



Orthopaedic registries: the Australian experience

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- The Australian Orthopaedic Association National Joint Replacement Registry first began data collection on 1 September 1999 and full nationwide implementation commenced in January 2003.
- The purpose of the Registry is to improve the quality of care for individuals receiving joint replacement surgery.
- The Registry enables surgeons, academic institutions, governments and industry to request specific data that are not available in published annual reports.
- There is an established system for identifying prostheses with a higher than anticipated rate of revision (HTARR) which was introduced in 2004.
- The higher rate of revision for the ASR Hip Resurfacing System was first identified by this process in 2007.
- There has been a reduction in revision hip and knee replacement over the years that the Registry has been in operation, and the addition of Patient Reported Outcome Measures (PROMs) and data linkage will enable more extensive analysis of joint replacement surgery in the future.

Keywords: hip arthroplasty; joint registries; knee arthroplasty; outcomes

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Background

In 1993, largely as a result of the Scandinavian experience, the Australian Orthopaedic Association (AOA) recognized the need to establish a national joint replacement registry and, after consultation with the Commonwealth Department of Health and Ageing, an agreement was signed to fund the AOA to establish a joint registry. Data collection first began on 1 September 1999 and full nationwide implementation commenced in January 2003. While it was accepted that there were already international quality registries, it was not clear whether the outcomes could be attributed to the Australian population. This was largely due to the range of different prostheses used in Australia not recorded by these registries, differences in methods of

fixation of the implants, possible dissimilarities in patients and surgeons, and different methods of healthcare delivery. The method of data collection was based on the Scandinavian process and has been refined over time.^{1–3}

Registry aims

The purpose of the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) is to define, improve and maintain the quality of care for individuals receiving joint replacement surgery. The Annual Report was first published in 2000⁴ and outlined the aims of the AOANJRR:

- Determine demographic and diagnostic characteristics of patients undergoing joint replacement surgery nationally.
- Provide accurate information on the use of different types of prostheses in both primary and revision joint replacements.
- Evaluate the effectiveness of different types of joint replacement prostheses and surgical techniques at a national level.
- Compare the Australian joint replacement experience to that of other countries.
- Provide confidential data to individual surgeons and hospitals to audit their joint surgical techniques to achieve successful outcomes.

Data collection and validation

The Australian Orthopaedic Association is the data custodian of the registry, contribution by surgeons is voluntary with almost 100% compliance, and surgeons have a distinct sense of ownership of the data. Data are submitted by hospitals on specific paper-based forms which are completed in the operating theatre. Information includes, but is not limited to, age, date and side of surgery, surgeon, type of prosthesis inserted, patient diagnosis, methods of implant fixation, and other information associated with the operation. Additional information is collected at the time of revision on the type of revision, the reasons for revision and further details of prostheses used. These forms are sent

to the Registry office and then entered by experienced data-entry personnel. The Registry is able to query incomplete or incorrect forms by contacting the designated supervisor at each participating hospital, enabling corrections to be made. Validation of Registry data is by a sequential multi-tiered matching process against state and territory health department separation record data. Following retrieval of unreported records and further checking of unmatched data, the Registry is able to obtain an almost complete record of hip and knee replacements performed in Australia. A matching program is run monthly to search for all primary and revision arthroplasty procedures recorded in the Registry that involve the same side and joint of the same patient, thus enabling each revision to be linked to the primary procedure. Data are also matched bi-annually with the Department of Health and Ageing National Death Index to obtain information on the date of death. Survivorship is estimated using the Kaplan–Meier method⁵ and the survival estimate at each time is accompanied by a 95% confidence interval based on the method of Greenwood.⁶ The Registry presents the survival information by the proportion of prostheses revised by a certain time, rather than surviving (not revised). This is termed the cumulative percent revision (CPR) and is the complement of the Kaplan–Meier survivorship. Age and gender-adjusted hazard ratios (HR), calculated from Cox proportional hazard models, are used to compare the rate of revision between different groups of interest. The Kaplan–Meier method overestimates the risk of revision in the presence of competing risks and in such circumstances the Registry uses the cumulative incidence function for all competing risks. In this method patients who have already had a revision, or who have died, are excluded from the set of observations at risk of being revised. Competing risk graphs are most often used by the Registry to demonstrate the different causes of revision for joint replacements.

The Registry initially began with a minimal dataset, which has ensured a high degree of completeness, and has recently expanded the data collection to include Level II data on American Society of Anesthesiologists (ASA), Body Mass Index (BMI) and surgical technique for total hip replacement and Level III data with a pilot study for Patient Reported Outcome Measures (PROMs) which began in 2018.

The AOANJRR is designated as a Federal Quality Assurance Activity under the Commonwealth Health Insurance Act of 1973. This ensures that the information is free from subpoena and allows surgeons to contribute data with confidence that it will not be used for purposes other than quality improvement.

Provision of registry data

Using data to improve both short and long-term outcomes for joint replacement surgery has been a priority of

the Australian Registry. The AOANJRR has endeavoured to provide accurate and timely information to all surgeons regularly, and in numerous formats. The Annual Report, in its printed version, is distributed to all surgeons performing arthroplasty in Australia, trainee surgeons within the AOA-accredited training scheme, as well as surgeons who have ceased operating, but who still have an interest in the field of joint replacement. The Annual Report has also been available on the AOA website since 2001. Lectures on interpretation of the AOANJRR are now part of the national training curriculum. The Annual Reports have had almost 2000 citations since 2004 and are increasingly viewed on the internet. The 2017 Annual Report has been viewed over 30 000 times since its release.

The Annual Report is published in September of each year and therefore a specific limitation of the Report is that data are up to date as of 31 December of the previous year. While the Report provides the most complete synopsis of Registry activity on the whole population, provision of data in a more up-to-date fashion is potentially more beneficial to surgeons. This can be provided by regular presentations at scientific meetings to disseminate up-to-date information. Over the past ten years Registry staff have given over 350 scientific presentations at state, national, and international conferences. Information from the Registry Annual Reports, particularly the figures, is also widely used by both Australian and international surgeons and researchers when giving presentations.

Since 2001, the Registry has allowed surgeons, academic institutions, governments and industry to request specific data from the Registry that is not available in the published reports. This is in the form of an ad hoc request which outlines what data are required and then the reports are reviewed by the Registry directors and staff prior to release. One of the most common requests from surgeons is for the provision of a data analysis of the surgeon's performance including full demographics of the surgeon's practice, reasons and types of revisions, a list of prostheses they use, hospitals where they treat their patients and revisions by year of implantation. There has been a fivefold increase in the number of ad hoc requests by surgeons between 2006 and 2017, and feedback from surgeons who have received analyses of their own data from the Registry indicates that the process is an important element in the way they practice. There are many examples of surgeons changing their practice as a result of these investigations and refining and improving surgeon reporting has been a major focus of the Registry.

In 2017 the Registry introduced funnel plots to display variation in revision rates and illustrate comparative performance of individual surgeons. A funnel plot is a scatter plot where each point represents a single surgeon's rate of revision with the X axis representing volume of procedures performed (individual procedures performed by the

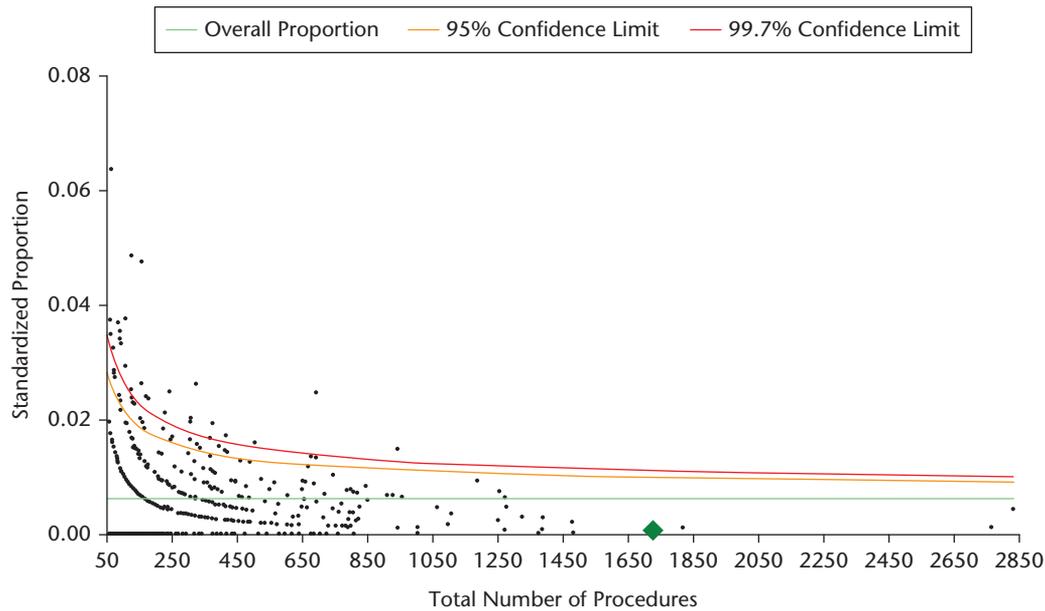


Fig. 1 Funnel plot of primary total conventional hip replacement (excluding large-head metal-on-metal, all diagnoses, revision for prosthesis dislocation within 2 years).

surgeon and recorded by the Registry). The Y axis is a measure of performance given by a standardized proportion of the ratio of the number of revisions observed to the number of revisions expected, multiplied by the overall proportion of revisions. The degree of variation is displayed on the graph with both 95% upper confidence limits and 99.97% upper confidence limits, which indicate the confidence limits around the overall revision rate for all procedures. The overall revision rate is represented by a separate green line and each surgeon is recorded in the scatter plot. The individual surgeon whose data are displayed is then represented by a green diamond that demonstrates their performance with respect to their peers. Funnel plots are provided for several options associated with both total hip replacement (THR) and total knee replacement (TKR) including overall outcomes for all diagnoses and all types for revisions, and outcomes for specific revision diagnoses such as prosthesis dislocation, or revision for infection within two years. This enables surgeons to identify their performance, compare themselves to the national average and examine the reasons for revision (Fig. 1). Only surgeons who have performed 50 or more procedures are included in the analysis.

The Australian Orthopaedic Association has recommended access of a surgeon's individual reports with funnel plot data be counted as a specific requirement of continuous professional development (CPD) for those surgeons performing joint replacement.

Since its inception, the AOANJRR has worked closely and co-operated with government and the Therapeutic Goods Administration (TGA) which is part of the Australian

Government Department of Health. The TGA is responsible for regulating therapeutic goods across a wide range of medicines, vaccines and medical devices. The Registry has worked closely with the TGA to develop a robust reporting of all joint prostheses implanted in Australia and the TGA has had access to its own AOANJRR web portal from 2010. This allows the TGA to independently identify devices or classes of devices which they believe warrant further investigation, and request an in-depth ad hoc report from the industry sponsor responsible for the prostheses. The TGA can take regulatory action to suspend a prosthesis from the Australian Registry of Therapeutic Goods (ARTG) when they deem that the safety of the prostheses is not acceptable. These recalls are accompanied by a notification to surgeons and hospitals that have implanted the relevant devices and are undertaken in a voluntary fashion. Relationships with the TGA have been built over a period of time and reflect the increased understanding of the value of the data.

The AOANJRR has also co-operated closely with the US Food and Drug Administration (FDA), and allowed access to a secure web portal of our Registry database in 2010. This has enabled the FDA to access another source of information to aid in their assessment and monitoring of devices.

Prosthesis outcomes

One of the major functions of all joint replacement registries is the ability to compare the performance of individual prostheses or entire classes of devices within a population. Reporting of outcomes of devices with respect

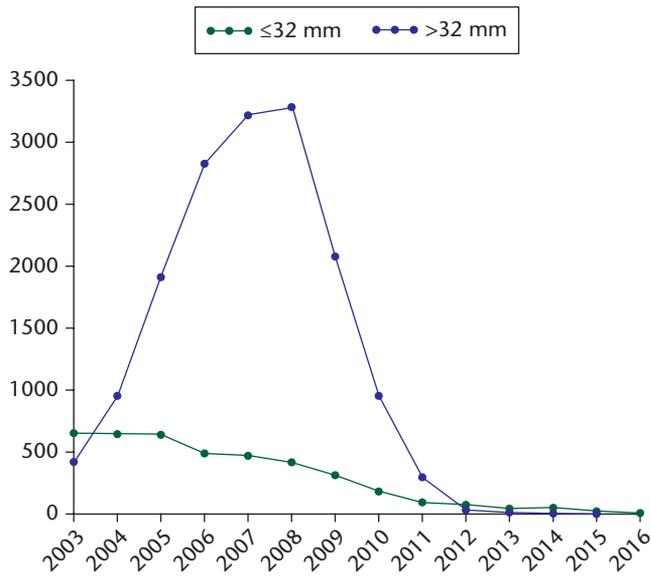


Fig. 2 Use of metal-on-metal total conventional hip replacement by head size over time.

to age and gender is also important as some prosthesis outcomes are dependent on these variables. Providing these data enables surgeons to make an informed choice and is an important way for registries to identify variation, which can lead to the adoption of best practice.

The AOANJRR was one of the first registries, in 2004, to formally establish a system for identifying prostheses with a higher than anticipated rate of revision (HTARR).⁷ This system is based on a three-stage process consisting of an automated algorithm, an extensive analysis of individual prostheses or combinations by registry staff, and finally a combined meeting involving a panel from the Australian Orthopaedic Association Arthroplasty Society and the Registry staff. Outlier prostheses are listed in the Annual Report as being identified for the first time, those that have been re-identified and are still used, and those that are identified but no longer used in Australia. This has led to a marked reduction in the number of patients exposed to devices with a higher than anticipated rate of revision. The Registry has continued to refine and update this process and the publication of these data has become an important method by which information on these prostheses is distributed to a national and international audience. Our identification process now includes a careful analysis by more detailed prosthesis identification including catalogue number, and lot numbers if required, and also the methods by which implants are fixed to bone. For example, there are TKRs that only have a higher rate of revision when they are performed without cement or with a posterior stabilized version. These prostheses are then identified with the appropriate characteristics separate from other knees with the same family name.

In 2007 the Registry was the first body to identify a significantly higher rate of revision for the ASR Hip Resurfacing System and the following year the ASR XL Acetabular System.⁸ The identification of these particular prostheses was associated with a substantial reduction in their use by surgeons and the subsequent withdrawal of these prostheses from the Australian market in December 2009. Confirmation from other studies and from both the New Zealand and the National Joint Registry of the United Kingdom resulted in the worldwide withdrawal of the prostheses in August 2010.^{9–14} This was a prime example of the AOANJRR influencing the global outcome of joint replacement surgery. This also demonstrates how a single registry’s data are strengthened by other sources including other registries and clinical studies.

The identification of the ASR led to a closer examination of all prostheses that had a large-head metal-on-metal bearing (defined as a femoral head greater than or equal to 32 mm in diameter). This class of large-head metal-on-metal devices was introduced with little clinical data and was employed to address several factors. These included revision of resurfacing hip arthroplasty due to fracture to avoid revising the acetabulum, to reduce revision for wear-related issues as metal-on-metal bearings had reportedly low-wear characteristics, and to use large-diameter femoral heads to reduce the risk of hip dislocation. The AOANJRR first raised concerns about all large-head metal-on-metal bearings for THR in the 2009 Annual Report¹⁵ and a more detailed analysis was performed the following year.¹⁶ The higher risk of revision for those prostheses with large-head metal-on-metal bearings became evident after two years and was greatest for younger patients and females. The reasons for revision of large-head metal-on-metal THR were also examined and compared to metal on polyethylene. There was a higher incidence of revisions for loosening/lysis and metal sensitivity for the metal-on-metal group. In order to determine whether the higher revision rate of articulations with large-head metal-on-metal bearings was prosthesis specific, the Registry analysed all prostheses head/acetabular combinations with more than 200 procedures with either metal-on-metal or other bearing surfaces. There were 12 combinations that met these criteria and many of these devices contributed to the higher revision rate, lending further weight to the argument that the large metal head bearing surface was a problem, and it was not just the ASR hip. This information was clearly demonstrated in the 2010 Annual Report.¹⁶ The use of larger-head metal-on-metal bearing surfaces peaked in 2009 and then there was a 85.7% reduction in the use of large-head metal-on-metal in the year after the 2010 Annual Report compared to the peak in 2009 (Fig. 2). The AOANJRR was the first registry to report these findings and, as a consequence, the use of this bearing surface declined in Australia before other countries.

Table 1. Cumulative percentage revision of primary total knee replacement (TKR) combinations with 15-year data (primary diagnosis OA)

Femoral component	Tibial component	N revised	N total	Type of revision				5 Years	10 Years	15 Years
				TKR	Femoral	Tibial	Other			
AGC	AGC*	264	5026	103	5	25	131	3.2 (2.7, 3.7)	5.0 (4.4, 5.7)	7.6 (6.6, 8.7)
Active Knee	Active Knee	591	9057	162	27	37	365	4.9 (4.4, 5.4)	8.2 (7.5, 8.9)	12.3 (10.9, 13.8)
Advance	Advance II	104	1604	40	2	13	49	5.1 (4.1, 6.3)	7.2 (5.9, 8.7)	7.9 (6.4, 9.7)
Advantim	Advantim*	64	1454	30	3	3	28	3.1 (2.3, 4.2)	4.8 (3.7, 6.3)	6.3 (4.7, 8.5)
Duracon	Duracon*	1118	19828	276	29	67	746	3.5 (3.2, 3.7)	5.1 (4.8, 5.5)	7.4 (6.9, 7.9)
Genesis II CR	Genesis II	843	22172	158	60	54	571	3.4 (3.2, 3.7)	4.7 (4.4, 5.1)	6.0 (5.4, 6.5)
Genesis II CR	Profix Mobile*	107	1209	43	9	7	48	5.4 (4.2, 6.8)	8.1 (6.5, 9.9)	11.2 (9.2, 13.7)
Genesis II	Genesis II	396	8093	71	24	22	279	3.7 (3.2, 4.1)	6.3 (5.7, 7.0)	10.1 (8.6, 11.8)
Oxinium CR (ctd)										
Genesis II PS	Genesis II	696	17407	108	27	50	511	3.8 (3.5, 4.1)	5.4 (5.0, 5.8)	6.6 (5.9, 7.4)
Kinemax Plus	Kinemax Plus*	118	1815	67	3	5	43	3.2 (2.4, 4.1)	4.6 (3.7, 5.8)	8.4 (7.0, 10.1)
LCS CR	LCS	580	8305	236	23	86	235	4.4 (4.0, 4.9)	6.3 (5.8, 6.9)	7.9 (7.3, 8.6)
LCS CR	MBT	977	27887	311	44	127	495	3.5 (3.2, 3.7)	4.9 (4.6, 5.3)	6.1 (5.5, 6.9)
LCS CR	MBT Duofix	652	14084	175	29	39	409	4.1 (3.7, 4.4)	5.3 (4.9, 5.8)	7.5 (6.7, 8.5)
MBK (Zimmer)	Nexgen*	32	448	17	1	13	13	4.1 (2.6, 6.5)	5.9 (4.0, 8.6)	8.0 (5.6, 11.3)
Maxim	Maxim*	185	2447	59	15	12	99	3.9 (3.2, 4.8)	6.0 (5.1, 7.1)	11.1 (9.4, 13.1)
Natural Knee II	Natural Knee II*	375	6443	157	9	58	151	2.8 (2.4, 3.2)	5.2 (4.7, 5.9)	9.6 (8.5, 10.8)
Nexgen CR	Nexgen	362	11200	115	15	31	201	2.1 (1.9, 2.4)	3.1 (2.8, 3.5)	4.6 (4.1, 5.2)
Nexgen LPS	Nexgen	309	6755	75	19	32	183	3.2 (2.8, 3.7)	4.9 (4.4, 5.6)	6.7 (5.8, 7.6)
Nexgen LPS Flex	Nexgen	1146	32785	289	57	192	608	3.2 (3.0, 3.4)	5.3 (5.0, 5.6)	8.5 (6.9, 10.3)
Optetrak-CR	Optetrak*	39	504	12	2	4	21	5.9 (4.1, 8.4)	8.4 (6.1, 11.6)	11.4 (7.7, 16.7)
Optetrak-PS	Optetrak	198	2359	68	4	26	100	6.2 (5.3, 7.3)	9.7 (8.4, 11.2)	11.5 (9.9, 13.5)
PFC Sigma CR	AMK Duofix*	57	1890	18	-	1	38	2.3 (1.7, 3.1)	3.0 (2.3, 4.0)	4.4 (3.1, 6.2)
PFC Sigma CR	MBT	278	5872	47	31	43	157	4.0 (3.5, 4.6)	5.2 (4.6, 5.9)	7.4 (6.0, 9.0)
PFC Sigma CR	MBT Duofix	127	2768	15	17	3	92	4.1 (3.4, 5.0)	5.8 (4.8, 7.1)	8.5 (6.5, 11.0)
PFC Sigma CR	PFC Sigma	670	23240	142	47	57	424	2.4 (2.2, 2.6)	3.5 (3.2, 3.8)	5.7 (5.0, 6.5)
PFC Sigma PS	MBT	273	6232	80	13	19	161	3.7 (3.3, 4.2)	5.2 (4.6, 5.9)	6.5 (5.5, 7.7)
PFC Sigma PS	PFC Sigma	295	7546	91	10	24	170	3.3 (2.9, 3.8)	4.8 (4.2, 5.4)	7.4 (6.2, 8.8)
Profix	Profix Mobile*	102	986	31	6	5	60	8.2 (6.6, 10.1)	9.8 (8.0, 11.9)	11.7 (9.6, 14.2)
Profix	Profix*	273	5370	62	13	18	180	3.8 (3.3, 4.3)	5.3 (4.7, 5.9)	6.0 (5.2, 6.9)
RBK	RBK	446	10187	167	11	36	232	4.0 (3.6, 4.4)	5.5 (5.0, 6.1)	7.9 (6.6, 9.5)
Rotaglide Plus	Rotaglide Plus*	71	616	31	1	5	34	5.8 (4.1, 8.0)	11.2 (8.8, 14.2)	14.3 (11.3, 17.9)
Scorpio CR	Scorpio+*	174	2448	40	10	26	98	4.3 (3.6, 5.2)	6.9 (6.0, 8.1)	8.8 (7.4, 10.4)
Scorpio CR	Series 7000	539	11561	129	26	44	340	3.4 (3.0, 3.7)	5.3 (4.8, 5.8)	6.9 (6.3, 7.6)
Scorpio PS	Scorpio+*	141	2036	36	14	10	81	5.1 (4.2, 6.2)	6.8 (5.7, 8.0)	8.4 (7.0, 10.1)
Scorpio PS	Series 7000	313	4693	103	8	63	139	4.7 (4.1, 5.3)	6.9 (6.1, 7.7)	10.0 (8.6, 11.6)
TOTAL		12915	286327	3564	614	1245	7492			

Note: Only prostheses with over 350 procedures have been listed.

*denotes prosthesis combinations that have not had any reported use in primary total knee procedures in 2017.

As well as individual devices, the Registry has also reported on many classes of prostheses and their outcomes. The use of unicompartmental knee replacement markedly reduced after the Registry reported twice the rate of revision compared to total knee replacement in the 2004 Annual Report,¹⁷ and this was particularly evident in younger patients. Unicompartmental knee replacements represented 19% of knee replacements performed for osteoarthritis in 2003 and this proportion has gradually reduced to 5.7% in 2017. A whole class of conventional THRs has been classified as ‘Exchangeable Neck Prostheses’ by the Registry and the AOANJRR is the only registry to report on the outcomes of this class. These devices offered the opportunity for surgeons to adjust leg length and offset with potential greater accuracy. The Registry first reported that this class of devices had over twice the rate of revision as conventional fixed neck prostheses in the

2010 Annual Report.¹⁶ The use of primary THAs for OA with exchangeable neck prostheses peaked in Australia at 6.6% of all primary THR in 2010 and their use has steadily decreased since that time. In 2017 only 0.8% of all procedures for THR used an exchangeable neck. The Registry evidence suggests that the continued use of femoral components with an exchangeable neck in primary THA undertaken for OA can no longer be justified.¹⁸

As well as reporting devices with a HTARR, from 2011 the Registry has presented data on prosthesis combinations that have a ten-year follow up, and from 2017, prostheses with a 15-year follow up. A prosthesis combination is included if there have been more than 350 procedures recorded by the Registry and the appropriate length follow up is available. In 2018 the AOANJRR reported on the 15-year outcomes of 47 hip and 35 knee prosthesis combinations. The listed prostheses were used in 41.7% of all

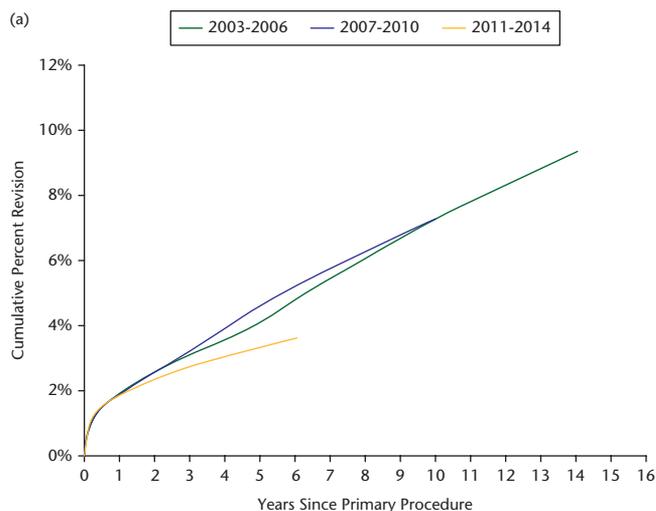


Fig. 3a Cumulative percentage revision of all hip replacements by procedure year.

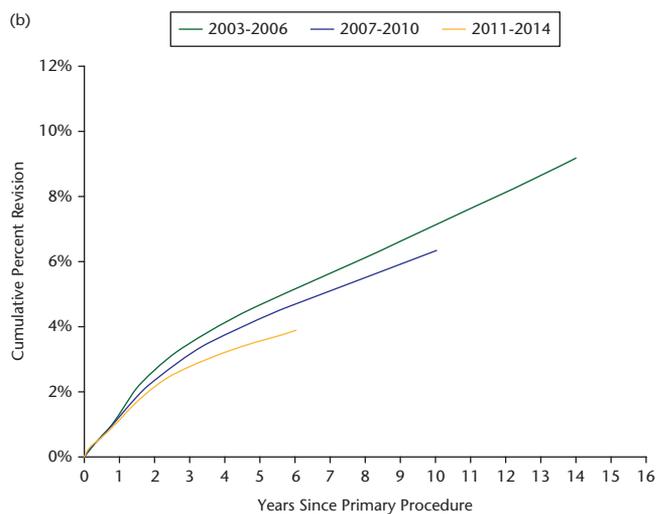


Fig. 3b Cumulative percentage revision of knee replacements by procedure year.

primary THR for osteoarthritis and 48.7% of all primary TKR procedures performed for osteoarthritis. The 15-year cumulative percentage revision for the primary THR ranged from 2.5% to 16.6% with 16 combinations that have a cumulative percentage revision of less than 6.5% and six with less than 5%. For TKR the 15-year cumulative percentage revision ranged from 4.4% to 14.3%. Seven of the combinations have a cumulative percentage revision of less than 6.5% and two with less than 5% at 15 years. These comparative data give surgeons valuable information on which devices to select for their patients (Table 1).

The AOANJRR has also set up systems to record and monitor the effects of new technology introduced with the aim of improving the position of implants at the time

of surgery. Compared to standard instrumented surgery, the Registry has reported reduced rates of revision for younger patients with computer navigation for TKR,¹⁹ similar outcomes for the use of image derived instruments for TKR,²⁰ and is currently monitoring the use of robotics for joint replacement. The Registry has also carefully monitored the introduction and performance of cross-linked polyethylene for both hips and knees and has demonstrated a reduction in revision surgery compared to conventional polyethylene.^{21,22} The Registry has developed increased understanding of analysing large datasets to limit the confounders associated with observational datasets. A method that the Registry is employing more frequently to examine a variable of interest is the use of prosthesis-specific analysis where there are sufficient data. This has been used in the above publications to determine the effect of cross-linked polyethylene to conventional polyethylene when they are both used with the identical components to account for known differences in prosthesis revision rates.

Reduction in revision of joint replacement over time

All joint replacement registries have a common goal of improving the outcomes of surgery and the AOANJRR has examined the revision rates for THR and TKR over consecutive time periods, a method that has been used by the Scandinavian registries to demonstrate improvement. Three consecutive time periods of four years were chosen from the commencement of full national data collection: 2003 to 2006, 2007 to 2010, and 2011 to 2014. This allowed for calculation of revision rates up to six years for the latter group. In Australia the cumulative percentage revision at six years for hip replacements has decreased from 4.8% for the time period 2003 to 2006 to 3.6% for surgery performed between 2011 and 2014. A similar reduction is also seen for knee replacements over the same period with a decrease in the rate of revision from 5.1% for procedures performed from 2003 to 2006 compared to 3.8% for procedures performed from 2011 to 2014 (Fig. 3a, Fig. 3b).

Conclusion

The AOANJRR has been instrumental in improving outcomes of joint replacement surgery in Australia and has had an increasing global influence. The Registry has worked closely with all stakeholders involved in joint replacement including surgeons, hospitals, government and regulatory bodies, industry, medical insurers and patients, to effect change. Future projects that the Registry will undertake include the addition of PROMs and linking the Registry database with other existing government

health data to permit more extensive and detailed analyses of the outcomes of joint replacement.

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LICENCE

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REFERENCES

1. **Fevang BTS, Lie SA, Havelin LI, Engesaeter LB, Furnes O.** Improved results of primary total hip replacement: results from the Norwegian Arthroplasty Register, 1987–2007. *Acta Orthop* 2010;81:649–659.
2. **Herberts P, Malchau H.** How outcome studies have changed total hip arthroplasty practices in Sweden. *Clin Orthop Relat Res* 1997;344:44–60.
3. **Robertsson O, Ranstam J, Sundberg M, W-Dahl M, Lidgren L.** The Swedish Knee Arthroplasty Register: a review. *Bone Joint Res* 2014;3:217–222.
4. **Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2000*. Adelaide, Australia: AOA, 2000.
5. **Kaplan EL, Meier P.** Nonparametric estimation from incomplete observations. *J Amer Statist Assoc* 1958;53:457–481.
6. **Kalbfleisch JD, and Prentice RL.** *The statistical analysis of failure time data*. New York: John Wiley & Sons, 1980.
7. **de Steiger RN, Miller LN, Davidson DC, Ryan P, Graves SE.** Joint registry approach for identification of outlier prostheses. *Acta Orthop* 2013;84:348–352.
8. **de Steiger RN, Hang JR, Miller LN, Graves SE, Davidson DC.** Five-year results of the ASR XL acetabular system and the ASR hip resurfacing system: an analysis from the Australian Orthopaedic Association National Joint Replacement Registry. *J Bone Joint Surg [Am]* 2011;93:2287–2293.
9. **Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2007*. Adelaide, Australia: AOA, 2007.
10. **Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2008*. Adelaide, Australia: AOA, 2008.
11. **The New Zealand Joint Registry – Ten year Report – January 1999 to December 2008.** Christchurch: New Zealand Orthopaedic Association, 2009.
12. **Jameson SS, Langton DJ, Nargol AV.** Articular surface replacement of the hip: a prospective single-surgeon series. *J Bone Joint Surg Br* 2010;92:28–37.
13. **Langton DJ, Jameson SS, Joyce TJ, Hallab NJ, Natsu S, Nargol AV.** Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement: a consequence of excess wear. *J Bone Joint Surg Br* 2010;92:38–46.
14. **Smith AJ, Dieppe P, Howard PW, Blom AW, National Joint Registry for England and Wales.** Failure rates of metal-on-metal hip resurfacings: analysis of data from the National Joint Registry for England and Wales. *Lancet* 2012;380:1759–1766.
15. **Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2009*. Adelaide, Australia: AOA, 2009.
16. **Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2010*. Adelaide, Australia: AOA, 2010.
17. **Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2004*. Adelaide, Australia: AOA, 2004.
18. **Graves SE, de Steiger R, Davidson D, et al.** The use of femoral stems with exchangeable necks in primary total hip arthroplasty increases the rate of revision. *Bone Joint J* 2017;99-B:766–773.
19. **de Steiger RN, Liu YL, Graves SE.** Computer navigation for total knee arthroplasty reduces revision rate for patients less than sixty-five years of age. *J Bone Joint Surg Am* 2015;97:635–642.
20. **The Australian Orthopaedic Association National Joint Replacement Registry.** *Annual Report 2018*. Adelaide, Australia: AOA, 2018.
21. **de Steiger R, Lorimer M, Graves SE.** Cross-linked polyethylene for total hip arthroplasty markedly reduces revision surgery at 16 years. *J Bone Joint Surg Am* 2018;100:1281–1288.
22. **de Steiger RN, Muratoglu O, Lorimer M, Cuthbert AR, Graves SE.** Lower prosthesis-specific 10-year revision rate with crosslinked than with non-crosslinked polyethylene in primary total knee arthroplasty. *Acta Orthop* 2015;86:721–727.