

The development of AUS-OA - a population health economic model of osteoarthritis in Australia

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Abstract Simulation modelling is a powerful tool for assessing the impact of diseases and guiding healthcare policy decisions. This paper introduces AUS-OA, a dynamic discrete time microsimulation model of osteoarthritis and its treatment in Australia. AUS-OA aims to provide policy makers and researchers with increased capacity to evaluate the burden and treatment of osteoarthritis across Australia. AUS-OA uses a synthetic base population of individuals with age, sex, Body Mass Index (BMI), osteoarthritis and other attributes weighted to the Australian population. Body mass index, osteoarthritis incidence and progression, primary and revision joint replacement are modelled over time based on econometric equations derived from linked and longitudinal data. Costs and health-related quality of life outcomes are then assigned based on an individual's health conditions and treatments. AUS-OA is calibrated with observed data between 2013 and 2022. Base case and 'what-if' scenarios can then be simulated from 2023. For an initial application, AUS-OA was used for an economic evaluation of a decision support tool, SMART Choice, that improves patient selection into surgery. Comparisons of univariate and bivariate distributions across key population attributions such as BMI, osteoarthritis and joint replacement between the synthetic and actual populations highlight that the AUS-OA model accurately reflects the Australian population over the calibration period. The evaluation of the SMART Choice decision support tool highlighted that the tool is cost-effective. AUS-OA provides a robust analytical framework for evaluating the long-term, population-level impact of osteoarthritis and its treatments.

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1. Introduction

Osteoarthritis is a common and debilitating disease. In Australia, people with osteoarthritis are almost twice as likely to rate their health as 'fair' to 'poor', and to report 'moderate' to 'very severe' bodily pain compared to those without the condition (*Australian Institute of Health and Welfare, 2023*). Federal government spending on osteoarthritis reached \$4.3 billion in 2020-21, or 2.9% of total spending on healthcare (*Australian Institute of Health and Welfare, 2023*), and is expected to continue grow rapidly to 2030 (*Ackerman et al., 2019*). Substantial effort is being made to reduce the health and economic burden of osteoarthritis, including the development of new streamlined models of care (*Minister for Health et al., 2023*), community-based lifestyle interventions to reduce the need for end-stage surgeries (*The University of Sydney, 2023*), and trials to investigate the use of stem-cell therapies to avoid the progression of osteoarthritis altogether (*Watkins, 2022*). However,

the epidemiology of osteoarthritis is complex and progresses over a lifetime, while population demographics and behaviours are changing over time. It is a major challenge to extrapolate the results from clinical trials and quasi-experimental studies to broader, long-term population outcomes, to understand which interventions are effective and cost-effective.

Simulation modelling addresses that challenge and is a powerful tool for assessing the impact of diseases and guiding healthcare policy decisions (*Schofield et al., 2018; Zucchelli et al., 2010*). Its advantages include the ability to model the social determinants of health and disease progression over a patient's lifetime, and to capture the heterogeneity of a population within a systematic analytical framework (*Zucchelli et al., 2010; Kopasker et al., 2023*). Complex population trends can be modelled by a series of relatively simple equations at the individual level, such as how the progression of osteoarthritis varies depending on age, gender and/or Body Mass Index (BMI). New policies and models of care can be evaluated by changing inputs into the model, and sensitivity analyses can be completed to test the robustness of the results.

The efficacy of simulation models for the study of osteoarthritis is exemplified by OAPOL, a Markov model developed in the United States that has been widely utilised for health economic policy research (*Losina et al., 2011*); a New Zealand adaption of OAPOL, NZ-MOA (*Wilson and Abbott, 2018*); and POHEM-OA, a continuous time microsimulation model developed originally out of Statistics Canada (*Kopeck et al., 2010*). Simulation modelling has been employed in Australia to model the impact of policy (*Hayes et al., 2019*), and the indirect costs of chronic disease (*Schofield et al., 2015*). This paper introduces AUS-OA, a dynamic microsimulation model of osteoarthritis and its treatment in Australia. The aim of AUS-OA is to provide policy makers, healthcare providers, and researchers with the critical capability to assess the lifetime and population-wide impacts of interventions and innovations to reduce the burden of osteoarthritis across Australia.

2. The AUS-OA dynamic simulation model

2.1. Overview of model

AUS-OA is a probabilistic, discrete time, dynamic microsimulation model representative of the Australian population of adults aged 45 years and older.¹ Individual agents within the model have a range of attributes including age, gender, BMI and osteoarthritis, the presence of comorbidities including mental illness, the use of medications for osteoarthritis or mental illness, private health insurance status, socio-economic position as proxied by completion of year 12 secondary schooling, and state of residence (see *Table 1*). Each year, new agents enter the model at age 45, while existing agents in the model grow older, experience a change in BMI, acquire comorbidities, potentially develop osteoarthritis or experience it worsen, seek treatments such as pain relief or total joint replacement, and in some cases, die. Health service utilisation and costs, and health-related quality of life, are then evaluated based on the individual agent's attributes, health conditions, and treatments. Presently, the focus of AUS-OA is osteoarthritis of the knee, but the model has the capacity to be adapted to include other bodily sites. AUS-OA simulations begin in 2013 to allow the model to be validated against observed data between 2013 and 2022. Base case projections and 'what-if' scenarios can then be simulated for up to 30 years from 2023 until 2053, to evaluate the impact of socio-demographic trends, changes in costs or advances in osteoarthritis treatment and models of care. The model is coded in both R 2024.04.2 (*R Core Team, 2020*) and Matlab R2022b (*MATLAB, 2022*).

Table 1. Key variables tracked within the model.

Domain	Variable
Socio-demographics	Age, gender, socio-economic position, private health insurance, state
Risk factors	BMI, mental illness, comorbidities
Outcomes	Osteoarthritis, health-related quality of life, costs
Treatments	Osteoarthritis medications, primary care health, joint replacement and revisions

2.2. Base population

A 2013 synthetic Australian population is derived from a long-running Australian longitudinal study, the Household, Income and Labour Dynamics in Australia (HILDA) survey (**Wooden and Watson, 2007**), and weighted to the Australian population using the SimPop synthetic data generator package in R (**Templ et al., 2017**). HILDA contains data for all key variables, including age, gender, year 12 completion (the proxy for socio-economic position), BMI, mental illness (as defined as a diagnosis of depression or anxiety), comorbidities (modelled as a count of illnesses including heart disease, diabetes, cancer as recorded in HILDA), osteoarthritis and health-related quality of life measured using the Short Form 6D generic instrument (**Melbourne Institute: Applied Economic & Social Research, 2024**). A range of visual and empirical diagnostics were completed to ensure the synthetic population captures the cross-correlations between key population attributes (e.g. between age, BMI and osteoarthritis). These diagnostics, including univariate and bivariate distributions between the synthetic and actual populations, are provided in Supplementary materials.

2.3. Dynamics

2.3.1. BMI

Changes in BMI over time are modelled as a function of age, gender, socio-economic position as proxied by year 12 completion, which is time invariant, and current BMI, based on previous research using a simulation modelling approach to match cohorts with National Health Surveys reporting population-level BMI (**Hayes et al., 2019**).

2.3.2. Osteoarthritis

Osteoarthritis incidence rates are derived from HILDA and based on age, sex, socio-economic position, and BMI (see Supplementary materials). The Kellgren-Lawrence (KL) grade is used to characterise osteoarthritis severity as is common in the literature (**Joo et al., 2022**). AUS-OA assumes that all new incidents of osteoarthritis have a KL grade of 2. KL progression equations are derived from the Osteoarthritis Initiative (OAI), a large longitudinal study of osteoarthritis and are based on age, sex and BMI. Note that national statistics tend to report osteoarthritis at the person-level, rather than the individual site within the body (e.g. knee). In AUS-OA, while the total population prevalence of osteoarthritis can grow over time, a fixed proportion (49 per cent) of those reporting the presence of osteoarthritis are assumed to have knee osteoarthritis, based on a recent review that found in Australia this share has remained relatively constant over time (**Long et al., 2022**). AUS-OA does not specify the side of the knee osteoarthritis (left or right), but previous total knee replacements (TKRs) are explicitly counted, and used as a predictor of a subsequent TKR.

2.3.3. Comorbidities

Mental health incidence is modelled as a function of gender such that the prevalence of mental illness within AUS-OA increases in-line with observed population trends. Incidence of other chronic comorbidity is modelled as a function of age and gender based on analysis of HILDA over time and incorporated in the model as a count of comorbidities (see Supplementary materials). AUS-OA currently assumes no remission for mental health or other comorbidities. Further modelling of the dynamics of comorbidities and mental illness can be incorporated at a later date.

2.3.4. Total knee replacement

The incidence of TKR is modelled as a function of age, sex, BMI, mental health, and previous TKR, based on a Fine and Gray competing risks model, with death the competing risk, as published previously (**Thuraisingam et al., 2022**). Two adjustments are made for AUS-OA: first incidence rates are adjusted up or down based on the individual's osteoarthritis severity (see Supplementary materials), a known risk factor used as a dependent variable in high performing international models (**Liu et al., 2022**); second, trends over time are incorporated into the baseline hazard rate and calibrated to observed trends in utilisation by age and sex from the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) which captures data on 98 per cent of Australia's joint

replacements (*Smith et al., 2023*). Future iterations of the model will differentiate models of TKR incidence by private health insurance status.

2.3.5. Revisions of total knee replacement

Equations to model TKR revisions are developed from a bespoke data request from the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) which predicts revisions using a parametric regression based on age, sex, and BMI (see Supplementary materials).

2.3.6. Death

Death rates are derived from the lifetables from the national statistics agency, amended with increased relative risks associated with joint replacement; obesity and comorbidities (*Hayes et al., 2019; Australian Bureau of Statistics, 2014; Zhou et al., 2023*). AUS-OA can also be run using standard unadjusted lifetables to investigate the impact of these adjustments. Full details of amendments to death rates are provided in the Supplementary materials.

2.3.7. Health-related Quality of Life

Health-related quality of life (HRQOL) measured in HILDA using the SF6D forms the base 2013 population. Over time, movements in HRQOL occur as a result of changes in age, BMI, comorbidities

Table 2. Key dynamics within AUS-OA.

Variable	Model	Key covariates	Data	Source
BMI	Multivariate regression	Age, sex, SEP BMI	NHS	Hayes et al., 2019
OA incidence	Logistic regression	Age, sex, SEP BMI	HILDA	Author's own – see Supplementary materials
OA progression	Logistic regression	Age, sex, BMI	OAI	Author's own
Mental health	Calibration	Sex	HILDA, NHS	Author's own
Other comorbidities	Calibration	Age, sex	HILDA, NHS	Author's own
TKR incidence	Fine and Gray competing risks	Age, sex, BMI, mental health, previous TKR, KL score	Linked primary care and AOANJRR	Thuraisingam et al., 2022, modified for AUS-OA
TKR complication	Logistic regression	Age, sex, BMI, mental health, comorbidities, HRQOL	SMART Registry	Author's own;
Inpatient rehabilitation	Logistic regression	Age, sex, BMI, mental health, comorbidities, HRQOL, complications	SMART Registry	Author's own;
TKR revision	Weibull parametric regression	Age, sex, BMI	AOANJRR	AOA bespoke request 2024
Death	Life tables; standardised mortality ratios	Age, sex, BMI, SEP, TKR	NZJR, NHS	Zhou et al., 2023; Hayes et al., 2019
HRQOL decrements	Various	Age, sex, BMI, KL score, comorbidities	HILDA, OAI	Author's own; Carrello et al. (2021), Wilson and Abbott (2018)
HRQOL after surgery	Multivariate regression	Age, sex, BMI, comorbidities	SMART	Author's own, based on Schilling et al. (2017) (Schilling et al., 2017)

AOA = Australian Orthopaedic Association. AOANJRR = Australian Orthopaedic Association National Joint Replacement Registry. BMI = Body mass index. HILDA = Household Income and Labour Dynamics of Australia. HRQOL = Health-related quality of life. KL = Kellgren-Lawrence. NZJR = New Zealand Joint Register. NHS = National Health Survey. OA = osteoarthritis. OAI = Osteoarthritis Initiative. SEP = socio-economic position as proxied by completion of year 12. TKR = Total knee replacement

and severity of osteoarthritis. Age and comorbidity HRQOL decrements are derived from analysis of HILDA; osteoarthritis decrements are based on a longitudinal analysis of the OAI (*Wilson et al., 2018*). BMI decrements are obtained from a meta-analysis (*Carrello et al., 2021*). HRQOL scores are used to estimate Quality Adjusted Life Years (QALY) for each individual for each year. It is assumed that the HRQOL score for a given year is accrued across the year such that the QALY accrued in one year is equal to the HRQOL score in that year. The HRQOL improvements from TKR are derived from a regression analysis of the St Vincent's Melbourne Arthroplasty (SMART) registry data that has captured joint replacements for over two decades (*Gould et al., 2021*), as a function of preoperative HRQOL, age, sex, BMI, comorbidities and mental health. This is an update on earlier 2017 analysis (*Schilling et al., 2017*). Further details are provided in the Supplementary materials.

2.3.8. Costs

A range of costs associated with osteoarthritis and its treatment are incorporated into AUS-OA, including the costs of surgical hospital admissions, both primary and revisions, rehabilitation costs at home or inpatient, and primary care costs that are captured by the Medical Benefits Scheme (MBS) and the Pharmaceutical Benefits Scheme (PBS). A full list of cost inputs is provided in the Supplementary materials (see **Table 2**). All costs are in Australian dollars. AUS-OA can provide economic evaluations from different perspectives, including from a government, health payer or consumer perspective, however at present wider societal costs such as productivity costs and costs borne by carers are not included in the model. The modelling framework allows these to be incorporated at a later date. A discount rate of 5 per cent is applied to costs and outcomes as per standard Australian health technology assessment guidelines (*Medical Services Advisory Committee, 2021*).

3. Validation of AUS-OA

3.1. Internal validation

Validation is not a simple check-box exercise or unified process, nor is there one single way of validating a complex dynamic microsimulation model (*Kaye-Blake et al., 2014*). For AUS-OA, we have conducted a systematic set of validation exercises to build trust in the model. First, internal validation

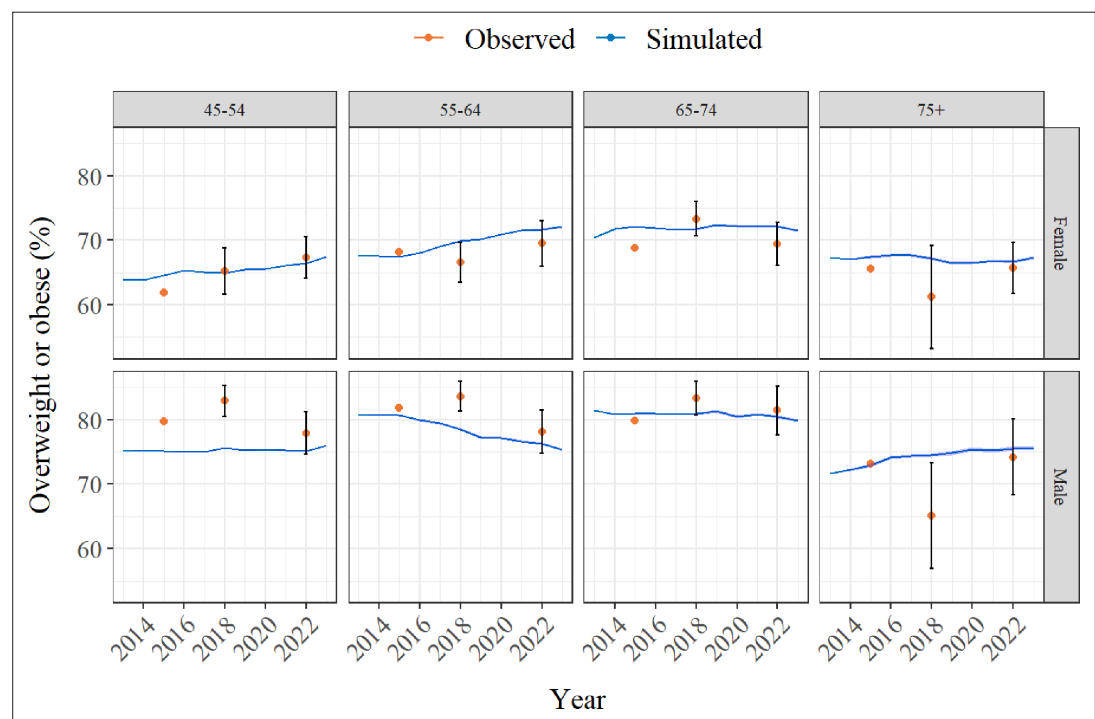


Figure 1 AUS-OA (simulated) versus National Health Survey (observed) rates of overweight and obese, by age and sex categories, 2013 to 2022.

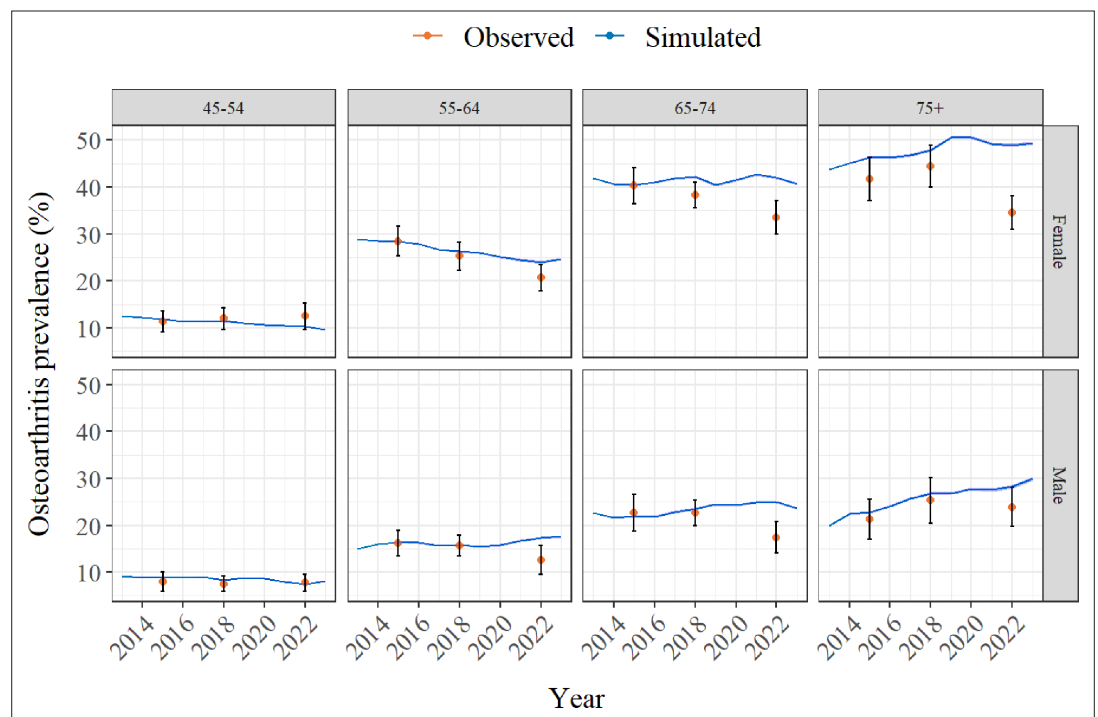


Figure 2 AUS-OA (simulated) versus National Health Survey (observed) prevalence of osteoarthritis, by age and sex categories, 2013 to 2022.

was conducted by reproducing the model in two software languages: R and Matlab, and by two coders, and comparing simulation outputs. A range of shocks were imposed in the model and results tested to confirm that AUS-OA was working as expected. For example, a sharp increase in BMI was modelled, to confirm that an increase in a key risk factor for osteoarthritis led to higher rate of disease incidence and progression; higher rates of osteoarthritis progression were tested to confirm that the AUS-OA then predicted a higher rate of TKR.

3.2. External validation

Following the internal validation, AUS-OA simulations for 2013 to 2022 were compared with observed data from National Health Surveys for BMI and osteoarthritis (*Australian Bureau of Statistics, 2022*), and national registry data for rates of TKR per 100,000 population (*AOANJRR, 2022*). Some model dynamics were then calibrated to improve the accuracy of the AUS-OA simulations (see Supplementary materials *Figures 1–3*). In general the AUS-OA model adequately captures the trends in these variables, however one area of inconsistency is the higher level of overweight and obese in 75+ aged cohort, particularly for women, in AUS-OA relative to the National Health Surveys.

4. Application of AUS-OA: evaluation of the SMART Choice decision support tool

4.1. Application

As an example application, we used AUS-OA to complete a model-based economic evaluation of a novel decision support tool, SMART Choice, to improve patient selection into surgery. Both the SMART Choice tool and the randomised control trial (RCT) to evaluate it are detailed elsewhere (*Zhou et al., 2023; Zhou et al., 2022; Zhou et al., 2024*), but in short the tool provides a prediction for outcomes from surgery based on an individual's age, gender, pain and functional impairment. The RCT found that the SMART Choice tool reduced patient preference for surgery in a cohort unlikely to benefit (OR 0.46, 95% CI 0.20-1.03, p value 0.06, *Zhou et al., 2024*).

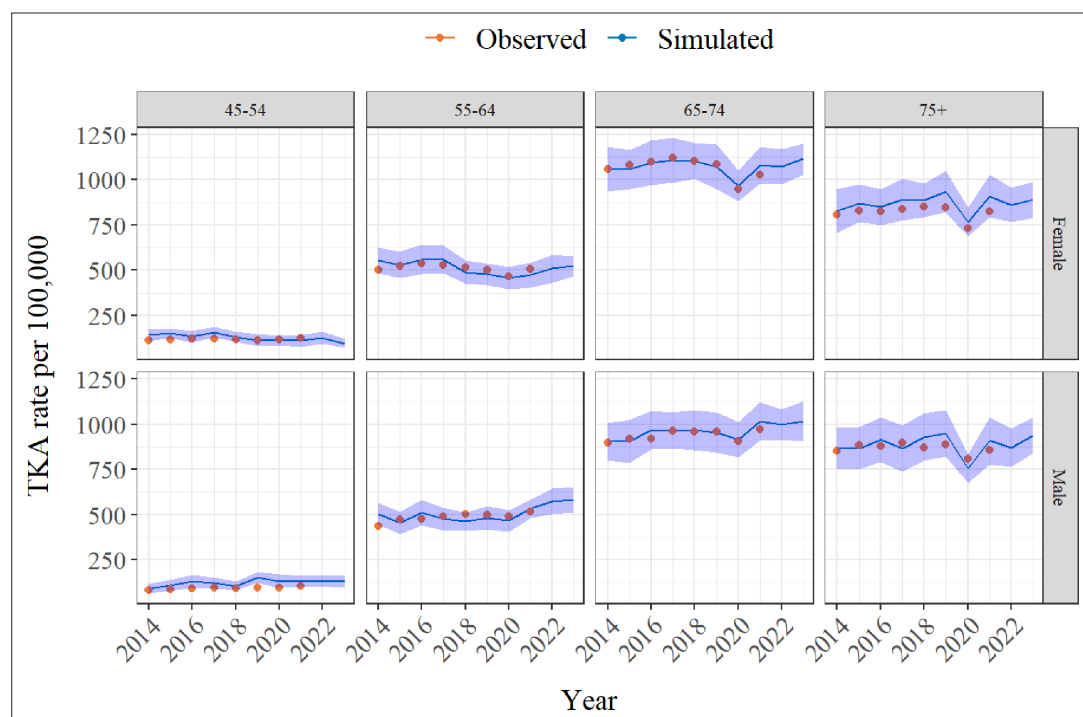


Figure 3 AUS-OA (simulated) versus AOANJRR (observed) rates of TKR by 100,000 population, by age and sex categories, 2013 to 2022.

4.2. Economic evaluation

We completed a cost-utility analysis from a health funder perspective. We compare costs and HRQOL outcomes under a scenario where 3 per cent (sensitivity test 1 and 5 per cent) of those with osteoarthritis and a preference for surgery use SMART Choice, versus the status quo baseline without SMART Choice. The mechanism through which the tool delivers benefit is by improving the mix of patients receiving TKRs. The impact of SMART Choice is modelled by applying the odds ratio observed in the trial to the rate of surgeries in those unlikely to benefit (*Zhou et al., 2024*). The decision support tool is not an active treatment that would be expected to alter the progression of osteoarthritis, and there are large waiting lists for surgery, so it is unlikely to reduce overall numbers of TKR in any given year. We therefore offset the lower rates of TKR in those unlikely to benefit by an increase in the rate of TKRs for those likely to benefit. The costs of SMART Choice are largely sunk in the development of the web-based tool, however we consider annual operational costs of \$150,000 to cover website hosting and maintenance. We compute an incremental cost effectiveness ratio (ICER) and assess cost-effectiveness relative to a common threshold of \$50,000 per QALY (*Wang et al., 2018*). We simulate the analysis 100 times over 10 years, discounting both costs and HRQOL outcomes at 5 per cent.

4.3. Results of model-based economic evaluation

The cost-effectiveness results are shown in **Table 3** and a cost-effectiveness plane is shown in the Supplementary materials. On average, the results suggest that SMART Choice delivers an increase in population QALYs because of improved patient selection into surgery, resulting in a highly

Table 3. Cost effectiveness of SMART Choice

Use of SMART Choice in surgical population	Increment costs	Incremental QALYs	Incremental Cost/QALY
Baseline – 3%	\$707,918	2,910	\$243
1%	\$1,008,146	970	\$1,039
5%	\$407,691	4,850	\$84

cost-effective ICER of \$243 per QALY. Note that the incremental costs are lower than the direct costs of the intervention as the improved patient mix also results in reduced costs due to lower rates of complications and inpatient rehabilitation. In sensitivity analysis, the ICER falls to \$84 per QALY if 5 per cent of the surgical population use SMART Choice; conversely the ICER increases to \$1,039 if only 1 per cent use it.

5. Conclusion

5.1. Strengths and limitations

AUS-OA combines research about the epidemiology and health economics of osteoarthritis and its treatments, into a consistent and repeatable analytical framework. This allows testing of policy changes, improvements to models of care and development of innovative treatments. In general, the data underpinning the model is from high quality datasets and research, including long-running longitudinal surveys and registries, meta-analyses, and bespoke analysis. A number of verification and validation exercises have been conducted to gain trust in the model, including coding the model in two languages by different coders. The R version of the model is publicly available through a GITHUB repository.

Importantly, AUS-OA includes key risk factors associated with osteoarthritis, particularly age, sex, and BMI. However, we also note that other risk factors for osteoarthritis such as injury are not currently included. There is also uncertainty in the population trends for key variables, and bias in the self-reported BMI data for HILDA and the 2022 NHS, which moved to self-report post pandemic. Both BMI distributions and osteoarthritis prevalence rates have tended to fluctuate in the national survey data over the last decade. We have provided a range of validation graphs to highlight how AUS-OA compares to observed population results, but there is uncertainty as to how accurate our baseline projections will be. We note that AUS-OA overestimates the prevalence of osteoarthritis relative to the 2022 health survey, and as a result, economic evaluations of interventions targeting this older cohort may overestimate the size of the population, and potentially the benefit from the intervention.

5.2. Potential applications and future improvements

There are two major applications of AUS-OA currently planned:

- Incorporation of further differences for priority cohorts including Aboriginal and Torres Strait Islander peoples, and culturally and linguistically diverse populations. We plan to extend the current parameters and dynamics to capture differences in these populations, which will allow us to evaluate the equity of new policies and interventions.
- Inclusion of further early risk factors for osteoarthritis, such as injury and microtears, to allow AUS-OA to model the costs and benefits of interventions earlier on in the disease pathway. We are currently supporting a trial of a novel stem-cell therapy that has the potential to alter the disease trajectory of osteoarthritis. AUS-OA will be used to provide analysis of the likely cost-effectiveness of such interventions, and to highlight areas where further improvements are necessary.

Further improvements to the model will be driven by our end-users in policy and government. These may include but are not limited to:

- Further regional disaggregation to capture differences across locations, and allow policy simulations around consolidation of health service providers;
- More detail about surgery hospitalisations, including endogenizing length of stay and cost, to allow analysis of changes to hospital-level models of care;
- Incorporation of productivity and wider societal costs of osteoarthritis. We know that these costs are substantial and important for decision-making; adding these will allow us to complete economic evaluations from a variety of perspectives.











Critically, we aim to keep the AUS-OA 'open source' and promote the use of synthetic data, so that the model can be widely used. Methodologically, we are also considering moving to a discrete event framework that would allow us to model time to event.

5.3. Summary

In conclusion, this paper introduces the AUS-OA dynamic microsimulation model of osteoarthritis and its treatment. The example provided highlights how AUS-OA can be used to evaluate interventions

such as the SMART Choice decision support tool. We believe AUS-OA can provide a significant uplift in the capability and capacity for detailed analysis of current and emerging innovations to reduce the burden of osteoarthritis.

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Conflict of Interest

The other authors declare that no competing interests exist.

Data and code availability

The model code and sample dataset are available on GitHub: <https://github.com/microsimulation/ijm-supplements/tree/ijm-00317>. Supplementary material is available from the Journal's GitHub repository: https://github.com/UnimelbHealthEconomics/AUS_OA_public.

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