SN Comprehensive Clinical Medicine (2019) 1:1038–1047
https://doi.org/10.1007/s42399-019-00164-4

MEDICINE

# The Epidemiology of Joint Replacements Across Western Victoria, Australia: a Cross-sectional Study

Kara L. Holloway-Kew[1] · Muhammad A. Sajjad[1] · Mark A. Kotowicz[1,2,3] · Stephen Graves[4] · Alana Cuthbert[4] · Patricia M. Livingston[1] · Mustafa Khasraw[5] · Sharon Hakkennes[3] · Trisha L. Dunning[1,3] · Susan Brumby[1,6] · Richard S. Page[1,3,8] · Alasdair Sutherland[1,7] · Sharon L. Brennan-Olsen[2,9] · Lana J. Williams[1] · Julie A. Pasco[1,2,3,10]

Accepted: 10 October 2019 / Published online: 21 November 2019


## Abstract

Contemporary data are required to plan interventions and identify gaps in health service provision. As part of the larger Ageing, Chronic Disease and Injury study, we mapped joint replacements across the western region of the Australian state of Victoria. Primary total joint replacement data were extracted from the Australian Orthopaedic Association National Joint Replacement Registry for men and women aged ≥ 40 years during 2010–2013, inclusive. Crude and age-adjusted rates (per 10,000 population/year) of primary total joint replacements at the hip, knee and 'other' were determined for the entire region, and separately for each local government area (LGA). The reason and distance travelled for replacement were determined. Age-adjusted rates of joint replacements per 10,000 population/year in men and women (combined) were 39.3 (95% CI 37.9–40.6) for the hip, 42.2 (95% CI 40.8–43.6) for the knee and 3.7 (95% CI 3.3–4.1) for 'other' joint replacements. Age-adjusted incidence rates varied across rural LGAs. For residents of Ballarat, Greater Geelong and Warrnambool, most procedures (> 80%) were performed in the LGA of patient residence. For other LGAs, the percentage varied from 0 to 44.2%. Outside major population centres, the distance travelled ranged from 2.9 to 1111.0 km (median 97.5, IQR 61.2–190.0). Overall, rural LGAs had higher rates of joint replacements. Distance travelled for replacement procedures varied. The methods used in this study provide a model for similar research in rural environments, as well as providing important policy direction in the planning of health service provision across rural and regional communities.

**Keywords** Joint replacements · Women · Men · Australia · Incidence · Rural

This article is part of the Topical Collection on *Medicine*

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s42399-019-00164-4) contains supplementary material, which is available to authorized users.

✉ Kara L. Holloway-Kew
k.holloway@deakin.edu.au

[1] Deakin University, Geelong, Australia

[2] Department of Medicine, Western Health, Melbourne Medical School, The University of Melbourne, Melbourne, VIC, Australia

[3] University Hospital Geelong, Barwon Health, Geelong, Australia

[4] Australian Orthopaedic Association National Joint Replacement Registry, Adelaide, Australia

[5] The University of Sydney, Sydney, Australia

[6] National Centre for Farmer Health, Western District Health Service, Hamilton, Australia

[7] South West Healthcare, Warrnambool, Australia

[8] Barwon Centre of Orthopaedic Research and Education (B-CORE), St John of God Hospital and Barwon Health, Geelong, Australia

[9] Australian Institute for Musculoskeletal Science (AIMSS), The University of Melbourne, Melbourne, Australia

[10] Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, VIC, Australia

## Introduction

Joint replacements are common elective procedures that are cost-effective, substantially improve quality of life, reduce pain and increase mobility for end-stage joint disease [1]. Several studies have shown that certain occupations such as farming, fishing and construction work are associated with an increased risk of hip or knee osteoarthritis [1] which is the main reason for joint replacement [2]. The most important risk factors for osteoarthritis include older age, female sex, genetics, obesity and occupational physical activity, particularly heavy lifting and kneeling [1, 3–8].

Rural residence has been identified as a risk factor for joint replacement, with many studies reporting that despite reduced access to healthcare, a greater number of individuals in rural areas receive joint replacements than those in urban areas [9–12]. This may be due to specific risk factors that are more prevalent in rural populations such as physical inactivity, poorer diet, higher obesity levels and agricultural occupations [13, 14]. Differences in joint replacements by geographical area and socioeconomic position (SEP) have been reported by some [1, 6, 9, 10, 15], but not all studies [16, 17], though it has been suggested that under servicing in disadvantaged and over servicing in advantaged areas may explain the lack of differences observed. Although these other studies describe the distribution of joint replacement procedures by geographical location and SEP, few Australian studies have specifically examined areas characterised by rurality, though some studies in international settings have been completed [5, 10, 11, 17, 18].

This study forms part of the larger Ageing, Chronic Disease and Injury (ACDI) study [19], which aims to map the pattern of chronic diseases and injury across the western region of the Australian state of Victoria [20]. The ACDI study includes geographical locations with a variety of urban, rural and agricultural areas and a range of socioeconomic status. To identify gaps in healthcare service delivery and implement intervention and prevention strategies, contemporary data are required. The ACDI study aims to provide this information and inform targeted resource allocation to aid management of the burden of conditions and procedures associated with ageing. The study also aims to develop a profiling model for assessing rates of disease, which can be used in other geographical regions, monitor changes in health practices and compare with data from other regions. This will allow broader validation of not only joint replacements, but also the factors that influence joint replacement procedures and healthcare outcomes. In this sub-study, we investigated the incidence of joint replacements in men and women aged ≥ 40 years across western Victoria as part of the ACDI study.

## Methods

### Study Region

In Australia, there are eight states and territories; the state of Victoria ranks second in terms of population (Fig. 1) and contains 79 clearly defined geographical regions known as local government areas (LGAs). This study included 21 of these 79 LGAs, which encompass around one-third of the total area of the state of Victoria. These 21 LGAs were selected because they form the region managed by the Western Victoria Primary Health Network [21]. This organisation has two main aims: "(1) increasing the efficiency and effectiveness of health services for patients, particularly those at risk of poor health outcomes and (2) improving coordination of care to ensure patients receive the right care, in the right place, at the right time [21]." The estimated residential population (ERP) for this region was 617,794 in 2011 [22], which is approximately 11% of the population in the state of Victoria. The largest cities by population are located in the LGAs of Greater Geelong (ERP = 221,515), Ballarat (ERP = 98,684) and Warrnambool (ERP = 33,300). The study region has a high proportion of individuals aged 40 years or older, making up approximately 51% (~ 316,000) of the total population [23]. A larger proportion of these individuals reside in the more western (rural) areas of the study region (Fig. 1). The study region covers large agricultural areas that generate 60% of the state's total dairy production and major cropping areas in its north-west sector. Wool and beef farming are also common in these areas. The study region is a sentinel area from which data may inform other regions and geographical locations.

### Data Source

The data source for this study was the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR), which is a complete and comprehensive registry pertaining to all joint replacement surgeries performed in Australia [24]. The performance and outcome of joint replacements are assessed by the National Joint Replacement Registry: all public and private hospitals in Australia contribute to this registry. Data are matched and verified by cross-linking registry data with government hospital separation data for all arthroplasty procedures. Previous work has shown that the National Joint Replacement Registry captures more than 99% of all joint replacement surgeries undertaken in Australia [25]. It has been validated against medical records using a sequential multi-level matching process coupled with the retrieval of unreported procedures [24].

This study included data for primary total joint replacements of the hip, knee and 'other' (ankle, elbow, shoulder, spine and wrist) during 2011–2013 inclusive. Procedures as a result of any diagnosis were included. Revision surgeries were excluded. Across the study region, orthopaedic services

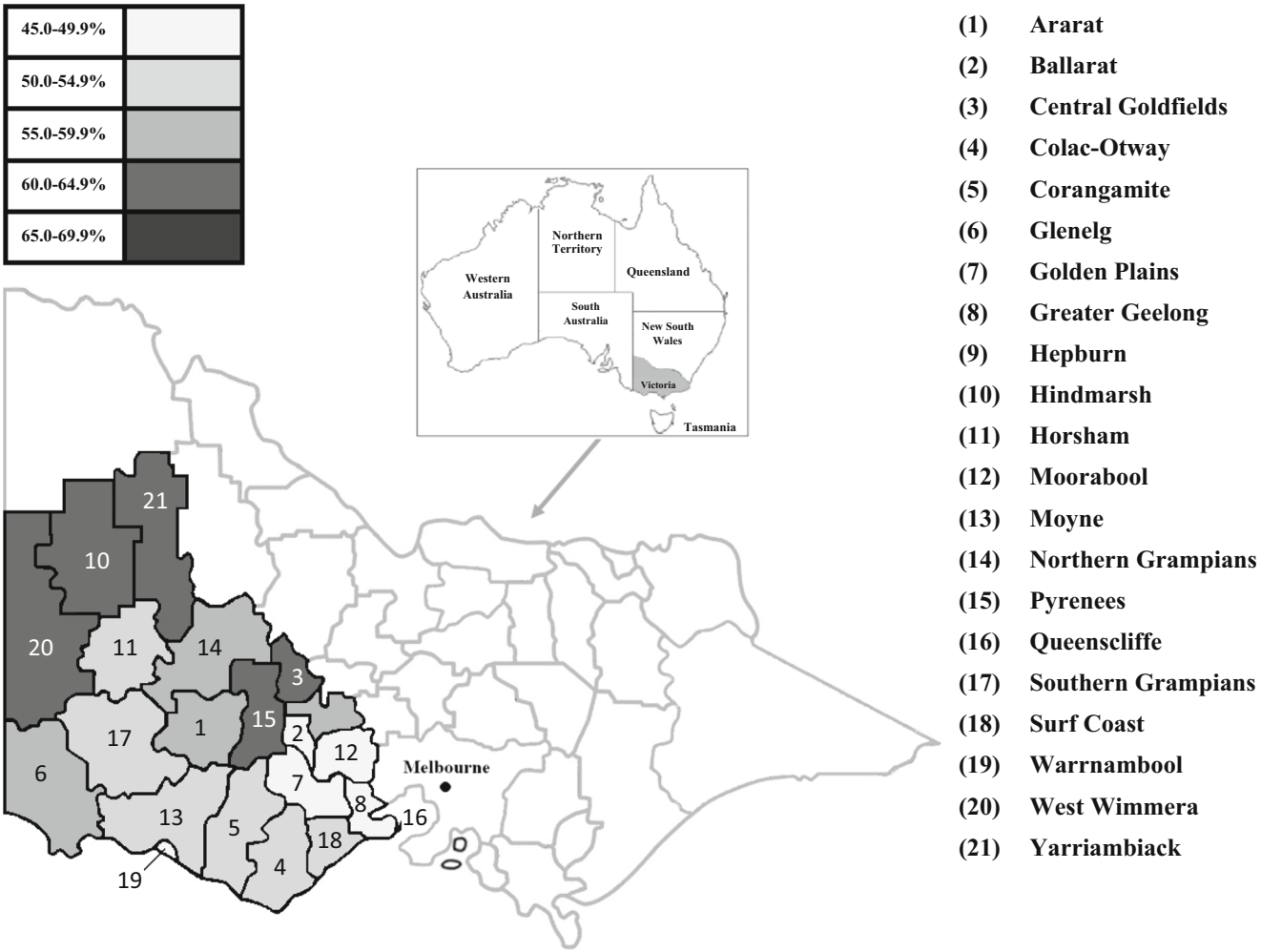


**Fig. 1** Location of the study region. Local government areas (LGAs) included in the study are shaded according to the percentage of individuals aged ≥ 40 years. Data for graphic was obtained from the Department of Health and Human Services, State Government of Victoria, Australia (graphic prepared by MAS and KLH-K). Graphic from Sajjad et al. J Public health Res. 2016;5:678–683

are available in the LGAs of Ararat, Ballarat, Colac-Otway, Glenelg, Greater Geelong, Hindmarsh, Horsham, Moorabool, Northern Grampians, Southern Grampians and Warrnambool. To determine whether access to orthopaedic surgeons affected the rates of joint replacements across the region, we obtained the postcode of the patient and the hospital where each replacement surgery was performed.

The AOANJRR Data Review Committee approved access to National Joint Replacement Registry data for this study and the Barwon Health Human Research Ethics Committee approved this study (HREC 15/11). This article does not contain any studies with human participants or animals performed by any of the authors.

## Analyses

Analyses were performed using data from 2011 to 2013 inclusive. Separate analyses were completed for primary total replacements at the (i) hip, (ii) knee and (iii) 'other' (ankle, elbow, shoulder, spine and wrist).

For the entire study region, we calculated crude, and age-adjusted, incidence rates for primary total joint replacements for men and women aged ≥ 40 years, as this is the age range covered by the ACDI study. Direct age-standardisation to the 2011 Australian population at risk was performed using data from the Australian Bureau of Statistics 2011 Census Community Profile Series. Incidence rates were expressed as replacements per 10,000 population per year. The 95% confidence intervals (CIs) were calculated using population data from the Australian Bureau of Statistics National Regional Profiles by LGA for 2011 [22]. Crude and age-standardised incidence rates of replacements were calculated for each LGA. The proportion of individuals who travelled to a hospital outside their LGA of residence was also determined. An estimation of distance travelled was also calculated by determining the distance between the geographic centre of the patient and hospital postcodes.

Additionally, we determined the proportion of comparatively younger individuals who received a primary joint replacement by calculating the proportion of men and women who were aged above and below 70 years at the time of surgery. The age cut-point of < 70 years was chosen because the lifetime risk of revision for patients over 70 years of age is low [26] and we aimed to compare with younger individuals with a higher lifetime risk of revision. Finally, we completed a subset analyses to calculate the proportion of replacements performed due to osteoarthritis of the joint, which may reflect specific risk factors in different geographical areas. Hip fracture was excluded from this subset analysis.

## Results

### Hip Replacements

#### Total Number, Age Distribution and Location of Procedure

There were a total of 3960 primary hip joint replacements for adults aged ≥ 40 years (men 1689 and women 2271): most were performed for osteoarthritis (77.9%) (Supplementary Table 1).

For men and women combined, the highest proportion (15.5%) of hip joint replacements occurred in the 70–74-year age group (Fig. 2a).

The age distribution of hip replacements in those aged < 70 years varied by LGA (Supplementary Table 1); in men and women combined, the highest rate occurred in two LGAs with agriculture as their main industry, Golden Plains (68.6%) and Pyrenees (60.0%). The lowest in Hindmarsh (26.8%), which represents a sparsely populated area of western rural Victoria used for cropping and grazing. When examining men and women individually, the patterns were similar to that seen in men and women combined; however, a greater number of younger men underwent hip joint replacements compared to women.

All patients in LGAs without orthopaedic services travelled to another LGA for their joint replacements (Central Goldfields, Corangamite, Golden Plains, Hepburn, Moyne, Pyrenees, Queenscliffe, Surf Coast, West Wimmera and Yarriambiack). Most individuals undergoing joint replacement surgery in one of the three most populous LGAs (Ballarat, Greater Geelong and Warrnambool) did so in the same LGA of their residence (> 80%, Supplementary Table 4). For other LGAs where orthopaedic services were available, the proportion of patients undergoing joint replacements in their LGA of residence ranged from 13.2% in Moorabool to 44% in Horsham. Distance travelled by patients for joint replacement procedures was highest in Yarriambiack (median 180.0 km, IQR 81.9–230.0; Supplementary Table 4 and Fig. 6a) and lowest in Warrnambool (median 2.4 km, IQR 2.4–2.4).

#### Hip Joint Replacement Rates Across the Entire Region

Crude rates of primary hip joint replacements across the whole region (per 10,000 population/year) were 42.5 (95%CI 41.2–43.8) for men and women combined, 37.6 (95%CI 35.8–39.4) for men and 47.1 (95%CI 45.2–49.1) for women. Age-standardised rates of primary hip joint replacements across the whole region were 39.3 (95%CI 37.9–40.6) for men and women combined, 35.0 (95%CI 33.2–36.8) for men and 43.3 (95%CI 41.3–45.2) for women.

#### Rates Across LGAs

For men and women combined, the LGA with the highest crude rate was Queenscliffe (60.0 per 10,000 population/year, 95%CI 42.3–82.6, Supplementary Table 7), which has a high proportion of retirees. The lowest crude rate was observed in Surf Coast (35.9 per 10,000 population/year, 95%CI 30.4–42.2), which has the highest socioeconomic status in the study region, with the main industries being tourism, as well as agriculture, electricity supply and building construction. For men only, the highest crude rates were in the largely retired population of Queenscliffe (64.1) and the lowest in two LGAs with central cities: Ballarat (33.1) and Warrnambool (33.1). For women only, the highest crude rate was in Yarriambiack (68.2) and the lowest was in

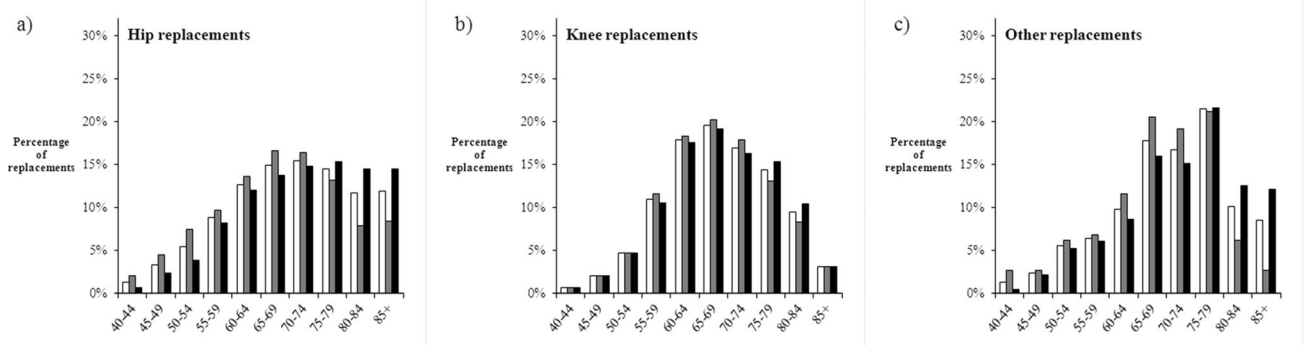


**Fig. 2** Age distribution of **a** hip replacements, **b** knee replacements and **c** other (ankle, elbow, shoulder, spine and wrist) replacements, across the entire study region for men and women combined (unfilled bars), men (light shading) and women (dark shading)

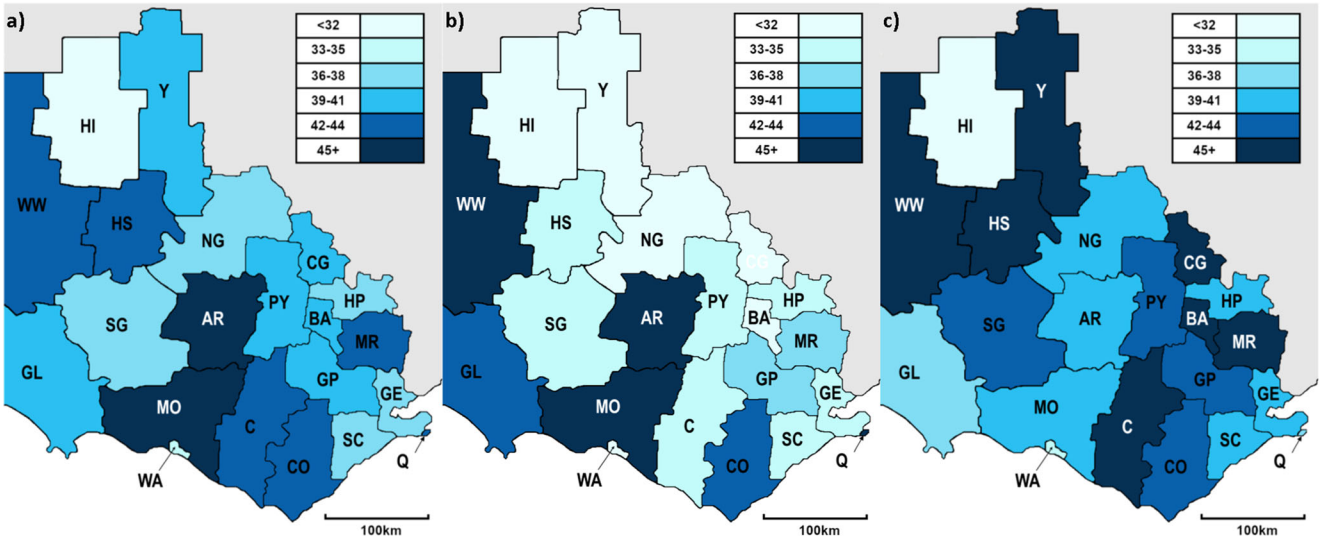


**Fig. 3** Heat map showing age-adjusted incidence rates for **a** men and women combined, **b** men and **c** women aged ≥ 40 years with primary total hip joint replacements across the study region during 2011–2013 inclusive. The legend shows the shading as incidence rate per 10,000 population/year. AR = Ararat, BA = Ballarat, CG = Central Goldfields, CO = Colac-Otway, C = Corangamite, GL = Glenelg, GP = Golden Plains, GE = Greater Geelong, HP = Hepburn, HI = Hindmarsh, HS = Horsham, MR = Moorabool, MO = Moyne, NG = Northern Grampians, PY = Pyrenees, Q = Queenscliffe, SG = Southern Grampians, SC = Surf Coast, WA = Warrnambool, WW = West Wimmera and Y = Yarriambiack

Hindmarsh (36.0), both of which are LGAs in western rural Victoria involved in cropping and grazing.

Age-standardised rates across the LGAs are shown in Fig. 3 and Supplementary Table 7. The highest age-standardised rates for both men and women combined (Fig. 3a) occurred in the rural LGA of Moyne (47.7, 95%CI 39.1–56.3), the main industry of this area is grazing, dairying and grain production and Ararat (45.2, 95%CI 35.1–55.3), which is located in the centre of the study region and has a large viticulture industry, employing up to 16% of the workforce. The lowest age-standardised rate occurred in Hindmarsh (29.5, 95%CI 17.3–41.6). For men only (Fig. 3b), the highest rate was in Moyne (55.0), while the lowest was in Yarriambiack (28.5). For women only (Fig. 3c), the highest age-standardised rate was observed in Central Goldfields (53.8), which is primarily a cropping and sheep farming area, as well as meat and meat product manufacturing, other food manufacturing and printing, and has the lowest SEP in the entire state. The lowest rate was in Hindmarsh (26.8).

## Primary Total Knee Joint Replacements

### Total Number, Age Distribution and Location of Procedure

A total of 4228 primary knee replacements were performed in adults aged ≥ 40 years (men 1841 and women 2387): the majority of which were performed for osteoarthritis (98.6%) (Supplementary Table 2).

For both men and women combined, the highest proportion (19.6%) of knee replacements were observed in those aged 65–69 years (Fig. 2b): this peak was similar for both men and women separately.

The proportion of younger (< 70 years) individuals undergoing knee replacements varied across the LGAs (Supplementary Table 2). In men and women combined, the highest proportion was in Golden Plains (65.0%), which contains a large area of agricultural land [27] and the lowest in Hindmarsh (44.2%).

Most individuals in Ballarat, Greater Geelong and Warrnambool had their knee replacement surgery in the same LGA where they resided (> 80%). For other LGAs with orthopaedic services, the proportions ranged from 10.1% in Moorabool to 46.6% in Horsham. Distance travelled was highest for residents of Southern Grampians (median 183.0 km, IQR 14.2–224.5) and Yarriambiack (median 180.0 km, IQR 63.6–248.0; Supplementary Table 5 and Fig. 6b).

### Knee Joint Replacement Rates Across the Entire Region

For men and women combined, the crude knee replacement rate across the entire study region was 45.4 per 10,000 population/year (95%CI 44.0–46.8): rates for men and women separately were 40.9 (95%CI 39.1–42.8) and 49.5 (95%CI 47.6–51.5), respectively. After age standardisation, rates were similar, albeit slightly lower: for men and women combined, rates were 42.2 (95%CI 40.8–43.6), and for men and women separately, rates were 37.9 (95%CI 36.0–39.8) and 46.2 (95%CI 44.3–48.2).

### Rates Across LGAs

Crude rates for knee replacements across the different LGAs are shown in Supplementary Table 8. Age-standardised rates across the LGAs are given in Supplementary Table 8 and Fig. 4. For men and women combined, the highest rates occurred in Pyrenees (67.1, 95%CI 51.5–82.8) and the lowest in Surf Coast (34.7, 95%CI 29.0–40.3) and Hepburn (34.7, 95%CI 27.3–42.2, Fig. 4a). These patterns were similar for men (Fig. 4b) and women (Fig. 4c).

## 'Other' (Ankle, Elbow, Shoulder, Spine, Wrist)

### Total Number, Age Distribution and Location of Procedure

There were 377 primary 'other' joint replacements (35 ankle, 29 elbow, 306 shoulder, 3 spine and 4 wrist) in adults aged ≥ 40 years (men 146 and women 231): the majority of these were performed for osteoarthritis (56.8%) (Supplementary Table 3).

For men and women combined, the highest proportion of 'other' replacements occurred in those aged 75–79 years (Fig. 2c) and this peak was similar in both men and women.

There were too few 'other' joint replacements to describe the proportions of individuals aged < 70 years; however, values are shown in Supplementary Table 3 for descriptive purposes.

The proportions of 'other' joint replacements performed in the same LGA as the patient resided were lower than for hip and knee replacements. Most patients in the LGAs of Ballarat, Greater Geelong and Warrnambool had their 'other' replacement procedure performed in the same LGA in which they resided (> 75%). For other LGAs with orthopaedic services, the proportions ranged from 6.7% in Southern Grampians to 16.7% in Moorabool (Supplementary Table 6). Distance travelled for joint replacement was higher in the western areas of the study region, such as West Wimmera (median 352.0 km, IQR 312.0–414.0) and Glenelg (median 280.0 km, IQR 148.3–304.8; Fig. 6c).

### 'Other' Joint Replacement Rates Across the Entire Region

For men and women combined, the crude 'other' replacement rate across the entire study region was 4.1 per 10,000 population/year (95%CI 3.7–4.5): rates for men and women separately were 3.3 (95%CI 2.7–3.8) and 4.8 (95%CI 4.2–5.5), respectively. The age-standardised rate for men and women combined was 3.7 (95%CI 3.3–4.1). For men, the rate was 3.0 (95%CI 2.5–3.5) and for women, 4.4 (95%CI 3.8–5.0).

### Rates Across LGAs

Crude rates for 'other' replacements across the different LGAs are shown in Supplementary Table 9. Age-standardised rates across the LGAs are given in Supplementary Table 9 and Fig. 5. For men and women combined, the highest rates occurred in Corangamite (6.3) and the lowest in Hindmarsh (1.9). For men, the highest rate was in Horsham (7.7) and the lowest in Moyne (0.7). For women, the highest rate occurred in Surf Coast (7.2) and the lowest in Hindmarsh (no replacements) (Fig. 6).

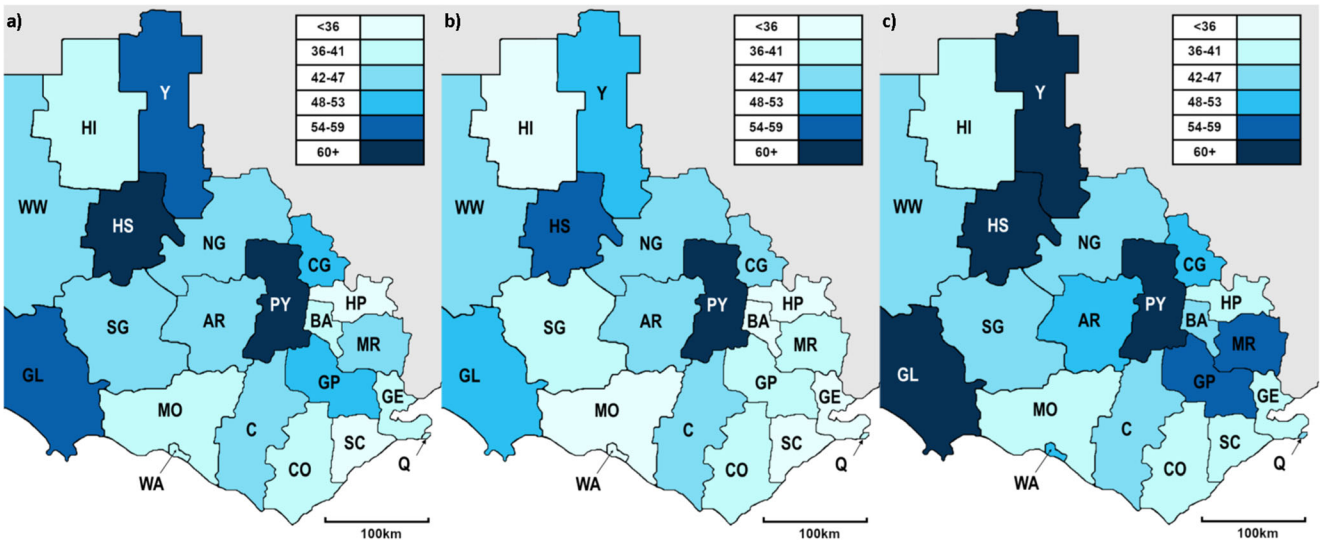


**Fig. 4** Heat map showing age-adjusted incidence rates for **a** men and women combined, **b** men and **c** women aged ≥ 40 years with primary total knee joint replacements across the study region during 2011–2013 inclusive. The legend shows the shading as incidence rate per 10,000 population/year. AR = Ararat, BA = Ballarat, CG = Central Goldfields, CO = Colac-Otway, C = Corangamite, GL = Glenelg, GP = Golden Plains, GE = Greater Geelong, HP = Hepburn, HI = Hindmarsh, HS = Horsham, MR = Moorabool, MO = Moyne, NG = Northern Grampians, PY = Pyrenees, Q = Queenscliffe, SG = Southern Grampians, SC = Surf Coast, WA = Warrnambool, WW = West Wimmera and Y = Yarriambiack.

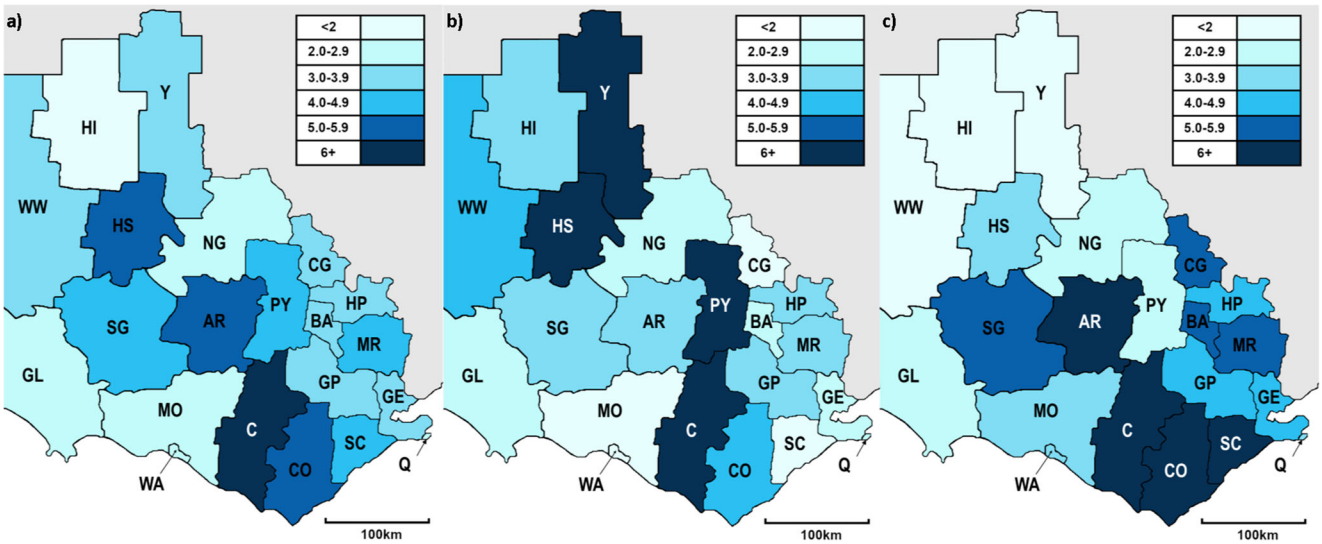


**Fig. 5** Heat map showing age-adjusted incidence rates for **a** men and women combined, **b** men and **c** women aged ≥ 40 years with primary total 'other' (ankle, elbow, shoulder, spine and wrist) joint replacements across the study region during 2011–2013 inclusive. The legend shows the shading as incidence rate per 10,000 population/year. AR = Ararat, BA = Ballarat, CG = Central Goldfields, CO = Colac-Otway, C = Corangamite, GL = Glenelg, GP = Golden Plains, GE = Greater Geelong, HP = Hepburn, HI = Hindmarsh, HS = Horsham, MR = Moorabool, MO = Moyne, NG = Northern Grampians, PY = Pyrenees, Q = Queenscliffe, SG = Southern Grampians, SC = Surf Coast, WA = Warrnambool, WW = West Wimmera and Y = Yarriambiack

## Discussion

This study reports the incidence rates for hip, knee and 'other' (ankle, elbow, shoulder, spine and wrist) primary joint replacements across the study region. There were variations in rates across the different LGAs, with many of the more rural LGAs having a higher rate of joint replacements. This study also identified that most primary joint replacement procedures in the LGAs of Ballarat, Greater Geelong and Warrnambool were conducted within an individual's LGA of residence. The other LGAs with orthopaedic services had lower proportions of replacements performed within a patient's LGA of residence.

Data for the whole of Australia is available for crude rates of replacements in men and women combined during 2011 [28], and the crude rates for our study region were similar for

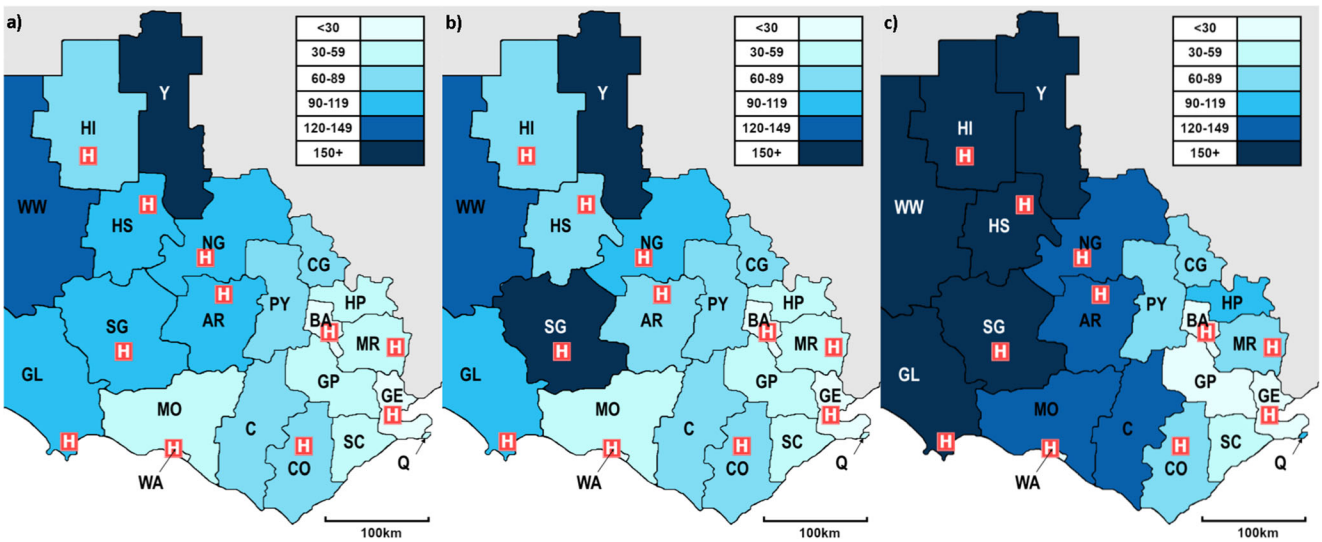


**Fig. 6** Heat map showing median distance travelled by male and female patients aged ≥ 40 years for primary replacements of the **a** hip, **b** knee and **c** other joints across the study region during 2011–2013 inclusive. The legend shows the shading as distance in kilometres. Red H's show the location of all hospitals in the region which conduct joint replacement procedures. AR = Ararat, BA = Ballarat, CG = Central Goldfields, CO = Colac-Otway, C = Corangamite, GL = Glenelg, GP = Golden Plains, GE = Greater Geelong, HP = Hepburn, HI = Hindmarsh, HS = Horsham, MR = Moorabool, MO = Moyne, NG = Northern Grampians, PY = Pyrenees, Q = Queenscliffe, SG = Southern Grampians, SC = Surf Coast, WA = Warrnambool, WW = West Wimmera and Y = Yarriambiack

knee replacements (this study: 45.4 vs Australia: 45.7 per 10,000 population/year) and "other" replacements (4.1 vs 4.5 per 10,000 population/year). However, our study region had a higher crude rate of hip replacements (42.5 vs 36.8 per 10,000 population/year).

In this study, we observed that some LGAs had a higher proportion of individuals aged < 70 years receiving joint replacements, including two LGAs with agriculture as a large component of their industry (Pyrenees and Golden Plains). There are an increasing number of individuals receiving joint replacements at younger ages, partially due to patient request, and by 2030, it is estimated that 52% of hip and 55% of knee replacements will be performed in individuals aged less than 65 years [26]. In those who undergo a primary joint replacement at the age of 50–54 years, the lifetime risk of hip replacement revision is 29% and 35% for knee joint revisions [26]. As obesity and life expectancy are increasing in the population, this will impact on the longevity of joint replacements [29]. Thus, it has been suggested that the management of young patients should focus on reversing or slowing down the progression of joint disease, rather than recommending joint replacement [2, 29].

We observed that many individuals travelled long distances for primary joint replacement procedures. This underpins need for new/novel models or care and review of these patients' travel burden, perhaps using high-quality data registries, as previously described [30, 31]. Many of the joint replacement procedures were performed in hospitals located within the three most populous LGAs of Ballarat, Greater Geelong and Warrnambool ($n$ = 6485, 75.7% of all replacements). However, although orthopaedic services were available in 11 of the 21 LGAs in the study region, around one in ten patients travelled to hospitals in and adjacent to the LGA of Melbourne ($n$ = 849, 9.9% of all joint replacements). Additionally, < 50% of procedures in LGAs with orthopaedic services (excluding Ballarat, Greater Geelong and Warrnambool) were performed in the same LGA that the patient resided. Concerns have been raised that performing joint replacements in rural settings may be associated with poorer outcomes, but a study by Stewart et al. [18] has shown that acceptable outcomes can be obtained for primary hip and knee replacement surgeries conducted in a rural hospital.

Previous studies have shown that farmers have a higher risk of hip and knee osteoarthritis [3, 4, 13], which may contribute to a higher rate of joint replacements. Banerjee et al. [5] reported that people who live in rural areas of the USA were more likely to be over 65 years of age when receiving a joint replacement, and women in rural areas were less likely to have a joint replacement compared to women living in urban areas. The authors suggested that those in rural settings wait until they meet the criteria for Medicare support before choosing to have an elective joint replacement surgery and have less choice for private access. A study by Dixon et al. [9] has also reported that a higher rate of hip and knee replacements in 2005–2007 occurred in regional areas compared to major cities in Australia. In the current study, the highest rates of joint replacements occurred in the more rural areas of the study region. Rural areas also tend to be more stable genetically, and therefore, a family history for arthritis may be another reason for the observations in this study; however, we do not have data to investigate this further.

The LGA of Pyrenees had the highest rate of primary knee replacements in both men and women. In men, the reason for this observation may be related to the primary economies in Pyrenees, which include wool (sheep), viticulture and forestry activity, with 30% of the workforce being involved in agriculture. There are a number of activities carried out by farmers that can increase the risk of developing osteoarthritis including heavy lifting, frequent bending, driving for long periods of time and walking long distances over uneven ground [8]. Kirkhorn et al [8] provided suggestions on how to reduce the risk of osteoarthritis in farmers including reducing obesity, reducing the amount of load carried and the time carried, as well as providing more equipment and machinery designed to reduce musculoskeletal loading.

The LGA of Pyrenees also has a high level of obesity (21.4%) [19], which has been associated with an increased risk of hip and knee osteoarthritis [4, 9, 14] and may explain the observed association in women; it has been estimated that 27% of hip and 69% of knee replacements in women are due to obesity [32]. Overall, obesity levels are higher in the western rural LGAs of the study region, such as Yarriambiack (30.9%), Hindmarsh (22.0%), West Wimmera (24.3%) and Glenelg (21.7%) [19].

An Australian group known as MOVE, muscle, bone and joint health, which is aimed at improving the quality of life of people who have, or at risk of developing musculoskeletal conditions, have reported that the rates of osteoarthritis (2007–2008) are higher in the eastern area of the study region. However, we observed a higher rate of joint replacements in the western LGAs. Based on these data, it appears that a higher rate of osteoarthritis is not the primary driver of an increased rate of joint replacements in western LGAs. Differences in joint replacement uptakes related to geographical area may be due to a variation in risk factors (for example those increasing risk such as certain occupations or obesity), but also may reflect patient preferences such as willingness to undergo surgery, particularly if their occupation requires agility [9]. Some of the differences we observed between LGAs may be a result of social deprivation in some areas, with individuals in more advantaged areas more likely to receive a total joint replacement for osteoarthritis of the hip or knee compared to their disadvantaged counterparts [15], independent of LGA. One other reason for differences in joint replacement rates may be variation in clinical practice; however, there are a limited number of orthopaedic surgeons in the study region which would be expected to limit clinical variation.

Most patients had a joint replacement for osteoarthritis: 77.9% for hip joints and 98.6% for knee joints. Another study conducted in Australia [9] across the years 2005 to 2007 reported a similar proportion of knee replacements were due to osteoarthritis (96.3%), whereas the value for hip replacement was higher (88.1%) than reported in the current study. The reasons for the differences between our population and the total Australian population are not clear.

This study has several strengths. The AOANJRR is a comprehensive database of all joint replacements in Australia, including our study region. Data from both state-funded public hospitals as well as private hospitals are included in the dataset for this study. The LGAs included in this study have a high level of diversity, from cities to large regional and rural centres as well as LGAs with small populations and large areas including agricultural lands. We investigated a specific area of the state of Victoria, Australia, and changes in healthcare policies can be monitored across the ACDI study region, which is not possible for the entirety of Australia. This study also has some limitations. We were unable to determine the reasons for differences in joint replacement rates between LGAs, though we have speculated that occupation, obesity and SEP may play a role. Additionally, we determined all-cause procedures and are unable to determine specific diseases resulting in replacement. Data from this region may also not be generalisable to other populations.

## Conclusion

The incidence rates of primary joint replacements were different across the LGAs studied. A large proportion of joint replacements were due to osteoarthritis, particularly for the knee. Orthopaedic services were available in 11 of the 21 LGAs in the study region and we observed that many individuals had to travel long distances for primary joint replacement procedures. Not surprisingly, the majority of joint replacements took place in the major centres of Geelong, Ballarat and Warrnambool. The findings from this study have implications for planning health service provision across the region, particularly in the more rural areas such as aiding in resource targeting and management. These results also provide a model for other researchers to conduct similar work in their local environments.

**Acknowledgements** This study is funded by the Western Alliance Academic Health Science Centre, a partnership for research collaboration between Deakin University, Federation University and 13 health service providers operating across western Victoria. SLB-O and LJW are each supported by a NHMRC Career Development Fellowship (1107510 and 1064272, respectively). KLH-K is supported by an Alfred Deakin Postdoctoral Research Fellowship, Deakin University. MAS is supported by a Deakin University stipend via the IMPACT Strategic Research Centre. The funding sources had no impact on the study design, analysis or interpretation.

**Authors' Contributions** KLH-K, MAS, MAK and JAP conceived the study. JAP obtained research funding. KLH-K, AC, SG and RP contributed to the data collection. KLH-K, MAK and JAP were responsible for the data analyses. KLH-K drafted the manuscript, and all other authors contributed substantially to its revision. KLH-K takes responsibility for the paper as a whole.

**Funding** This study is funded by the Western Alliance Academic Health Science Centre, a partnership for research collaboration between Deakin University, Federation University and 13 health service providers operating across western Victoria. SLB-O and LJW are each supported by a NHMRC Career Development Fellowship (1107510 and 1064272, respectively). KLH-K is supported by an Alfred Deakin Postdoctoral Research Fellowship, Deakin University. MAS is supported by a Deakin University stipend via the IMPACT Strategic Research Centre. The funding sources had no impact on the study design, analysis or interpretation.

## Compliance with ethical standards

**Conflict of Interest** SG is the Director of The Australian Orthopaedic Association National Joint Replacement Registry. KLH-K, MAS, MAK, AC, PML, MK, SH, TLD, SB, RSP, AS, SLB-O, LJW and JAP declare that they have no conflicts of interest.

**Ethical Approval** The AOANJRR Data Review Committee approved access to National Joint Replacement Registry data for this study and the Barwon Health Human Research Ethics Committee approved this study (HREC 15/11).

**Informed Consent** This article does not contain any studies with human participants or animals performed by any of the authors.

## References

1. Judge A, Welton NJ, Sandhu J, Ben-Shlomo Y. Geographical variation in the provision of elective primary hip and knee replacement: the role of socio-demographic, hospital and distance variables. J Public Health. 2009;31:413–22.
2. Carr AJ, Robertsson O, Graves S, Price AJ, Arden NK, Judge A, et al. Knee replacement. Lancet. 2012;379:1331–40.
3. Andersen S, Thygesen LC, Davidsen M, Helweg-Larsen K. Cumulative years in occupation and the risk of hip or knee osteoarthritis in men and women: a register-based follow-up study. Occup Environ Med. 2012;69:325–30.
4. Apold H, Meyer HE, Nordsletten L, Furnes O, Baste V, Flugsrud GB. Risk factors for knee replacement due to primary osteoarthritis, a population based, prospective cohort study of 315,495 individuals. BMC Musculoskelet Disord. 2014;15:217.
5. Banerjee D, Illingworth KD, Novicoff WM, Scaife SL, Jones BK, Saleh KJ. Rural vs. Urban Utilization of Total Joint Arthroplasty. J Arthroplast. 2013;28:888–91.
6. Harcombe H, Davie G, Derrett S, Abbott H, Gwynne-Jones D. Equity of publicly-funded hip and knee joint replacement surgery in New Zealand: results from a national observational study. N Z Med J. 2016;129:8–18.
7. Jarvholm B, Lewold S, Malchau H, Vingard E. Age, bodyweight, smoking habits and the risk of severe osteoarthritis in the hip and knee in men. Eur J Epidemiol. 2005;20:537–42.

8. Kirkhorn S, Greenlee RT, Reeser JC. The epidemiology of agriculture-related osteoarthritis and its impact on occupational disability. Wis Med J. 2003;102:38–44.
9. Dixon T, Urquhart DM, Berry P, Bhatia K, Wang Y, Graves S, et al. Variation in rates of hip and knee joint replacement in Australia based on socio-economic status, geographical locality, birthplace and indigenous status. ANZ J Surg. 2011;81:26–31.
10. Dowsey MM, Petterwood J, Lisik JP, Gunn J, Choong PF. Prospective analysis of rural-urban differences in demographic patterns and outcomes following total joint replacement. Australian J Rural Health. 2014;22:241–8.
11. Francis ML, Scaife SL, Zahnd WE, Cook EF, Schneeweiss S. Joint replacement surgeries among medicare beneficiaries in rural compared with urban areas. Arthritis Rheum. 2009;60:3554–62.
12. Schafer T, Pritzkuleit R, Jeszenszky C, Malzahn J, Maier W, Gunther KP, et al. Trends and geographical variation of primary hip and knee joint replacement in Germany. Osteoarthr Cartil. 2013;21:279–88.
13. Franklin J, Ingvarsson T, Englund M, Lohmander S. Association between occupation and knee and hip replacement due to osteoarthritis: a case-control study. Arthritis Res Therapy. 2010;12:R102.
14. Croft P, Coggon D, Cruddas M, Cooper C. Osteoarthritis of the hip: an occupational disease in farmers. Br Med J. 1992;304:1269–72.
15. Brennan-Olsen S, Vogrin S, Holloway KL, Page RS, Sajjad MA, Kotowicz MA, et al. Geographic region, socioeconomic position and the utilisation of primary total joint replacement for hip or knee osteoarthritis across western Victoria: a cross-sectional multilevel study of the Australian Orthopaedic Association National Joint Replacement Registry. Arch Osteoporos. 2017;12:97–103.
16. Brennan-Olsen SL, Page RS, Lane SE, Lorimer M, Buchbinder R, Osborne RH, et al. Few geographic and socioeconomic variations exist in primary total shoulder arthroplasty: a multi-level study of Australian registry data. BMC Musculoskelet Disord. 2016;17:291–9.
17. Milner PC, Payne JN, Stanfield RC, Lewis PA, Jennison C, Saul C. Inequalities in accessing hip joint replacement for people in need. Eur J Pub Health. 2004;14:58–62.
18. Stewart GD, Stewart PC, Nott ML, Long G. Total joint replacement surgery in a rural centre. Australian J Rural Health. 2006;14:253–7.
19. Sajjad MA, Holloway KL, Kotowicz MA, Livingston PM, Khasraw M, Hakkennes S, et al. Ageing, Chronic Disease and Injury: a study in western Victoria. J Public Health Res. 2016;5:678–83.
20. Holloway KL, Sajjad MA, Mohebbi M, Kotowicz MA, Livingston PM, Khasraw M, et al. The epidemiology of hip fractures across western Victoria, Australia. Bone. 2018;108:1–9.
21. Western Victoria Primary Health Network. PHN Western Victoria [Internet]. 2019 [cited 2019 Aug 21]. Available from: https://www.westvicphn.com.au/
22. Australian Bureau of Statistics (2001-2013) Estimated Resident Population by Sex by Age Group by LGA, 2001-2013 on ASGS 2013.
23. Australian Bureau of Statistics. Census of Population and Housing. Basic Community: Profile; 2011.
24. Australian Orthopaedic Association. National Joint Replacement Registry [Internet]. 2019. Available from: https://aoanjrr.sahmri.com/home
25. Brennan SL, Stanford T, Wluka AE, Page RS, Graves SE, Kotowicz MA, et al. Utilisation of primary total knee joint replacements across socioeconomic status in the Barwon Statistical Division, Australia, 2006-2007: a cross-sectional study. BMJ Open. 2012;2.
26. Schreurs BW, Hannink G. Total joint arthroplasty in younger patients: heading for trouble? Lancet. 2017;389:1374–5.
27. Golden Plains Shire Council (2017) Golden Plains Food Production Precinct Concept Plan.
28. Australian Orthopaedic Association. Procedures Reported - AOANJRR [Internet]. 2011. Available from: https://aoanjrr.sahmri.com/procedures-reported
29. Crowninshield RD, Rosenberg AG, Sporer SM. Changing demographics of patients with total joint replacement. Clin Orthop Relat Res. 2006;443:266–72.
30. Page RS, Beattie S, Williams S, Gill SD. Clinical quality registries: local registries complement national registries. An example from joint arthroplasty. ANZ J Surg. 2018;88:667–8.
31. Reynolds B, Maister N, Gill SD, Waring S, Schoch P, Beattie S, et al. Identifying complications requiring re-operation following primary hip or knee arthroplasty: a consecutive series of 98 patients. BMC Musculoskelet Disord. 2018;19:91.
32. Liu B, Balkwill A, Banks E, Cooper C, Green J, Beral V. Relationship of height, weight and body mass index to the risk of hip and knee replacements in middle-aged women. Rheumatology. 2007;46:861–7.