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Excess Indigenous mortality: are Indigenous Australians more severely disadvantaged than other Indigenous populations?

Kenneth Hill,[1,*] Bridget Barker[2] and Theo Vos[2]

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Background International targets for reducing health inequalities, such as the Millennium Development Goals, are stated in terms of national targets. However, dramatic health differentials exist within countries, even developed ones. Studies indicate that the Indigenous population of Australia suffers a life expectancy disadvantage greater than differentials found in Indigenous populations of other developed countries. We re-examine recent national mortality levels and trends of Indigenous Australians.

Methods Analyses of Indigenous mortality are plagued by 'numerator–denominator bias', whereby reporting of Indigenous status differs in deaths (numerators) and population (denominators). We apply demographic evaluation methods developed to address such problems to data from the 1991, 1996 and 2001 censuses of Australia and to the death registration data for the period.

Results The propensity of Australia's population to report Indigenous status increased between each census, particularly between 1991 and 1996, while recording of deaths as Indigenous increased sharply. Adjusted for bias, the Indigenous population had a life expectancy ~13 years below that of the non-Indigenous population, a 2-year greater disadvantage than recently estimated for the Maori in New Zealand. Indigenous mortality fell during the 1990s, but slightly more slowly than that of non-Indigenous Australians, leaving differentials slightly increased.

Conclusions Around the world Indigenous populations are estimated to suffer a mortality disadvantage compared with non-Indigenous populations. However, establishing the magnitude of and trend in the disadvantage is difficult because of bias. Using appropriate methods to adjust for bias, the Indigenous population of Australia is estimated to suffer a life expectancy shortfall of about 13 years, greater than similar gaps in other developed countries.

Keywords Mortality, Indigenous, Australia, numerator–denominator bias

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Background

Paragraph six of the United Nations Millennium Declaration[1] states the fundamental value that 'no individual and no nation must be denied the opportunity to benefit from development'. The Millennium Development Goals laid out by the Declaration are broadly stated, but the targets are implicitly expressed in terms of country performance. Major inequalities, however, exist within countries, one of the largest and most persistent being the health disadvantage of Indigenous peoples.

Studies repeatedly show, whatever the world region, that Indigenous populations experience higher levels of mortality than their non-Indigenous co-residents. Blakely and colleagues[2] estimate that the gap in life expectancy at birth between the Maori and the non-Indigenous population of New Zealand was 10.8 years in 1996–99. Martens and colleagues[3] estimate a gap of 8 years in life expectancy at birth between First Nations and other Manitobans in Canada from 1995 to 1999, whereas the gap in life expectancy at birth between American Indians/Alaska Natives and the total population (US All Races) was estimated to be 5.9 years for 1996–98.[4] Behm and Primante[5]

[1] Center for Population and Development Studies, Harvard University, Cambridge, Massachusetts, USA.

[2] School of Population Health, University of Queensland, Brisbane, Australia.

* Corresponding author. Kenneth Hill, Center for Population and Development Studies, Harvard University, 9 Bow Street, Cambridge MA 02138, USA. E-mail: Kenneth_hill@harvard.edu.

use census data to show that Indigenous populations of Latin America suffered risks of dying by age 2 about two-thirds higher than those of the non-Indigenous. Most studies have found that the excess risk of the Indigenous populations is highest in the young and middle adult age range. Robles[6] finds some improvement in Indigenous child mortality in Guatemala, but no reduction in adult mortality, a similar conclusion to that for Australia of Ring and Firman,[7] who find that the mortality disadvantage of Indigenous Australians (the working definition of an Indigenous Australian adopted by the Australian Government is 'a person of Aboriginal or Torres Strait Islander descent who identifies as an Aboriginal or Torres Strait Islander and is accepted as such by the community in which they live'[8]) is largely accounted for by four groups of causes: circulatory conditions, respiratory conditions, injury and poisoning and endocrine conditions.

Conclusions about relative trends of Indigenous and non-Indigenous mortality are mixed, but some studies find sharply widening gaps: Blakely and colleagues[2] find the Maori life expectancy at birth gap increasing by 3 years from 1980–84 to 1996–99, and Condon and colleagues[9] find that although Indigenous mortality in Australia's Northern Territory (NT) declined over the last four decades of the 20th century, the mortality gap increased. That such health disparities exist in rich countries demands targeted health policies which in turn need to be developed on a stronger evidence base.

Numerous cross-national comparative studies[7,10–13] conclude that the Indigenous mortality gap is larger in Australia than in other OECD countries with disadvantaged Indigenous populations. Experimental life tables for the Indigenous population of Australia recently developed, for population estimation and projection purposes, by the Australian Bureau of Statistics (ABS) using unconventional methods support this conclusion, indicating a staggering gap in life expectancy at birth for the Indigenous population of Australia for the interval 1996–2001 of over 17 years.[14] An earlier ABS experimental exercise, using different methodology, arrived at an estimate of an even larger gap for the period 1991–96 of over 18 years.[15] However the ABS cautions against using the experimental life tables for any analysis of trends and indeed for 'any other purpose' because of uncertainty about their accuracy,[14] and assumes no change in mortality of the Indigenous population both for its estimates of that population from 1991 to 2001 and for its population forecasts from 2002 to 2009.[16]

The purpose of this article is 2-fold: (i) to explore further whether the Australian Indigenous population, at a national level, is much more disadvantaged in mortality terms than Indigenous populations in other OECD countries; and (ii) to try to assess whether this disadvantage is worsening. The reason this is problematic in a country with complete recording of deaths is primarily numerator–denominator bias.[17] Life tables and life expectancies are conventionally calculated from age–sex specific mortality rates with deaths (compiled from the civil registration system) in the numerator and population exposure time (derived from population censuses) in the denominator. If ethnicity is not recorded in a consistent fashion in both sources of data, bias will result. Numerator and denominator inconsistency is likely since ethnicity is generally self-declared in census counts, but assigned by relatives, attending physicians or funeral directors for deaths.[18] Measurement of trends is problematic because reporting within source is not consistent over time: the enumerated First Nation populations of the United States have expanded since 1970 as propensity to declare oneself Indigenous increased,[19] and the same process has occurred in Canada,[20] New Zealand[21] and Australia.[22] For example, the cohort of persons reported to be Indigenous Australians aged 20–39 numbered 85 879 in the 1991 census, increasing to 97 848 persons aged 25–44 in the 1996 census, and increasing again to 99 769 persons aged 30–49 in 2001. Inconsistency of recording Indigenous status of deaths is even more pronounced: the state of Queensland went from recording no deaths as Indigenous in 1991 (when the death certificate in this state did not record ethnicity) to recording over 500 Indigenous deaths in 1997.

Solutions to numerator–denominator bias include anonymous linkage studies, whereby census and death records are probabilistically linked and ethnic consistency can be assured,[17] and analytical approaches based upon laws of population dynamics.[23] In this article we employ the latter strategy, though future work on the former is recommended.

Methods

The principle sources of data used in this analysis are Indigenous population counts by sex and 5-year age groups from the 1991, 1996 and 2001 censuses; deaths recorded as Indigenous by 5-year age groups and sex for calendar years 2000–02 compiled from the vital registration (VR) system according to year of death registration (About 87% of Indigenous deaths occurring in a given year are registered in the same year, compared with around 95% in the non-Indigenous population; a comparison of the average number of Indigenous deaths by year of occurrence and year of registration for the 3-year period 2000–2002 showed very little difference in either numbers or age patterns.); and births and infant deaths recorded as Indigenous from the VR system for 1991–2001 by state of usual residence.

For infant mortality, we also use 2001 reports of births and neonatal deaths compiled by the Australian Institute for Health and Welfare's (AIHW) National Perinatal Data Collection using data collected in hospitals, birth centres and communities;[24] consistency of reporting of ethnicity in these data is likely to be high since a birth and any death will occur close together in time. However, the data only provide estimates of the neonatal mortality rate, not the infant mortality rate. An additional source, particularly relevant to the exploration of consistency, is a linked birth-infant death data set available for Western Australia (WA) from 1980 onwards;[25] the linkage ensures consistent reporting of Indigenous status for births and infant deaths.

In our analysis, we group states into four regions: (We group states into four regions: South-East (New South Wales, Victoria, Tasmania and Australian Capital Territory); South-West (South Australia and WA); North (Northern Territory); and North-East (Queensland), based on the ABS rationale of geographical proximity.[14] Each of these regions has a substantial Indigenous population and a rather different tradition in terms of reporting on Indigenous deaths) We use different methods for assessing observed infant and post-infant

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mortality rates. For infant mortality, we assess the consistency of reporting ethnicity between births and infant deaths in the VR system in two ways: first, by comparing national VR estimates of IMR, excluding Tasmania and NT (These two States were excluded because AIHW has not published neonatal mortality rates for them.) for 2000–02 with 2001 estimates of neonatal mortality from the AIHW perinatal database; and second, by comparing VR estimates of IMR for WA for 1992–94, 1995–97 and 1999–2001 with alternative estimates derived from a linked birth and death record system in WA for 1990–94, 1995–97 and 1998–2001. In addition we also check the consistency between deaths and census counts for grouped Australian states.

For post-infant mortality, we evaluate the consistency of reporting population and deaths using one of a number of standard demographic techniques.[23] We use the 'General Growth Balance' (GGB) method[26] because it conveniently allows for errors in age-specific population growth rates arising from changes in the completeness of census coverage (equivalent to changes in propensity to record Indigenous status). The method is based on the fact that in a population unaffected by migration, the exit (death) rate is equal to the difference between the entry (birth) rate and the population growth rate: it essentially compares the recorded death rate of the population above a range of ages x with a residual estimate of each death rate above age x based only upon census data, calculated by subtracting the growth rate of the population $x+$ from the entry rate into that population (see Appendix for a more complete description of the method and a worked example of its application). If deaths and population are consistently recorded, the observed and residual measures will be the same; if, on the other hand, deaths are under-reported relative to population, the recorded death rate will be smaller than the residual estimate by the extent of the inconsistency. If the inconsistency does not vary with age, it can be estimated by linear methods, and the data can be adjusted to achieve consistency. The key advantage of this methodology for assessing the recording of Indigenous deaths relative to population is that the results are not biased if the completeness of recording of population changes from one census to the next.

We apply the GGB method to 'raw' census Indigenous population counts, prior to any adjustment for coverage. However, the 'raw' counts already include some adjustments: those carried out during the editing and processing of the data[14] are 'built-in', and have not been removed.

We do not use raw death counts in our GGB application. The methodology assumes that the deaths observed adequately represent the true age pattern of the deaths that actually occurred in the population of interest. As is indicated by the Queensland example cited earlier, the number of deaths recorded as Indigenous was extremely low in the early 1990s in several Australian States, so low that the deaths recorded are unlikely to be representative in age distribution of all Indigenous deaths. We have therefore attempted to assess completeness of reporting of deaths, given the 2001 propensity to declare oneself as Indigenous. By 1999, reporting of Indigenous deaths appears to have achieved approximate consistency from year to year in all states; we assume that the distribution of deaths by age from 1999 onwards is as close to a representative pattern of true deaths as can be obtained. We therefore first calculate age–sex specific Indigenous death rates using deaths for the three years centred on 2001 divided by the census population for 2001, and then estimate the numbers of deaths that would have occurred for each intercensal period 1991–96 and 1996–2001 given those rates, multiplying the appropriate age-specific rate by exposure time calculated from the censuses.

The GGB methodology predicts a straight line relationship between two largely independent estimates of death rates over a series of ages x, one based on reported deaths, the other on the age distribution and growth rate of the population. The slope of the line estimates a correction factor for deaths relative to recorded population. We fit straight lines by orthogonal regression, as suggested by Bhat,[27] to the points for ages 5+ to 65+ and 15+ to 55+.

Results

Since the methods used are very different, we discuss results for infant mortality and subsequent mortality separately.

Infant mortality

The IMR is conventionally calculated by dividing registered infant deaths in a given year by registered live births in the same year. This measure for the Indigenous population will not be affected by numerator–denominator bias if ethnicity is recorded consistently in birth and death records. A national estimate may be biased, however, if regional differentials in IMR exist, and recording of births and deaths as Indigenous varies substantially between regions. We examine first the issue of numerator–denominator bias through consistency checks.

The first test of consistency uses the AIHW Perinatal Mortality statistics, a source independent of VR. The AIHW does not provide Indigenous neonatal mortality rates (NMR) (NMR is the death rate of infants during the first 28 days of life.[24]) for the NT or Tasmania, so the comparison is with the rest of Australia. For 2001, the AIHW records the Indigenous NMR as 6.0 deaths/1000 births (compared with 3.2 for other Australians).[24] The VR estimate of Indigenous IMR for 2000–02 for Australia excluding the NT and Tasmania is 11.3/1000. Thus the AIHW NMR is slightly more than half the VR IMR; in low mortality populations, NMR is usually at least 70% of IMR.[28] Thus the AIHW data do not suggest that the VR IMR for 2001 is an underestimate.

The second, and more powerful, consistency check is with the linked birth and death data from WA, available from 1980 to 2001. Freemantle *et al*.[25] report Indigenous IMRs for cohorts born in 1990–94, 1995–97 and 1998–2001 based on linked data of 20.1, 16.9 and 16.1/1000, respectively, compared with VR-based Indigenous IMRs for WA only of 21.5 for calendar years 1992–94 (the recording of Indigenous births is clearly incomplete prior to 1992), 18.7 for the period 1995–97 and 16.6 for 1999–2001.[30] This consistency check supports the conclusion that, at least for WA, the reporting of Indigenous status was approximately consistent between births and infant deaths from 1992–2001, and hence WA IMRs do not suffer from major bias. Freemantle[29] also reports a ratio of neonatal to infant deaths of only 47%, much lower than generally found in low mortality populations, but providing added support for the

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conclusion that AIHW neonatal and ABS infant mortality estimates are roughly consistent; applying Freemantle's 47% to the AIHW NMR of 6.0/1000 would estimate an IMR of 12.6/1000, instead of the VR estimate of 11.3.

Based on these considerations we proceed on the assumption that the reporting of Indigenous status for births and infant deaths is approximately consistent, and that the VR estimates of Indigenous IMR for 1991–96 and 1996–2001 for the State groups can be accepted. (The censuses of 1991, 1996 and 2001 were held in early August. In order to make the IMR calculations as temporarily consistent with the intercensal periods as possible, we have calculated the IMRs by including (for the 1991–96 period) only 40% of 1991, and only 60% of 1996, births and infant deaths, and similarly for the period 1996–2001). We therefore adopt the regional values of IMR in Table 1 as our infant mortality estimates; it is important to note the large variation in IMR between regions, from 23/1000 live births in the North region 1991–96 to below 10/1000 in the South-East 1996–2001. We cannot accept the total Australia IMR, however, without assessing possible regional variation in the recording of births as Indigenous: the regional estimates might be individually correct but the total for the country biased upwards if, for example, the recording of births as Indigenous was much more comprehensive in one area where IMR is high, than in another where the IMR is lower.

To assess the extent to which the recording of births as Indigenous is consistent with the reporting of population as Indigenous for each of the regional areas, we calculate ratios of the population under age 5 recorded as Indigenous (P) in each region in the 1996 and 2001 censuses to the Indigenous births (B) recorded in the 5 years preceding the census (Table 1). This ratio cannot (in the absence of migration and with consistent recording) exceed 1.0, and should, in a low mortality population, be slightly smaller than the complement of the IMR expressed per birth (so if the IMR is 15/1000, the P: B ratio should be slightly smaller than 0.985). Highly implausible values in Table 1 are in italics. Clearly, the reporting of Indigenous status for births and for the child population differs in both time periods 1991–96 and 1996–2001 in the South East (few births relative to population) and North (too many births relative to population) regions, and in the time period 1991–96 in the North East (few births).

The trend in all-Australia Indigenous IMR based on vital registration, from 17.2/1000 live births for the period 1991–96 to 12.9/1000 live births for the period 1996–2001, is distorted by the gross under-recording of Indigenous births in the earlier period in the South East and North East regions revealed by the P/B ratios. These two regions have below average Indigenous IMR, and also too few births recorded as Indigenous; hence the all-Australia Indigenous IMR for 1991–96 is artificially inflated. We estimate the all-Australia Indigenous IMRs by weighting the regional Indigenous births and infant deaths by the regional P/B ratios (over-weighting the births in the South East and under-weighting the births in the North), thus bringing the births and infant deaths into consistency with the population reporting of Indigenous status. The corrected IMRs are 13.9 and 12.5/1000 for the periods 1991–96 and 1996–2001, respectively.

Post-infant mortality

Results of the GGB methodology are most easily assessed graphically. Figure 1 shows results for 1991–96 (Panel a for males, Panel b for females), and Figure 2 shows results for 1996–2001. The points conform to a straight line reasonably well, with two provisos: the agreement is ragged for the elderly (the three right-most points in each graph are for ages 70+, 75+ and 80+), and there is a 'wiggle' in the line for the young (the left-most points), more pronounced for males than females and more pronounced for the period 1996–2001 than for the period 1991–96. The raggedness for the elderly is in all likelihood a consequence of age misreporting or small numbers; the 'wiggle' is commonly observed in applications of GGB and is generally associated with migration, though Bhat[27] shows that it will also result from typical patterns of age misreporting. The parameters of the straight lines (fitted by orthogonal regression to the points for ages 5+ to 65+ and 15+ to 55+) plus a summary mortality measure (the probability of dying between ages 15 and 60, ${}_{45}q_{15}$) based on the 2000–02 age-specific mortality rates adjusted by the slope are shown in Table 2.

The performance of the GGB method can also be assessed by comparing the estimates of census coverage (here interpreted as the propensity to report oneself Indigenous) of males and females; these might normally be expected to be similar. The comparisons are reassuring: the male and female coverage change estimates are similar, especially for 1991–96. Another simple diagnostic is the similarity of parameter estimates using

Table 1 Infant mortality for the Indigenous population of Australia by Region[a], 1991–2001

Indicator	Intercensal period	South east	South west	North	North east	Australia Recorded	Australia Reweighted[b]
IMR	1991–96	11.0	21.3	23.2	9.3[c]	17.2	13.9
P/B Ratio[d]	1991–96	*1.86*	1.01	*0.86*	*8.83*	*1.74*	
IMR	1996–2001	9.5	14.2	22.0	11.9	12.9	12.5
P/B Ratio[c]	1996–2001	*1.12*	0.95	*0.85*	0.98	1.01	

[a] Regions are: South-East (New South Wales, Australian Capital Territory, Tasmania, Victoria), South-West (south Australia and WA), North (Northern Territory) and North-East (Queensland).

[b] Regional numbers of Indigenous births and deaths are reweighted by the P/B ratios before calculating the national IMR; see text.

[c] The IMR for the period 1991–96 for the North East Region (Queensland) is based essentially on births and infant deaths in 1996 only, since no record of Indigenous status of deaths is available prior to 1996.

[d] P/B Ratio is the ratio of the Census population aged 0–4 at the end of the period to births in the preceding 5 years (see text).

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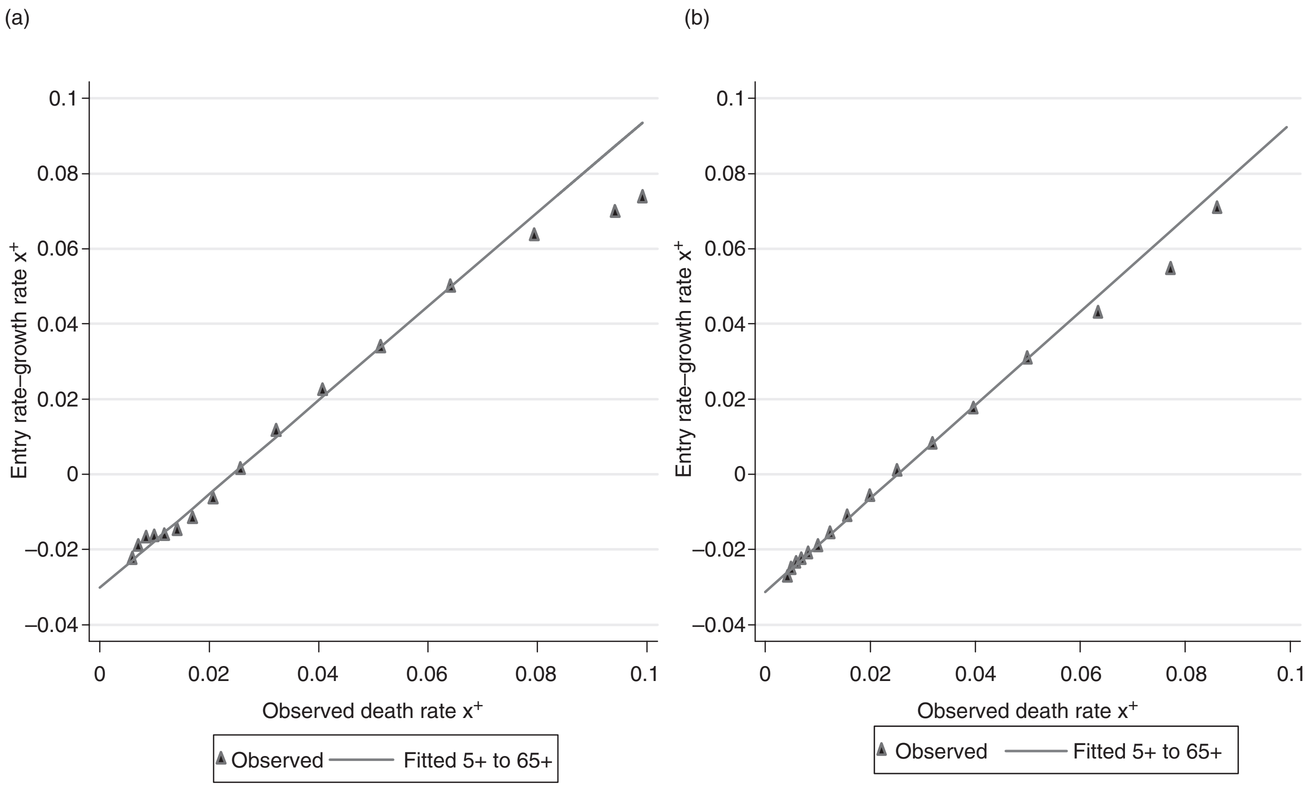

Figure 1 Application of the GGB method to the Indigenous population of Australia 1991–96. (a) Males; (b) Females

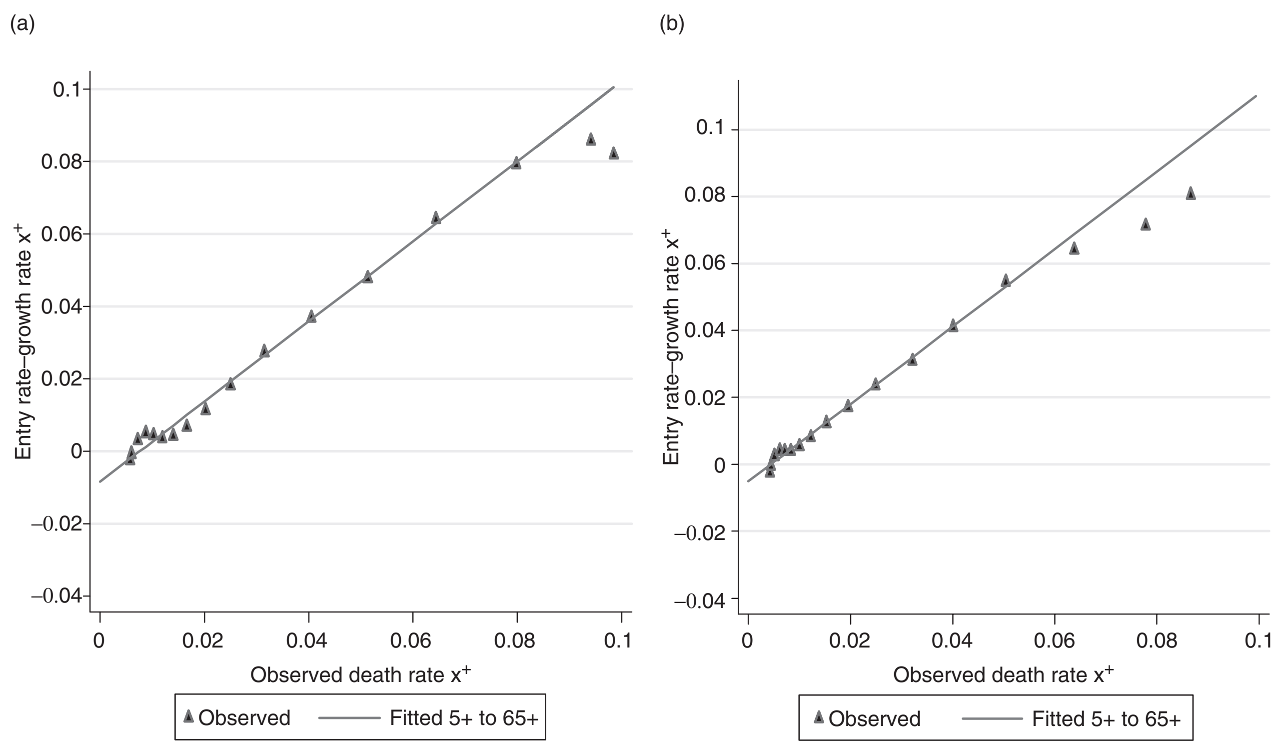

Figure 2 Application of the GGB method to the Indigenous population of Australia 1996–2001. (a) Males; (b) Females

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Table 2 Key parameters of the GGB fitted lines and derived summary measures of mortality

	1991–96		1996–2001	
	Fitted 5+ to 65+	Fitted 15+ to 55+	Fitted 5+ to 65+	Fitted 15+ to 55+
Males				
Observed $_{45}q_{15}$	*0.309**		*0.309**	
Slope	1.16	1.20	1.07	1.07
Intercept	−0.0296	−0.0307	−0.0082	−0.0090
Coverage census 1: Census 2	86.3%	85.8%	96.0%	95.6%
Adjusted $_{45}q_{15}$	0.347	0.359	0.326	0.327
Females				
Observed $_{45}q_{15}$	*0.205**		*0.205**	
Slope	1.23	1.23	1.15	1.08
Intercept	−0.0316	−0.0314	−0.0053	−0.0046
Coverage census 1: Census 2	85.4%	85.5%	97.4%	97.7%
Adjusted $_{45}q_{15}$	0.246	0.246	0.231	0.220

* 'Observed' mortality measure is an average for the years 2000–02 for both periods 1991–96 and 1996–2001 for reasons explained in the 'Methods' section.

different age ranges (5+ to 65+ and 15+ to 55+) of points; results in terms of adjusted $_{45}q_{15}$ are almost identical.

The increase in the propensity to report oneself as Indigenous, as estimated from the intercept of the GGB linear relationship, is substantial between 1991 and 1996, about 14%, but only about 3% between 1996 and 2001.

Life tables have been constructed by combining the estimates of IMR in Table 1 with the age-specific mortality rates for ages 1–74 adjusted by the factors in Table 2. Mortality for ages 75 and over was modelled by extrapolating the linear relationship between logged age-specific rates and age between 30 and 74. Table 3 shows summary measures of mortality for the Indigenous population of Australia for 1991–96 and 1996–2001 from two sources: 'experimental' life tables developed by the ABS (15,16) (using different methodologies for the two time periods, the estimates thus not being comparable); and life tables calculated using the adjustments developed in this article. According to our estimates, Indigenous life expectancy increased from 63.0 years for 1991–96 to 64.2 years for 1996–2001 for males, and from 67.9 years to 68.9 years for females, increases somewhat smaller in absolute terms than those experienced by the Australian population overall. Mortality risks according to our analysis have fallen somewhat for both males and females, and for children as well as adults. The gap in life expectancy at birth between the Indigenous Australian population for 1996–2001 and the total Australian population for 1998–2000 is 12.4 (64.2 vs 76.6) and 13.1 (68.9 vs 82.0) years, respectively, for males and females.[31]

Discussion

Numerator–denominator and other biases introduce substantial uncertainty into the measurement of Indigenous mortality. In general, numerator–denominator bias in the absence of adjustment leads to underestimates of the mortality (and hence of the mortality disadvantage) of Indigenous populations; this may be part of the reason why the scandalously large differentials have not received greater public attention. Existing experimental results for Australia seem to have had the opposite effect: our estimate of the life expectancy gap is substantially less than the ABS differential[31] of 17 years shown in Table 3. Kinfu and Taylor[32] applied Hill's (1987) GGB method to the 1996–2001 intercensal period for Indigenous Australians and found life expectancy at birth differentials of a similar magnitude to the ABS estimates. Personal correspondence with the authors suggests the stark differences in their findings and the present study's results may be due to the use of a 'relational approach', based on a life table for the NT, 'both to estimate the rates for younger ages as well as smooth the GGB based rates for older ages'.[33] Our findings indicate that Indigenous people in the NT have considerably higher infant mortality, in all probability followed by higher mortality in adulthood also, than Indigenous people in jurisdictions of Eastern Australia. Hence, taking the NT as the 'standard' may have biased the results of Kinfu and Taylor's work towards lower life expectancy at birth estimates than for Indigenous people elsewhere in Australia.

Our methodology assumes that net overseas migration is negligible, a reasonable assumption for the Indigenous population of Australia.[14] Further we assume that the propensity to record ethnic status is constant across age (but not across data sets). The results of the 1996 Census Post-Enumeration Survey (PES) found that net undercount rates for Indigenous people varied significantly by age, sex and geographical area,[34] suggesting that this assumption does not hold true. However the PES is limited in the following ways for the Indigenous context: (i) the Indigenous net undercounts for all of Australia for 1996 and 2001 (7.1 and 6.1%) have very high levels of variability attached to them (21.5 and 17.8%, respectively) (34,16); (ii) the PES is not conducted in remote areas;[34] (iii) the PES coverage estimate assumes that the survey 'is a random sample of those captured as well as those missed from the Census (it assumes that people do not actively avoid being recorded in both collections)';[35] and (iv) the PES methodology is very different to census methodology (interviewer-based vs self-enumerated) and the ABS concludes that the considerable variations observed in the number of people identified as Indigenous over time (1986, 1991, 1996 and 2001) in the

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Table 3 Summary adjusted mortality measures, indigenous population of Australia 1991–2001

Indicator	ABS experimental life tables		Adjusted life tables	
	1991–96	1996–2001	1991–96	1996–2001
Males				
Expectation of life at birth (years)	56.9	59.4	63.0	64.2
Infant mortality rate ‘000	25.7	14.0	14.9	13.4
Under-5 mortality rate ‘000	31.3	18.4	17.6	16.1
Probability of dying between 15 and 60	0.486	0.436	0.347	0.326
Females				
Expectation of life at birth (years)	61.7	64.8	67.9	68.9
Infant mortality rate ‘000	22.8	11.3	12.9	11.6
Under-5 mortality rate ‘000	26.8	14.5	15.5	14.0
Probability of dying between 15 and 60	0.405	0.312	0.246	0.231

census and PES ‘can probably largely be attributed to the difference in collection methodologies’.[16] Despite these limitations in the PES, it is clearly desirable to test the sensitivity of our results to plausible age-specific variations in census coverage of the Indigenous population.

We focus our sensitivity tests on the period 1996–2001, since sensitivity of 1991–96 results is likely to be very similar. The ABS has not published age–sex specific estimates of coverage of the Indigenous population for either the 1996 or the 2001 censuses, because ‘the results are not sufficiently reliable to use at that level’,[36] so we cannot use such estimates in a sensitivity analysis. Nor can we use the ABS estimates of resident Indigenous population (ERP) for 1996 and 2001 arrived at on the basis of the 2001 census results, since the 1996 estimates are obtained using the ABS experimental Indigenous life table. Having little firm evidence about possible error patterns, we test sensitivity to some simple patterns. First, in place of the reported Indigenous populations we use the 1996-based ERP in 1996 with the 2001-based estimates for 2001. Second, we take simple patterns of underenumeration by age (highest for young adults, particularly males) superimposed on overall ABS estimates of coverage for Indigenous Australians to adjust the reported age distributions before applying the GGB methodology. Specifically, we take the PES net estimates of undercoverage of the Indigenous population (7.1% in 1996 and 6.1% in 2001), assume that overall males are more likely to be omitted than females, and then assume that for both males and females the age groups most likely to be omitted are 15–19 through 35–39; we do two variants of this model, doubling the excess omission of young adults from one to the other. In a final consistency check, we take the lower age-specific population omission model and combine it with the further assumption that the under-recording of deaths between the ages of 15 and 39 is 10% greater than at other ages. The estimated expectations of life at birth resulting from each test are shown in Table 4.

The results of these sensitivity analyses suggest that our results are reasonably robust to the types of error tested; it may also be noted that in all cases but one, the estimates of life expectancy obtained are actually higher than in the baseline case. The largest differences, 1.4 years, arise from using the ERPs for 1996 and 2001 in place of observed populations. The remaining differences are all less than a year of life expectancy. There are of course an infinite number of possible patterns of error, but unless the patterns of error affecting the Indigenous population of Australia are very different from patterns found elsewhere (and ABS states that omission is highest for males aged 20–29,[15] the common pattern), it is unlikely that our baseline case is underestimating adult mortality risks.

Much has been made, in Australia and internationally, of the stark differentials in the health of Indigenous Australians compared with the Indigenous peoples of other OECD nations—the US, Canada and New Zealand—due largely to the 17-year gap in life expectancy between Indigenous and other Australians suggested by previous work.[7,9–12] Several historical, socio-political and cultural reasons have been postulated to explain these differences.[7] The results of the present re-assessment change the landscape for these comparisons. However it is also important to ascertain what approaches have been utilized by other countries to adjust for the Indigenous numerator-denominator bias.

Most confidence can be put in the New Zealand estimates of life expectancy at birth as their results are derived from probabilistic linking of death and census records. The most recent New Zealand estimates[2] indicate an increasing gap in life expectancy (10.8 years in 1996–99 vs 7.7 years in 1980–84). The authors state that this gap is due to strong mortality reductions among non-Maori compared with little, if any, reduction among Maori people.

A regional examination in the Manitoba province of Canada[3] probabilistically linked death and health records to estimate the life expectancy of First Nation people. The gap of 8 years between Canada’s Manitoban Indigenous population and total Manitoban population was in keeping with the overall gap estimated for Canadian First Nation people.

The US approach for adjusting mortality is less rigorous than either of these methods. The United States derives specific adjustment factors for the age group under 1 year based on linked birth/infant death data sets. However, all other ages are adjusted using the results of a one-off study in 1986–88 which matched patient (from Indian Health Service records) and death records.[4] In 1996–98, the life expectancy at birth (both sexes) for the American Indians/Alaskan Natives was

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Table 4 Sensitivity tests of estimates of adult mortality 1996–2001 to different error patterns

Sex	estimated expectation of life at birth				
	Baseline model	Estimated resident populations in 1996 and 2001	Excess population omission (a)	Excess population omission (b)	Excess pop omission (a) and excess omission of deaths
Male	64.2	65.6	64.5	64.9	64.2
Female	68.9	70.3	69.3	69.6	69.1

Note: Excess Population Omission (a) and (b) are based on the ABS estimate of overall omission of the Indigenous population of 7.0% in 1996 and 6.1% in 2001; the distribution of the undercount by sex is assumed to be 8.0% and 7.1% for males in 1996 and 2001, respectively, and 6.1% and 5.2% for females. Omission (a) then increases this omission by 25% for the age groups 15–19 and 35–39, and by 50% for the age groups 20–24 through 30–34, adjusting undercoverage at other ages downwards to maintain the overall totals. Omission (b) follows the same process, but using increases of omission of 50% (15–19 and 35–39) and 100% (20–24 through 30–34). The fourth model takes the age distributions from the second (intermediate excess omission) and assumes that deaths at ages 15–39 are omitted by 10% more than at other ages.

estimated to be 5.9 years less than the 1997 life expectancy at birth for the US all-races population.[4] This gap in life expectancy is also an increase on the previous gap reported of 4.7 years although again it is not clear whether this reflects real trends.[37]

Further work on the mortality of the Indigenous population of Australia should focus on record linkage studies between population and deaths, as is intended on the basis of the 2006 census. In this way numerator–denominator bias can be eliminated. However, it should be noted that linking records may not be the complete solution to the Indigenous Australian mortality measurement problem since it does not eliminate errors in trends: if the ethnic identification of the population substantially changes between censuses, the linked measures from one census will pertain to a different population than the linked measures from the next census, and will thus not be strictly comparable. Given that the working definition of Indigenous cited earlier does not unambiguously define a person as being Indigenous or non-Indigenous, such changes over time in ethnic identification cannot be ruled out.

Our results broadly confirm that the Indigenous population of Australia is more disadvantaged in terms of excess mortality than those of Canada, New Zealand or the United States, although caution should be exercised when comparing the mortality experience of Indigenous populations given the different estimation approaches used. We estimate expectation of life at birth of 66.5 years (both sexes) for 1996–2001, 2 years less than that estimated for the New Zealand Maori for 1996–99, and 4 years less than for First Nation Manitobans for 1995–99. Our estimates suggest modest increases of life expectancy for Indigenous Australians between 1991–96 and 1996–2001 of about 1 year for both males and females. These increases are somewhat smaller, especially for males, than those for the Australian population as a whole over the same period,[38] so no progress seems to have been made in reducing the unacceptable health inequities Indigenous Australians experience.

Appendix

The general growth balance methodology

The General Growth Balance method (GGB)[26] is a generalization to non-stable populations of the Growth Balance method devised by Brass[39] for populations that are approximately stable. In any closed population, that is, one not affected by migration, the growth rate of the population is equal to the difference between the birth rate and the death rate. This necessary relationship also holds for open-ended age groups such as, for example, the population 10 and over, if the 'birth rate' is replaced by the rate of entry into the age group 10+ as a result of 10th birthdays. Thus in any open-ended age segment of the population age $x+$, the growth rate $r(x+)$ is equal to the difference between the entry rate into the population $x+$, that is, the number of people having an xth birthday, $B(x)$, divided by the person-years of exposure $x+$, $N(x+)$, and the exit rate from the population $x+$, that is, deaths $D(x+)$ at age x and over divided by the person-years of exposure $x+$. Thus

$$r(x+) = \frac{B(x)}{N(x+)} - \frac{D(x+)}{N(x+)} \qquad (A1)$$

Equation (A1) can be rearranged as

$$\frac{B(x)}{N(x+)} - r(x+) = \frac{D(x+)}{N(x+)} \qquad (A2)$$

Given two censuses t years apart, $B(x)$, $N(x+)$ and $r(x+)$ for the interval t can be estimated from the census age distributions. If the first and second censuses have coverage, constant at all adult ages, of k_1 and k_2, respectively, the true entries into the population $x+$, $B(x)$, can be approximated as

$$B(x) = \left(\frac{t}{5}\right) * \sqrt{\frac{{}_5N1^o_{x-5}}{k_1} * \frac{{}_5N2^o_x}{k_2}} \qquad (A3)$$

where ${}_5N1^o_{x-5}$ and ${}_5N2^o_x$ are the observed populations at the first and second censuses, respectively, aged $x-5$ to x and x to $x+5$, respectively. Note that this calculation cannot be carried out for $x=0$ or for x equal to the starting age of the open age interval. The true exposure at ages x and over can be approximated as

$$N(x+) = \sum_{a=x}^{\omega} t * \sqrt{\frac{{}_5N1^o_a}{k_1} * \frac{{}_5N2^o_a}{k_2}} \qquad (A4)$$

Since the entry rate $b(x+)$ is equal to the entries divided by the exposure, the t, k_1 and k_2 cancel out:

$$b(x+) = \frac{\sqrt{{}_5N1^o_{x-5} * {}_5N2^o_x}}{5 * \sum_{a=x}^{\omega} \sqrt{{}_5N1^o_a * {}_5N2^o_a}} \qquad (A5)$$

The true growth rate can be calculated as

$$r(x+) = \left(\frac{1}{t}\right) \ln\left(\frac{\sum_{a=x}^{\omega} \left({}_5N2^o_a/k_2\right)}{\sum_{a=x}^{w} \left({}_5N1^o_a/k_1\right)}\right) = r^o(x+) + \left(\frac{1}{t}\right) * \ln\left(\frac{k_1}{k_2}\right) \qquad (A6)$$

That is, the true growth rate is equal to the observed growth rate $r^{\circ}(x+)$ plus a constant across all age groups determined by the relative magnitudes of k_1 and k_2, that is, by the change in census coverage from census 1 to census 2.

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Table A.1 Illustration of GGB application to Indigenous males, 1996–2001

Age group $x,x+4$	Initial population 6-Aug-96	Final population 7-Aug-01	Average annual deaths	Initial population $x+$	Final population $x+$	Deaths $x+$	Average birthdays age x	Person-years lived $x+$	Population growth rate $x+$	Observed death rate $x+$	Residual death rate $x+$
0–4	25 591	26 741	85	173 830	202 946	1078	N/A	187 825	0.0310	0.0057	N/A
5–9	24 811	29 095	5	148 239	176 205	993	5457	161 618	0.0346	0.0061	-0.0008
10–14	21 806	26 622	9	123 428	147 110	988	5140	134 750	0.0351	0.0073	0.0031
15–19	17 483	21 303	28	101 622	120 488	979	4311	110 654	0.0340	0.0088	0.0049
20–24	16 068	16 492	37	84 139	99 185	951	3396	91 353	0.0329	0.0104	0.0043
25–29	14 494	15 772	53	68 071	82 693	914	3184	75 027	0.0389	0.0122	0.0035
30–34	12 522	14 687	69	53 577	66 921	861	2918	59 878	0.0445	0.0144	0.0043
35–39	10 727	12 884	72	41 055	52 234	792	2540	46 308	0.0481	0.0171	0.0067
40–44	8639	11 136	81	30 328	39 350	720	2186	34 546	0.0521	0.0209	0.0112
45–49	6813	8859	86	21 689	28 214	640	1750	24 737	0.0526	0.0259	0.0181
50–54	4889	6746	81	14 876	19 355	553	1356	16 968	0.0526	0.0326	0.0273
55–59	3401	4486	86	9987	12 609	473	937	11 222	0.0466	0.0421	0.0369
60–64	2579	3162	90	6586	8123	387	656	7314	0.0419	0.0529	0.0477
65–69	1739	2194	94	4007	4961	297	476	4459	0.0427	0.0666	0.0640
70–74	1033	1278	72	2268	2767	203	298	2505	0.0398	0.0811	0.0793
75–79	625	675	59	1235	1489	131	167	1356	0.0374	0.0963	0.0858
80–84	315	387	41	610	814	72	98	705	0.0577	0.1017	0.0819
85+	295	427	31	295	427	31	N/A	355	0.0739	0.0872	N/A
Total	173 830	202 946	1078								

If intercensal deaths are recorded with completeness c, also constant at all adult ages, the true death rate can be written as

$$d(x+) = \frac{\sum_{a=x}^{\omega} \frac{{}_5D_a^o}{c}}{5 * \sum_{a=x}^{\omega} t * \sqrt{\frac{{}_5N1_a^o}{k_1} * \frac{{}_5N2_a^o}{k_2}}} = \sqrt{\frac{k_1 * k_2}{c}} * \frac{\sum_{a=x}^{\omega} {}_5\bar{D}_a^o}{5 * \sum_{a=x}^{\omega} \sqrt{{}_5N1_a^o * {}_5N2_a^o}} \qquad (A7)$$

where ${}_5D_a^o$ and ${}_5\bar{D}_a^o$ are the observed deaths and average annual observed deaths, respectively, at ages a to $a+5$.

The observed entry rate $x+$ minus the observed growth rate $x+$ will be linearly related to the observed death rate $x+$ with an intercept determined by k_1 and k_2 and a slope determined by the value of c relative to an average of k_1 and k_2. Since the methodology is only applied for ages 5 and over, there is no need to estimate intercensal births. Age-specific growth rates are assumed to be constant within an intercensal period.

The GGB method conceptually compares a direct mortality estimate calculated from observed deaths by age to a residual estimate calculated by subtracting the observed growth rate from the observed 'birthday' rate. Table A.1 shows the calculations underlying the results shown in Figure 2(a).

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