristics and the sports they were involved in (43, 44). High attendance and compliance to prescribed programs by players was another facilitating factor for effective implementation of IPPs. Weir et al. (37) reported 81% ± 25% and 88% ± 20% attendance and compliance respectively, with attendance only missed due to injury as advised by team medical staff. Athlete engagement was high, with 89% ± 12% athlete commitment, 90% ± 11% motivation, and 92% ± 10% (37). Similarly, Olsen et al. reported 87% compliance and suggested that training young players who have not yet established a motion pattern may be an easier target for implementing IPPs than older athletes (45). U15-U19 teams were more likely to have a coach that used an IPP, and more likely to perceive lower extremity injuries to be a problem for their team and their athletes to be at high risk, as opposed to coaches of younger athletes (44).

Barriers

Older, overweight, and less physically fit coaches tended to include fewer exercises suggesting that coaches are less likely to implement IPPs if they have difficulties in demonstrating the exercise (36)**.** Another study indicated that inexperienced coaches tended to implement IPPs less frequently than experienced coaches (46). It was also found that motivation of coaches to implement neuro-muscular training (NMT) programs declines as the season progresses (47)**.** Similarly, Pfiefer et al. reported that coaches were not willing to participate in the prevention program because it changed their practice (48).

Deteriorating player attendance at training sessions over the season (47) and players' perception that injuries do not have long-term consequences i.e., a belief that the only concern is having to undergo surgery and 6-9 months of missed sports participation. This belief was common among team handball players, which could have led to low compliance (49). One study involving balance board training for female soccer players showed that dropout athletes in the intervention group (n=32) were significantly older (22.5 vs. 20.4 years) and taller (169 vs. 165 cm) than the players who continued to play soccer throughout the season (50). However, the authors did not mention whether the dropout from the IPP was due to IPP or due to other factors. Low attendance by players and complaints from the players reporting less satisfaction and low motivation was also other reported in another study (33).

On the other hand, coaches' perceived time constraints (34, 35, 39, 40) , unawareness of ACL IPPs(39, 40), lack of knowledge and skill on how to implement programs (35, 39) and lack of knowledge on how to give adequate feedback to athletes on injury prevention techniques(35) were some of the barriers to adopt IPPs. One study showed that coaches' perceived time constraints to participate in interactive workshops, and variability in implementation compliance were barriers to implementing the IPP (51). Furthermore, if coaches believe that

IPPs do not reduce injury but instead steal valuable time for preseason sports training, they are less likely to implement IPPs (52). Not having enough time to develop the program and not wanting an IPP at all were also reported (42). Similarly, “did not have time to complete the program” and “forgetting to do the program” – possibly due to boredom with doing exercise alone at home by athletes – were also identified as barriers to program implementation in at-home settings (53). Coaches’ lack of knowledge on the benefits of IPPs (41, 44), lack of awareness about whether sport-related injuries can be prevented (21), and being unaware of long-term ramifications of lower extremity injuries were deemed to be barriers to the use of IPPs by coaches of younger female soccer players (44). Male coaches were more likely to disagree with the statement "I believe conditioning athletes at the high school level is secondary to sport skill development" (43).

Table 6.1 People related facilitators and barriers to implementing ACL IPPs

CFIR element	Facilitators	Barriers
People-related	▪ Highly motivated coaches (33, 34, 36, 39, 42). ▪ Coaches’ autonomy to decide modality of (37,38). ▪ Coaches’ personal experience (team impacted by ACL injury, years of coaching experience, coaches’ playing (35,41). ▪ High attendance, motivation, commitment, and compliance with	▪ Coaches with difficulty demonstrating either due to unawareness or lack of skill (36, 46). ▪ Lack of knowledge and skill on how to implement IPP, and how to give feedback (35, 39). ▪ Coaches’ perceived time constraints (34, 39, 40, 42, 52). ▪ Player and coach motivation declines over the time (47).

	the prescribed programs by players (37, 45). ▪ Training young players who have not yet established a motion pattern (45,49).	▪ Low compliance by players (due to perceived time constraints among athletes (47), boredom of doing exercise alone in an at-home setting (53). ▪ Low attendance, less satisfaction, and compliants from players (33).

6.3.2 Intervention/program related factors

Facilitators

An IPP that is internally designed with the involvement of relevant stakeholders, especially with the involvement of coaches, is more likely to succeed (37, 54) (Table 17). Kiani et al. designed a soccer specific IPP for female athletes by involving a physician, an orthopedic surgeon, a physiotherapist, and elite soccer coaches (54). Similarly, coaches were given authority to design the intervention to fit their cohort and to determine intensity and duration of training in another (37). Therefore, programs designed by athletes and practitioners who know the circumstances where the IPP will be implemented can increase chances of its implementation (37, 55).

The IPP needs to be adaptable and context-specific without compromising its clinical effectiveness (Table 17). Kiani et al. introduced education to both coaches and athletes with a clear instruction on how to perform the IPP (54). The authors highlighted that the IPP needs to be specifically designed according to the athletes' needs, while also keeping the athletes' gender into account (54). The IPP exercises need to be tailored to the sport (45), and requirements of the team by age and skill level (33). If IPP exercise is integrated into the sport-specific exercises, then they are more likely to save time and improve sports performance while simultaneously preventing injury (52)**.** Similarly, the exercises and modules employed need to be gender-specific and suitable for the daily routine of athletes (55).

A program that has a variation/progression of exercises from easy to difficult over time can motivate athletes and coaches. Weir et al. introduced a phase-wise implementation involving a control season, an intensive intervention season (4 times a week *20-minute sessions) for nine weeks, followed by a maintenance phase (3 times a week *10-minute session) for 16 weeks (37). Athlete attendance, motivation, and compliance were >80%. Similarly, Achenbach et al. implemented a 15-minute training program over a period of 10 to 12 weeks pre-season (two to three times a week) and once a week during the season with exercises progressing from easy to difficult (55).

If IPPs can be used as a part of warm-up exercise and take 20 minutes or less, has easy-to-use instruction materials, and easy-to-follow exercises which take less than 20 minutes, they were more likely to be adopted (34, 53). Pfeiffer et al. also highlighted that because of limited practice time for many youth-sport and school-based programs, an IPP that requires less than 20 minutes may be easier to implement (48)**.**

Kiani et al. used the combination of existing sports-specific agility exercises, which required no extra equipment, made the program easy to implement by teams at no cost (54). Achenbach et al. highlighted that IPP exercises that require no or low financial investment to integrate into the daily routine of the players was a facilitator to implementation (55).

Barriers

The low compliance with IPPs is caused by a number of intervention/program-related factors (56). The short duration of pre-season, mid-season preparation period, and a short competitive season means athletes have less time to focus on IPPs (45, 56). In addition, having matches scheduled on weekdays further limited the time available for IPP training (56). Furthermore, having too many exercises to be carried out during every training session, generally without progression or variation can reduce motivation among coaches and players

(42). Long duration exercise programs (>15-minute exercise) was reported by participants with (<50% compliance) in another study (53).

Table 6.2 Program-related facilitators and barriers to implementing ACL IPPs

CFIR element	Facilitators	Barriers
Program/ Intervention	▪ Internally designed program (especially coach involvement (37, 54). ▪ IPP with enough stimulus but not too long (less than 15 or 20 minutes (37, 55). ▪ At least three times a week with 10-15 minutes per session (37, 55). ▪ Program with variation of exercise over time from simple to difficult exercise (37, 55). ▪ IPP that can enhance sports performance while reducing injury (35, 37). ▪ IPP tailored to athlete needs and gender, specific to sports (33, 46, 54). ▪ Good instruction (50, 52). ▪ Program with no/less cost (54, 55).	▪ Short duration of pre-season, mid-season preparation time. ▪ Having matches scheduled (45, 56). ▪ Too many exercises in each training session, little progression, and no variation in IPP exercise (42, 45, 56). ▪ Just once or twice a week during competitive season (45, 56). ▪ Long duration of IPP exercise (53).

6.3.3 Internal environment-related factors

Facilitators

Provision of supportive resources and materials is also a facilitator to implementation of an IPP (Table 18). Steffen et al. provided balance mats and a brochure detailing the intervention program (56). Similarly, Pfiefer et al. provided personal instruction, Knee Ligament Injury Prevention (KLIP) program manual, instructional videotape, and printed handouts to the teams participating in the intervention arms to enhance the effective implementation of the program (48). Data-reporting forms were provided to all participating team coaches to track all players (48). In another study, Frank et al. set up a predetermined IPP schedule, and mechanisms for reminders/emails to facilitate coaches implementing IPPs (51).

Having rewards and incentives for implementing IPPs can motivate athletes and coaches (Table 18). Kiani et al. found that availability of monthly newsletters helped to increase athlete motivation and adherence by keeping them informed of the club and external news (54). In another study by Caraffa et al. (57), the players were promised an immediate check-up by the senior author in case of a possible knee injury in return for participating in the study. Therefore, having a club policy to implement IPP backed up by provision of rewards and punishment can enhance motivation.

Availability of additional staffing and resources increased chances of program implementation. Coaches who have access to athletic resources (39), who have a presence of additional support staff (strength and conditioning coach or athletic trainer) (35), access to intervention resources and coaching courses (34), and availability of facilities in schools (43), were more likely to use IPPs. Further, providing coaches with training opportunities and instruction methods about ACL IPPs and education on the use of programs that can be used with minimal time requirements could be helpful to improve program implementation (40).

Having IPP policy in place at the institution (46, 51), and trustful environment in the team (21) can enhance program implementation. Confidence and trust in the coach that they can deliver an injury prevention program (21), and a belief that the IP program can contribute to injury prevention/player safety, performance enhancement (40) were identified as facilitators to IPP implementation.

Barriers

Time constraints and competing schedules may prevent participants from participating in the IPP sessions (48). Furthermore, absence from a game or practice session occurs because of injury (50). Additionally, discontinuation of IPPs by some clubs after an initial intensive phase (45), and not tracking/monitoring the program fidelity is also a barrier to effective implementation of IPPs (38).

Governing bodies such as sports associations and district-level bodies not being aware of guidelines regarding IPP education, information, and implementation can be an impeding factor for widespread IPP program (46).

Similarly, lack of formal policies/guideline for implementation and use, lack of internal education to coaches (33), lack of information/misinformation about efficacy and accessibility of IPP (34) reduces the chances of IPP implementation. Additionally, not getting athletes and parents to support the program (35) also affected implementation. Furthermore, lack of coaches' confidence on whether they can implement the IPP program, combined with lack of athletes’ trust in coaches, were other barriers to implement IPPs (21).

Table 6.3 Internal environment-related facilitators and barriers to implement ACL IPPs

CFIR element	Facilitators	Barriers
Internal environment	▪ Availability of resources, i.e., video, manual, forms (48, 51, 56). ▪ Predetermined schedule, reminder/recalls (51). ▪ Availability of supporting manpower (strength and conditioning coach, athletic trainer) (35, 39). ▪ Training/education opportunities for coaches (40). ▪ Having IPP policy in the club (46, 51). ▪ Confidence and trust in coach that s/he can deliver the program (21). ▪ Common belief that an IPP reduces injury and enhances performance (40). ▪ Provision of incentives and rewards (54, 57).	▪ Time constraints, conflicting time scheduling (48). ▪ Unawareness about IPPs among governing bodies, e.g., sports associations, district bodies (45). ▪ Gap between policy and practice (45, 51). ▪ Misinformation about program efficacy (34). ▪ No support from parents/athletes (35). ▪ Lack of confidence among coaches (21).

6.3.4 External environment-related factors

Facilitators

Support from district-level association and the club (e.g., by practical workshops and annual follow-ups) and other coaches on the team, more possibilities to vary and tailor the IPP to the needs of the team (e.g., based on age group or proficiency), and easy access to the IPP were some of the facilitators for program adoption and use (46) (Table 19).

A study reported that availability of evidence demonstrating that they would suffer fewer injuries as a result of IPPs was a motivating factor for females to follow IPPs, while males are more concerned about performance (21). If IPP training improved sports performance despite taking time away from practice sessions, it was more likely to be implemented (37). Joy et al. also reported that the evidence of injury prevention benefits and performance enhancing benefits most notably influenced adoption and implementation of IPPs (35). Similarly, quality of instruction by trainers/coaches/physiotherapists on how to perform the training program can be a positive factor for effective program implementation (50, 52).

Community outreach programs allowing coaches the opportunity to present ACL IPPs to athletes and the public (parents and general population) can increase participants' awareness of ACL injury and ACL IPPs (41). Furthermore, governing bodies such as the National Football Association emphasizing the IPPs' effectiveness, was a facilitator for program implementation (33).

Coaches agreed that enacting a provision of compulsory education on ACL injury prevention for coaching licensure, and policy enactment by soccer associations to implement IPPs, can support implementation (35). They also believed that soccer organizations should take the prime responsibility to disseminate information regarding IPPs. Further, Achenbach et al. opined that provision of sports-specific injury prevention principles need to be included in coach education courses (55).

Barriers

How the media portrays injury and trivializes its consequences also has an impact on athletes' motivation to perform IPPs (49). Furthermore, lack of communication between sporting associations and coaches (34), as well as lack of education for coaches, were barriers to implementing IPPs (34). Lack of widespread appreciation for the long-term sequelae of lower extremity injuries has negatively affected the rate of IPP adoption by coaches (44).

Table 6.4 External environment-related facilitators and barriers to implement ACL IPPs

CFIR element	Facilitators	Barriers
External environment-related	▪ Evidence showing injury prevention benefit of IPPs can motivate athletes (21, 35). ▪ Community outreach programs to spread message about IPPs, support from parents and public (41). ▪ Policy enactment by sporting associations (35, 51). ▪ Mandatory ACL IP education for coach licensure, sports-specific injury prevention in coaching courses (35, 55). ▪ Sports associations disseminating information regarding IPPs and their effectiveness (33, 35).	▪ Under-appreciation of long term ramifications of ACL injury in media and sports community (44, 49). ▪ Coaching courses lack content on IPPs (34, 35). ▪ No communication between sports association and coaches (34, 41).

6.3.5 Process-related factors

Facilitators

Supervision/monitoring by professional athletic trainers and/or external observers with a close involvement of coaches was found to facilitate the implementation of IPPs (Table 20). Gilchrist et al. reported that **t**wo observers visited the eight teams twice during the season (58). Similarly**,** study therapists were instructed to make two unannounced visits to each intervention team during the season, while coaches documented whether the team completed the NMT program in another study (47). In a Swedish study, *s*tudy therapists made two unannounced visits to each intervention team to monitor compliance and execution of the program (38). In another study, the physical therapists attended team-training sessions three times a week for a five- to seven-week period and once a week during the season to supervise the training program (49).

Carrow et al. reported that provision of instant verbal feedback and verbal reinforcement during the exercise and written feedback after the session contributed to successful program implementation (59). In another study by Steffen et al., instructors visited the teams three times during training at the start of the study and again after the summer break, and remained in regular contact with the coaches by phone/mail and by site visits on the pitch to facilitate program implementation (56). Coaches and teammates were encouraged to provide feedback to athletes during the training sessions (56).

Practical training with regular support is necessary to increase program adoption and compliance in addition to education/orientation for coaches about IP exercise to promote coaches' knowledge and attitude. In a study by Myklebust et al. (49), all the physical therapists participated in an eight-hour seminar in which they were given theoretical and practical training on how to conduct the ACL injury prevention program, as well as on the procedures of data collection (49). The IPP implementation rate and compliance with the program improved. However, in another study, Frank et al. spent just 30-40 minutes in an informational session to orient coaches about ACL IPPs (51). Although the information session improved attitude and intention of coaches to implement an IPP after workshop, only half of the coaches actually implemented an IPP (51). The implementation compliance among adopters also showed great variation.

The involvement of many supportive people around the athlete to provide care and feedback was also found to improve IPP adoption and implementation (56). In Omi et al.'s study, the student athletic trainers were regularly present on the training site and actively encouraged all players to perform hip-focused injury prevention (HIP) training (60). To attain a high level of compliance, student athletic trainers were the key. The authors argue that the student athletic trainers also played an integral role in maintaining close communication between the research team and the players by reporting issues in HIP training, filming HIP training videos, tracking injuries, and recording athletic exposure (60). Involvement of club administrators from the planning of the program, regular monitoring of program compliance was reported in another study (51). In Carrow et al.'s study, all exercise instructors in one group completed six training sessions (30 minutes each) with the faculty and the study staff to learn, practice, and provide feedback on the proper execution of their group's assigned warm-up exercises (59). The emphasis on the importance of not overusing young, talented players in matches were found to be facilitators for effective implementation of the IPP (54).

Including parents in meetings with medical staff as a way to reduce barriers was reported in one of the studies (40). Similarly, Haggalund et al. indicated that involving various sports stakeholders including parents and athletes can lead to improved buy-in to the ACL IPPs (47).

Barriers

Some of the common process-related barriers reported in the studies included clubs not regularly introducing warm-up exercise to prevent injury after an initial intensive introduction program (45), lack of policy enforcement, and lack of regular supervision from club administrators (51). Lack of enforcement of national policy by district level/local sports associations in their daily practice results in inadequate injury prevention training to players

(45). It was also found that some teams implemented programs with low fidelity by either modifying the content or not performing the program regularly (33).

Table 6.5 Process-related facilitators and barriers to implement ACL IPPs

CFIR element	Facilitators	Barriers
Process-related	▪ Frequent supervision, monitoring, and support (47, 51, 54, 58–60). ▪ Instant feedback, verbal reinforcement during exercise by teammates and coaches (56, 59). ▪ Practical education/orientation to coach on IPP followed by regular support (49, 51). ▪ Involvement of multiple stakeholders, including parents (40, 47, 51).	▪ Not following national policy in daily routine by district/local sports bodies (45, 46). ▪ No policy enactment, lack of regular supervision (51). ▪ Low program fidelity (33, 51).

6.4 Discussion

A growing interest is observed in identifying strategies for dissemination and implementation of effective interventions to reduce ACL injuries in different sports (61, 62). The present study aimed at systematically reviewing the evidence on strategies, facilitators, and barriers to implement IPPs from studies aimed at reducing ACL injuries or those exploring the experiences/views of concerned stakeholders (athletes, coaches, and sports associations). Nineteen experimental studies and 11 cross-sectional studies were identified. Most of the studies were from the United States and Scandinavian countries. Soccer, basketball, and football were the most common sports studied. Methodologically, most of the included studies were of moderate to low quality.

Findings from experimental and cross-sectional studies confirm that coaches are critical for IPP implementation. Therefore, improving coach motivation by orienting them in double benefits (sports performance enhancement and injury reduction) of the IPP and correcting the perceived time constraints is important (34). Simultaneously, creating an enabling environment by availing coaches of required knowledge, skills, and enough resources is vital to enhance their capacity to implement IPPs (36). Readily available courses such as "11+" and "11+ Kids" can be included in coaches' courses, and nationwide campaigns can be launched for large scale implementation (63). Finally, provision of compulsory ACL IPP education for coach licensure has the potential to complement strategies to promote implementation of ACL IPPs (35).

Since player attendance and motivation was found to drop over the season, identifying factors to improve player attendance needs to be a priority. One of the factors to motivate athletes would be to design IP exercise with progression from easy to difficult over time and tailoring exercise according to a different proficiency level, age, and gender (56). Similarly, provision of feedback and verbal reinforcement during IPP exercise can keep athletes focused and motivated. Furthermore, ACL IPPs need to be of short duration –. 10-15 minutes during competitive season – and integrated into routine warm up to maintain coach and athlete motivation. Given the inverse dose response relationship between IPP training volume and injury incidence (6), implementing a IPP at least twice a week (15 minutes*2 days totaling 30 minutes per week) during the season may be a practical approach. Furthermore, the IPP needs to be started preseason and continued throughout the season (55).

A number of studies showed that involvement of trained personnel/external experts and provision of instant feedback or written feedback was a key factor for program effectiveness (56, 59). However, the involvement of athletic trainers/physiotherapists throughout the season can be costly. Therefore, initial involvement of external experts (athletic trainers/physiotherapists) and program continuation by coaches may be a cost-effective approach to maintain program fidelity without significantly increasing cost.

Since support from the parents and athletes can be a strong force for adoption and long-term program sustainability, parents and athletes should be involved from the very beginning to increase their awareness and eventually increase program compliance (47,51). Finally, having a multidisciplinary team for an IPP, including those implementing the program, program supporters (parents, administrators), athletes, and decision makers/policymakers, can help to reduce barriers and improve program sustainability.

Improved communication between country/district level sports associations and clubs/coaches is vital not only to inform coaches of various IPPs, but also helps in large-scale dissemination of evidence-based IPPs. The gap between injury prevention researchers and safety promotion practitioners can be bridged by open communication, transdisciplinary approaches and collaborative efforts among researchers, policymakers and the sports community (64). It also helps to convert ”evidence-based practice” to ”practice-based evidence” so that IPPs are owned and implemented by coaches and athletes.

Only few experimental studies explicitly mentioned strategies, facilitators, and barriers to implementation of IPPs in their results section. Most of the studies indirectly mention them in the methods and discussion section. Therefore, there is a need of pragmatic trials that assess effectiveness of the IPP, as well as offer a detailed description of facilitators and barriers encountered during implementation. CFIR can be a useful framework for reporting implementation experience to inform policymakers, practitioners, and researchers.

Strengths/limitations

Since most of the experimental studies included in our study were large-scale implementation trials, it is not surprising that the included studies were of moderate to poor quality.However,our findings on facilitators and barriers to implement IPPs are unlikely to be impacted by quality of these studies. Some of the facilitators and barriers identified from experimental studies are not reported as definitive findings from their research; rather, they are mentioned as strategies adopted or indicative as facilitators or barriers. Since the primary aim of most of the selected intervention studies was usually to look at effectiveness of the program to reduce ACL injuries, barriers and facilitators were often reported in the ”Methods” and “Discussion” section. Finally, it is to be noted that having a facilitator in a study does not necessarily mean a program was effective, it simply means it enabled the implementation of an IPP.

6.5 Conclusion

Given the paucity of evidence on facilitators and barriers to implement ACL IPPs, pragmatic trials need to be conducted. Existing evidence suggests that coach motivation and competency improvement, along with easy availability of resources, has the potential to improve IPP implementation. Programs co-designed by researchers and practitioners considering the needs of the athletes and coaches that can be implemented with little to no cost might be easier to implement. Finally, a collaborative effort by researchers, practitioners, and policymakers is imperative to produce”practice-based evidence” ensuring large scale implementation of IPPs.

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Table 6.6. Experimental studies included in the review

Author, year	Country, State/Province	Study design	Sport	Participant age	Participant gender and number	Intervention	Effective to reduce ACL injury	PEDRO SCORE
Caraffa et al, 1996	Umbria and Marche, Italy	A prospective cohort study	Soccer	Not reported. Semi-professional and amateur teams	600 players in 40 teams. Gender (NA)	Gradually increasing proprioceptive training on four different types of wobble-boards	Yes	2
Söderman et al, 2000	Umeå and Stockholm, Sweden	Prospective randomized intervention study	Soccer	Mean age = 20.4 years	Female = 140	Balance board training program which contained five exercises with progressively increasing degree of difficulty	No	4
Myklebust et al, 2003	Norway	Prospective intervention study	Handball team: Division I - III	Not reported	Control season, n=942, First intervention season n= 855, Second intervention season n=850, female players	A five-phase program (15-minute duration) with three different balance exercises focusing on neuromuscular control and planting/landing skills and addresses many aspects of risk for injury (agility, balance, awareness of vulnerable knee positions, playing technique)	Yes	5
Odd-Egil Olsen et al, 2005	Central and Eastern Norway	Cluster randomized controlled trial	Handball	15 - 17 years	Male=251 Female=1586	A structured warm-up program to improve running, cutting, and landing technique as well as neuromuscular control, balance, and strength	Yes	7

Mandelbaum et al., 2005	Southern California, United States	Non-randomized cohort study	Soccer	14-18 years	Competitive female youth soccer players.	Instructional videotape, literature packet to players, education, stretching, strengthening, plyometrics, and sport-specific agility drills Briefing to coaches on Prevent Injury and Enhance Performance (PEP)	Yes.	3
Petersen et al., 2005	Northern Germany	Prospective case-controlled study	Handball	Not reported	Female = 276	Information about injury mechanism, balance-board exercises, and jump training	Yes	2
Pfeiffer et al., 2006	Southwestern Idaho, United States	Prospective cohort design	Soccer, basketball, and bolleyball	Varsity, junior varsity, and sophomore levels, not reported age	Female = 1439	Knee ligament injury prevention exercise program for development of sound body mechanics when decelerating during running with directional changes and when landing on one or two feet	No	2
Gilchrist et al., 2008	United States	Cluster randomized controlled trial	Soccer	Not reported	Female = 1435	PEP program, which consists of warm-up, stretching, strengthening, plyometrics, and sport-specific agility exercises to address potential deficits in the strength and neuromuscular coordination of the stabilizing muscles around the knee joint	Yes	4
Steffen et al, 2008	Norway	Cluster-randomized controlled trial	Football	13 - 17 years	Female n = 109 teams (2020 players)	The intervention program – the ‘‘11’’ – includes 10 exercises focusing on core stability, balance, dynamic stabilization, and eccentric hamstrings strength	No	7

Kiani et al., 2010	Uppland and Dalarna Counties, Sweden	Nonrandomized Community-based intervention trial	Soccer	13 - 19 years	Female = 1506	HarmoKnee preventive program to increase overall awareness of injury risk, to provide a structured warm-up program, and to provide strengthening exercises aimed at achieving an improved motion pattern that produces less strain to the knee joint	Yes	4
LaBella et al., 2011	Chicago, United States	Cluster randomized controlled trial	Soccer and Basketball	Students in varsity, junior varsity, sophomore, and freshman teams (age not stated)	Female = 1492	Neuromuscular training which combines progressive strengthening, balance, plyometric, and agility exercises with education on avoiding dynamic knee valgus, a position that increases ACL injury risk, and landing jumps with flexed hips and knees, which reduces ACL strain	Yes	6
Waldén et al., 2012	Sweden	Stratified cluster randomized controlled trial with clubs as the unit of randomizatio nrandomization	Football	12-17 years	Female = 4564	Neuromuscular warm-up program targeting core stability, balance, and proper knee alignment	Yes	7
Hägglund et al., 2013	Sweden	Prospective cohort study based on a cluster randomized controlled trial	Football	12-17 years	Female n = 4556	The NMT program described by Knäkontroll, SISU Idrottsböcker©, Sweden, 2005 on acute knee injuries in female adolescent football players	Yes	5

Frank et al., 2015	North Carolina, United States	Pre-post study after a workshop	Soccer	30 male coaches, age = 34.6 ± 9.1 years)	34 coaches of 15 female teams	Workshop to coaches with information on injury, instruction for on-field set up, exercise for players, video and online materials	No	4
Weir et al.,2015	Australia	Experimental design : repeated measures experiment	Hockey	Mean age: 22.1 ± 2.3 yr;	Elite female hockey players n=26	Team strengthening and conditioning coaches implemented the injury prevention training. Training aimed at increasing knee flexion angle, improve dynamic control of trunk and upper body, strengthen hip external rotator to prevent dynamic knee valgus, strengthen gastrocnemius	Yes	4
Carow et al., 2016	United States	Cluster-randomized controlled trial	Military physical training	Age range = 18–22 years	1st phase: Cadet Basic Training (CBT) = 1313 (n = 243 women, n = 1070 men)	DCS group performed the DIME warm-up under the supervision of upper-class cadet instructors only and DES group performed the DIME warm-up under the direction of the upper-class cadet instructors with the additional supervision of an athlete trainer or a physical therapist. The exercises included a progression from bilateral jumping to unilateral hopping, progression from a forward-plank exercise to a unilateral plank, and from a unilateral balance exercise to a unilateral squat and reach	No	7

Achenbach et al., 2017	Germany	A randomized controlled intervention study	Handball	Intervention group Mean age = 14.9 ± 0.9 Control group mean age = 15.1 ± 1.0	Both genders n = 279	A handball specific injury-prevention program developed for the daily routine in adolescent team handball which included jump exercises, landing exercises, proprioceptive exercises, plyometric exercises and strength exercises for the quadriceps, hamstring and core muscles	Yes.	5
Malin A°man et al., 2018	Sweden	Retrospective cohort study	Soccer	All licensed soccer players—adolescent, amateur, and professional—from a whole nation. Age range was not reported	All soccer players both male and female. Number not stated	KCP include core muscle strengthening and stabilization, proprioceptive training, and dynamic stabilization with the knee, hip, and core aligned with the center of gravity	Yes	5
Omi et al., 2018	United States and Japan	Cohort study	Basketball	Control = 19.6 +/- 1.2 Intervention = 19.6 +/- 1.1	Female n= 757	Education and HIP training to improve hip joint function.	Yes	6

Table 6.7. Cross-sectional studies included in the review

Author, year	**Country, State/ Province**	**Sport**	**Number and type of participants responding**	**Respondent Age**	**Survey method (web based , interview)**	**Proportion reporting use of injury prevention program**	**Quality of the study**
Terrell, 2002 (Dissertation)	Michigan, United States	High school girls basketball, volleyball, and soccer	55 male, 39 female coaches	21-60 years	32-item questionnaire	Those implementing resistance training at least one day per week in season: 50% Those implementing resistance training at least one day per week off season: 79% Those implementing plyometric training for greater than 15 minutes in-season: 51% Those implementing plyometric training for greater than 15 minutes off season: 45%	Medium
Erwin, 2004	Michigan, United States	Boys and girls soccer, boys and girls	Coaches from 21 schools	Not stated	Mailed questionnaire; survey was designed	16 coaches reported being aware of an ACL prevention program, only 5 reported implementing an ACL IPP, no coaches with boys only experience that implemented ACL	Medium

		basketball, girls volleyball			and distributed by mail	IPP, 17.4% of girls only experience implemented an ACL IPP	
Kristoffer J Friend, 2011	United States	Soccer	49 males, 17 females Coaches	Mean age 41.5 +/- 11.2 years	A survey on Surveymonkey.com website	47.8% of coaches had teams that performed the program	Medium
Bailey,2012	United States	Basketball, ski, soccer, football, baseball,	71 males, 70 females athletic trainers	36.09 (±9.46) years	surveymonkey.com	72 participants (48.3%) said they had a injury prevention program in place	Medium
Joy et al, 2013	Utah, United States	Soccer	71 males, 29 females coaches	Mean 41 years	Web-based survey Best practice coaches (those with a program specifically aimed at ACL injury	27 of the 136 identified ACL IPP 914 best practice coaches identified)	High

					prevention and incorporated at least three of the five program elements) were asked to participate in a telephone interview		
Lindblom et al,2014	Sweden	Female Football (Soccer)	126 trial coaches +132 current coaches=258 94 females	46.3(6.4) : trial coaches 43.8(5.9) current coaches	Questionnaire sent through email	72 % among intervention group 58% among control group 74% among current coaches	High
Jill Thein-Nissenbaum, 2016	Wisconsin, United States	Basketball, fall sport (volleyball,	175 female high school students of them n=66 were present	not stated	Action research. Involved a survey of students about their experience of home-based injury	Of the 27 participants who completed post-training surveys, 7 (26%) completed the program more than 11 times (out of 24 total	Medium

		cross country)	at the initial training,		prevention program based on DVD instructions.	sessions), or at least 50% of the requested time.	
Martinez et al., 2017	Connecticut, United States	Field Hockey N = 21, Soccer N = 31, Volleyball N = 24	76 female athletes	15 ± 1 years	Injury Prevention Program Attitude Survey (IPPAS), Paper and pencil-based survey, Likert scale and open-ended questions Repeated measures design (Interviewing people before and after an intervention)	Median compliance with warm-up program was 69% (range: 11–95%)	Medium
Mawson et al., 2018	Ontario, Canada	Soccer	101 coaches	Not stated	Online survey: Survey monkey	29.8% of respondents used an injury prevention intervention	High

Morgan et al., 2018	Oregon and Washingt on States, United States	Soccer	54 coaches 76 teams	42.8 +/- 8.5 years of age	Web-based survey	57 female U9-14 teams and 19 female U15-19 teams (76 teams). 49 (65%) coach was aware of an efficacious lower extremity IPP, 23 (30%) coach used a proven IPP, 13 (17%) coach reported using IPP exactly as designed	Medium
Kingston, 2019	Pennsylv ania, United States	High school soccer coaches	16 male, 14 female coaches	Mean age 39 years (range 23-70)	Online web-based survey hosted by Qualtrics	45% implementation, one commonly used ACL IPP was found to be familiar to greater than 50% of participating coaches (FIFA 11+)	Medium

7. Discussion and Conclusion

Recent population-based studies from developed countries indicate a growing incidence of ACLR, especially in adolescents (1–3). However, there is limited population-based epidemiological data on ACL injury and ACLR in Canada. This thesis aimed to fill this knowledge gap by investigating epidemiological trends of ACLR, by exploring factors associated with ACLR and factors associated with post-operative health care use. The trend of ACLR may be considered a proxy for trends of ACL injury; however, real incidence rate of ACL injury is usually higher than the incidence of diagnosed ACL injuries, as well as the number of ACLRs conducted (4).

The incidence of knee injuries presenting to the ED has declined over the years in Alberta. There was a larger decline among males compared to females, resulting in a narrowing gender gap in knee injuries. Chapter 2 **investigated the epidemiology of knee injuries presented to the ED in Alberta. The results indicate there was a 30% decline in knee injury-related ED visits among males between 2002/03 and 2018/19**, **whereas it has remained almost constant among females.** Females aged 10-19 years and 50-59 years showed an increase in knee injury-related ED visits. ACL injury was reported among nearly one-fifth of knee injuries, making it the most common ligament injury, followed by the medial collateral ligament. Most knee injuries were related to sports and recreation (approximately 30%). Among those having data available in place of injury, sports, and athletic area was the reported place of injury for nearly half of the injuries (45-50%).

The incidence of ACLR is in increasing trend in Alberta, especially among adolescents. Chapter 3 estimated the trends of ACLR between 2002/03 and 2018/19. The annual growth rate was higher in females compared to males and was the highest among females aged 50 years and above and females under 20 years of age. The increase in incidence of ACLR is most likely due to increasing incidence of ACL injury. Since a wide-scale implementation of ACL IPPs has the potential to reverse this trend, ACL IPPs need to be designed by involving athletes, who understand their needs according to the sports they are involved in.

Chapter 4 estimated a three-year cumulative incidence and correlates of ACLR among patients with diagnosed ACL injury in the ED. **Revisiting our earlier figure from the first chapter, our findings show that among patients with an ACL injury, more than half (56.6%) undergo ACLR within three years from injury diagnosis.** There was a big difference in chances of ACLR by place of diagnosis. While less than half (45%) of those diagnosed in the ED received ACLR over three years of follow-up, nearly two-thirds (64.5%) of those diagnosed in non-emergency setting received ACLR. **The average time to ACLR was nearly one year from the date of diagnosis at ED and over 8 months among those diagnosed in a non-ED setting.** This interval is much longer than what is recommended by American Academy of Orthopedic surgeons.

In addition to place of diagnosis, age was a strong correlate of primary ACLR among ACL injuries. Females aged 10-19 years had a higher chance of ACLR than rest of the male and female age categories. Those in the poorest income neighbourhoods and people from rural areas had a significantly lower chance of ACLR.

Chapter 5 investigated post-operative health care utilization following primary ACLR. **Along the continuum of care, among patients with a history of ACLR** conducted between 2010/11 and 2015/16**, about 4% underwent a revision ACLR and a similar proportion required primary ACLR in the contralateral knee over an average follow-up period of 5.7 years after primary ACLR**. Among those with post-operative reconstruction, the mean reconstruction period was 3.0 years.

The chances of post-operative ACLR (ipsilateral revision ACLR and contralateral primary ACLR) use was higher among those aged 10-19 years and 20-29 years compared to middle-aged patients (30-39 years). However, we found no gender differences in post-operative ACLR.

Having primary ACLR in winter compared to summer was associated with higher chances of ipsilateral revision ACLR. Having allograft compared to autograft and having initial primary ACLR in an inpatient setting compared to outpatient were associated with increased risk of ACL revision. Similarly, having initial primary ACLR in an inpatient setting compared to outpatients was associated with increased risk of contralateral primary ACLR. Inpatients in this analysis had a longer follow-up period (6.2 years) compared to outpatients (5.5 years) due to change in clinical practice over time. Patients in the earlier years were more likely to be inpatients and patients in the later years were more likely to be outpatients. This could be one of the factors for higher incidence of subsequent reconstruction among the inpatient sample. However, further exploration of this finding is warranted.

In this thesis, we investigated epidemiological trends of knee injuries and ACLR, correlates of ACLR among ACL injured patients and investigated incidence and correlates of subsequent ACLR. Since the analysis of trends and risk factors of our study indicated greater increase in knee injuries and ACLR among females and younger age groups, and considering limited availability of evidence on strategies, facilitators and barriers to implement ACL IPPs (8), we conducted a systematic review to identify those factors. We believed that the findings from such evidence synthesis can be helpful to stimulate adoption, implementation, and continuity of community-focused ACL IPPs in a wide scale.

As mentioned in the first chapter, this thesis attempts to offer a solution to the problem, in addition to identifying populations at higher risk of ACLR and factors associated with primary and revision ACLR. We strongly believe that epidemiologists can make greater impacts by stepping up from working in silos to a more collaborative and action-oriented practice. By gathering available evidence from several experimental and cross-sectional studies, we offer strategies that practitioners and policymakers can use to accelerate the implementation of ACL IPP on a large scale.

Thus, Chapter 6 synthesized literature on strategies, facilitators, and barriers to ACL IPPs. **Systematic review has found that that coach motivation and capacity enhancement, easy resource availability, collaborative program design tailored to local needs, and continuous support, feedback, and reinforcement to athletes were key facilitators to implementation of IPPs**. Major barriers were related to lack of motivation among coaches and athletes, coaches' and athletes' perceived time constraints, lack of information and often misinformation, lack of communication between coaches and sports associations, and lack of favourable policy environment.

7.1 Contextualizing the current findings with the extant literature

We found that knee injury-related ED visits declined in Alberta between 2002/03 and 2018/19 and at a significantly higher rate among males. This may be partly associated with decreasing sports participation, and implementation of injury prevention programs among the youth population (9). It could also be due to missed reporting of acute knee injury visits to AKIC (personal communication, AKIC Calgary, 2022).

Consistent with the literature from other countries, our results show an increasing trend of ACLR (2, 3), specifically among adolescents and adults. It is suggested that ACL injury peaks in adolescence and declines thereafter (10). Age-specific incidence rate showed that ACL injury peaked among the younger population and declines after age 20. Although both genders show higher risk of ACL injury during adolescence, girls experience increased risk immediately after puberty at the age of 17 -18 years (11). With the increase in height, the body's centre of mass is pushed higher, which makes muscular control of the body difficult for the adolescents (11). Rapid growth of the tibia and femur during adolescence results in increased torques on the knee (12). Furthermore, increase in body weight produces higher joint force and makes it difficult to balance during high-speed movements (11). Growing incidence of ACLR partly suggests a growing trend of ACL injury. Additionally, growing incidence of ACLR may be a result of growing awareness of the procedure among public and clinicians, improved diagnostic procedures, and increased access to magnetic resonance imaging (MRI) and increased number of orthopedic surgeons (3, 13–15).

The growing incidence of ACLR among 50-55-year-old females may be due to multiple factors. It could be driven by growing clinician recommendation to undergo surgical reconstruction rather than undergoing conservative management. In recent days, there is a growing trend of participation in athletics (8), and remaining physically active among females. This may result in higher injury rates; however, this needs further investigation.

After controlling for level of athletic exposure, sport type and level of play, females are at twice the risk than male counterparts to have a first ACL injury (16). Females are shown to exhibit lower neuromuscular control and decreased dynamic knee stability, leading to higher risk of knee injury during jumping and turning movements (12). While male adolescents regain neuromuscular control after changes in body height and weight, girls fail to develop such adaptation (12). Although there is a lack of conclusive evidence on the role of sex hormones on ACL injury (17), some studies find injury possibility is higher during early and late follicular phase of the menstrual cycle among females (18). It is proposed that the menstrual cycle may be associated with anterior-posterior knee laxity, although further investigation on this subject is needed (19). Due to the possible link between hormonal variation during the menstrual cycle, taking oral contraceptive pills might reduce risk of sports-related injuries (20). However, the evidence base on the role of hormones on risk of ACL injury is evolving.

This study is one of the few studies to show the influence that season of diagnosis has on the chances of primary ACLR. Having an ACL injury diagnosed in spring and fall was associated with higher chances of ACLR than having the injury diagnosed in summer. It is suggested that environmental risk factors including weather conditions, type of surface, type of footwear, and use of protective equipment (17) affect the chances of injury. Shoe and surface interaction is suggested to play a crucial role directly through traction and indirectly through athletes' altered movement pattern to make adjustment with the surface. Harder surface and shoes with longer cleats might increase the risk of knee injury in a low rainfall season (17). A recent systematic review found certain weather conditions (dry or icy conditions) to be strong risk factors for ACL injury (21). Orchard et al. conducted a cohort study among Australian footballers and showed that low rainfall and high evaporation season were contributing to higher risk of ACL injury (22). The authors posited that increased traction between shoes and hard surface may be a contributory factor for increased risk of non-contact injury. Those receiving ACL injury diagnosis in spring in Alberta might have had their ACL injured in winter or early spring seasons. Winter and early spring seasons in Alberta have sub-zero temperatures and icy conditions. A high proportion of ACL injuries associated with winter sports such as skiing, snowboarding/snow skating, and ice hockey in our study also support that surface conditions in winter and early spring seasons might have contributed to higher number of injuries. The association of season of diagnosis of ACL injury with chances of ACLR may be linked with proximity to playing season and intention to return to sport. The literature suggests there is a heightened risk of ACL injury in pre-season and training camps than during the season (23). Lower chancers of ACLR among injuries occurring in summer may also be due to reduced availability of health care staff due to staff going on holidays, although this needs further investigation.

Similarly, having primary ACLR in winter compared to summer was associated with increased chances of revision ACLR. We hypothesize that the seasonal pattern to probability of revision ACLR are mainly driven by return to the sport. Those who have ACLR in winter may want to return to normal activity as soon as the spring or summer seasons arrive. However, further research is needed to understand the relationship between season of ACL injury diagnosis with chances of ACLR, and season of ACLR and risk of revision ACLR.

Timely diagnosis and appropriate management of ACL injury is critical for knee stability and overall knee health (24, 25). Since ACL rupture results in immediate pain and swelling, most of the patients visit a health care facility within 24 hours (26). We found that the majority of patients undergoing ACLR visited ED for their possible ACL injury but did not receive an ACL injury diagnosis. Therefore, delay in presentation to health facility by patients after a suspected ACL injury plays a minor role in delays in diagnosis and treatment for ACL injury.

In Alberta, acute knee injury clinics (AKIC) were established in 2010 in Calgary and in 2013 in Edmonton (personal communication). Acute knee injury patients either visit their family/general practitioners (GPs), or visit the ED. Upon assessment by GPs/emergency physicians, many patients may have been referred to the AKIC or some of them might have chosen/recommended to undergo conservative management such as physiotherapy. It has been found that open access acute knee clinics can reduce the time to diagnosis for soft tissue ligament injuries including ACL injury (27). In a UK-based study, AKIC led to 89% reduction in time to diagnosis for patients referred by ED and 32% reduction for patients referred by GPs (27). Although we could not study time from injury to diagnosis, due to lack of data on time of injury, we can deduce that AKIC might have contributed to reduced time from injury to diagnosis in Alberta.

We found that of the total ACL injuries, less than half were diagnosed in the ED. Previous studies investigating proportion of ED diagnosis among ACL injuries report consistent findings (26, 28-30), Misdiagnosis and underdiagnosis of ACL injury on initial presentation to ED has been widely reported in the literature (25, 26, 28, 31). Misdiagnosis on initial presentation can lead to delayed diagnosis or remaining undiagnosed for a prolonged period.

Moreover, in our study, two-thirds of those who received ACL injury diagnosis in the ED had to wait a longer than five months from diagnosis to undergo ACLR. Altogether, these findings suggest that delays in care/inadequate care for ACL injury occurs due to health system-related factors. AKIC have less impact on time-from-injury diagnosis to ACLR, since time from diagnosis to treatment depends on a number of factors, such as resource availability and funding (27).

Delays in diagnosis and treatment of ACL injury has multiple ramifications on both the individual and family (29, 32). The physical and psycho-social consequences (32) directly affect patients' quality of life (33). There is a three times greater chance of meniscal tear (72% vs 23%) if diagnosis is made after six months from injury, compared to a diagnosis made within four months(29). In-depth interviews with patients in a UK-based study found that patients felt frustrated and annoyed while waiting for diagnosis or surgery (32). They felt they had been lost within the health system and their life had been put on hold (32). Additionally, socio-economic consequences include days lost from work, which has a significant impact on self-employed individuals (34).

Our results show that ACLR overall is a successful procedure in Alberta. However, revision rate is much higher than the average rate among those aged 10-19 years (7.7%). Previous studies from Denmark (5) and United States (6) also found a high revision rate among the under-20 age group. Achieving a low revision rate is necessary because revision surgery is associated with low subjective outcome score (7), pain and suffering to the individual, and a significant burden to the health system. Therefore, improvement in clinical practice and patient education can reduce high revision rates in younger age groups.

Given the significant impact of ACL injury and its sequel on health, economic, and social fronts, implementation of ACL injury prevention on a large scale is a no-brainer. However, implementation of ACL IPPs on a large scale is unsatisfactory (35). Furthermore, there is limited evidence on strategies, enablers, and barriers to implement community-based ACL IPPs. Chapter 6 of this thesis systematically synthesized information on strategies, facilitators, and barriers to implement ACL IPPs. We found published intervention trials assessing effectiveness of IPPs did not routinely report strategies, enablers and barriers faced during implementation. Synthesis of data from published cross-sectional and experimental studies showed that people-related factors (motivation, skill, time, compliance), program related factors (adaptability, cost, collaborative program design), internal environment (information availability and communication between different levels), external environment (policy environment, ACL IPP in coach education), and process of program development and implementation (frequent support and feedback to athletes and involvement of all stakeholders) were critical factors to IPP implementation. Bogardus et al. identified five major barriers to ACL IPP implementation, namely motivation, time requirements, skill requirements, cost, and compliance (36). A cross-sectional survey of women's soccer coaches also identified cost of hiring additional staff to implement IPPs as a primary barrier (37).

7.2 Strengths and Limitations

We used population-based administrative data for identifying the trend of ACLR, risk factors for primary ACLR and revision ACLR. Use of the population registry and administrative databases means our study has adequate power to generalize findings to the province of Alberta. We had adequate data points (17 years) to investigate a trend for primary and revision ACLR. Retrospective cohort design using administrative data gave us the strength to estimate incidence of specific outcomes of interest. We used multivariable Cox proportional hazard regression analysis to study factors associated with ACLR or revision ACLR/contralateral ACLR. Use of these methods allowed us to make use of time variables, as well as allowed the opportunity to adjust for potential confounders (38). We synthesized evidence on facilitators and barriers to implement ACL IPPs among female athletes. However, since we excluded studies including “only males,” most of the findings from our systematic review are also applicable to male athletes.

However, this thesis has some limitations. Our objective in this thesis was to study the epidemiological trend of ACLR and post-operative health utilization. However, we need to be cautious when interpreting the findings from this study. Increase in ACLR incidence is not solely due to increase in injury incidence; it also could be associated with growing preference to undergo ACLR among service users and change in clinical practice among service providers. Further factors such as age of athletes, level of sports, and quality of the health system also determine whether an athlete with ACL injury will undergo ACLR. Given these limitations, we cannot make inference about causality of increasing ACLR incidence in Alberta. Since we used total population of Alberta as a denominator to calculate annual incidence rate, changes in activity and sports pattern in a general population might also have contributed to this increase.

Many people with an ACL injury may never get ACLR either due to patient or clinical preferences. Those who prefer to undergo conservative management of ACLR are not captured in this study. Information of knee sidedness was not available, which limited our ability to identify multiple reconstructions on a single individual. Since we used administrative data available from Alberta’s Ministry of Health, our data quality depends on data completeness and quality of the record-keeping system. Furthermore, administrative data did not include many variables possibly associated with our outcome variables. Therefore, we cannot rule out the chances of residual confounding. Since we missed to capture patients using conservative approaches to management of ACL injuries, the real incidence of ACL injuries could be much higher in Alberta. Furthermore, change in coding practices over time and use of ICD-9 codes for physician claims data might have contributed to misclassification of ACL injuries.

Missing or unspecified activity at the time of injury was another concern in analysis of the data. We found that many individuals had missing data on place of injury (U codes) or ICD-10 activity code at the time of injury (V or W codes) in the NACRS database. Similarly, SR sub-codes were available for only some patients. It is suggested that the incomplete data on activity codes likely underestimates the true incidence of sports-related injury (39). Missing data on activity code might have led to under-estimation of the proportion of knee injuries or ACL injuries associated with different sports. Therefore, recording and reporting of cause of injury and place of injury needs to be improved. Finch and Boufous suggest three possible reasons for missing data on activity codes, namely information not being recorded at the point of care by service provider, information not being coded by the medical coder, or issues with coding schema (39). Therefore, it is imperative to understand why there is a large proportion of missing data on activity at the time of injury and improve the coding of routinely collected data.

7.3 Implication for future policies, programs, and clinical practice

The increasing ACLR rate in Alberta, especially among younger age groups, warrants urgent efforts to implement a provincial ACL injury prevention program. Province-wide implementation of such a program can be cost-effective in terms of present and future health cost savings due to injury (40). Targeting younger athletes (13-19 years) might achieve higher success in terms of reduction of injury (41). Therefore, implementing prevention programs by trained implementers starting from high school-aged adolescents needs to be a priority.

Emergency physicians need orientation and provision of improved diagnostic tests for improving the diagnosis rate of ACL injuries so that appropriate management can be planned on time. Provision of a clinical algorithm/guideline for assisting ED staff with diagnosis of ACL injury may be helpful. ED physicians need to increase clinical suspicion for ACL injury while examining patients presenting with knee injury (42). Currently used tests, such as the Lachman test and anterior drawer test are found to result in many false negatives (42). More recently developed tests with a higher sensitivity, such as the "Lever test"(42) may be candidates for testing in Alberta.

One of the reasons for underdiagnosis and misdiagnosis of ACL injury in the ED may be due to growing patient volume and crowding in EDs (43, 44). Crowding in EDs can lead to poor quality of care, such as long waiting time, underdiagnosis, or patients choosing to leave without care (43). Therefore, efforts to improve quality of care for knee injury patients might include introduction and evaluation of alternative pathways for diagnosis and management of soft tissue knee injuries. It is found that majority of interventions in the ED can be provided in urgent care centers (44–46), which are 'free-standing physician offices with extended hours" (47). Development and testing of alternative redirection protocols for paramedics that consider patient eligibility based on both clinical and non-clinical factors, patient needs, values, and preferences (45,46) has the potential to improve diagnosis and management of soft tissue injuries, including ACL injury.

Given the significant delay from diagnosis to treatment, policymakers need to revisit the funding and resource availability for management of knee injuries. This can include increasing the competency of existing human resources in diagnosis of an ACL injury, revising the curriculum of clinical education with a greater focus on musculoskeletal conditions, such as soft tissue knee injury, and increasing the number of orthopedic surgeons, among others.

Education programs for parents and athletes is also important to make them understand the underappreciated risk factors for ACL injury, the role of IPPs to prevent ACL injuries, and the importance of early diagnosis and management. Given the chances of ACL injury to be undiagnosed, knee-injured patients with typical symptoms of ACL injury need to be advised to limit participating in sports or physical exercise until an ACL injury has been ruled out. This can protect the knee from further damage.

We found a high chance of ACL revision and contralateral ACLR in younger patients compared to adults. A United States-based study showed that use of hamstring grafts (13%) were twice as likely to fail compared to bone patellar-tendon-bone (BTB) grafts (6%), and allografts showed a higher tendency to fail in comparison to autografts (6). The Danish study showed that the primary cause for ACL revision was new trauma and a malposition of tunnel in some revision cases (5). It is possible that soft tissue grafts, such as hamstring grafts, may be less resistant to trauma compared to BTB grafts. Given this finding, clinicians need to educate young patients and their parents about the risk of re-rupture(5) and continually update clinical practice based on recent evidence-based guidelines.

7.4 Implications for administrative data management and future research

We studied the incidence of ACLR and its correlates. However, real incidence of ACL injury remains unknown. Investigating incidence of ACL injury using administrative data is challenging for two main reasons. First, it is difficult to ascertain the exact number of ACL injuries at a population level because not all patients visit a health facility. Second, there is a lack of a precise denominator to express incidence of ACL injury. Calculating incidence rate using a denominator that includes number of people involved in different sports or recreational activities, multiplied by their time of exposure in such activities in a given period, would be ideal. However, recording and management of such data is arduous (4). At a population level, it is recommended to present annual incidence expressed as a percentage of total population at risk, or in terms annual number of injuries per 100,000 person years (4).

There is a need to investigate effectiveness of existing referral pathways for diagnosis and treatment of ACL injury in Alberta. Cost-effectiveness studies are needed to assess the role of AKIC to reduce delays and improve patient outcomes. Furthermore, other strategies for reducing diagnostic delays and treatment delays need to be tested, and those strategies with favourable results need to be implemented on a large scale. Future research examining post-operative health care use (readmission to hospital, drug utilization for pain management, repeat revision) and mental health consequences of ACL injury are warranted.

Another idea is an ACL registry, as has been established in Scandinavian countries, but this initiative is lacking in North America. It is believed that continuous surveillance of injury, characteristics of patients undergoing ACLR, and factors associated with graft failure is necessary for tracking the incidence of injury and to assess quality of the ACLR procedure (48). While initial setup cost for a provincial/national register is high, long-term return on investment, in terms of prevention of injury and lower graft failure, is enormous. Recording side of the injured/reconstructed knee in administrative databases is important for effective tracking of the injury and its outcomes.

It was found that most of the clinical trials included in our systematic review which were conducted to assess effectiveness of ACL IPPs do not explicitly report strategies, barriers, and facilitators. It may either be due to a journal's word limitations or due to a lack of reporting guidelines (49). Transparent reporting of implementation strategies provides a clear picture of what results to expect in a given context when adopting a specific strategy (49). Ultimately, such information on strategies, facilitators, and barriers will help in narrowing the research-to-practice gap. Therefore, I recommend that future effectiveness trials need to report implementation strategies, facilitators, and barriers. Researchers can use available frameworks, including CFIR, to report their strategies and experience.

7.5 Conclusion

There is a growing incidence of ACLR in Alberta. Although males have a higher incidence of ACLR, higher annual growth rate among females compared to males has led to a narrowing gender gap. Females aged 10-19 years and males aged 20-29 years have the highest ACLR incidence. The adolescent population has a high proportion of revision ACLR compared to other age groups in both sexes. This indicates a high risk of initial ACL rupture and re-rupture in adolescents. Therefore, adolescents and their parents need education about preventive strategies and importance of early diagnosis and management. Clinicians also need to pay special attention to this group while providing patient education and care.

Given significant delays from diagnosis to ACLR for more than two-thirds of those diagnosed with ACL injury in an ED setting, the government needs to review resource allocation for service expansion and to ensure increased availability of trained human resources.

To reduce significant burden to individuals, family and the health system, urgent efforts are needed to implement ACL IPPs. Since a large-scale implementation of IPPs has a higher cost-effectiveness than small-scale programs, a provincial ACL injury prevention program is warranted. Establishment of a provincial ACL registry may be an initial step towards a provincial ACL IPP.

More population-based research is needed to identify real incidence of an ACL injury. Pragmatic trials need to be conducted to test the effectiveness of ACL IPPs in Alberta. Lessons learned from such effectiveness trials will inform large-scale injury prevention programs.

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Appendices

Appendix 1: Literature search in different databases

Ovid MEDLINE(R) ALL <1946 to February 13, 2020>

#	Search Statement	Results
1	exp *Anterior Cruciate Ligament/ or (acl or (knee adj3 ligament*) or anterior cruciate).ti,ab.	25502
2	exp Athletic Injuries/ and ((prevent* or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*)).ti,ab.	1107
3	((tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk) and ((prevent*or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*))).ti,ab.	26290
4	2 or 3	27075
5	1 and 4	264
6	exp *Anterior Cruciate Ligament Injuries/ and ((avoid* or protect* or prevent* or reduc* or "warm up") adj3 (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*)).ti,ab.	222
7	5 or 6	339
8	Male/ or (male or males or men or man or boy or boys or masculin*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	8814680

9	Female/ or (female* or girl or girls or women or woman or feminin*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	8903839
10	8 not (8 and 9)	2950728
11	exp Animals/ not (exp Animals/ and Humans/)	4673892
12	7 not 10	315
13	12 not 11	314

Embase <1974 to 2020 February 13>

#	Search Statement	Results
1	exp *anterior cruciate ligament/ or (acl or (knee adj3 ligament*) or Anterior Cruciate).ti,ab.	31751
2	exp sport injury/ and ((prevent* or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or mentor* or trainer* or practice*)).ti,ab.	1110

3	((tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk or trauma*) and ((prevent* or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or mentor* or trainer* or practice*))).ti,ab.	92288
4	2 or 3	92332
5	1 and 4	568
6	exp *anterior cruciate ligament injury/ and ((avoid* protect* or prevent* or reduc* or "warm up") adj3 (program* or training or education* or intervention* or coach* or mentor* or trainer* or practice*)).ti,ab.	177
7	5 or 6	576
8	Male/ or (male or males or men or man or boy or boys or masculin*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word]	9180138
9	Female/ or (female* or girl or girls or women or woman or feminin*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word]	9275737
10	8 not (8 and 9)	2966552
11	exp Animals/ not exp Humans/	4577654
12	7 not 10	532

13	12 not 11	527

ERIC <1965 to August 2019>

#	Search Statement	Results
1	(acl or (knee adj3 ligament*) or Anterior Cruciate).ti,ab.	97
2	((tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk or trauma*) and ((prevent* or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or teacher* or trainer* or mentor* or practice*))).ti,ab.	4612
3	1 and 2	3
4	exp Injuries/ and ("anterior cruciate ligament" or ACL).mp. and ((prevent* or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or teacher* or trainer* or mentor* or practice*)).mp. [mp=abstract, title, heading word, identifiers]	3
5	3 or 4	3
6	"Men's Athletics"/ or Male/ or (male or males or men or man or boy or boys or masculin*).mp. [mp=abstract, title, heading word, identifiers]	88641
7	"Womens Athletics"/ or Female/ or (female* or girl or girls or women or woman or feminin*).mp. [mp=abstract, title, heading word, identifiers]	110524

8	6 not (6 and 7)	31736
9	5 not 8	3

PsycINFO <1806 to February Week 2 2020>

#	**Search Statement**	**Results**
1	(acl or (knee adj3 ligament*) or anterior cruciate).mp.	717
2	((tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk) and ((prevent*or protect* or reduc* or avoid* or "warm up") adj3 (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*))).ti,ab.	9725
3	(exp Accident Prevention/ or (exp Prevention/ and exp Injuries/)) and (exp Sports/ or (sports or athletics).ti,ab.)	135
4	2 or 3	9842
5	1 and 4	12
6	Male/ or (male or males or men or man or boy or boys or masculin*).mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures, mesh]	1242917
7	Female/ or (female* or girl or girls or women or woman or feminin*).mp. [mp=title, abstract, heading word, table of contents,	1194308

	key concepts, original title, tests & measures, mesh]	
8	6 not (6 and 7)	351410
9	5 not 8	12

SPORTDiscus with Full Text   Searched February 21, 2020

#	Query	Limiters/Expanders	Results
S1	(acl or (knee N3 ligament*) or anterior cruciate)	Expanders - Apply equivalent subjects Search modes - Find all my search terms	12,212
S2	((tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk) and ((prevent*or protect* or reduc* or avoid* or "warm up") N3 (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*)))	Expanders - Apply equivalent subjects Search modes - Find all my search terms	3,574
S3	S1 AND S2	Expanders - Apply equivalent subjects Search modes - Find all my search terms	172
S4	(male or males or men or man or boy or boys or masculin*)	Expanders - Apply equivalent subjects Search modes - Find all my search terms	229,243

S5	(female* or girl or girls or women or woman or feminin*)	Expanders - Apply equivalent subjects Search modes - Find all my search terms	227,287
S6	S4 NOT (S4 and S5)	Expanders - Apply equivalent subjects Search modes - Find all my search terms	147,856
S7	s3 NOT s6	Expanders - Apply equivalent subjects Search modes - Find all my search terms	163

SCOPUS Searched February 13, 2019 Results = 627

662 document results

(((TITLE-ABS-KEY ((acl OR (knee W/3 ligament*) OR "Anterior Cruciate") AND (tear OR tears OR damag* OR injur* OR ruptur* OR accident* OR harm* OR risk OR trauma*))) AND (TITLE-ABS-KEY ((prevent* OR protect* OR reduc* OR avoid* OR "warm up") W/3 (program* OR training OR education* OR intervention* OR coach* OR teacher* OR trainer* OR mentor* OR practice*)))) AND NOT ((TITLE-ABS-KEY ((male OR males OR men OR man OR boy OR boys OR masculin*))) AND NOT ((TITLE-ABS-KEY ((male OR males OR men OR man OR boy OR boys OR masculin*))) AND (TITLE-ABS-KEY ((female* OR girl OR girls OR women OR woman OR feminin*)))))) AND NOT (TITLE-ABS-KEY ((animal* AND NOT (animal* AND human*))))

Proquest Dissertations and Theses Global Results =80

(((((noft(acl) OR (noft(knee W/3 ligament*)) OR noft("Anterior Cruciate")) AND (noft(tear) OR noft(tears) OR noft(damag*) OR noft(injur*) OR noft(ruptur*) OR noft(accident*) OR noft(harm*) OR noft(risk) OR noft(trauma*)))) AND (((noft(prevent*) OR noft(protect*) OR noft(reduc*) OR noft(avoid*) OR noft("warm up")) NEAR/3 (noft(program*) OR noft(training) OR noft(education*) OR noft(intervention*) OR noft(coach*) OR noft(teacher*) OR noft(trainer*) OR noft(mentor*) OR noft(practice*))))) AND NOT ((((noft(male) OR noft(males) OR noft(men) OR noft(man) OR noft(boy) OR noft(boys) OR noft(masculin*)))) AND NOT ((((noft(male) OR noft(males) OR noft(men) OR noft(man) OR noft(boy) OR noft(boys) OR noft(masculin*)))) AND (((noft(female*) OR noft(girl) OR noft(girls) OR noft(women) OR noft(woman) OR noft(feminin*))))))) AND NOT (((noft(animal*) AND NOT (noft(animal*) AND noft(human*)))))

PROSPERO Searched February 14, 2020

#1	(acl or "knee ligament*" or "anterior cruciate"):TI	157
#2	tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk or trauma*	50482
#3	#1 and #2	148
#4	(prevent* or protect* or reduc* or avoid* or "warm up"):TI	3669
#5	(program* or training or education* or intervention* or coach* or teacher* or trainer* or mentor* or practice):TI	8542
#6	#4 or #5	11048
#7	#3 and #6	11

CINAHL Plus with Full Text Searched Feb 14, 2020 Result = 130

#	Query	Limiters/Expanders	Results
S1	(MH "Anterior Cruciate Ligament") or acl or knee N3 ligament* or "anterior cruciate"	Expanders - Apply equivalent subjects Search modes - Find all my search terms	13,526

S2	**(tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk) or (MH "Athletic Injuries+")**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**1,178,727**
S3	**(MH "Athletic Training Programs")**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**1,225**
S4	**((prevent* or protect* or reduc* or avoid* or "warm up") N (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*))**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**45,887**
S5	**S1 AND S2 AND S3**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**30**
S6	**S1 AND S2 AND S4**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**110**
S7	**S5 OR S6**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**139**
S8	**S5 OR S6**	**Expanders - Apply equivalent subjects** **Narrow by SubjectGender: - male** **Search modes - Find all my search terms**	**53**

S9	**S5 OR S6**	**Expanders - Apply equivalent subjects** **Narrow by SubjectGender: - female** **Search modes - Find all my search terms**	**88**
S10	**S8 NOT (s8 and s9)**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**9**
S11	**S7 NOT S10**	**Expanders - Apply equivalent subjects** **Search modes - Find all my search terms**	**130**

Cochrane Central Register of Controlled Trials

#1 MeSH descriptor: [Anterior Cruciate Ligament] explode all trees 657

#2 ((acl or (knee adj3 ligament*) or anterior cruciate)):ti,ab,kw 2897

#3 #1 or #2 2897

#4 MeSH descriptor: [Athletic Injuries] explode all trees 656

#5 (tear or tears or damag* or injur* or ruptur* or accident* or harm* or risk):ti,ab,kw 313539

#6 #4 or #5 313539

#7 (((prevent* or protect* or reduc* or avoid* or "warm up") NEAR/3 (program* or training or education* or intervention* or coach* or trainer* or mentor* or practice*))):ti,ab,kw 36430

#8 #3 and #6 and #7 127

#9 MeSH descriptor: [Anterior Cruciate Ligament Injuries] explode all trees 717

#10 #7 and #9 59

#11 #8 or #10 127

#12 ((male or males or men or man or boy or boys or masculin*) not ((male or males or men or man's or men's or man or boy or boys or masculin*) and (female* or girl or girls or women* or woman* or feminin*)) 103710

#13 #11 not #12 117

Appendix 2. Ethics approval letter

Notification of Approval (Renewal)

Date:	June 22, 2020
Amendment ID:	Pro00090820_REN1
Principal Investigator:	Donald Voaklander
Study ID:	MS2_Pro00090820
Study Title:	Epidemiology of knee injury and anterior cruciate ligament reconstruction (2002-2018) in Alberta, Canada
Sponsor/Funding Agency:	Alberta Health & Wellness AH

RSO-Managed Funding:

	Project ID	Title	Grant Status	Program	Project Start Date	Project End Date	Purpose	Other Information
View	RES0030339							

Approval Expiry Date: June 21, 2021

Thank you for submitting this renewal application. Your application has been reviewed and approved.

This re-approval is valid for another year. If your study continues past the expiration date as noted above, you will be required to complete another renewal request. Beginning at 30 days prior to the expiration date, you will receive notices that the study is about to expire. If you do not renew on or before the renewal expiry date, you will have to re-submit an ethics application.

All study-related documents should be retained so as to be available to the Health REB upon request. They should be kept for the duration of the project and for at least 5 years following study completion.

Approval by the Research Ethics Board does not encompass authorization to recruit and/or interact with human participants at this time. Researchers still require operational approval (e.g., Alberta Health Services) and must meet the requirements imposed by the public health emergency (link to Alberta COVID page).

Sincerely,

Emily Nolan
REB Specialist
on behalf of
Anthony S. Joyce, PhD.
Chair, Health Research Ethics Board - Health Panel

Note: This correspondence includes an electronic signature (validation and approval via an online system).