



Original research

Likelihood of knee replacement surgery up to 15 years after sports injury: A population-level data linkage study

Ilana N. Ackerman^{a,b}, Megan A. Bohensky^b, Joanne L. Kemp^{c,*}, Richard de Steiger^{d,e,f}^a School of Public Health and Preventive Medicine, Monash University, Australia^b Department of Medicine (Royal Melbourne Hospital), The University of Melbourne, Australia^c La Trobe Sport and Exercise Medicine Research Centre, La Trobe University, Australia^d Epworth HealthCare, Australia^e Department of Surgery, The University of Melbourne, Australia^f Australian Orthopaedic Association National Joint Replacement Registry, Australia

ARTICLE INFO

Article history:

Received 19 June 2018

Received in revised form

24 September 2018

Accepted 13 December 2018

Available online 21 December 2018

Keywords:

Sports injuries

Knee injuries

Knee arthroplasty

Knee replacement

Osteoarthritis

Healthcare costs

ABSTRACT

Objectives: Knee injury is strongly associated with the development of knee osteoarthritis. While there is preliminary evidence for an increased risk of knee replacement (KR) surgery after sports injury, no studies have investigated this at a population level. This population-level study aimed to quantify the likelihood of KR surgery and direct healthcare costs 10–15 years after sports injury.

Design: Statewide population-based cohort study.

Methods: The cohort was established by linking two key administrative datasets capturing all hospital admissions and emergency department (ED) presentations in Victoria, Australia. Sports injury presentations from 2000–2005 and KR admissions from 2000–2015 were identified using ICD-10-AM codes. A Cox proportional hazards model estimated likelihood of KR using time to surgery admission data, adjusting for potential confounders. KR costs for the sports-injured cohort were estimated from the health system perspective using diagnosis codes and national hospital cost weights.

Results: Over the study period there were 64,038 sports injuries (including 7205 knee injuries) resulting in ED presentation or hospitalisation, and 326 KR procedures. Multivariate analysis showed that having a knee injury more than doubled the hazard of subsequent KR (hazard ratio 2.41, 95%CI 1.73–3.37), compared to all other sports injuries. Direct healthcare costs for KR totaled \$AUD7.93 million for the cohort, with 21% of costs attributable to the knee injury group.

Conclusions: Sports-related knee injury manifests in a significantly greater likelihood of KR, at considerable cost to society. Targeted health policy and effective interventions are needed to prevent sports-related knee injuries and contain this substantial burden.

© 2018 Crown Copyright. Published by Elsevier Ltd on behalf of Sports Medicine Australia. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Practical implications

- A history of sport-related knee injury is strongly associated with future knee replacement surgery. Prevention of injuries, as well as appropriate and timely rehabilitation after injury, is critical
- Increasing awareness of the potential downstream impacts of sports injuries is important at individual and population levels
- Periodic monitoring of individuals who sustain a knee injury may help to identify deterioration and provide opportunities for early intervention

1. Introduction

It is increasingly recognised that younger people are impacted by knee osteoarthritis (OA).¹ While there is no ‘cure’, knee replacement (KR) surgery is the treatment of choice for severe joint disease after non-surgical management options are exhausted. KR is a cost-effective intervention that can reduce pain and improve function.^{2,3} In Australia, over 53,000 primary KR procedures are performed annually,⁴ with a lifetime risk of 21% for females and 15% for males.⁵

The greatest risk factor predicting knee OA development in younger people is traumatic knee injury.⁶ A recent study into sports injury burden in the state of Victoria, Australia reported a significant rise in sports injuries over a 7-year period, even after accounting for increasing sports participation.⁷ The overall number

* Corresponding author.

E-mail address: J.Kemp@latrobe.edu.au (J.L. Kemp).

of sports injuries increased by 37%, with knee and lower leg injuries rising by 27%. Direct hospital costs for knee and lower leg injuries exceeded \$AUD82 million, highlighting the substantial burden that sports injuries place on healthcare systems. Given the strong link between injury and accelerated OA development, it is anticipated that rising sports injury rates may lead to marked growth in future knee OA cases.⁷

It has been hypothesised that an increase in sports-related injuries has contributed to rising KR rates in the United States (US).⁸ To date, only three studies have examined the risk of KR in relation to previous sports involvement and none has investigated KR risk at a population level. A Swedish study investigated knee OA, hip OA, KR and hip replacement outcomes among former male elite athletes, compared to matched controls.⁹ The authors reported an increased odds of KR for the athlete group, although this association was not statistically significant.⁹ Two small clinical studies retrospectively explored the relationship between sports-related knee injury and KR.^{10,11} Nebelung et al. examined knee surgery outcomes for 19 former German Olympic athletes who had an anterior cruciate ligament (ACL) injury; of these, 10 (53%) had received KR within 35 years of injury.¹⁰ Tjoumakaris et al. reported a history of sports-related knee injury in 22% of patients presenting for primary KR at a single hospital.¹¹ Most recently, a computer simulation model was used to estimate lifetime risk of KR after ACL tear in early adulthood.¹² From this model, the lifetime risk of KR ranged from 6% for a simulated non-injured cohort up to 22% in a simulated ACL and meniscal tear injury cohort.¹² While these studies provide preliminary evidence that sports injury confers a heightened risk of subsequent KR, the full burden on health systems remains unclear. Using a population-level approach, this study aimed to quantify the burden of KR 10–15 years after sports injury, in terms of the hazard of KR and direct healthcare costs.

2. Methods

A population-based cohort study for the state of Victoria, Australia was undertaken using data linkage of two key administrative data sources. The Victorian Admitted Episodes Dataset (VAED) is maintained by the Victorian Government Department of Health and includes all hospital episode data compiled by public and private hospitals, including day procedure units. The Victorian Emergency Minimum Dataset (VEMD) captures emergency department (ED) presentations to all Victorian public hospitals. All Australians have access to publicly-funded healthcare in public hospitals under the national Medicare scheme. Private health insurance can be purchased separately to pay for care in private hospitals (57% of Australian adults have private health insurance¹³). Ethics approval was obtained from The University of Melbourne Human Research Ethics Committee (#1545763).

A data request application was submitted to the data custodian for access to VAED and VEMD data. De-identified data were obtained for people aged ≥ 18 years who had an ED presentation or hospitalisation involving a sports-related injury in a Victorian hospital between 1 June 2000 and 31 December 2005. Hospitalisation data included public and private hospital admissions. All subsequent hospital admissions coded to an orthopaedic specialty were obtained for each patient up to 30 June 2015.

Within the VAED, sports-related injuries were identified using International Classification of Diseases and Related Health Problems, Tenth Revision, Australian Modifications (ICD-10-AM) activity and injury codes, similar to previous methods.⁷ Prior to 2002, the activity code used for sports was Y930. From 2002 onwards, the activity codes for sports was in the range U50–U71. All patients were required to have a principal diagnosis code in the range of S00 to T98 to indicate an injury had occurred. Sports

injuries were also identified within the VEMD according to ICD-10-AM coding, using the activity field code for sport (activity code = S). Codes in the VAED and VEMD are assigned by trained clinical coders with audits conducted regularly to ensure coding accuracy. The VAED records up to 40 diagnostic codes per admission, whereas the VEMD records only 3 diagnostic codes per episode. A review of injury codes within the hospital admissions dataset demonstrated high levels of completeness ($>97\%$ at a national level from 2001/2002 to 2005/2006).¹⁴ Patients with planned follow-up visits to EDs were excluded from further analyses ($n = 562$ episodes), to avoid injury double-counting.

Three linkages were undertaken as part of these analyses. Person-level linkage was undertaken between the VEMD and VAED to identify ED presentations that were followed by a hospital admission. Person-level linkage was also undertaken to longitudinally link episodes over time and identify subsequent orthopaedic admissions. To preserve individual patient privacy, linkages involving person-level data were undertaken by the Victorian Government Department of Health using a stepwise deterministic linkage process based on personal identifiers.¹⁵ The de-identified linked dataset was then provided to the researchers for analysis. Patients' statistical local area codes were linked to available Socio-Economic Indexes for Areas (SEIFA) and Accessibility/Remoteness Index of Australia (ARIA) datasets to approximate socioeconomic status and residential remoteness. This linkage was undertaken by the researchers using a deterministic linkage process based on the statistical local area code. Using this method, 99% of patients in the cohort were successfully matched.

Methods for defining each variable of interest were applied across all hospital episodes to ensure consistency of patient characteristics and outcomes. Patient and injury characteristics (age group, sex, length of hospital stay, and patient insurance type) were generated from VAED variables (Supplementary file) and ED length of stay (in minutes) was generated from VEMD variables. The bodily region of injury was generated using either dataset, depending on where the patient presented. Socioeconomic status at the time of injury was approximated using quantiles of the SEIFA Index of Relative Socio-economic Disadvantage.¹⁶ The ARIA Index was used to assess remoteness of each patient's residence.¹⁷ Statistical local areas that could not be linked to the SEIFA or ARIA datasets due to missing values (1% of cases for each dataset) were imputed to the median value or metropolitan regions, respectively.

The primary outcome of interest was time to KR during the study period. Relevant procedure codes for KR surgery including hemiarthroplasty, patellofemoral joint replacement, unilateral total knee replacement, and bilateral total knee replacement procedures (Supplementary file) were used to identify these surgeries in hospital episodes throughout the follow-up period. Time to KR was calculated as the number of days between the sports injury admission date and the KR admission date. As only the month and year of admissions and presentations were provided by data custodians as part of the de-identification process, it was assumed that all admissions occurred mid-month. Where patients had multiple KR procedures over the follow-up period, the first KR was used for analysis.

All analyses were performed using Stata version 14.2 (College Station, Texas, USA). Descriptive analysis was used to summarise demographic, sports injury and KR characteristics. Age group, sex, patient insurance type, socioeconomic status, residential remoteness and bodily injury region were treated as categorical variables. ED and hospital length of stay, time to KR, and cost data were treated as continuous variables. Differences between KR and non-KR groups were tested for statistical significance ($p < 0.05$) using chi-square, Fisher's exact or Wilcoxon signed-rank tests.

A Cox proportional hazards model was used to calculate hazard ratios (HRs) and 95% confidence intervals (95%CI) for time to KR

Table 1
Demographic and injury admission characteristics for the sports-injured cohort.

Variable	Total		Subsequent knee replacement		No knee replacement	
	n	%	n	(%)	n	(%)
Sport-related injury presentations ^a	64,038	100.0	357	0.6	63,681	99.4
Sex						
Female	13,989	21.8	150	42.0	13,839	21.7
Male	50,049	78.2	207	58.0	49,842	78.3
Age group at time of injury						
<20 years	7897	12.3	6	1.7	7891	12.4
20–29 years	31,514	49.2	34	9.5	31,480	49.4
30–39 years	14,448	22.6	33	9.2	14,415	22.6
40–49 years	6109	9.5	82	23.0	6027	9.5
50–59 years	2248	3.5	95	26.6	2153	3.4
60–69 years	928	1.5	73	20.4	855	1.3
≥70 years	894	1.4	34	9.5	860	1.4
Remoteness of residential location ^b						
Highly accessible	57,751	90.2	324	90.8	57,427	90.2
Accessible	5317	8.3	32	9.0	5285	8.3
Moderately accessible	943	1.5	1	0.3	942	1.5
Remote	10	0.0	0	0.0	10	0.0
Very remote	17	0.0	0	0.0	17	0.0
Socioeconomic status ^c						
Quantile 1 (most disadvantaged)	8345	13.0	34	9.5	8311	13.1
Quantile 2	7951	12.4	43	12.0	7908	12.4
Quantile 3	16,802	26.2	102	28.6	16,700	26.2
Quantile 4	17,236	26.9	97	27.2	17,139	26.9
Quantile 5 (least disadvantaged)	13,704	21.4	81	22.7	13,623	21.4
Injury region						
Shoulder/arm/hand	21,604	33.7	92	25.8	21,512	33.8
Lower leg/ankle/foot	15,849	24.7	77	21.6	15,772	24.8
Head/face	11,489	17.9	46	12.9	11,443	18.0
Knee	7205	11.3	73	20.4	7132	11.2
Abdomen/lower back/pelvis/hip/thigh	2761	4.3	35	9.8	2726	4.3
Unspecified	2402	3.8	16	4.5	2386	3.7
Neck/thorax	2324	3.6	17	4.8	2307	3.6
Multiple injuries	404	0.6	1	0.3	403	0.6
Hospital admission for injury	28,131	43.9	217	60.8	27,914	43.8

^a Number of sport-related injuries resulting in emergency department presentation or hospitalisation; number of people with injuries = 57,558 (some had >1 sport-related injury presentation or hospitalisation over the period of interest).

^b Based on the Accessibility/Remoteness Index of Australia (ARIA) using residential statistical local area.

^c Based on SEIFA codes using residential statistical local area.

admission. Guided by clinical judgment, all patient-level variables that showed a significant relationship to the outcome in univariate analysis ($p < 0.05$) as well as likely confounders (age group and sex) were included in multivariate models. The largest category was used as the reference group for each variable. To account for patients who had multiple sport-related injuries over the study period, all analyses were clustered on patient identifier using a Huber-White sandwich estimator of variance to adjust for within-cluster correlation. Patients without a linked KR episode were censored as at the end of the follow-up period (30 June 2015).

Hospital admission costs were estimated from the perspective of the Australian healthcare system. For the costs analysis, Australian refined diagnosis-related groups codes (AR-DRG) were extracted from VAED data for each surgical episode. The AR-DRG cost weights for public and private hospitals were obtained from the most recent version of the National Hospital Cost Data Collection (Round 18, 2012–13 and Round 13 was used for AR-DRG code I04Z, which was replaced with AR-DRG codes I04A and I04B after 2009).^{18–20} To obtain a current price for KR procedures, the national efficient price for 2016–17 was used (as published by the Independent Hospital Pricing Authority).²¹ All costs are reported in Australian dollars (1 AUD = 0.60 GBP).

3. Results

From 2000 to 2005, there were 64,038 sports-related injuries for 57,558 people (including 7205 knee injuries for 6591 people) that resulted in ED presentation or hospitalisation. As shown

in [Table 1](#) most sports injuries were sustained by people aged 20–29 years (49% of all injuries) and those aged 30–39 years (23% of all injuries). Sports injuries were more common among males (78% of all injuries). Diversity in socioeconomic status was evident ([Table 1](#)).

[Table 1](#) presents a summary of bodily injury regions. The most commonly injured regions were the shoulder, arm or hand (34% of all presentations), the lower leg, ankle or foot (25%), the head or face (18%) and the knee (11%). Knee injuries were predominantly soft tissue injuries ($n = 6233$, 86.5%), with relevant codes covering meniscus tears, collateral ligament injuries, cruciate ligament injuries, articular cartilage tears, and other knee-related sprains/strains. Fractures ($n = 479$, 6.7%), dislocations ($n = 358$, 5.0%) and multiple injuries affecting the knee ($n = 135$, 1.9%) were less common. Sports injuries resulted in 28,131 hospitalisations over the study period. On average, ED length of stay was brief (median 124 min, interquartile range (IQR) 77–192 minutes) and for patients admitted to hospital, the average length of stay was short (median 1 day, IQR 1–2 days). Most of the cohort were public patients (not privately insured) at the time of injury admission ($n = 18,762$, 67%).

A total of 326 KR procedures were performed for the cohort between 2000 and 2015 ([Table 2](#)). Of these, 67 procedures were performed for the knee injury group (1.02% of the knee injury group) and 259 were performed for people who had sustained sports injuries affecting other bodily regions (0.51% of the 'other injury group'). The majority of KRs were performed for males ($n = 189$, 58%). KR was more common among the 50–59, 60–69, and ≥70 year age groups (each representing 29% of all KR procedures)

Table 2
Characteristics of patients receiving knee replacement.

Variable	Knee replacement patients (n = 326)	
	n	(%)
Sex		
Female	137	42.0
Male	189	58.0
Age group at KR admission		
<20 years	0	0.0
20–29 years	7	2.1
30–39 years	7	2.1
40–49 years	30	9.2
50–59 years	94	28.8
60–69 years	94	28.8
≥70 years	94	28.8
Patient type at KR admission		
Public	85	26.1
Private	212	65.0
Other	29	8.9
Primary diagnosis ^a at KR admission		
Other primary gonarthrosis (M171)	286	87.7
Gonarthrosis, unspecified (M179)	10	3.1
Primary gonarthrosis, bilateral (M170)	8	2.5
Other post traumatic gonarthrosis (M173)	5	1.5
Other primary diagnosis	17	5.2

KR: knee replacement.

^a Codes shown are ICD-10-AM codes representing knee osteoarthritis.

and privately-insured patients (65%). At knee replacement admission, most people (95%) had a recorded primary diagnosis (based on ICD-10-AM codes) consistent with knee OA (Table 2).

The median (IQR) hospital length of stay for the KR admission was 5 days for the overall cohort (IQR 4–7 days). For those who received KR, there were no differences in sex ($p=0.43$), age group ($p=0.28$), patient insurance type ($p=0.14$), hospital length of stay ($p=0.05$) or primary diagnosis at time of knee replacement ($p=0.47$) for the subgroup who sustained a knee injury compared with those who sustained non-knee injuries.

The median time from sports injury to KR admission was 8.8 years for the overall cohort (IQR 5.6–11.2 years), and this

Table 3
Cox proportional hazards analysis of time to knee replacement surgery.

Variable	Hazard ratio (95%CI)	
	Univariate analysis	Multivariate analysis ^a
Injury region		
Other injury region ^b	1.00 (reference ^c)	1.00 (reference ^c)
Knee	1.88 (1.37–2.58)	2.41 (1.73–3.37)
Sex		
Male	1.00 (reference ^c)	1.00 (reference ^c)
Female	2.60 (2.00–3.37)	1.31 (1.00–1.71)
Age group at time of injury		
<20 years	0.77 (0.29–2.03)	0.78 (0.30–2.05)
20–29 years	1.00 (reference ^c)	1.00 (reference ^c)
30–39 years	2.29 (1.30–4.04)	2.41 (1.37–4.23)
40–49 years	14.22 (8.47–23.89)	14.75 (8.76–24.84)
50–59 years	46.88 (28.24–77.83)	52.62 (31.57–87.70)
60–69 years	90.97 (53.42–154.89)	102.75 (59.69–176.90)
≥70 years	42.38 (23.10–77.75)	50.06 (26.38–94.97)
Hospital length of stay (injury admission)	1.01 (1.01–1.02)	1.00 (0.97–1.02)
Patient insurance type (injury admission)		
Public	1.00 (reference ^c)	1.00 (reference ^c)
Private	1.66 (1.19–2.30)	1.05 (0.75–1.46)
Other	1.36 (0.70–2.63)	0.90 (0.46–1.76)
Emergency department presentation only	0.59 (0.44–0.81)	1.43 (1.04–1.97)

^a Model adjusted for sex, age group, hospital length of stay (injury admission), patient insurance type and presentation type (emergency department presentation or hospital admission).^b Includes head/face injuries, neck/thorax injuries, shoulder/arm/hand injuries, abdomen/lower back/pelvis/hip/thigh injuries, lower leg/ankle/foot injuries, unspecified injuries and multiple injuries.^c The largest category was used as the reference group for each variable.

was comparable for the knee injury (median 8.8 years, IQR 4.7–11.2 years) and other injury subgroups (median 8.8 years, IQR 5.7–11.1 years) ($p=0.46$). The results of the Cox proportional hazards analysis are presented in Table 3. The unadjusted hazard ratio for KR was 1.88 (95% CI 1.37–2.58) for people with a knee injury, compared to those with other injuries (comprising, head/face injuries, neck/thorax injuries, shoulder/arm/hand injuries, abdomen/lower back/pelvis/hip/thigh injuries, lower leg/ankle/foot injuries, unspecified injuries and multiple injuries). In a multivariate model, knee injury was even more strongly associated with an increased hazard of KR (HR 2.41, 95%CI 1.73–3.37). Patients aged 30–39 years, 40–49 years, 50–59 years, 60–69 years and ≥70 years were all more likely to have KR, compared to those aged 20–29 years (Table 3). ED presentation only (without hospitalisation) was associated with an increased hazard of KR (HR 1.43, 95%CI 1.04–1.97).

We also examined the hazard of KR for specific body regions, using shoulder/arm/hand injuries as the reference category. In a multivariate model, none of the other bodily injury regions (besides knee injuries) was significantly associated with KR (Supplementary file).

The average (IQR) cost of KR surgery was \$AUD25,791 (\$22,169–\$25,791) per procedure. Direct healthcare costs associated with KR for the overall sports-injured cohort were estimated at \$AUD7,931,290. Direct healthcare costs for KR specifically for the knee injury subgroup were estimated at \$AUD1,658,090, representing 21% of the cost for the overall cohort.

4. Discussion

To our knowledge, this study is the first to evaluate the population burden of KR in people who have previously sustained a sports-related knee injury. A key finding was that sports-related knee injury more than doubled the hazard of subsequent KR over the 15-year study period, after adjusting for potential confounders. While the absolute number of KR procedures was relatively small, the likelihood estimate is both statistically and clinically significant.

An advance over earlier case-control and clinical studies examining relationships between knee injury, knee OA and KR surgery,^{9–11} our study used prospective population-level data to quantify the relationship between sports-related knee injury and subsequent KR. It is not possible to directly compare our findings with previous studies given differences in patient populations, study designs, and available data. Earlier studies have simply reported frequency data (such as the proportion of athletes who proceeded to KR¹⁰ or the proportion of KR patients with a prior injury¹¹) that do not take potential confounders into account. In the study by Tjoumakaris et al., one-fifth of KR patients self-reported a history of sports-related knee injury; however, the injuries were not confirmed by medical record review.¹¹ Only one study investigated the likelihood of KR in former elite athletes, compared to matched controls, with adjustment for factors such as age, injury and occupational load.⁹ However, only 36% of athletes had a prior soft tissue knee injury,⁹ making the specific impact of injury versus elite-level training and competition difficult to elucidate. None of the earlier studies specifically reported average time from injury to KR and this may reflect the use of self-reported injury data in some instances. In contrast, our data linkage approach enabled time to KR admission data to be quantified for each patient. These data were used to characterise the cohort (describing average time from injury to surgery) and as the primary outcome for the Cox proportional hazards (time to event) analysis.

In our study, we examined a range of predictor variables in our models, but only knee injury, age group (≥ 30 years) and emergency department presentation were ultimately associated with an increased hazard of KR. In particular, people aged 40 years and over had the highest likelihood of KR in both the univariate and multivariate analyses. While female sex was associated with an increased likelihood of KR in univariate analysis, this association was no longer evident after including other variables in the model. We used sports injury presentation type (emergency department presentation only or hospital admission) as a proxy for injury severity. We anticipated that less severe injuries would be treated in the emergency department only and more severe injuries would result in hospital admission. It is therefore unclear why emergency department presentation was associated with an increased likelihood of KR in multivariate analysis. However, the contribution of this variable to the overall model was minimal, with little change to the knee injury hazard ratio after removing presentation type from the analysis (HR 2.38 vs 2.41 previously).

The present study identified 7205 sports-related knee injuries between 2000–2005 that resulted in ED presentation or hospitalisation. Epidemiological research has identified a significant increase in sports-related injury rates in Victoria from 2004–2010, even after adjusting for sports participation growth.⁷ Of great concern is that the frequency of knee and lower leg injuries rose by 27%.⁷ Given knee joint injury is a strong predictor of future OA, it is highly likely the observed growth in sports injury rates will fuel a future surge of knee OA requiring surgical intervention. Knee OA is the primary reason for KR in Australia (98% of primary KR procedures are performed for knee OA⁴) and consistent with this, 95% of KR in the present study were performed for a diagnosis pertaining to knee OA.

As almost 90% of sports injuries in our study were categorised as soft tissue injuries (with diagnosis codes covering meniscus/ligament/chondral damage), these are most likely driving our findings. As this study sought to quantify the likelihood of KR surgery after sports injury (using bodily injury region as a key predictor variable), the relationship between specific types of knee injuries (as indicated by administrative ICD-10-AM codes) and subsequent KR was not investigated. However, the relationship between meniscal or knee ligament tears and subsequent knee OA is well-established.^{22,23} In our study, KR admission occurred at an

average 8.8 years after the index knee injury (interquartile range 4.7–11.2 years) and this was comparable for the overall cohort. Given that 18.8% of sport-related injury presentations with subsequent KR involved people who were aged 20–39 years at the time of their injury, it is concerning that these individuals may require KR surgery at a relatively young age. In our study, 9.2% and 28.8% of the knee replacement group were aged 40–49 years and 50–59 years, respectively. This has implications for participation in work and family roles; the risk of prosthesis failure and revision KR is also significantly higher among younger patients aged 55 years or less.^{24,25}

Our findings can be used to develop evidence-informed policy recommendations that support health promotion activities and healthcare planning. Targeted sports injury prevention programs may reduce the societal burden of knee OA and subsequent KR surgery. The increased risk of KR identified in this study provides evidence to support (a) the implementation of injury prevention programs in sporting clubs and schools; and (b) initiatives to reduce sporting injuries at the population level (such as social media campaigns). Evidence-based injury prevention programs such as the FIFA 11+ program²⁶ and the FootyFirst program²⁷ have been shown to reduce the risk of acute knee injury in football by up to 50% and could be implemented earlier in the sports participation continuum (eg for school-aged children) to minimise downstream injury impacts in later life. Information about such sports injury prevention programs has not yet been disseminated at a population level using social media. However, the success of previous programs in Australia (such as Life. Be In it²⁸ and SunSmart²⁹) at creating public awareness using popular media suggests that such strategies should be explored in order to maximise the public health benefits of these resources. Understanding the population burden of knee OA is also critical for ensuring KR demand can be met, in view of limited health budgets and ageing populations. Our methodology can be easily re-applied at future time points, to evaluate the impact of sports injury prevention efforts and monitor changes in knee OA disease burden at the population level.

This study has considerable strengths that should be acknowledged. We included data from the public and private hospital systems, to ensure the findings were relevant to the broader population. ED presentation and hospitalisation databases were utilised to capture a range of injury severities. Our analyses incorporated total KR and unicompartmental KR procedures (the latter are more common in younger patients in Australia with an average age of 65 years for these procedures,⁴ although their use is declining⁵) to ensure all primary KR procedures were included. Finally, our multivariable analysis clustered for individuals, ensuring patients with multiple admissions for the same knee injury did not distort our findings.

We also acknowledge the study limitations. The VEMD dataset is restricted to ED presentations in 38 Victorian public hospitals (only 6 private hospitals have EDs). Similar to other KR research involving administrative datasets,³⁰ the VEMD and VAED datasets do not contain information on laterality (side of injury and side of surgery). However, given the strong established link between joint injury and knee OA,^{6,31} and in the absence of population-level sports injury data where the affected side is recorded, it is biologically plausible that KR was performed on the same side that sustained the injury. Sports injuries treated outside the hospital setting were not included, as reliable injury data are not available for primary healthcare settings. Patients receiving KR surgery in other Australian states were not captured and given the long follow-up period, it is possible that some patients may have moved interstate. Given these limitations, our analyses represent a conservative estimation of the burden of KR after sports-related injury. We also acknowledge that there may be other potential confounders of OA requiring KR surgery (such as body mass index, lower limb align-

ment, or physical activity levels) that were not able to be included in our models as these data were not available for analysis.

5. Conclusion

Sports-related knee injury manifests in a greater likelihood of KR surgery at considerable cost to society. In a sports-injured, population-based cohort, individuals who sustained a knee injury were twice as likely to receive KR within 15 years, compared to those who had not. Future studies may utilise a longer follow-up period to identify additional KRs attributable to sports injury. From an economic perspective, the costs of KR associated with previous knee injury represented 21% of the KR costs for the overall sports-injured cohort. Targeted health policy and injury prevention are urgently needed to prevent sports-related knee injuries and contain this societal burden.

Acknowledgments

We thank the Victorian Data Linkages team (Victorian Department of Health and Human Services) for providing the linked data used for this study.

Funding

This research was supported by a partnership grant from Musculoskeletal Australia. Associate Professor Ackerman was supported by a National Health and Medical Research Council of Australia Public Health (Australian) Early Career Fellowship (#520004). Dr Joanne Kemp is supported by a National Health and Medical Research Council of Australia Public Health (Australian) Early Career Fellowship (#1119971). These institutions had no role in the study design, collection, analysis and interpretation of data, in the writing of the manuscript, or in the decision to submit the manuscript for publication.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.jsams.2018.12.010>.

References

- Ackerman IN, Kemp JL, Crossley KM et al. Hip and knee osteoarthritis affects younger people, too. *J Orthop Sports Phys Ther* 2017; 47:67–79.
- Waimann CA, Fernandez-Mazarambroz RJ, Cantor SB et al. Cost-effectiveness of total knee replacement: a prospective cohort study. *Arthritis Care Res* 2014; 66:592–599.
- Elmallah RK, Chughtai M, Khlopas A et al. Determining cost-effectiveness of total hip and knee arthroplasty using the Short Form-6D utility measure. *J Arthroplasty* 2017; 32:351–354.
- Australian Orthopaedic Association National Joint Replacement Registry. *Annual report – hip, knee and shoulder arthroplasty*, Adelaide, Australian Orthopaedic Association, 2016.
- Ackerman IN, Bohensky MA, De Steiger R et al. Substantial rise in the lifetime risk of primary total knee replacement surgery for osteoarthritis from 2003–2013: an international, population-level analysis. *Osteoarthritis Cartilage* 2017; 25:455–461.
- Roos EM. Joint injury causes knee osteoarthritis in young adults. *Curr Opin Rheumatol* 2005; 17:195–200.
- Finch CF, Kemp JL, Clapperton AJ. The incidence and burden of hospital-treated sports-related injury in people aged 15+ years in Victoria, Australia, 2004–2010: a future epidemic of osteoarthritis? *Osteoarthritis Cartilage* 2015; 23:1138–1143.
- Losina E, Thornhill TS, Rome BN et al. The dramatic increase in total knee replacement utilization rates in the united states cannot be fully explained by growth in population size and the obesity epidemic. *J Bone Joint Surg Am* 2012; 94A:201–207.
- Tveit M, Rosengren BE, Nilsson JA et al. Former male elite athletes have a higher prevalence of osteoarthritis and arthroplasty in the hip and knee than expected. *Am J Sports Med* 2012; 40:527–533.
- Nebelung W, Wuschech H. Thirty-five years of follow-up of anterior cruciate ligament – deficient knees in high-level athletes. *Arthroscopy* 2005; 21:696–702.
- Tjoumakaris FP, Van Kleunen J, Weidner Z et al. Knee sports injury is associated with an increased prevalence of unilateral knee replacement: a case-controlled study. *J Knee Surg* 2012; 25:403–406.
- Suter LG, Smith SR, Katz JN et al. Projecting lifetime risk of symptomatic knee osteoarthritis and total knee replacement in individuals sustaining a complete anterior cruciate ligament tear in early adulthood. *Arthritis Care Res* 2016; 69:201–208.
- Australian Bureau of Statistics. 4364.0.55.002 – Australian Health Survey: Health service usage and health related actions, 2011–12. Available from: <http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/E334D0A98272E4DCCA257B39000F2DCF?opendocument>. [Accessed 17 July 2017].
- Soo IH, Lam MK, Rust J et al. Do we have enough information? How ICD-10-AM activity codes measure up. *HIM J* 2009; 38:22–34.
- Victorian Department of Health. The Centre for Victorian Data Linkage. Available from: <https://www2.health.vic.gov.au/about/reporting-planning-data/the-centre-for-victorian-data-linkage>. [Accessed 14 May 2018].
- Australian Bureau of Statistics. *Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA). Australia volume 2033.0.55.001*, Canberra, Australian Bureau of Statistics, 2006.
- The University of Adelaide. ARIA (Accessibility/Remoteness Index of Australia). Available from: https://www.adelaide.edu.au/apmrc/research/projects/category/about_aria.html. [Accessed 17 July 2017].
- Independent Hospital Pricing Authority. National Hospital Cost Data Collection: Cost report round 13 (2008–09). Sydney : The Independent Hospital Pricing Authority.
- PWC. National Hospital Cost Data Collection (NHDC) Private Sector. Round 18 Private Sector Overnight NHDC. Available from: https://www.ihpa.gov.au/sites/g/files/net636/f/publications/nhdc_r18_-_private_overnight.pdf. [Accessed 4 April 2017].
- Independent Hospital Pricing Authority. The National Hospital Cost Data Collection (NHDC) NHDC Round 18 Australian Public Hospitals Cost Report 2013–2014. Available from: <https://www.ihpa.gov.au/what-we-do/nhdc>. [Accessed 4 April 2017].
- Independent Hospital Pricing Authority. National Efficient Price Determination 2016–17, February 2016 Available from: https://www.ihpa.gov.au/sites/g/files/net636/f/publications/final_nep16_determination.pdf. [Accessed 4 April 2017].
- Englund M, Roos EM, Lohmander LS. Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: a sixteen-year followup of meniscectomy with matched controls. *Arthritis Rheum* 2003; 48:2178–2187.
- Culvenor AG, Collins NJ, Guermazi A et al. Early knee osteoarthritis is evident one year following anterior cruciate ligament reconstruction: a magnetic resonance imaging evaluation. *Arthritis Rheumatol* 2015; 67:946–955.
- W-Dahl A, Robertsson O, Lidgren L. Surgery for knee osteoarthritis in younger patients. *Acta Orthop* 2010; 81:161–164.
- Julin J, Jansen E, Puolakka T et al. Younger age increases the risk of early prosthesis failure following primary total knee replacement for osteoarthritis A follow-up study of 32,019 total knee replacements in the finnish arthroplasty register. *Acta Orthop* 2010; 81:413–419.
- Bizzini M, Dvorak J. FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide – a narrative review. *Br J Sports Med* 2015; 49:577–579.
- Finch CF, Twomey DM, Fortington LV et al. Preventing Australian football injuries with a targeted neuromuscular control exercise programme: comparative injury rates from a training intervention delivered in a clustered randomised controlled trial. *Inj Prev* 2016; 22:123–128.
- Recreation Australia Limited. A brief history of life. Be in it. Available from: <https://web.archive.org/web/20110224094218/http://www.lifebein.it.org/standard.php?id=879>. [Accessed 12 September 2018].
- SunSmart Victoria. Sunsmart program. Available from: <http://www.sunsmart.com.au/about/sunsmart-program>. [Accessed 12 September 2018].
- Harris IA, Madan NS, Naylor JM et al. Trends in knee arthroscopy and subsequent arthroplasty in an Australian population: a retrospective cohort study. *BMC Musculoskelet Disord* 2013; 14:143.
- Lohmander LS, Englund PM, Dahl LL et al. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med* 2007; 35:1756–1769.