

Children overdue for immunisation: a question of coverage or reporting? An audit of the Australian Immunisation Register

Charlee Law,^{1,2} Rhydwyn McGuire,¹ Mark J. Ferson,^{3,4} Su Reid,¹ Colleen Gately,⁸ Jody Stephenson,⁵ Sue Campbell-Lloyd,¹ Salwa Gabriel,⁹ Tambri Housen,² Vicky Sheppeard,¹ Paul Corben,⁷ David N. Durrheim,^{5,6} on behalf of the NSW Public Health Network AIR Study Group

In 1996, the Australian Childhood Immunisation Register (ACIR) was launched by the Australian Government to record the immunisation status of children younger than seven years of age.¹ In 2016, the ACIR became the Australian Immunisation Register (AIR), an all-of-life immunisation register designed to include all vaccines on the National Immunisation Program (NIP) schedule as well as most privately purchased vaccines.²

The AIR is used to assess local, state and national immunisation coverage, which in turn enables the mobilisation of targeted programs and resources to areas with lower coverage. At the individual level, the AIR identifies vaccinations that are overdue and required to be followed up to ensure children are fully vaccinated.

To be considered by the AIR to be fully vaccinated at 12 months of age on the NIP (prior to 1 July 2018), children must have three doses of diphtheria-tetanus-pertussis-containing vaccine (DTPa); three doses of polio vaccine; three doses of *Haemophilus influenzae* type b (Hib) vaccine; three doses of hepatitis B vaccine and three doses of pneumococcal conjugate vaccine. Two doses of PRP-OMP - containing Hib vaccine is also considered fully vaccinated.³

Abstract

Objective: Vaccinations in Australia are reportable to the Australian Immunisation Register (AIR). Following major immunisation policy initiatives, the New South Wales (NSW) Public Health Network undertook an audit to estimate true immunisation coverage of NSW children at one year of age, and explore reasons associated with under-reporting.

Methods: Cross-sectional survey examining AIR immunisation records of a stratified random sample of 491 NSW children aged 12≤15 months at 30 September 2017 who were >30 days overdue for immunisation. Survey data were analysed using population weights.

Results: Estimated true coverage of fully vaccinated one-year-old children in NSW is 96.2% (CI:95.9-96.4), 2.1% higher than AIR reported coverage of 94.1%. Of the children reported as overdue on AIR, 34.9% (CI:30.9-38.9) were actually fully vaccinated. No significant association was found between under-reporting and socioeconomic status, rurality or reported local coverage level. Data errors in AIR uploading (at provider level) and duplicate records contributed to incorrect AIR coverage recording.

Conclusions: Despite incentives to record childhood vaccinations on AIR, under-reporting continues to be an important contributor to underestimation of true coverage in NSW.

Implications for public health: More reliable transmission of encounters to AIR at provider level and removal of duplicates would improve accuracy of reported coverage.

Key words: immunisation, immunisation schedule, infant, public health practice, communicable diseases

Immunisation coverage varies substantially across NSW. Historical surveys, conducted prior to the 'No Jab No Pay' policy, found imprecision in ACIR-reported coverage.^{1,4-6} Coverage figures based on the Register cited in parliament and the media do not acknowledge that these estimates are

lower than true coverage reported in these studies.⁶ This raises the potential for undue public concern and perception of risk, as well as inappropriate resource mobilisation toward populations that may not require interventions as much as others.

1. Communicable Diseases Branch, Health Protection NSW, New South Wales

2. National Centre of Epidemiology and Population Health, Research School of Population Health, Australian Capital Territory

3. Public Health Unit, Planning, Population Health and Equity, South Eastern Sydney Local Health District, New South Wales

4. School of Public Health & Community Medicine, University of New South Wales

5. Hunter New England Local Health District Public Health Unit, New South Wales

6. School of Medicine and Public Health, University of Newcastle, New South Wales

7. Mid North Coast and Northern NSW Local Health Districts Public Health Unit, New South Wales

8. Central Coast Local Health District Public Health Unit, New South Wales

9. Western Sydney Local Health District Public Health Unit, New South Wales

Correspondence to: Ms Charlee Law, Communicable Diseases Branch, Health Protection NSW; Level 7, 73 Miller St, North Sydney 2060. Tel 02 9391 9723; e-mail: charlee.law@health.nsw.gov.au

Submitted: October 2018; Revision requested: January 2019; Accepted: February 2019

The authors have stated they have no conflict of interest.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

Aust NZ J Public Health. 2019; 43:214-20; doi: 10.1111/1753-6405.12891

With the introduction of the 'No Jab No Pay' policy in 2015,⁷ families of children who are not recorded as fully vaccinated on the AIR may be ineligible to receive Commonwealth benefits including the child care rebate, child care benefits and a family tax benefit.⁸ In NSW and some other states, children must be recorded on the AIR as fully vaccinated to access childcare services.^{7,9}

We postulated that as incorrect reporting on AIR may leave families financially disadvantaged; records on the AIR may have become more accurate, so an audit was conducted to determine whether the accuracy of AIR coverage estimates had improved.

The primary aim of the audit was to provide a better estimate of immunisation coverage in NSW for children at one year of age by identifying those who were genuinely overdue on the AIR. Secondary objectives included identifying reasons for AIR under-reporting and exploring whether the rate of under-reporting varied by reported local coverage level, socioeconomic status or provider setting (urban or rural and remote).

Methods

Ethics approval was granted by Australian National University as a Low-Risk Expedited E1 Protocol on 21/08/2017: Protocol 2017/570.

Selection and description of participants

The audit examined the provider- and/or parent-held immunisation records of a sample of NSW children listed on the AIR as >30 days overdue. The cross-sectional sample frame comprised all children aged 12≤15 months (birth cohort 1 July to 30 September 2016), residing in NSW, and recorded on the AIR as overdue as at 30 September 2017 for at least one immunisation. These children were identified using the AIR011A report¹⁰ extracted in early October 2017. Using the 'third dose assumption' in our definitions allowed our coverage estimates to be compared to national reporting.¹¹ The third dose assumption aims to minimise the impact of under-reporting on AIR coverage estimates due to delays registering the child onto Medicare by assuming that children are fully vaccinated if they have a record of receiving the third dose of a vaccine, regardless of whether a record exists of their previous

doses.¹² Children without at least one of the following contact details were excluded: parental email address, phone number or provider information.

Technical information

Taking the conservative assumption that 50% of children reported as overdue were incorrectly recorded, a stratified random sample¹³ was selected to provide 80% power at a 5% significance level for each of the planned analyses to detect a significant difference between overall NSW coverage according to the AIR and the audit. In addition, analyses were undertaken at a smaller geographical area level, based on Australian Bureau of Statistics (ABS) Statistical Area Level 3 (SA3) to detect differences in under-reporting between: areas of low (bottom third of SA3 areas <92%), medium (middle third of SA3 regions 92–94%) and high (top third of SA3 regions >94%) reported coverage; areas of low, medium and high socioeconomic status tertiles. We used the 2011 Index of Relative Socio-Economic Disadvantage (IRSD), which is an indicator value of the ABS Socio-Economic Indicators for Areas (SEIFA);¹⁴ and provider setting (urban/rural and remote) according to the Accessibility and Remoteness Index of Australia (ARIA+).¹⁵ We chose SA3 areas to assess coverage for this study as they reflect meaningful regional areas of the state instead of focusing on population alone; areas are segmented into standardised regions with similar characteristics in socioeconomic status and geography. These areas usually have a population of 30,000 to 130,000 and generally share borders with other administrative boundaries such as State Regional Development Areas or at least one Local Government Area.¹⁶

Statistical methods

The strata and sample size for each stratum were calculated using constrained optimisation, implemented in the R Package Sampling Strata.¹⁷ This allowed us to minimise the required sample size while answering our research questions. The final sample was selected using a random number generator. A stratified random sample (main sample) was selected by local health district (LHD) of residence. Where resources were available, public health unit staff in each LHD could opt to survey extra records sampled in order to improve precision of estimates at LHD level

and overall. Including this extra sample, a total of 491 records were surveyed (Figure 2). After the survey was conducted, the stratified sample was reweighted to account for loss to follow-up. For each coverage estimate we calculated 95% confidence intervals and used a Wald test for association to gain an overall p-value for differences in coverage over multiple parameters.

Data collection – provider level

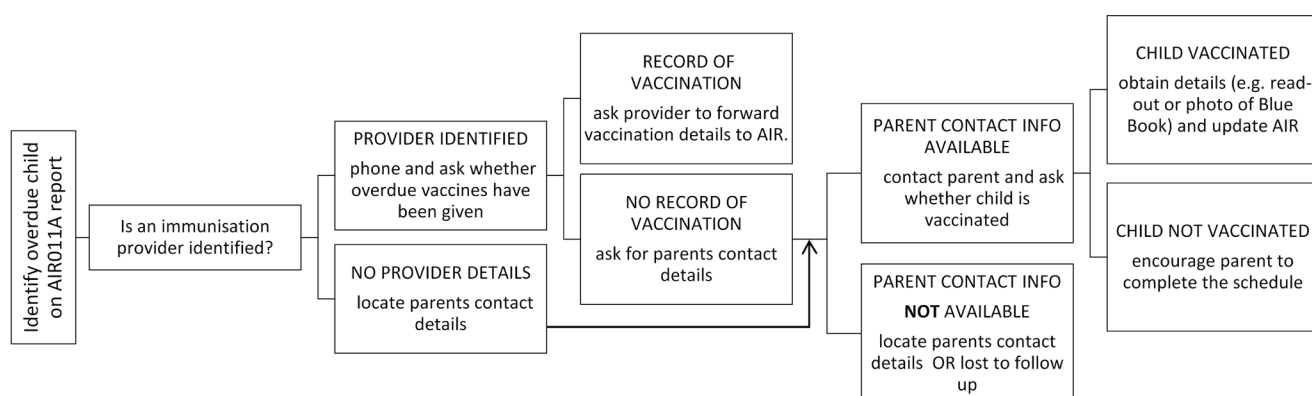
Details of children in the main and extra samples were provided to each public health unit via secure file transfer for follow-up in accordance with an audit tool developed to capture the relevant information from provider and parent-held records of children recorded on AIR as overdue.

Figure 1 summarises the audit process. Public health unit staff interviewed immunisation providers by telephone using a standardised questionnaire. Providers were asked questions about the type of practice (general practice [GP], Aboriginal health service, council clinic, community health centre, public/private hospital, public health unit or flying doctor service). If the provider type was a general practice, further questions were asked about how many GPs and authorised nurse immunisers were in the practice to gauge the size of the provider setting.

If the overdue vaccines had in fact been administered, the provider was asked: the date of vaccination; where the child received the vaccine (at the practice, overseas, another provider or other); and where the vaccines were recorded in the child's medical record (immunisation tab or clinical notes). The interviewer then confirmed whether this was a data error (error in transmission of information from child's medical record to the AIR) or a clinician's error (human error in putting incorrect vaccination information in the child's medical record, or incorrect vaccine or dose administered). The provider was asked to forward any corrected vaccination details to the AIR.

Providers were also asked whether the child's medical record indicated the reasons why a vaccination had not been administered (child sick, medical contradiction, parental hesitancy, parental refusal, family overseas, 'other' or unknown). In addition, the provider was asked about their primary method for transmitting immunisation encounters to the AIR.

Figure 1: Audit process for NSW public health network interviewers.

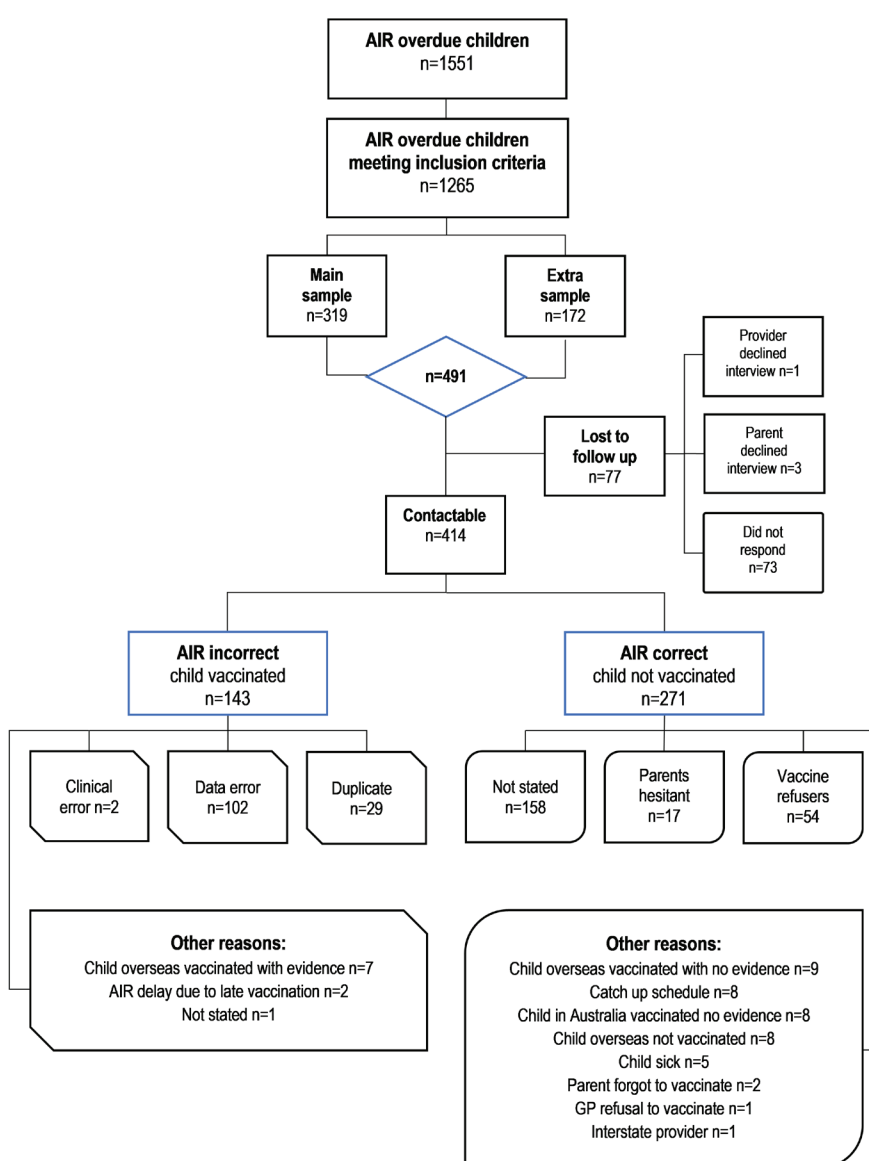


Data collection – parents and guardians

If the provider did not hold a record of administration of the overdue vaccine(s), or if the provider was unable to be reached, up to three attempts were made to contact the child's parents. Parents who were contacted and stated that their child was vaccinated were asked where the child received the vaccine (overseas, another provider, or 'other: specify'), the provider's name and date of vaccination. Where a vaccination was recorded, parents were asked to provide evidence of the vaccination and Medicare details so the interviewer could correct the AIR record. Evidence of completed vaccination required the parent to read out to the interviewer details from their parent-held child health record (Blue Book) or other evidence such as overseas vaccination record with antigens compatible with the NIP schedule. When parents claimed the child was fully vaccinated but were unable to provide documentation of the record, the child was classified as not fully vaccinated.

Children of parents who were unable to be contacted after three attempts were listed as 'lost to follow-up' (LTFU).

Figure 2: Flowchart depicting sampling frame and outcome.



Results

Primary results

Of the 25,934 children born from 1 July to 30 September 2016 and recorded on the AIR as residing in NSW, 1,551 (6.0%) were reported as not fully vaccinated at 30 September 2017. Of the 1,551 records, 286 were excluded (24 had insufficient residential address information to be assigned a SEIFA or ARIA+ index value; and 262 had no contact information including phone number, provider number or email address), leaving 1,265 records to sample from (Figure 2).

Of these, 491 were randomly selected for audit. Seventy-seven (15.7%) were classified as lost to follow-up. One GP and parents of three children declined to be interviewed, and for the remaining 73 cases the interviewer made at least three attempts to contact the parent, provider or both, with no answer or response to voice messages or email.

Of the 414 children whose immunisation status was able to be confirmed, 271 were correctly recorded on AIR as not fully vaccinated and 143 had evidence of being fully vaccinated (detailed in medical record or parental-held Blue Book).

Reasons for non-vaccination

Although it was not a requirement for parents to be asked or to offer reasons for being overdue for vaccination, information was obtained for 113 (41.7%) of the 271 children in the sample confirmed as not fully vaccinated.

Reasons given were vaccine refusal (54); parental hesitancy (17); vaccinated overseas with no evidence of vaccination (9); child overseas and not vaccinated (8); vaccinated in Australia with no record (8); currently on a catch-up schedule (8); child sick at the time (5); parent forgot to vaccinate (2); GP refused to vaccinate (1); and interstate provider (1).

Reasons for error on AIR

Of the 143 children incorrectly recorded as overdue on the AIR, 29 had duplicate AIR records (due to children having two Medicare numbers or name errors). Vaccinations of 102 children were not recorded on the AIR due to

presumed data transmission errors, and two were due to clinician errors, where incorrect doses had been recorded in one case and no reason offered for the second. Seven children had evidence of being vaccinated overseas; two children had received vaccines that were slightly delayed by documented illness. At the time of sampling, the encounter had not reached AIR for these two children. The reason was not stated for one child. Practices experiencing data errors used a range of patient record software brands and versions.

Coverage calculations

Overall, after adjustment for loss to follow-up from the defined sample, 34.9% (95%CI: 30.9-38.9%) of overdue children were actually up-to-date for vaccination, leading to an estimate of true coverage in this cohort of 96.2% (95%CI: 95.9-96.4%), compared to the AIR based coverage of 94.1% (Table 1). We found significant variability between LHDs in whether vaccinations were incorrectly recorded on AIR, with the proportion of children incorrectly recorded as overdue ranging between 12% and 54% (Table 1). Level of incorrect reporting was not associated with coverage level, rurality or socioeconomic status (Table 2). However, for the Aboriginal or Torres Strait Islander children in the sample, reporting error was significantly less than for non-Indigenous children (Table 2).

Sensitivity analysis

A sensitivity analysis was conducted to determine whether non-response would

affect the conclusions of the study, and how it would affect true coverage estimates (Table 3). In the first scenario, lost to follow-up records were set as 'fully vaccinated' (AIR incorrect), giving a true coverage estimate of 96.8% (CI: 96.6, 97.0). In the second scenario, lost to follow-up records were set as 'not vaccinated' (AIR correct), changing the true coverage estimate to 95.8% (CI: 95.6, 96.0).

A third scenario was created where those who claimed to be vaccinated but had no evidence of the encounter (AIR correct) were set as truly vaccinated (AIR incorrect). This had little effect on the true coverage estimate, which was slightly increased to 96.4% (CI: 96.2, 96.7).

The sensitivity analysis highlights that even in an extreme scenario the estimated true coverage for one-year-old children in NSW would continue to exceed both the AIR coverage estimate of 94.1% and the Australian Government's national aspirational immunisation target of 95% coverage.¹⁸

Discussion

Main findings

In this cohort of one-year-old NSW children, 34.9% (95%CI: 30.9-38.9%) recorded as overdue on AIR were found to be incorrectly assessed as overdue. Thus, the true immunisation coverage in NSW is estimated at 96.2% (95%CI: 95.9-96.4%), 2.1% higher than the AIR estimate of 94.1%.

Despite the policy incentives for families to ensure that their children are fully immunised,^{7,8} national recorded coverage remains inaccurate.¹⁸ Research prior to the 2015 policy change found that in 2001 a cohort of children from South Eastern Sydney Local Health District (SESLHD) aged 12≤15 months old, reported to have an immunisation coverage rate of 81% on the ACIR, had a true coverage rate of at least 91%.^{5,6} A similar study in Waverley and Sydney City local government areas in 2013 found that 33% of the cohort reported to be overdue for a vaccination were not overdue. This boosted the coverage rate of that area from 87% to 91%, a 4% difference.⁶

The current audit found a lower under-reporting rate that was fairly homogenous over most of the factors tested, with local coverage rates (low, medium and high), socioeconomic status (low, medium and high) and provider setting (urban/rural and remote) having no statistically significant association.

Table 1: Percentage incorrectly recorded on the AIR, and reported vs. corrected immunisation coverage for NSW children 12 months of age, by local health district of residence, 30 September 2017.

LHD name	n=414	% Incorrectly reported*	95%CI	% AIR Reported coverage	% Corrected coverage	95%CI	p-value
LHD 1	24	11.8	(1.9,21.6)	95.6	96.1	(95.7,96.6)	
LHD 2	33	12.6	(1.4,23.8)	90.0	91.3	(90.1,92.4)	
LHD 3	33	18.9	(7.5,30.2)	94.5	95.5	(94.9,96.2)	
LHD 4	28	21.7	(16.3,27.0)	92.5	94.1	(93.7,94.5)	
LHD 5	29	23.0	(9.5,36.5)	93.0	94.6	(93.7,95.6)	
LHD 6	23	29.9	(13.6,46.1)	94.2	95.9	(95.0,96.9)	
LHD 7	46	30.8	(19.3,42.2)	93.5	95.5	(94.8,96.2)	
LHD 8	25	40.2	(28.9,51.5)	96.0	97.6	(97.2,98.1)	(p=<0.0001)
LHD 9	12	41.8	(25.9,57.7)	95.7	97.5	(96.8,98.2)	
LHD 10	15	41.9	(21.5,62.2)	95.4	97.3	(96.4,98.3)	
LHD 11	42	44.6	(31.7,57.5)	94.0	96.7	(95.9,97.5)	
LHD 12	16	45.1	(31.4,58.8)	96.0	97.8	(97.3,98.4)	
LHD 13	45	51.9	(39.3,64.4)	93.7	97.0	(96.2,97.8)	
LHD 14	43	54.3	(42.1,66.5)	95.8	98.1	(97.6,98.6)	
All NSW	414	34.9	(30.9,38.9)	94.1	96.2	(95.9,96.4)	

Note:

* Percentage incorrectly recorded as overdue on the Australian Immunisation Register

Under-reporting did vary significantly by local health district and Aboriginality. This may reflect the impact of existing programs for all Aboriginal infants in NSW¹⁹ and that in some local health districts immunisation providers routinely review the status of children shown as overdue on AIR, correcting missing data and recalling overdue children.^{20,21}

Earlier research suggested that the primary reason for under-reporting in the AIR was due to immunisation providers being unable to submit the patient vaccine encounter details in a timely manner.^{1,5,6} Encounter forms are now an infrequent method of reporting with primary care patient record systems transmitting vaccination records directly to the AIR, usually on the same day. The introduction of medical practice software may alter the coverage estimates of the AIR positively through automatic notification, or negatively if there are systematic errors with data transfer or data errors. Later studies undertaken in the era of widespread use of electronic patient record systems have found lower, but consistent levels of under-reporting in the range of 2–4%,^{4,6} similar to this audit. The local study by Ferson and Orr⁶ found that key contributors to undercounting in the AIR included lack of knowledge by GPs about the reporting process, incorrect data entry and systematic issues relating to medical practice software feeding into the AIR.⁶

The main factor found to contribute to contemporary under-reporting is an error in data transmission of information from the child's medical record to the AIR. Almost three-quarters (102 of 143) of the incorrect classifications of children as overdue on the AIR were due to data transmission errors. We were unable to identify a consistent cause for data errors, which appeared unrelated to the brand or version of patient record software used; however, examination of specific software or transmission errors was beyond the scope of this study.

The second most common source of AIR inaccuracy was duplicate records, responsible for 20% of errors. Duplicates may occur on the AIR when a child has more than one Medicare number, or encounters are entered without a Medicare number. Other duplicates arose through errors in birth dates, use of different surnames, or in situations such as foster care. If PHU staff were able to locate the duplicate records pair (whether the pair was in the sample or not) they updated the AIR to consolidate them into one complete record.

Table 2: Incorrect recording on AIR by vaccine coverage area, rurality, SEIFA and Aboriginal status, for NSW children at one year of age, 30 September 2017.

Measure	Variable	n=414	% incorrectly reported [†]	95%CI	% AIR Reported coverage	% Corrected coverage	95%CI	p-value
Coverage area	Low coverage <92%	66	36.7	(26.5, 46.9)	–	–	–	p=0.9
	Mid coverage 92–94%	120	33.5	(25.9, 41.1)	–	–	–	
	High coverage >94%	228	35.4	(30.2, 40.5)	–	–	–	
Rurality (ARIA+)	Major City	268	34.9	(30.1, 39.8)	–	–	–	p=0.9
	Inner regional, outer regional, remote and very remote	146	34.6	(30.3, 38.9)	–	–	–	
SEIFA [‡]	Low SEIFA	170	37.2	(30.7, 43.6)	–	–	–	p=0.2
	Mid SEIFA	147	29.8	(23.5, 36.1)	–	–	–	
	High SEIFA	97	37.9	(29.4, 46.3)	–	–	–	
Aboriginal status	Aboriginal or Torres Strait Islander	37	23.5	(13.6, 33.4)	94.2	95.6	(95.0, 96.1)	p=0.007
	Neither Aboriginal or Torres Strait Islander	359	34.2	(29.9, 38.4)	94.1	96.1	(95.9, 96.4)	
	Unknown status	18	63.5	(45.3, 81.7)	–	–	–	

Notes:

* Percentage incorrectly recorded as overdue on the Australian Immunisation Register

† SEIFA=2011 Index of Relative Socio-Economic Disadvantage (IRSD)

– Not applicable to analysis

The AIR uses registration data from Medicare to calculate the denominator. Duplicate records artificially inflate the denominator, which in turn reduces estimated immunisation coverage.

Clinician errors, either human error entering information in the child's medical record or incorrect vaccine dose recorded, appear to be rare causes of being assessed as not fully vaccinated, with only two instances detected in our sample.

Twenty-four children who had moved overseas permanently were recorded as overdue on AIR. This information was reported by the provider or other family members (remaining parent, grandparent). Parents of 16 children who were living overseas claimed their child was up-to-date with vaccinations. Of these, seven were able to provide evidence of vaccination and were thus moved to the 'AIR incorrect: child vaccinated' category.

As these children live overseas, leaving them on the AIR adds to underestimation of coverage as they contribute to the denominator without being able to contribute to the numerator, irrespective of whether they are vaccinated, unless a parent and a local provider take the trouble to manually register the overseas vaccines with the AIR. The procedure to remove children from the AIR when they are overseas requires an immunisation provider to tick a 'returned mail indicator' within the child's AIR record, or to contact the AIR in writing. The Department of Human Services advises that this will then remove the child from state coverage reports.

There were 54 children in the sample whose parents reported they had chosen not to vaccinate. Many of these children were already known to the health services so were not re-contacted. Some parents who were contacted offered reasons why they have not vaccinated their children. One parent stated a family history of allergic reaction to Boostrix®

Table 3: Sensitivity analysis accounting for children claimed to be vaccinated with no evidence and lost to follow up (LTFU).

All NSW	n=	% Incorrectly reported [*]	95%CI	% Reported coverage	% Corrected coverage	95%CI
Reported results (excluding 77 LTFU)	414	34.9	(30.9, 38.9)	94.1	96.2	(95.9, 96.4)
Counting vaccinated without evidence as fully vaccinated (excluding 77 LTFU)	414	39.6	(35.5, 43.7)	94.1	96.4	(96.2, 96.7)
Including LTFU as fully vaccinated	491	45.8	(41.9, 49.6)	94.1	96.8	(96.6, 97.0)
Setting LTFU as not vaccinated	491	29.0	(25.5, 32.5)	94.1	95.8	(95.6, 96.0)

Note:

* Percentage incorrectly recorded as overdue on the Australian Immunisation Register

and another stated that a family member had died as a result of an adverse reaction to an unspecified vaccination. One family was not willing to vaccinate their child, citing cultural reasons.

A further 17 children had not been fully vaccinated as their parents were hesitant to vaccinate, some delaying their children's vaccinations until 'later'; vaccinating slowly, one vaccine at a time; or selectively choosing some vaccines.

This study shows that in NSW the national aspirational target of 95% fully vaccinated coverage¹⁸ has been achieved for children at one year of age but confirms that despite policy settings encouraging accurate recording of vaccinations on the AIR, under-reporting continues at around 2%. For Aboriginal children, and in regions where resources are dedicated to ensuring accurate and timely recording of vaccination on AIR, error rates are lower.¹⁸⁻²¹ Given the persistence of reporting errors in the absence of active local programs to clean and correct AIR records, consideration should be given to developing cost-effective centralised automated measures to identify and correct errors and duplicate records. Until this can be routinely achieved at a national level, AIR coverage data for children at one year of age should be treated as the minimum estimated coverage level for that age group.

Similar audits in the future may assess the magnitude of under-reporting in other age cohorts and provide further evidence of undercounting to enrich our understanding of how sociodemographic or practice level characteristics may contribute to under-reporting.

Limitations

As this study is cross-sectional, the prospect is raised that if another time frame had been sampled, different results may be uncovered. However, given the similarity between this and other relatively recent local audits we do not expect that would occur.

The 77 records that were lost to follow-up may have introduced non-response bias into the study and was countered by conducting a sensitivity analysis that indicated that conclusions of the study were not materially affected (Table 3).

We aimed to minimise interviewer bias by providing a questionnaire with mostly closed form responses.

Possibly of greater importance is that the under-reporting estimate at one year of age is not generalisable to other age groups. As children become older, they are increasingly likely to enrol in early childhood education, which should prompt correction of data transmission and clinician errors, as they are required to be recorded as fully vaccinated on the AIR to enrol in childcare in NSW and to receive Australian Government financial assistance to attend. Thus, if overdue children were sampled at two or five years of age the under-reporting rate is likely to be lower.

Lastly, this study was not tailored to measure specific factors relating to people from culturally and linguistically diverse backgrounds, with potentially different drivers influencing recorded immunisation coverage.

Conclusion

Despite widespread use of electronic patient record systems and policy settings encouraging accurate recording of childhood vaccinations, publicly reported coverage estimates at one year of age are approximately 2% lower than true vaccination rates. This systematic underestimating of coverage should be clearly conveyed whenever AIR coverage estimates are quoted. Data transmission errors were the most frequent cause for errors on the AIR; however, other factors included duplicate records and children living overseas. Reasons for correctly recorded incomplete vaccination included vaccine hesitancy or refusal, lack of documentary evidence/records of vaccination, delays due to illness or children on catch-up schedules.

Cost-effective measures should be developed to routinely identify and correct common errors leading to incomplete or duplicate records on the AIR.

Acknowledgements

We would like to dedicate this paper to the memory of Karen Orr, an outstanding worker for childhood immunisation in New South Wales.

The authors would like to acknowledge the NSW Public Health Network AIR Study Group: Lisa Allchin, Katie Anagnostou, Sue Botham, David Boucher, Sophie Carey, Hayley Carra, Kwendy Cavanagh, Trisha Collins, Rachelle Deaker, Michelle Dives, Bridget Doyle,

Michelle Ferguson-Hannah, Linda Granger, Sheila Hamm, Wendy Holmes, Essi Huhtinen, Andrew Ingleton, Jane Jelfs, Emily Keighran, Judith Kennedy, Liz Kirk, Julie McLean, Dee McNamara, Jackie Milsom, Amy Nicholson, Clare Pearson, Juhel Pritchard, Tania Simpson, Angela Shirlaw, Jane Thomas, Marianne Trent, John Turahui, Natasa Veselinovic, Cheryl Wasley, Kristie Waters, Jennifer Wedd and Robert Whybrow.

References

- Conaty SJ, McAnulty JM. The Australian Childhood Immunisation Register: Validation of the immunisation status of children who are very overdue. *Aust NZ J Public Health*. 2001;25(2):138-40.
- Australian Department of Human Services. *Australian Immunisation Register for Health Professionals* [Internet]. Canberra (AUST): Government of Australia; 2018 [cited 2018 Oct 2]. Available from: <https://www.humanservices.gov.au/organisations/health-professionals/services/medicare/australian-immunisation-register-health-professionals>
- Australian Department of Health. *National Immunisation Program Schedule (NIP)* [Internet]. Canberra (AUST): Government of Australia; 2016 [cited 2017 May 29]. Available from: <https://beta.health.gov.au/health-topics/immunisation/immunisation-throughout-life/national-immunisation-program-schedule>
- Hull BP, Lawrence GL, MacIntyre CR, McIntyre PB. Immunisation coverage in Australia corrected for under-reporting to the Australian Childhood Immunisation Register. *Aust NZ J Public Health*. 2003;27(5):533-8.
- Botham SJ, Poulos RG, McFarland KJ, Ferson MJ. Getting it right—the Australian Childhood Immunisation Register and immunisation rates in south-eastern Sydney. *Aust NZ J Public Health*. 2004;28(1):68-71.
- Ferson MJ, Orr K. Some truths about the "low" childhood vaccination coverage in Sydney's eastern suburbs. *Med J Aust*. 2015;203(3):153.
- Social Services Legislation Amendment (No Jab, No Pay) Act 2015 No. 158 [statute on the Internet]. 2015 [cited 2018 Oct 2]. Available from: <https://www.legislation.gov.au>
- Australian Department of Human Services. *Immunisation Requirements* [Internet]. Canberra (AUST): Government of Australia; 2017 [cited 2017 May 23]. Available from: <https://www.humanservices.gov.au/individuals/enablers/immunisation-requirements/35396>
- Public Health Act 2010 No 127, NSW [statute on the Internet]. 2018 [cited 2018 Oct 2]. Available from: <https://www.legislation.nsw.gov.au>
- Australian Department of Human Services. *Reports Available from the AIR Site* [Internet]. Canberra (AUST): Government of Australia; 2018 [cited 2018 Oct 2]. Available from: <https://www.humanservices.gov.au/organisations/health-professionals/enablers/reports-available-from-air-site>
- O'Brien ED, Sam GA, Mead C. Methodology for measuring Australia's childhood immunisation coverage. *Commun Dis Intell*. 1998;22(3):36.
- McIntyre PB, Hull BP, Lawrence GL, MacIntyre CR. Estimating immunisation coverage: Is the 'third dose assumption' still valid? *Commun Dis Intell Q Rep*. 2003;27(3):357.
- Ballin M, Barcaroli G. Joint determination of optimal stratification and sample allocation using genetic algorithm. *Surv Methodol*. 2013;39(2):369-93.
- Australian Bureau of Statistics. *Socio-Economic Indexes for Areas* [Internet]. Canberra (AUST): ABS; 2018 [cited 2018 Jul 18]. Available from: <http://www.abs.gov.au/websitedbs/censushome.nsf/home/seifa>

15. Australian Bureau of Statistics. 1270.0.55.005 - *Australian Statistical Geography Standard (ASGS): Volume 5 - Remoteness Structure, July 2016* [Internet]. Canberra (AUST): ABS; 2018 [cited 2018 Jun 14]. Available from: <http://www.abs.gov.au/ausstats/abs@.nsf/mf/1270.0.55.005>
16. Australian Bureau of Statistics. 1270.0.55.001 - *Australian Statistical Geography Standard (ASGS): Volume 1 - Main Structure and Greater Capital City Statistical Areas* [Internet]. Canberra (AUST); 2016 [cited 2018 Jun 14]. Available from: <http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/1270.0.55.001>
17. Barcaroli G. Sampling strata: An R package for the optimization of stratified sampling. *J Stat Softw.* 2014;61(4):1-24.
18. Australian Department of Health. *Immunisation Coverage Rates for all Children* [Internet]. Canberra (AUST): Government of Australia; 2018 [cited 2018 Sep 4]. Available from: <https://beta.health.gov.au/health-topics/immunisation/childhood-immunisation-coverage/immunisation-coverage-rates-for-all>
19. Hendry AJ, Beard FH, Dey A, Meijer D, Campbell-Lloyd S, Clark KK, et al. Closing the vaccination coverage gap in New South Wales: The Aboriginal Immunisation Healthcare Worker Program. *Med J Aust.* 2018;209(1):24-8.
20. Miles T, Granger L, Gately C. Improving the accuracy of ACIR data and increasing vaccination rates. *Proceedings of the 15th National Immunisation Conference, Immunisation: The Jigsaw – Fitting the Pieces Two Decades On #NIC2016*; 2016 Jun 7-9; Brisbane City, Australia. Canberra: Public Health Association Australia; 2018. p. 37.
21. Miles T, Brown S. Transmitting data electronically to ACIR: How accurate is it? *Proceedings of the 15th National Immunisation Conference, Immunisation: The Jigsaw – Fitting the Pieces Two Decades On #NIC2016*; 2016 Jun 7-9; Brisbane City, Australia. Canberra: Public Health Association Australia; 2018. p. 37.