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Transformation of mortality in a remote Australian Aboriginal community: a retrospective observational study

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Abstract

Objectives To describe trends in ages and causes of deaths in a remote-living Australian Aboriginal group over a recent 50 year period.

Design A retrospective observational study, from 1960 to 2010, of deaths and people starting dialysis, using data from local clinic, parish, dialysis and birthweight registers.

Setting A remote island community in the Top End of Australia's Northern Territory, where a Catholic Mission was established in 1911. The estimated Aboriginal population was about 800 in 1960 and 2,260 in 2011.

Participants All Aboriginal residents of this community whose deaths had been recorded.

Outcome measures Annual frequencies and rates of terminal events (deaths and dialysis starts) by age-group and cause of death.

Results In all, and against a background of high rates of low birthweight, 223 deaths in infants and children and 934 deaths in adults (age ≥15 years) were recorded; 88% were of natural causes. Most deaths in the 1960s were in infants and children. However, these fell dramatically, across the birthweight spectrum, while adult deaths progressively increased. The leading causes of adult natural deaths were chronic lung disease, cardiovascular disease and, more recently, renal failure, and rates were increased two-fold in those of low birthweight. However, rates of natural adult deaths have been falling briskly since 1986, most markedly among people of age 45+ years. The population is increasing and its age structure is maturing.

Conclusions The changes in death profiles, the expression of the Barker hypothesis and the ongoing increases in adult life expectancy, reflect epidemiologic and health transitions of astonishing rapidity. These probably flow from advances in public health policy and health care delivery, as well as improved inter-sectoral services, which are all to be celebrated. Other remote communities in Australia are experiencing the same phenomena, and similar events are well advanced in many developing countries.

Strengths and limitations of this study

- The broad sweep and historical depth of this study, the unique data sources and the integration of clinical and demographic information have allowed delineation of the profound and recent transformation of mortality not previously appreciated in the Australian Aboriginal setting.
- Although the failure to have captured some deaths is inevitable, it has probably resulted in understatement of the magnitude of this transition.

Introduction

Recent literature describes a rapid shift in patterns and causes of death in most countries and regions. Infant and childhood deaths have decreased, life expectancy has increased,[1] and more deaths in adults are associated with non-communicable chronic diseases.[2] Here we describe such a transition in a remote-living Aboriginal Australian group over the last 51 years.

The Tiwi people live in three major communities (and several smaller ones) on Bathurst and Melville Islands off the coast of the Northern Territory (NT), about 90 km by sea from Darwin (Figure 1). They lived in relative isolation for perhaps 7,000 to 15,000 years, and consider themselves distinct from mainland Aboriginal people, with their own unique origins, language, and customs.[3]

In 1911, a Catholic mission was established by the Missionaries of the Sacred Heart (MSC), led by Father Francis Xavier Gsell.[4] Changes followed in lifestyle (from nomadic hunter gatherers to living in fixed dwellings), in diet (from food from the bush and sea to depot supplies of less perishable, high caloric density food, of flour, fat, meat and sugar), in family and community structures (from polygamy and networks of carers within extended families to monogamy), and in the establishment of dormitories, schools and clinics. Transition has been especially accelerated since World War 2. Cigarettes were widely introduced around this time. The 1967 referendum formally recognised Aboriginal people in Australia,[5] and they were thenceforth included as residents in the national census. Legal access to alcohol began around that time. The first social club, serving alcohol, was opened in the largest Tiwi community in 1967.

Some early insights into remote-living Aboriginal people in the NT are provided by Ellen Kettle, the first Rural Survey Sister in the NT, who pioneered mobile health work in isolated areas and established health records for individuals, and by Dr John Hargrave, the first Aboriginal Health Officer, who personally examined members of many communities in 1957/1958. Both advanced understanding of Aboriginal health and development of services and policy. They described endemic conditions (yaws, malaria, infestations, trachoma), imported conditions like leprosy, syphilis (arguably), tuberculosis, measles, small pox and influenza. They documented florid malnutrition and frank starvation, high infant and maternal mortality and conspicuously low birthweight. They then described, over time, dramatic reductions in infant mortality, the appearance of alcohol related disorders, and of occasional overweight and obesity, as well as the emergence of non-communicable chronic diseases. [6,7]

These phenomena occurred against a background of continuous improvements in remote Aboriginal health services, including management of infections and infestations, immunisations, better obstetric services, better maternal and child care, and cancer surveillance. Chronic non-communicable diseases, predominantly type 2 diabetes,

cardiovascular disease, chronic lung disease and chronic kidney disease now dominate the adult health profile and are the focus of most of health service provision for remote-living Australian Aboriginal adults.[8]

Clinical services were established by the mission, starting as first aid facilities on the beach at Nguiu (now Wurrumiyanga) on Bathurst Island. These eventually evolved into a clinic and local hospital, run by the Sisters of the Order of Our Lady of Sacred Heart (OLSH), with additional clinics in the Melville Island communities of Milikapiti and Pirlangimpi. Medical records were established for individuals, along with clinic-based registers for births and deaths. Doctors from Darwin eventually provided backup support. More recently, there have been resident doctors for intermittent periods. Local hospital beds were closed in the early 1990s, and all persons needing hospital admission were thenceforth streamed to the Royal Darwin Hospital, transported by small plane. Responsibility for clinical services was transferred from the mission to the NT government in the early/mid-1990s.

Anthropologist Charles Hart enumerated a Tiwi population of 1,062 in 1928.[3] Dr John Hargrave estimated the Tiwi population at about 800 to 900 in 1957, compatible with a 1954 Commonwealth Government estimate of 920.[9,10] Regular government census estimates have been published every five years since 1986.

Traditionally, Tiwi people have only occasionally transmigrated, usually for purposes of intermarriage according to tribal edicts. The destinations of people who travel, and the movements and locations of community members, are known by all. Deaths of people who die out of community (usually in Darwin or while visiting other communities) are documented in their medical records on in their "home" community clinic and added to the death register.

Death rates in the Tiwi community, along with those in Aboriginal people in Arnhem Land, have among been the highest in Australia: in the 1990s, with age-standardisation, they were six times those of the Australian mainstream.[11] Cases of kidney failure began to attract attention in the 1980s; [12] for several decades Tiwi people had the highest rates of renal failure yet described, and the first hemodialysis unit in a remote Aboriginal location was established in Wurrumiyanga on Bathurst Island in the late 1990s. We have previously described the high rates of low birthweight in this community and the risk exacerbations for natural deaths in infants, children and young adults associated with low birthweight.[13,14]

Methods

Data sources were the written logs of deaths maintained by the clinics, dialysis unit records of NT Renal Services, and in this staunchly Catholic community, records maintained by the parish priests of all funerals and burials. We report recorded deaths over the 51 year period from 1960 to 2010, beginning when clinic recording of details of death (age, date and explanation) was becoming more systematic.

Starting in the 1980s, maintenance dialysis has been available to Tiwi persons with end-stage renal disease; numbers of patients starting treatment increased steadily until apparently stabilising at about 6 persons a year in the early 2000s. In this study, initiation of dialysis is considered a natural (renal) death, occurring when dialysis began, because without that treatment all participants would have died shortly thereafter.

Description of cause of death became more detailed over time. In the early years the only discrimination for some deaths was of natural versus unnatural causes, while, in later years, there was more detailed narrative on cause(s) and associations of death. In the early years, deaths in people over 60 years of age often received a causal assignment of "old age" or "debility", but with time "disease or organ-specific" assignments increased for them as well. In the context of sometimes sparse clinical detail, and conforming to the methodology for the Global Burden of Disease study, we derived and assigned a principal cause of death only.

Unnatural deaths, or deaths of misadventure, included those due to accidents, drownings, fire (burns and smoke inhalation), homicide, suicide, poisonings, jelly fish stings, crocodile and shark attacks etc. We defined the main categories of natural deaths as cardiovascular (heart attack, congestive heart failure, ischemic heart disease, coronary artery disease and stroke), respiratory (chronic lung disease, chronic obstructive airways disease, chronic bronchitis, bronchiectasis, pneumonia), renal (death with terminal renal failure, and also, after 1985, institution of dialysis in people with terminal renal failure), various other causes (eg sepsis, liver failure, lupus, cancer etc.), and debility or old age. When there was uncertainty about deaths or persons, data were checked with several senior community members, who had lived through much of the study interval and had known most community members.

Analyses were conducted using Stata 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP). Numbers and rates of deaths were calculated by age-group and cause of death. Five-year moving averages were created using the tssmooth package. Mortality rates, per 100,000 population, could be calculated only since 1986, the first year of the subsequent quinquennial national census that specifically enumerated Aboriginal Tiwi people. Total population estimates were also taken from census figures.[15]

Patient involvement

This study has retrospectively reviewed combined records of forerunning studies. There was no direct contact with patients or individuals. No patients were involved in setting the research questions or the outcome measures, nor were they involved in developing plans for recruitment, design, or implementation of the study. No patients were asked to advise on interpretation or writing up of results.

Results

1,190 deaths were recorded, and age was documented or age group could be inferred in 1,156 (97.1%) of these (for 95.0% of deaths in the first two decades, and 98.6% of deaths in the last three decades).

Of these 1,156 deaths, 222 were in infants and children (<1 years and 1 to <15 years respectively), and 934 (78·5%) were deaths of adults (at ages ≥15 years). Twenty-five (11·3%) deaths of infants and children were deaths of misadventure and 197 (88·7%) were of natural causes. Among adults, 114 (12·2%) of deaths were due to misadventure and 820 (87·8%) were natural deaths.

Figure 2 shows deaths by age-group and interval. Early on, most deaths were in infants and children. These fell rapidly at first, then more slowly. The main categories of death in infants and children were diarrhoea, respiratory disease and failure to thrive, with some cases of sudden infant death, and a few congenital abnormalities.[13] In 1973, a house fire killed six siblings, making a major contribution to deaths due misadventure in this group.

As infant and childhood deaths fell, numbers of deaths of adults increased. Many of these have been among young adults (ages 15 to <49 years) with high numbers of both natural death and deaths of misadventure. The latter include motor vehicle accidents, drownings, homicide, and suicide; there were 50 suicides between 1985 and 2010, of which 47 (94%) were among males.

Most deaths are now in people of ≥45 years, and most of these are of natural causes. The numbers have not perceptibly increased since the early 1990s. Only 2·6% of these older adult deaths were due to misadventure.

Figure 3 shows the trends in natural deaths in adults over time, by primary causal assignment. Numbers peaked in the later 1980s but have since had an indeterminate or falling trend. Through the mid-1980s there were substantial numbers of natural deaths with no further details and deaths with assignments of "old age" or debility", but there have been more "organ-system" assignments since the early 1990s. Among specific assignments, cardiovascular deaths, and cancer/liver/other deaths were represented over the continuum, while pulmonary (respiratory) deaths became prominent but more recently have been decreasing. Renal deaths become prominent in the 1980s; there were 25 renal deaths in the 1980s, 42 in the 1990s and 52 from 2000 to 2009, constituting 14·7, 24·1 and 31·7% of all natural deaths in those intervals.

Figures 4 A-C show the smoothed estimated rates of natural deaths by age-group since 1986.[15] Rates of death in infants and children have fallen remarkably. There was an early increase in death rates among young adults, followed by a progressive decline since the early 1990s. Death rates of people age ≥45 years have markedly declined, at least until the

last few years of the observation interval. The net effect of all these changes is a decrease overall death rates of the entire population.

These trends are further summarised in Table 1, which shows the rates of natural deaths by age-group in the first and last 5-year blocks of the observation interval. Death rates of infants and children fell by 89·5%, those of young adults fell by 23·5%, while of people age ≥45 years fell by 65·1%. For the population as a whole, rates of natural death fell by 52·2%.

Figures 5 A-D show that the population age structure has changed over <40 years to include higher numbers and proportions of young and middle age adults.[15,16] In addition, the size of the total population has increased by 85%.

Discussion

This is the most complete description of deaths in any indigenous Australian community. It shows a profound change in patterns, rates and causes of death over a 51 year interval. Infant and childhood deaths have fallen dramatically; now most people die as adults (≥15 years), and of natural causes. Furthermore, in the last 25 years, rates of natural deaths of adults have been falling. The population is increasing and is progressively ageing.

With continued improvements in prevention and treatment of infectious diseases, adult deaths are increasingly due to non-communicable diseases, with chronic lung disease, cardiovascular disease and renal disease making the greatest contribution. These chronic diseases have usually overlapped and been co-contributors to death, although this is obscured by our use of mutually exclusive categories of primary cause of adult death. Among specific assignments, cardiovascular deaths, and cancer/liver/other deaths etc. have been represented over several decades, while pulmonary deaths became prominent in the 1970s, but have decreased since the early 1990s. Kidney failure has become prominent since the 1980s, and is now the single leading assignment.

The improving but still excessive rates of natural deaths are, in large part, the representation of the "Barker hypothesis".[17] We have shown that the dramatic reductions in early life mortality have been experienced across the birthweight spectrum, so that, against a background of seriously low birthweights, large cohorts of underweight infants, who were previously at greatest risk for early death, have now survived to adult life. As adults, they have enhanced susceptibility to chronic disease, as the hypothesis proposes and as we have demonstrated.[13,18,19] Through 2010, rates of natural adult deaths before the age of 41 years in the Tiwi populations was twice that of those with higher birthweights, with the greatest accentuation of risk being for pulmonary deaths, a 6-fold increase (Med J Aust, submitted Jan 2017).[14]

The continued evolution of the chronic disease rates and patterns and rates over time is probably influenced by improving birthweights, changing age structure among adults, improved prevention, screening and management of chronic disease and changes in

competing causes of deaths. With reductions in deaths from pulmonary disease and postponement of cardiovascular deaths, flowing from a secular increase in birthweights,[13] and from better medical management, coexisting nephropathy has more opportunity to pursue its more leisurely course to renal failure.[20]

Availability and use of the clinic-based death records and the supporting parish burial records sets this study apart. The NT-wide government register of deaths dates only back to the mid-1980s, and in that register, community assignment has sometimes been incomplete. Moreover, government records do not capture the full burden of renal failure, due to deficient documentation of a renal cause of death, both in people receiving renal replacement therapy (RRT), and in those dying of renal failure without receiving RRT.[21,22] Our composite definition of "renal deaths" as the start of RRT and a renal death without RRT more fully reveals the burden of renal failure disease. That approach is necessary for monitoring, prevention and intervention strategies, especially in the context of the burden and costs of RRT.[23,24] Furthermore, it is the only way that kidney failure rates can be compared with populations in other countries for whom RRT is not widely available.

Our data also reveal an excess of deaths by misadventure in young adults in more recent years. Such deaths, often alcohol or drug-fuelled, are prominent among young Aboriginal adults nationwide, and are of grave concern.[25,26]

Limitations include the fact that some Tiwi deaths were probably not captured in our data sources. This is more likely in the earlier years, so that that the earlier numbers and rates of deaths, as well as the subsequent fall in deaths, have probably been understated. Moreover, from 1985 to 2009, the government agencies recorded 18% fewer deaths for the Tiwi community than we have recorded, with under-identification varying from 10 to 30% over five consecutive 5 years intervals (In an email from Y Zhao, (yuejen.zhao@nt.gov.au) 2016 Oct 24). An additional limitation is assignment of a single category of cause of death, whereas natural deaths in adults have multiple causes and associated conditions; the coexistence of cardiovascular risk and lung disease, and of renal disease with cardiovascular disease are well recognised. However, the use of a single underlying cause of death is dictated by the detail of the source data. It is also the approach employed until recently for the mortality component of the study of Global Burden of Disease.

Is it credible that about half the deaths in Tiwi people in the 1960s were in subjects less than 15 years of age? The World Health Organization estimated that, in 1955, fully 40% of global deaths were in children age <5 years, so presumably an even greater proportion were deaths of people <15 year old).[27] Furthermore, analyses of skeletal remains of some premodern cultures have suggested that up to 68% of deaths occurred people <15 years old (Chamberlain cited in Roser, 2006).[1,28] Hart's comment that, around 1928, five of 15 bestowed wives (females promised in marriage to specific Tiwi community members), died before puberty, supports a high childhood mortality.[3]

Other Aboriginal groups in remote areas of Australia over the same intervals have undoubtedly experienced similar transitions. NT government agencies have described similar trends in early life mortality since 1967, and improvements in natural death rates overall since the late 1980s (Figures 6 and 7).[29] In the Shire of Broome, Western Australia, Gracey et al. described excessive levels of Aboriginal infant and childhood infection and under-nutrition in the 1970s and 1980s and increasing deaths by misadventure in young Aboriginal adults between 1971 and 1994.[30] Our findings are also consistent with events in many other countries and regions. Figure 8 shows the fall in early life mortality since 1960, which is most dramatic in disadvantaged populations like Yemen, Afghanistan, Bangladesh and Nepal,[31] while Figure 9 shows the simultaneous increase in life expectancy at birth, again most marked in disadvantaged settings.[32] Our Tiwi data show that the improvement in life expectancy is a function of reduced early life morality as well as increasing adult longevity.

These changes represent triumphs of inter-sectoral improvements, public health policy and health care more broadly, which are to be celebrated. This is especially welcome news for the Tiwi Aboriginal people, whose mortality rates have been the worst in Australia,[11] and for remote-living Aboriginal people more broadly. It is also comforting for health care providers and policy makers to see such large scale progress demonstrated through an historical perspective, and should support resolve to stay the course in ongoing improvements.[8] More broadly, this information should moderate the negative discourse which has pervaded the Aboriginal health literature.

Encouraging as these trends are, further improvement in adult death rates can still be anticipated. Birthweights continue to improve, so that accentuated chronic disease risk from that source should decline; adult health services continue to improve, especially in prevention, screening and management of chronic disease,[8] and rates of smoking are falling.[33] Continuing challenges, however, include high rates of obesity,[34] poor diet, especially sugar excess,[35] drug use, alcohol abuse, and foetal alcohol syndrome.[7] Interpersonal violence, especially high rates of suicide and accidents, remain serious challenges. Efforts to improve education, skills training, employment opportunities, empowerment and socioeconomic status must be unflagging and be robustly supported.

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Contributors: WH conceived and designed this work, collected data, directed data analyses, interpreted the findings and wrote the manuscript. BMcL conducted field work, and performed data collection and data preparation. SM prepared data, performed analyses and contributed to interpretation, produced figures and tables, and coordinated preparation and editing of the manuscript. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. All authors reviewed, revised and approved the manuscript.

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Transparency: The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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Table

Table 1. Mean (95%CI) natural death rate per 100,000 population by five-year intervals and age-group

Time interval	<15 years	15-44 years	45+ years	All ages
1986-1990	547.4 (406, 689)	426.3 (240, 613)	8065.4 (6778, 9353)	1480.7 (1240,1721)
2006-2010	60.5 (-81, 202)	326.3 (140, 513)	2815.2 (1528, 4103)	716.8 (476,957)

Note: The mean of aggregate natural deaths over years 2001-2010 is used for deaths of those <15 years of age.

Sources: 1986-2011 census data, Australian Bureau of Statistics (Catalogues: 1987, #2460.0; 2012,#2002.0).[15]

Legend of Figures

Figure 1. The Tiwi Islands, Northern Territory, Australia

Note: Wurrumiyanga was formerly named Nguiu.

Source: Adapted from Google Map data. The Tiwi Islands. Google; ©2017 [cited 2017 Jan 10]. Available from: https://www.google.com.au/maps/@-12.2087082,130.7314414,8.75z

Figure 2. Numbers of Tiwi deaths by age-group and broad cause of death, 1960-2010

Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among natural deaths.

Figure 3. Numbers of Tiwi natural adult deaths by age-group and cause of death, 1960-2010

Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among renal deaths.

Figures 4 A-C. Tiwi natural death rates by age-group, 1986-2010

Note: A five-year rolling average of rates is presented; population data derivation: 1986-2010 from quinquennial Census estimates (Australian Bureau of Statistics Catalogues: 1987, #2460.0; 1993, #2730.7; 2000, #70609; 2007, #2001.0; 2002, #2002.0; 2012, #2002.0);[15] people who started dialysis are included among natural deaths; the low rates of death depicted for those <15 years from 2003 to 2010 are each based upon the average of the very small number of events (four) that occurred between 2001 and 2010.

Figures 5 A-D. Age distribution of the Tiwi population at four time-points, by sex, 1971-2011

Sources: 1971 data was cited in Peterson, 1988;[16] 1986-2011 census data, Australian Bureau of Statistics (Catalogues: 1987, #2460.0; 2000, #70609; 2012,#2002.0).[15]

Note for figure formatting – please enter the text given below in the top left of each graph for Figure 5 A-D:

A. 1971

Total population: 1,221

B. 1986

Total population: 1,806

C. 1996

Total population: 2,023

D. 2011

Total population: 2,263

Figure 6. Infant mortality, Northern Territory and Australia, 1967-2007

Source: Northern Territory Department of Health, 2011.[29]

Figure 7. Leading causes of death in the Aboriginal population of the Northern Territory: 1985-2006

Source: Northern Territory Department of Health, 2011.[29]

Figure 8. Under-five mortality rates for selected countries, 1960-2015

Source: adapted from UNICEF Global Database, 2015.[31]

Figure 9. Life expectancy at birth for selected countries, 1960-2013

Source: adapted from The World Bank, 2016.[32]

Source notes: Derived from male and female life expectancy at birth from sources such as: United Nations Population Division; World Population Prospects; United Nations Statistical Division. Population and Vital Statistics Report (various years); Census reports and other statistical publications from national statistical offices; Eurostat: Demographic Statistics; Secretariat of the Pacific Community: Statistics and Demography Programme; and U.S. Census Bureau: International Database.

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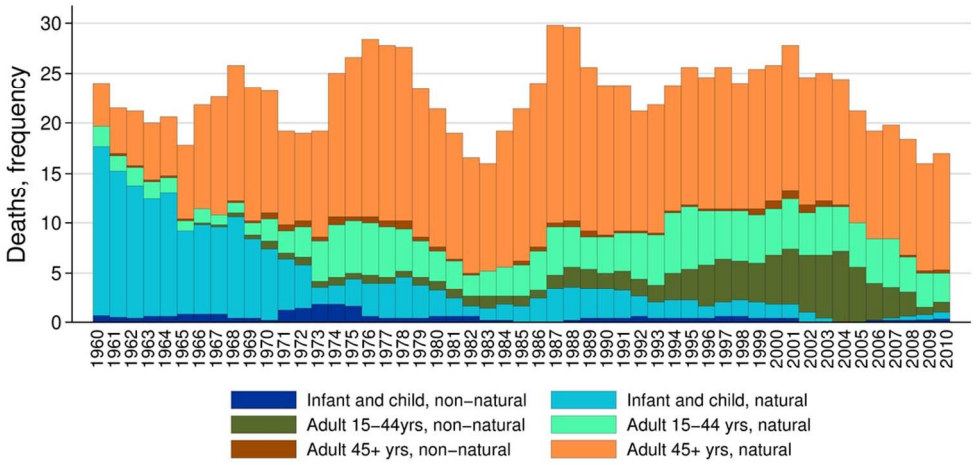

Figure 2. Numbers of Tiwi deaths by age-group and broad cause of death, 1960-2010
Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among natural deaths.

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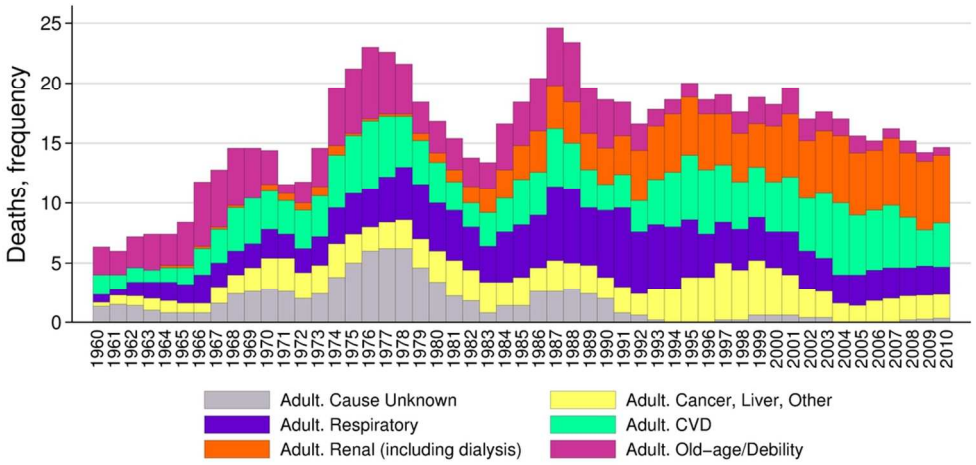

Figure 3. Numbers of Tiwi natural adult deaths by age-group and cause of death, 1960-2010
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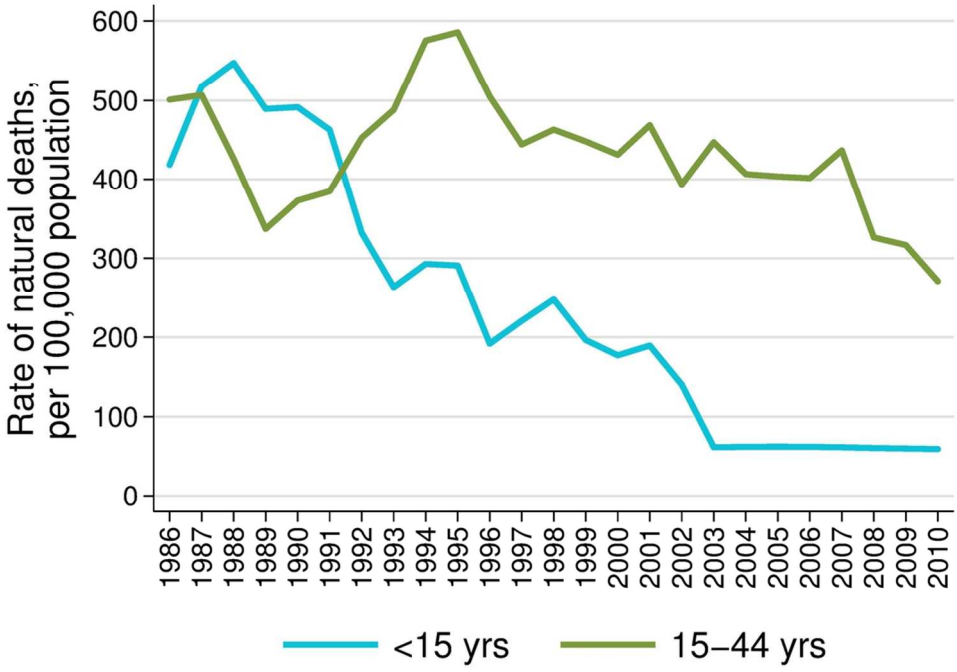

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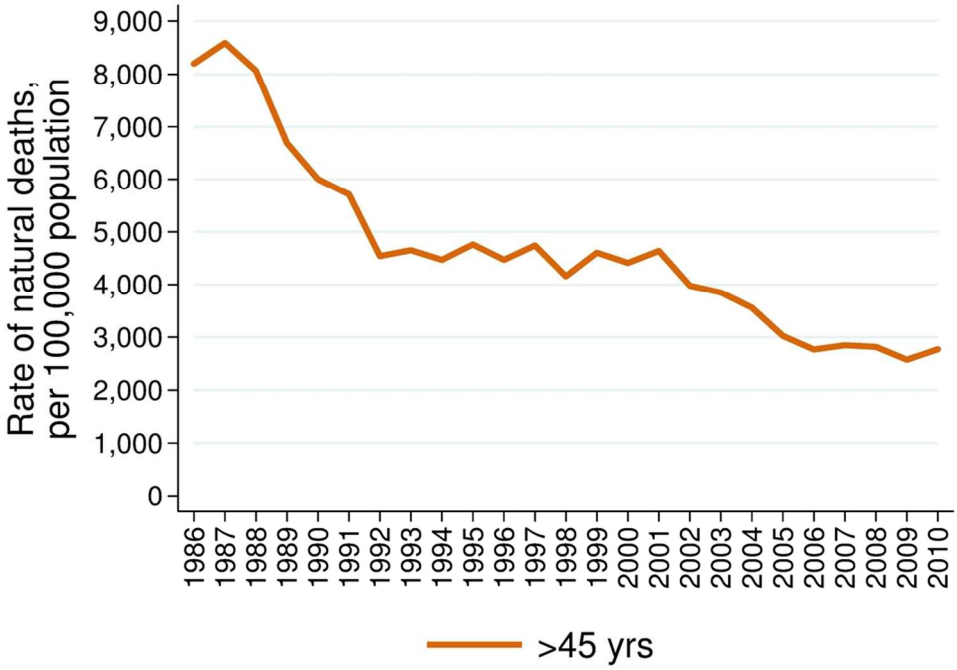

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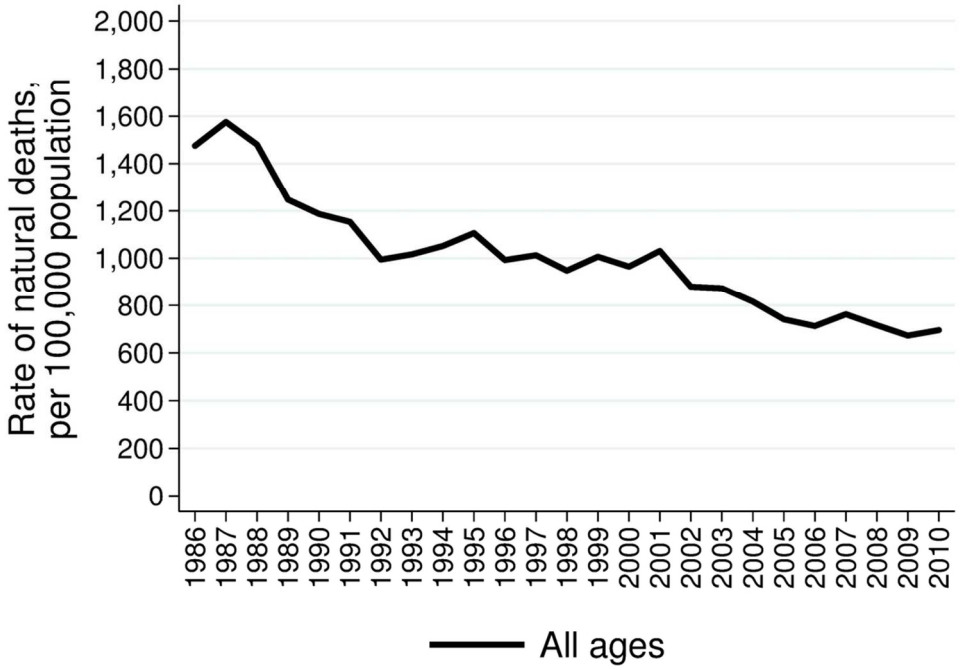

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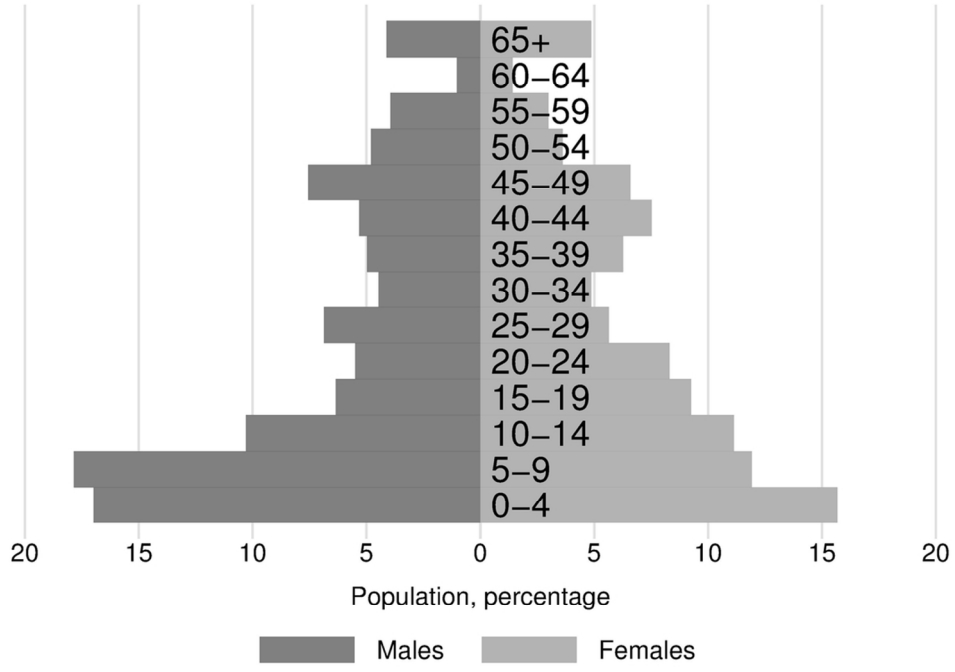

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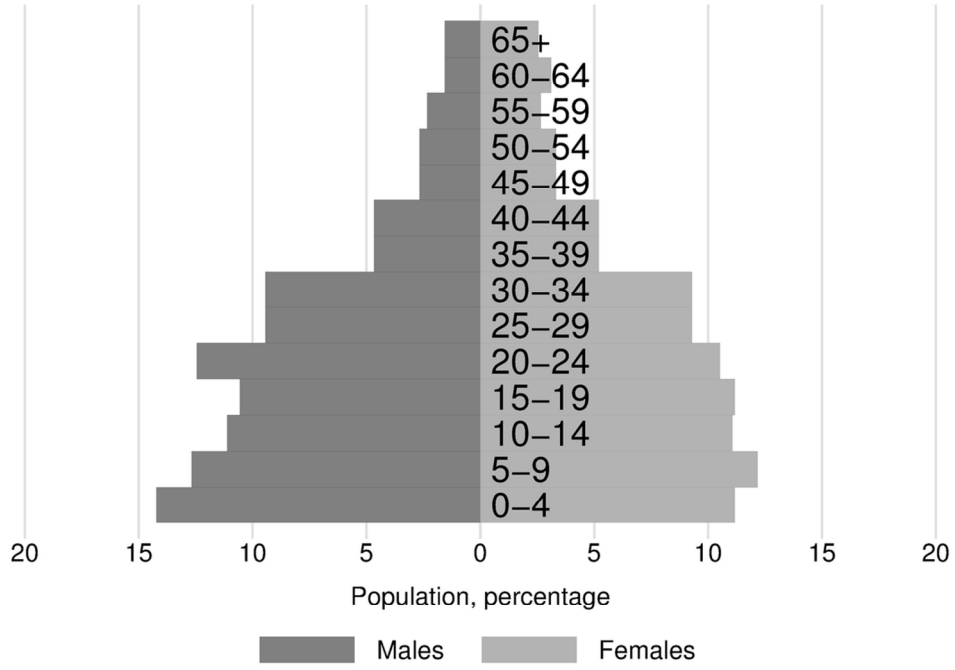

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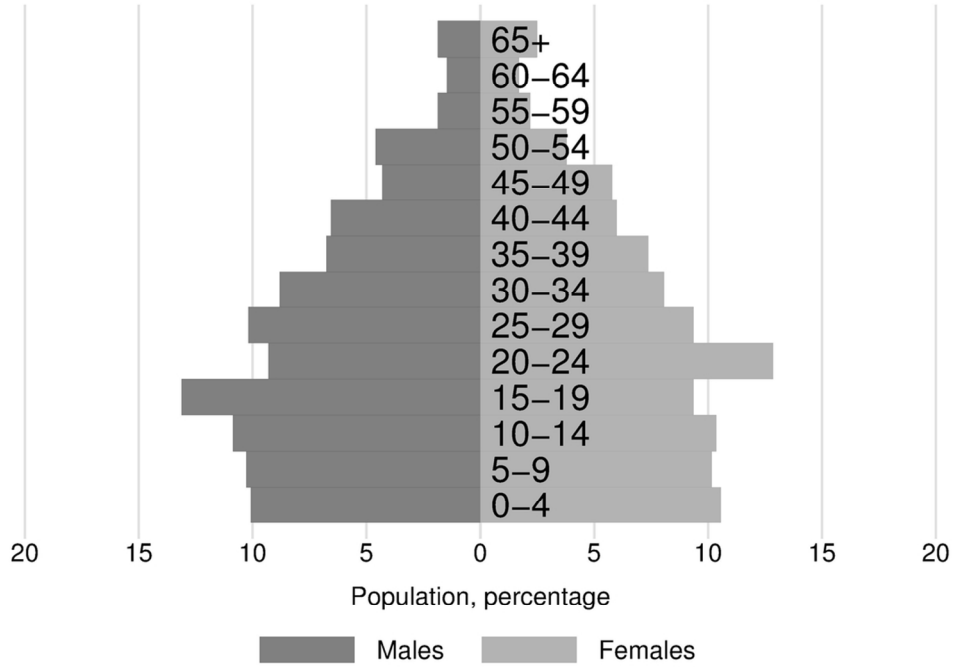

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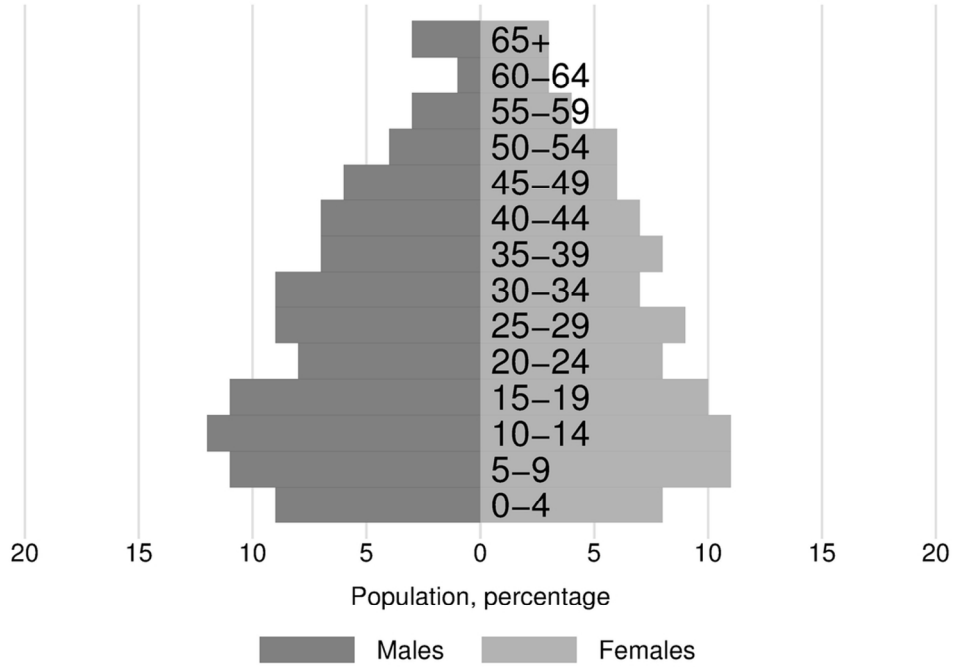

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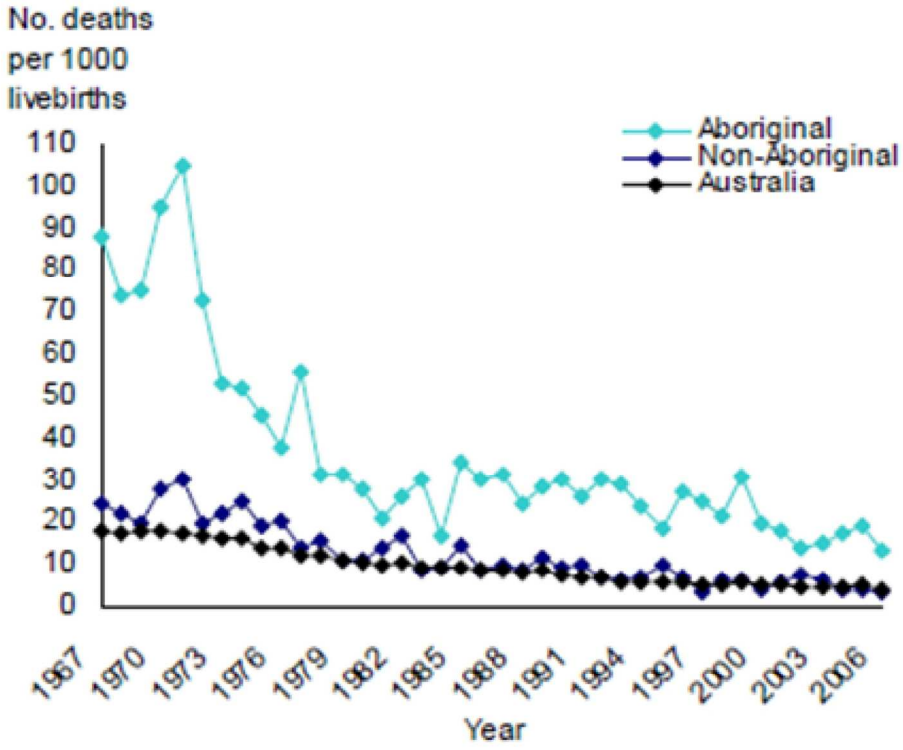

Figure 6. Infant mortality, Northern Territory and Australia, 1967-2007
Source: Northern Territory Department of Health, 2011.29

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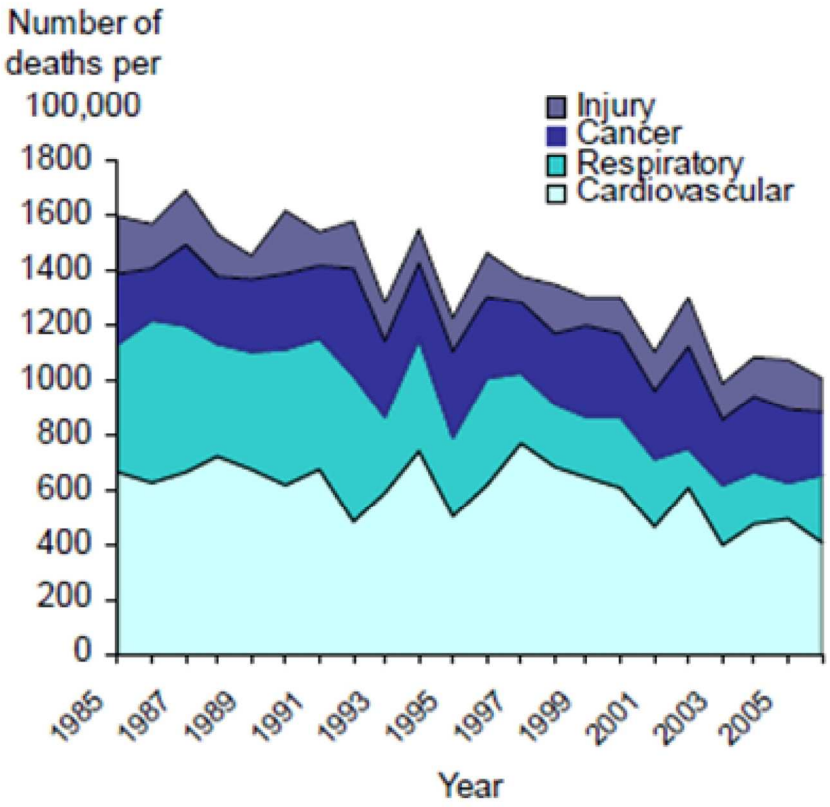

Figure 7. Leading causes of death in the Aboriginal population of the Northern Territory: 1985-2006
Source: Northern Territory Department of Health, 2011.29

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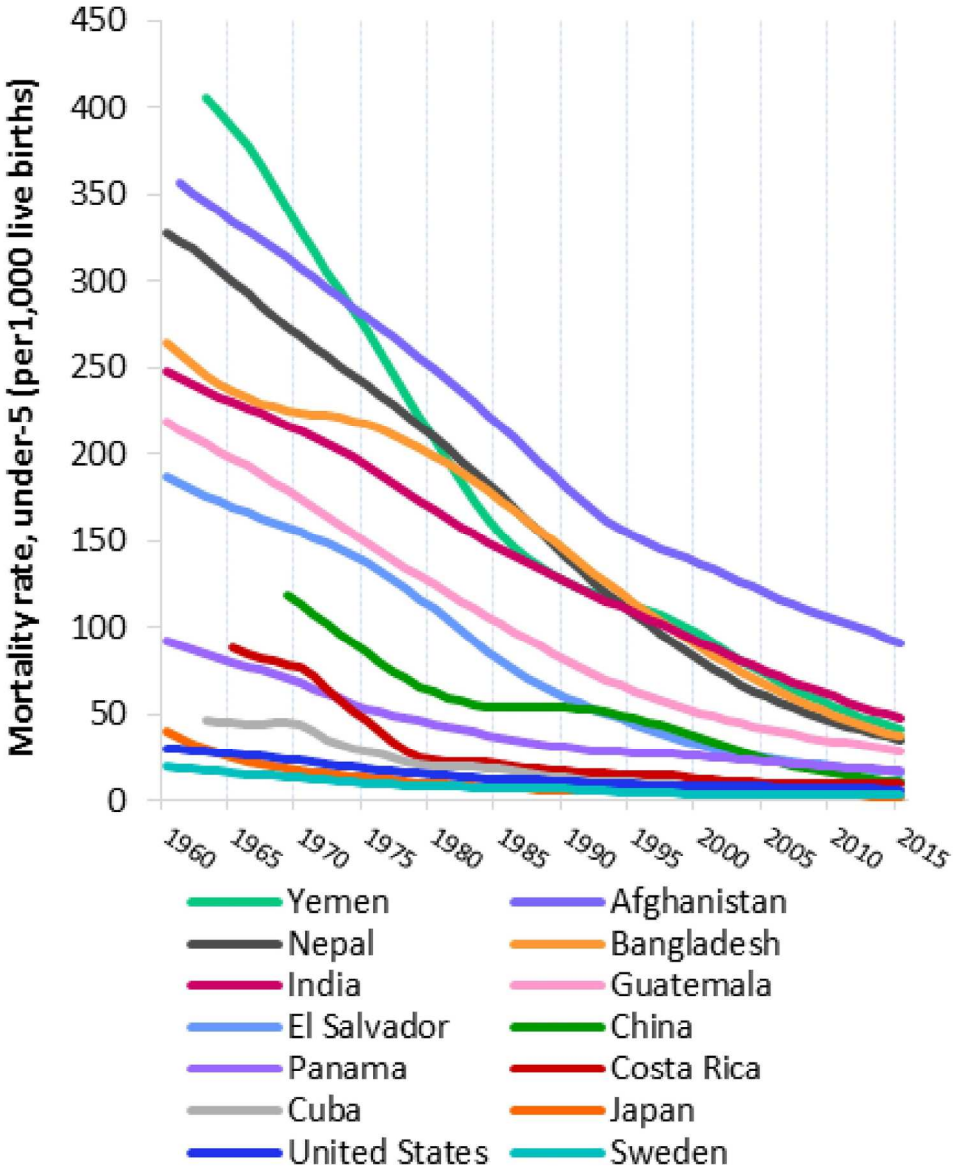

Figure 8. Under-five mortality rates for selected countries, 1960-2015
Source: adapted from UNICEF Global Database, 2015.31

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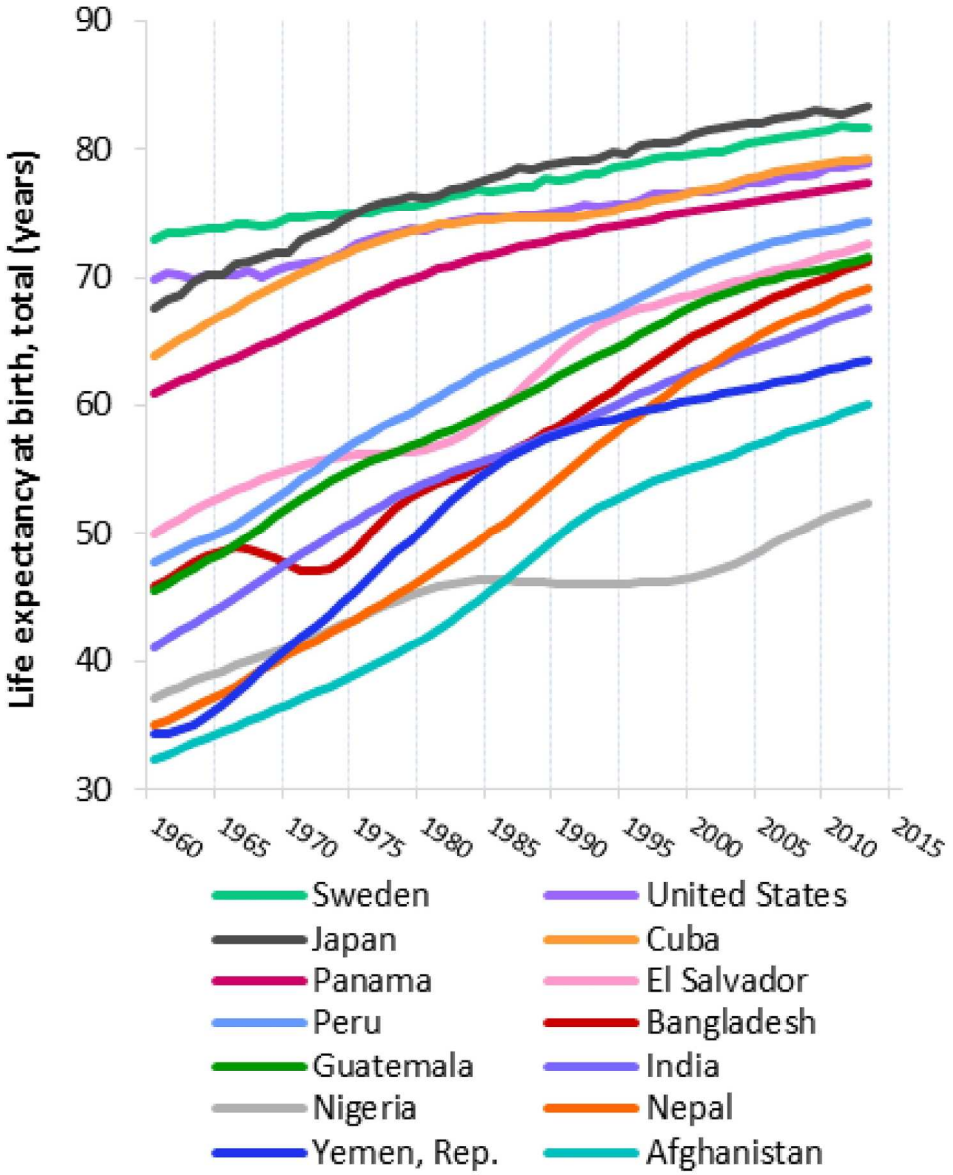

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B. 1986
Total population: 1,806

C. 1996
Total population: 2,023

D. 2011
Total population: 2,263

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No.(s) [Paragraph No.(s)]
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3[1-9]
Objectives	3	State specific objectives, including any prespecified hypotheses	3[1]
Methods			
Study design	4	Present key elements of study design early in the paper	4[6]-5[5]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4[6]-5[5]
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4[4] 5[5]
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4[5]-5[4]
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4[5]-5[4]
Bias	9	Describe any efforts to address potential sources of bias	5[1-3] 7[3-4] 8[1,3]
Study size	10	Explain how the study size was arrived at	4[5]-5[3]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	4[5]-5[4]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5[3]
		(*b*) Describe any methods used to examine subgroups and interactions	5[4]
		(*c*) Explain how missing data were addressed	
		We believe that the ascertainment of deaths overall is as good as it can be. We have accessed the original sources for this information (4[5]). There are no published government estimates prior to 1985. From 1985, our ascertainment compares favourably with that of government agencies (8[3]). Subjects included are those with available death data, plus age at death or age-group and natural or unnatural cause of death classification.	

		As a more detailed description of the cause of death was not consistently documented until after 1985 we restricted analyses by cause of death to 1985-2010. Additionally, as census data also became available from that time, death rates were calculated in the same time period.	
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	-
		(*e*) Describe any sensitivity analyses	

Continued on next page

Results			**Page No.(s) [Paragraph No.(s)]**
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6[1-2]
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6[1-5] Figures 1 & 2
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	7[3]-8[2]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8[3]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8[4]-9[3]

Generalisability	21	Discuss the generalisability (external validity) of the study results	9[1]
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11[3]

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Transformation of mortality in a remote Australian Aboriginal community: a retrospective observational study

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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health
Keywords:	Australian Aboriginal, Mortality transition, Demographic profile, Remote-living, Chronic disease

Transformation of mortality in a remote Australian Aboriginal community: a retrospective observational study

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Abstract

Objectives To describe trends in ages and causes of deaths in a remote-living Australian Aboriginal group over a recent 50 year period.

Design A retrospective observational study, from 1960 to 2010, of deaths and people starting dialysis, using data from local clinic, parish, dialysis and birthweight registers.

Setting A remote island community in the Top End of Australia's Northern Territory, where a Catholic Mission was established in 1911. The estimated Aboriginal population was about 800 in 1960 and 2,260 in 2011.

Participants All Aboriginal residents of this community whose deaths had been recorded.

Outcome measures Annual frequencies and rates of terminal events (deaths and dialysis starts) by age-group and cause of death.

Results In all, and against a background of high rates of low birthweight, 223 deaths in infants and children and 934 deaths in adults (age ≥15 years) were recorded; 88% were of natural causes. Most deaths in the 1960s were in infants and children. However, these fell dramatically, across the birthweight spectrum, while adult deaths progressively increased. The leading causes of adult natural deaths were chronic lung disease, cardiovascular disease and, more recently, renal failure, and rates were increased two-fold in those of low birthweight. However, rates of natural adult deaths have been falling briskly since 1986, most markedly among people of age 45+ years. The population is increasing and its age structure is maturing.

Conclusions The changes in death profiles, the expression of the Barker hypothesis and the ongoing increases in adult life expectancy, reflect epidemiologic and health transitions of astonishing rapidity. These probably flow from advances in public health policy and health care delivery, as well as improved inter-sectoral services, which are all to be celebrated. Other remote communities in Australia are experiencing the same phenomena, and similar events are well advanced in many developing countries.

Strengths and limitations of this study

- The broad sweep and historical depth of this study, the unique data sources and the integration of clinical and demographic information have allowed delineation of the profound and recent transformation of mortality not previously appreciated in the Australian Aboriginal setting.
- It is inevitable that we have failed to capture some deaths in the past, which probably resulted in understatement of the magnitude of this transition. In some recorded natural deaths the assignments were approximate and the contribution of multiple causes was underestimated.

Aims and objectives

To describe trends in mortality over more than fifty years in a remote Aboriginal community in the Northern Territory (NT) of Australia.

Background

Recent literature describes a rapid shift in patterns and causes of death in most countries and regions. Infant and childhood deaths have decreased, life expectancy has increased,[1] and more deaths in adults are associated with non-communicable chronic diseases.[2] Here we describe such a transition in a remote-living Aboriginal Australian group over the last 51 years.

The Tiwi people live in three major communities (and several smaller ones) on Bathurst and Melville Islands off the coast of the Northern Territory, about 90 km by sea from Darwin (Figure 1). They lived in relative isolation for perhaps 7,000 to 15,000 years, and consider themselves distinct from mainland Aboriginal people, with their own unique origins, language, and customs.[3]

In 1911, a Catholic mission was established by the Missionaries of the Sacred Heart (MSC), led by Father Francis Xavier Gsell.[4] Changes followed in lifestyle (from nomadic hunter gatherers to living in fixed dwellings), in diet (from food from the bush and sea to depot supplies of less perishable, high caloric density food, of flour, fat, meat and sugar), in family and community structures (from polygamy and networks of carers within extended families to monogamy), and in the establishment of dormitories, schools and clinics. Transition has been especially accelerated since World War 2. Cigarettes were widely introduced around this time (anecdotal evidence). The 1967 referendum formally recognised Aboriginal people in Australia[5] and they were thenceforth included as residents in the national census. Legal access to alcohol began around that time. The first social club, serving alcohol, was opened in the largest Tiwi community in 1967.

Some early insights into remote-living Aboriginal people in the NT are provided by Ellen Kettle, the first Rural Survey Sister in the NT, who pioneered mobile health work in isolated areas and established health records for individuals, and by Dr John Hargrave, the first Aboriginal Health Officer, who personally examined members of many communities in 1957/1958. Both advanced understanding of Aboriginal health and development of services and policy. They described endemic conditions (yaws, malaria, infestations, trachoma), imported conditions like leprosy, syphilis (arguably), tuberculosis, measles, small pox and influenza. They documented florid malnutrition and frank starvation, high infant and maternal mortality and conspicuously low birthweight. They then described, over time, dramatic reductions in infant mortality, the appearance of alcohol related disorders, and of occasional overweight and obesity, as well as the emergence of non-communicable chronic diseases.[6,7]

These phenomena occurred against a background of continuous improvements in remote Aboriginal health services, including management of infections and infestations, immunisations, better obstetric services, better maternal and child care, and cancer surveillance. Chronic non-communicable diseases, predominantly type 2 diabetes, cardiovascular disease, chronic lung disease and chronic kidney disease now dominate the adult health profile and are the focus of most of health service provision for remote-living Australian Aboriginal adults.[8]

Clinical services were established by the mission, starting as first aid facilities on the beach at Nguiu (now Wurrumiyanga) on Bathurst Island. These eventually evolved into a clinic and local hospital, run by the Sisters of the Order of Our Lady of Sacred Heart (OLSH), with additional clinics in the Melville Island communities of Milikapiti and Pirlangimpi. Medical records were established for individuals, along with clinic-based registers for births and deaths. Doctors from Darwin eventually provided backup support. More recently, there have been resident doctors for intermittent periods. Local hospital beds were closed in the early 1990s, and all persons needing hospital admission were thenceforth streamed to the Royal Darwin Hospital, transported by small plane. Responsibility for clinical services was transferred from the mission to the NT government in the early/mid-1990s.

Anthropologist Charles Hart enumerated a Tiwi population of 1,062 in 1928.[3] Dr John Hargrave estimated the Tiwi population at about 800 to 900 in 1957, compatible with a 1954 Commonwealth Government estimate of 920.[9,10] Regular government census estimates have been published every five years since 1986.

Traditionally, Tiwi people have only occasionally transmigrated, usually for purposes of intermarriage according to tribal edicts. The destinations of people who travel, and the movements and locations of community members, are known by all. Deaths of people who die out of community (usually in Darwin or while visiting other communities) are documented in their medical records on in their “home” community clinic and added to the death register.

Death rates in the Tiwi community, along with those in Aboriginal people in Arnhem Land, have among been the highest in Australia: in the 1990s, with age-standardisation, they were six times those of the Australian mainstream.[11] This generally reflects the much younger age of Tiwi people at death. Cases of kidney failure began to attract attention in the 1980s; [12] for several decades Tiwi people had the highest rates of renal failure yet described, and the first hemodialysis unit in a remote Aboriginal location was established in Wurrumiyanga on Bathurst Island in the late 1990s. High renal failure rates have followed in other remote communities. The characteristics and speculative causes of the renal disease have been described extensively.[12,13,14] We have previously described the high rates of low birthweight in this community and the risk exacerbations for natural deaths in infants, children and young adults associated with low birthweight.[15,16]

Methods

Data sources were the written logs of deaths maintained by the clinics, dialysis unit records of NT Renal Services, and in this staunchly Catholic community, records maintained by the parish priests of all funerals and burials. We report recorded deaths over the 51 year period from 1960 to 2010, beginning when clinic recording of details of death (age, date and explanation) was becoming more systematic.

Starting in the 1980s, maintenance dialysis has been available to Tiwi persons with end-stage renal disease; numbers of patients starting treatment increased steadily until apparently stabilising at about 6 persons a year in the early 2000s. In this study, initiation of dialysis is considered a natural (renal) death, occurring when dialysis began, because without that treatment all participants would have died shortly thereafter. There was no additional assignment of date or cause of death when they finally expired.

Description of cause of death became more detailed over time. In the early years the only discrimination for some deaths was of natural versus unnatural causes, while, in later years, there was more detailed narrative on cause(s) and associations of death. In the early years, deaths in people over 60 years of age often received a causal assignment of “old age” or “debility”, but with time “disease or organ-specific” assignments increased for them as well. In some recorded natural deaths the assignments were approximate and the contribution of multiple causes was underestimated. Cause of death was assigned by clinic directors and always took into account the previous health profile of each deceased person. In the context of sometimes sparse clinical detail, and conforming to the methodology for the Global Burden of Disease study, we derived and assigned a principal cause of death only.

Unnatural deaths, or deaths of misadventure, included those due to vehicular accidents, drownings, fire (burns and smoke inhalation), homicide, suicide, poisonings, jelly fish stings, crocodile and shark attacks etc. We defined the main categories of natural deaths as cardiovascular (heart attack, congestive heart failure, ischemic heart disease, coronary artery disease and stroke), respiratory (chronic lung disease, chronic obstructive airways disease, chronic bronchitis, bronchiectasis, pneumonia), renal (death with terminal renal failure, and also, after 1985, institution of dialysis in people with terminal renal failure), various other causes (eg sepsis, liver failure, lupus, cancer etc.), and debility or old age. When there was uncertainty about deaths or persons, data were checked with several senior community members, who had lived through much of the study interval and had known most community members.

Analyses were conducted using Stata 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP). Numbers and rates of deaths were calculated by age-group and cause of death. Five-year moving averages were created using the tssmooth package. Mortality rates, per 100,000 population, could be calculated only since 1986, the first year of the subsequent quinquennial national census that specifically

enumerated Aboriginal Tiwi people. Total population estimates were also taken from census figures.[17]

Results

1,190 deaths were recorded, and age was documented or age group could be inferred in 1,156 (97.1%) of these (for 452 or 95.0% of deaths in the first two decades, and 704 or 98.6% of deaths in the last three decades).

Of these 1,156 deaths, 222 (19.2 %) were in infants and children (<1 years and 1 to <15 years respectively), and 934 (78·5%) were deaths of adults (at ages ≥15 years). Twenty-five (11·3%) deaths of infants and children were deaths of misadventure and 197 (88·7%) were of natural causes. Among adults, 114 (12·2%) of deaths were due to misadventure and 820 (87·8%) were natural deaths.

Figure 2 shows deaths by age-group and interval (frequencies are tabulated in Supplementary Table 1). Early on, most deaths were in infants and children. These fell rapidly at first, then more slowly. The main categories of death in infants and children were diarrhoea, respiratory disease and failure to thrive, with some cases of sudden infant death, and a few congenital abnormalities.[15] In 1973, a house fire killed six siblings, making a major contribution to deaths due misadventure in this group.

As infant and childhood deaths fell, numbers of deaths of adults increased. Many of these have been among young adults (ages 15 to <45 years) with high numbers of both natural death and deaths of misadventure. The latter include motor vehicle accidents, drownings, homicide, and suicide; there were 50 suicides (50% of deaths of misadventure) between 1985 and 2010, of which 47 (94%) were among males.

Since 1975 most deaths are in people of ≥45 years, and most of these are of natural causes. The numbers have not perceptibly increased since the early 1990s. Only 13 (2.5%) of these older adult deaths were due to misadventure.

Figure 3 shows the trends in natural deaths in adults over time, by primary causal assignment. Numbers peaked in the later 1980s but have since had an indeterminate or falling trend. Through the mid-1980s there were substantial numbers of natural deaths with no further details and deaths with assignments of “old age” or debility”, but there have been more “organ-system” assignments since the early 1990s. Among specific assignments, cardiovascular deaths, and cancer/liver/other deaths were represented over the continuum, while pulmonary (respiratory) deaths became prominent but more recently have been decreasing. Renal deaths become prominent in the 1980s; there were 25 renal deaths in the 1980s, 42 in the 1990s and 52 from 2000 to 2009, constituting 14·7, 24·1 and 31·7% of all natural deaths in those intervals.

Figures 4 A-C show the smoothed estimated rates of natural deaths by age-group since 1986.[17] Rates of death in infants and children have fallen remarkably (4A). There was an early increase in death rates among young adults (4A), followed by a progressive decline since the mid-1990s. Death rates of people age ≥45 years have markedly declined, at least until the last few years of the observation interval (4B). The net effect of all these changes is a decrease overall death rates of the entire population.

These trends are further summarised in Table 1, which shows the rates of natural deaths by age-group in the first and last 5-year blocks of the observation interval. Death rates of infants and children fell by 88.9 %, those of young adults fell by 23·5%, while of people age ≥45 years fell by 65·1%. For the population as a whole, rates of natural death fell by 51.6 %.

Figures 5 A-D show that the population age structure has changed over <40 years to include higher numbers and proportions of young and middle age adults.[17,18] In addition, the size of the total population has increased by 85%.

Discussion

This is the most complete description of deaths in any indigenous Australian community. It shows a profound change in patterns, rates and causes of death over a 51 year interval. Infant and childhood deaths have fallen dramatically; now most people die as adults (≥15 years), and of natural causes. Furthermore, in the last 25 years, rates of natural deaths of adults have been falling. The population is increasing and is progressively ageing.

With continued improvements in prevention and treatment of infectious diseases, adult deaths are increasingly due to non-communicable diseases, with chronic lung disease, cardiovascular disease and renal disease making the greatest contribution. These chronic diseases have usually overlapped and been co-contributors to death, although this is obscured by our use of mutually exclusive categories of primary cause of adult death. Among specific assignments, cardiovascular deaths, and cancer/liver/other deaths etc. have been represented over several decades, while pulmonary deaths became prominent in the 1970s, but have decreased since the early 1990s. Kidney failure has become prominent since the 1980s, and is now the single leading assignment.

The still excessive (although improving) rates of natural deaths are compatible with the "Barker hypothesis", which proposes that survivors of lower birthweights have accentuated susceptibility to chronic diseases and premature natural death in adult life.[15,16,19] We have shown that the dramatic reductions in early life mortality have been experienced across the birthweight spectrum, so that, against a background of seriously low birthweights, large cohorts of underweight infants, who were previously at greatest risk for early death, have now survived to adult life. As adults, they have enhanced susceptibility to chronic disease, as the hypothesis proposes and as we have demonstrated.[15,20,21] Through 2010, rates of natural adult deaths before the age of 41, in Tiwi people of low birthweight, were twice that

of those with higher birthweights, with the greatest accentuation of risk being for pulmonary deaths, a 6-fold increase.[16]

The continued evolution of the chronic disease rates and patterns and rates over time is probably influenced by improving birthweights, changing age structure among adults, improved prevention, screening and management of chronic disease and changes in competing causes of deaths. With reductions in deaths from pulmonary disease and postponement of cardiovascular deaths, flowing from a secular increase in birthweights,[13] and from better medical management, coexisting nephropathy has more opportunity to pursue its more leisurely course to renal failure.[22] We have published extensively on the expression, course and biopsy representation of the underlying renal disease.[12] It is clearly multideterminant with risk enhanced by low birthweights, inflammation and infection, episodes of post-streptococcal glomerulo nephritis and higher BMIs and diabetes in adult life.[23,24]

Availability and use of the clinic-based death records and the supporting parish burial records sets this study apart. The NT-wide government register of deaths dates only back to the mid-1980s, and in that register, community assignment has sometimes been incomplete. Moreover, government records do not capture the full burden of renal failure, due to deficient documentation of a renal cause of death, both in people receiving renal replacement therapy (RRT), and in those dying of renal failure without receiving RRT.[14,25] Our composite definition of "renal deaths" as the start of RRT and a renal death without RRT more fully reveals the burden of renal failure disease. That approach is necessary for monitoring, prevention and intervention strategies, especially in the context of the burden and costs of RRT.[13,26] Furthermore, it is the only way that kidney failure rates can be compared with populations in other countries for whom RRT is not widely available.

Our data also reveal an excess of deaths by misadventure in young adults in more recent years. Such deaths, often alcohol or drug-fuelled, are prominent among young Aboriginal adults nationwide, and are of grave concern.[27,28]

Limitations include the fact that some Tiwi deaths were probably not captured in our data sources. This is more likely in the earlier years, so that that the earlier numbers and rates of deaths, as well as the subsequent fall in deaths, have probably been understated. Moreover, from 1985 to 2009, the government agencies recorded 18% fewer deaths for the Tiwi community than we have recorded, with under-identification varying from 10 to 30% over five consecutive 5 years intervals (In an email from Y Zhao, (yuejen.zhao@nt.gov.au) 2016 Oct 24). An additional limitation is assignment of a single category of cause of death, whereas natural deaths in adults have multiple causes and associated conditions; the coexistence of cardiovascular risk and lung disease, and of renal disease with cardiovascular disease are well recognised. However, the use of a single underlying cause of death is dictated by the detail of the source data. It is also the approach employed until recently for the mortality component of the study of Global Burden of Disease.

Is it credible that about half the deaths in Tiwi people in the 1960s were in subjects less than 15 years of age? The World Health Organization estimated that, in 1955, fully 40% of global deaths were in children age <5 years, so presumably an even greater proportion were deaths of people <15 year old).[29] Furthermore, analyses of skeletal remains of some premodern cultures have suggested that up to 68% of deaths occurred people <15 years old (Chamberlain cited in Roser, 2006).[1,30] Hart's comment that, around 1928, five of 15 bestowed wives (females promised in marriage to specific Tiwi community members), died before puberty, supports a high childhood mortality.[3]

Other Aboriginal groups in remote areas of Australia over the same intervals have undoubtedly experienced similar transitions. NT government agencies have described similar trends in early life mortality since 1967, and improvements in natural death rates overall since the late 1980s (Figures 6 and 7).[31] In the Shire of Broome, Western Australia, Gracey et al. described excessive levels of Aboriginal infant and childhood infection and under-nutrition in the 1970s and 1980s and increasing deaths by misadventure in young Aboriginal adults between 1971 and 1994.[32] Our findings are also consistent with events in many other countries and regions. Figure 8 shows the fall in early life mortality since 1960, which is most dramatic in disadvantaged populations like Yemen, Afghanistan, Bangladesh and Nepal,[33] while Figure 9 shows the simultaneous increase in life expectancy at birth, again most marked in disadvantaged settings.[34] Our Tiwi data show that the improvement in life expectancy is a function of reduced early life morality as well as increasing adult longevity.

These changes represent triumphs of inter-sectoral improvements, public health policy and health care more broadly, which are to be celebrated. This is especially welcome news for the Tiwi Aboriginal people, whose mortality rates have been the worst in Australia,[11] and for remote-living Aboriginal people more broadly. It is also comforting for health care providers and policy makers to see such large scale progress demonstrated through an historical perspective, and should support resolve to stay the course in ongoing improvements.[8] More broadly, this information should moderate the negative discourse which has pervaded the Aboriginal health literature.

Encouraging as these trends are, further improvement in adult death rates can still be anticipated. Birthweights continue to improve, so that accentuated chronic disease risk from that source should decline; adult health services continue to improve, especially in prevention, screening and management of chronic disease,[8] and rates of smoking are falling.[35] Continuing challenges, however, include high rates of obesity,[36] poor diet, especially sugar excess,[37] drug use, alcohol abuse, and foetal alcohol syndrome.[7] Interpersonal violence, especially high rates of suicide and accidents, remain serious challenges. Efforts to improve education, skills training, employment opportunities, empowerment and socioeconomic status must be unflagging and be robustly supported.

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Contributors: WH conceived and designed this work, collected data, directed data analyses, interpreted the findings and wrote the manuscript. BMcL conducted field work, and performed data collection and data preparation. SM prepared data, performed analyses and contributed to interpretation, produced figures and tables, and coordinated preparation and editing of the manuscript. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. All authors reviewed, revised and approved the manuscript.

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Transparency: The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Ethical approval: Human Research Ethics Committee of the Northern Territory Department of health and Community Services and Menzies School of Health Research (91/20, 94/02 and 03/51); The University of Queensland (2004000028).

Provenance and peer review: Not commissioned; externally peer reviewed.

Data sharing statement: Data are potentially accessible for all legitimate parties under standard and usual conditions.

Table 1. Mean (95%CI) natural death rate per 100,000 population by five-year intervals and age-group

Time interval	<15 years	15-44 years	45+ years	All ages
1986-1990	547.4 (406, 689)	426.3 (240, 613)	8065.4 (6778, 9353)	1480.7 (1240,1721)
2006-2010	60.5 (0, 202)	326.3 (140, 513)	2815.2 (1528, 4103)	716.8 (476,957)

Note: The mean of aggregate natural deaths over years 2001-2010 is used for deaths of those <15 years of age.

Sources: 1986-2011 census data, Australian Bureau of Statistics (Catalogues: 1987, #2460.0; 2012,#2002.0).[17]

Figure 1. The Tiwi Islands, Northern Territory, Australia
Note: Wurrumiyanga was formerly named Nguiu.
Source: Adapted from Google Map data. The Tiwi Islands. Google; ©2017 [cited 2017 Jan 10]. Available from: https://www.google.com.au/maps/@-12.2087082,130.7314414,8.75z

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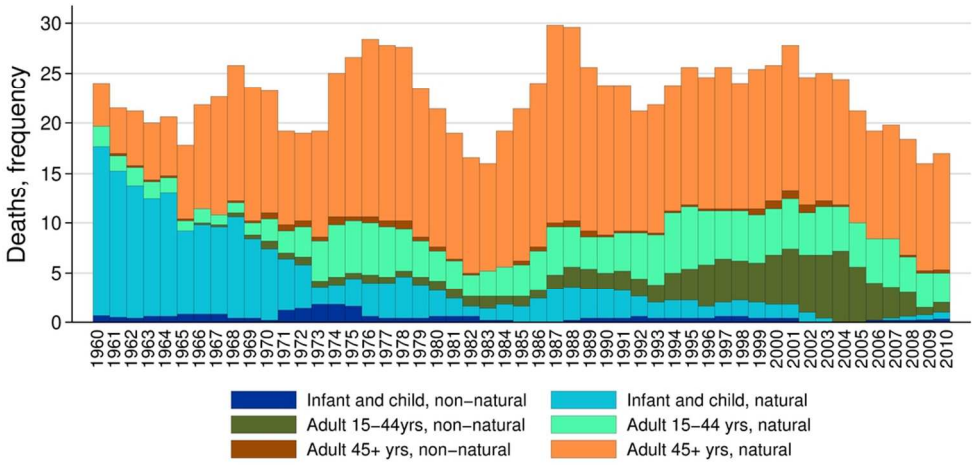

Figure 2. Numbers of Tiwi deaths by age-group and broad cause of death, 1960-2010
Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among natural deaths.

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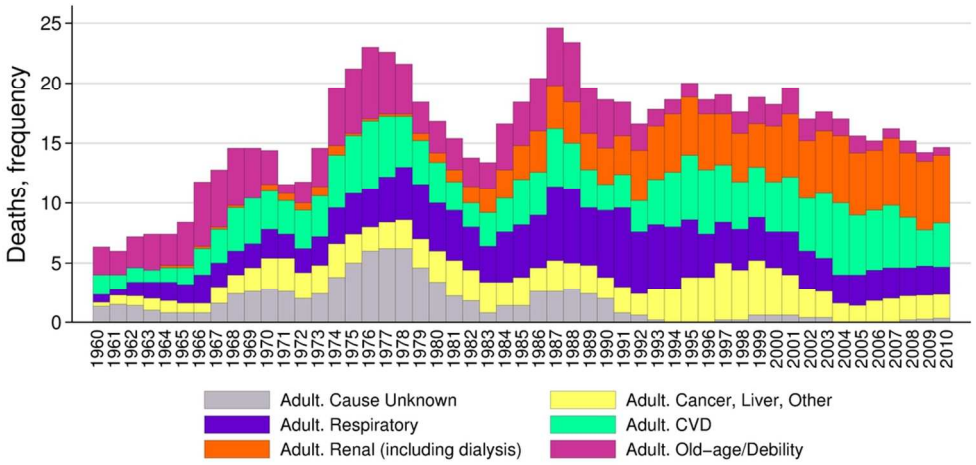

Figure 3. Numbers of Tiwi natural adult deaths by age-group and cause of death, 1960-2010
Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among renal deaths.

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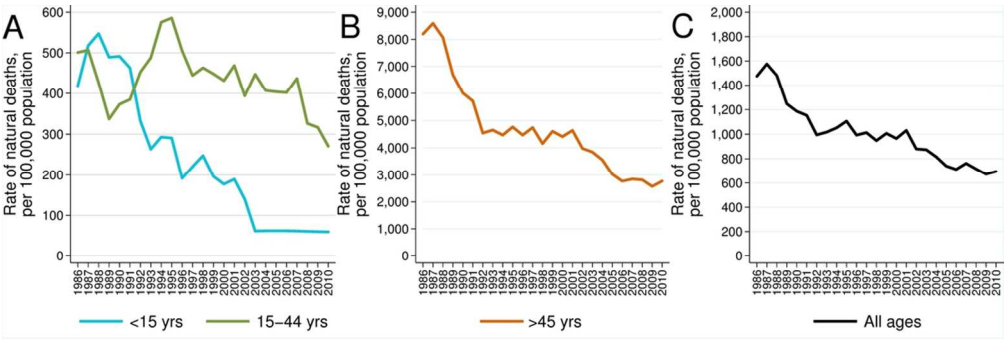

Figures 4 A-C. Tiwi rates of natural death per 100,000 population by age-group, 1986-2010
Note: The figure presents a five-year rolling average of natural death rates by age-group: <15 and 15-45 years (A); ≥45 years (B); all ages (C). People who started dialysis are included among natural deaths. The low rates of death depicted for those <15 years from 2003 to 2010 are each based upon the average of the very small number of events (four) that occurred between 2001 and 2010.

Sources of 1986-2010 population data: quinquennial Census estimates (Australian Bureau of Statistics Catalogues: 1987, #2460.0; 1993, #2730.7; 2000, #70609; 2007, #2001.0; 2002, #2002.0; 2012, #2002.0);17

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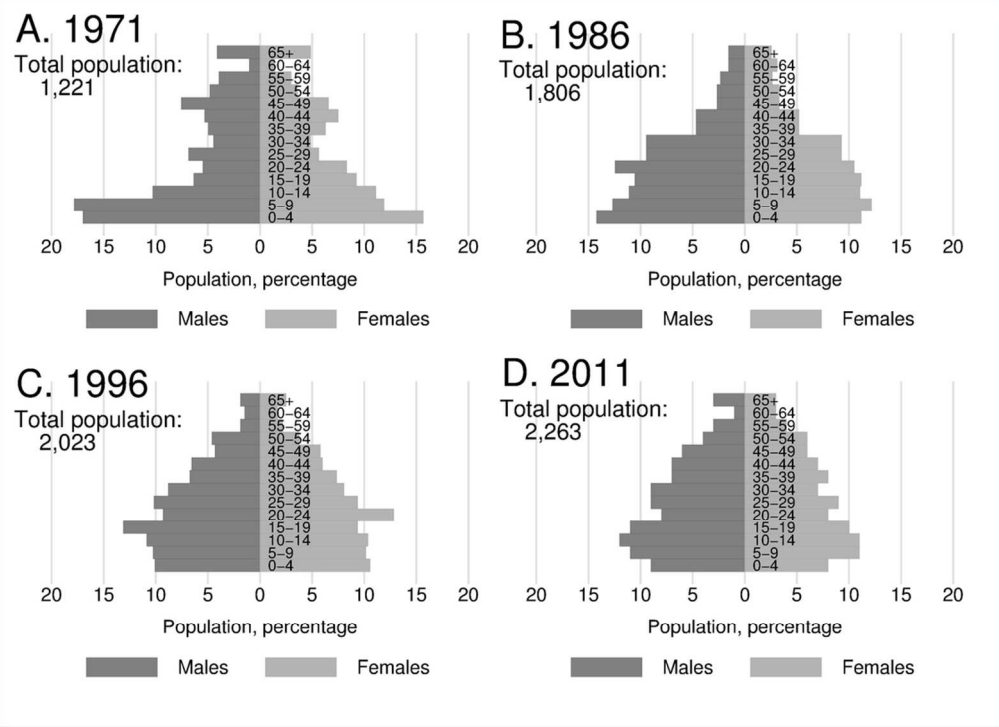

Figures 5 A-D. Age distribution of the Tiwi population at four time-points, by sex, 1971-2011
Note: The figure presents population pyramids and total population for 1971 (A); 1986 (B); 1996 (C); 2011 (D).
Sources: A, cited in Peterson, 1988;18 B-D, census data, Australian Bureau of Statistics (Catalogues: 1987, #2460.0; 2000, #70609; 2012,#2002.0).17

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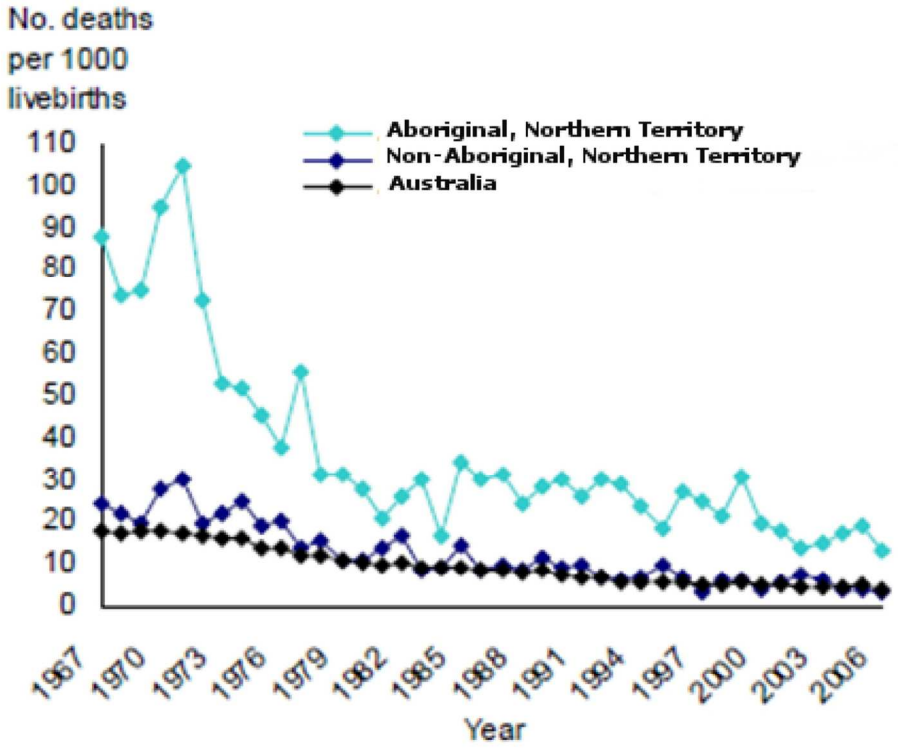

Figure 6. Infant mortality, Northern Territory and Australia, 1967-2007
Source: Northern Territory Department of Health, 2011.31

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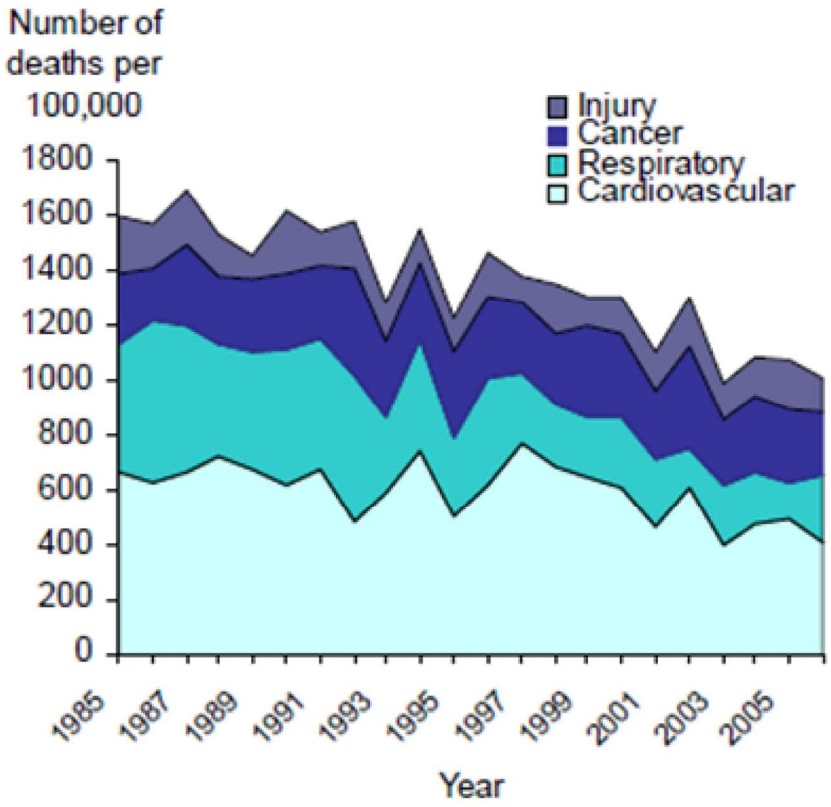

Figure 7. Leading causes of death in the Aboriginal population of the Northern Territory: 1985-2006
Source: Northern Territory Department of Health, 2011.31

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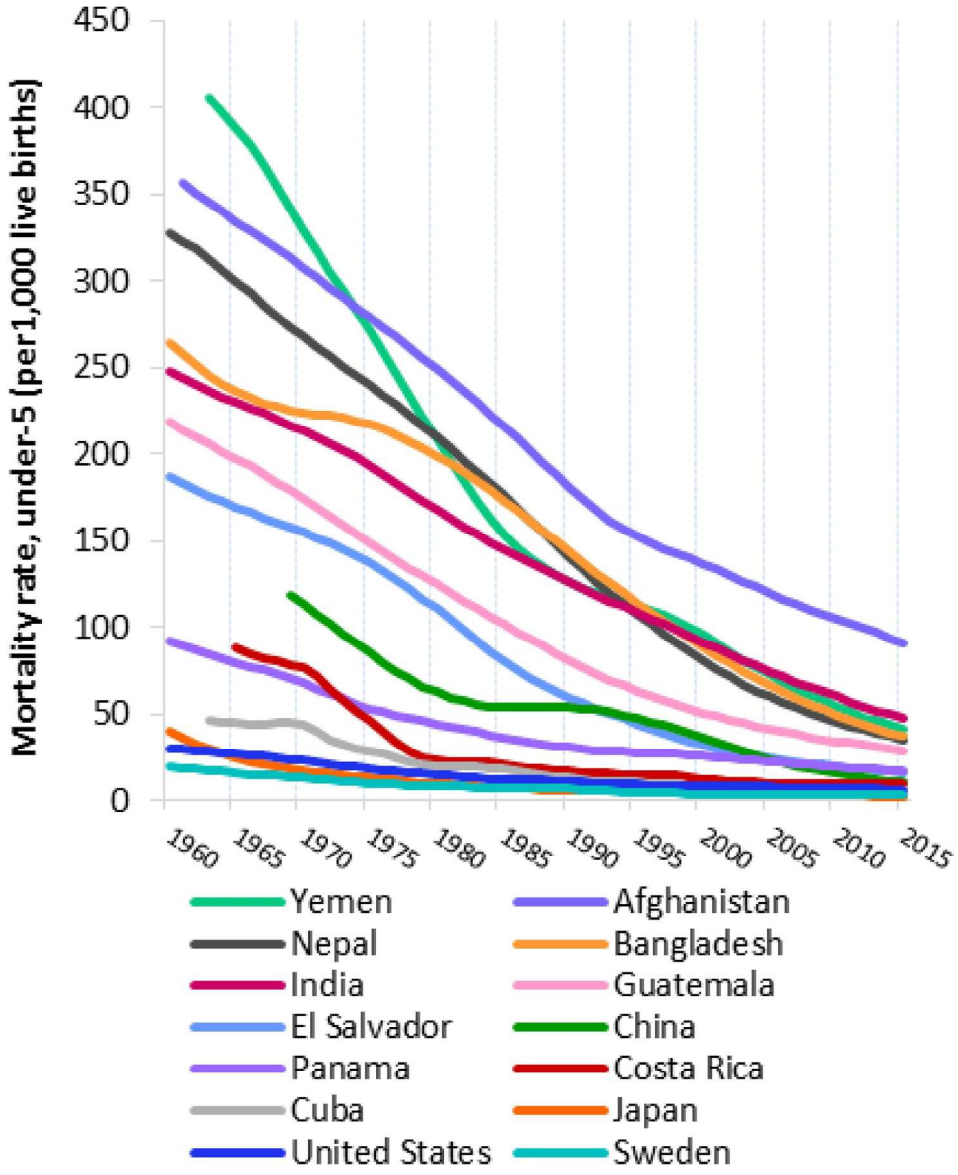

Figure 8. Under-five mortality rates for selected countries, 1960-2015
Source: adapted from UNICEF Global Database, 2015.33

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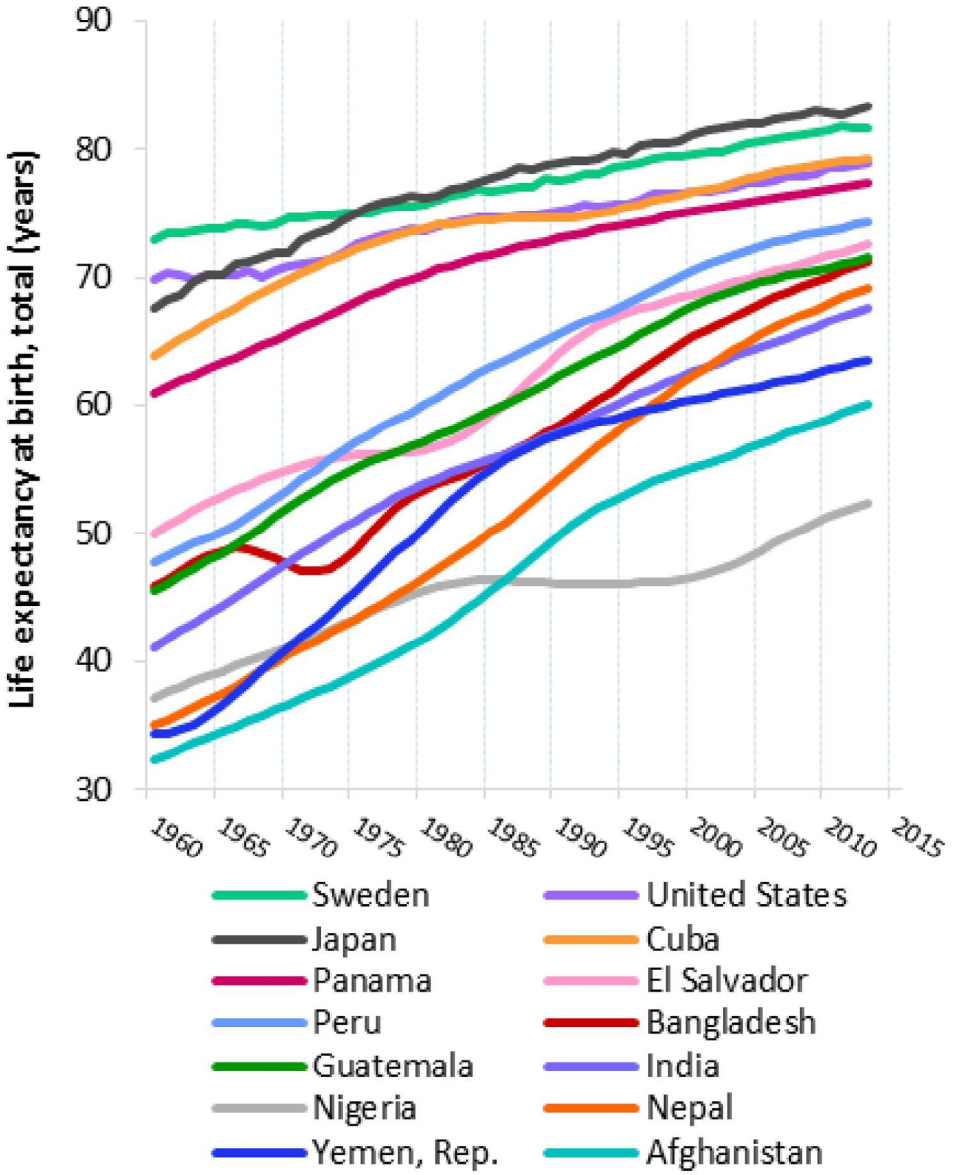

Figure 9. Life expectancy at birth for selected countries, 1960-2013
Source: adapted from The World Bank, 2016.34
Source notes: Derived from male and female life expectancy at birth from sources such as: United Nations Population Division; World Population Prospects; United Nations Statistical Division. Population and Vital Statistics Report (various years); Census reports and other statistical publications from national statistical offices; Eurostat: Demographic Statistics; Secretariat of the Pacific Community: Statistics and Demography Programme; and U.S. Census Bureau: International Database.

189x223mm (300 x 300 DPI)

Supplementary Table 1. Frequencies of Tiwi deaths by age-group and time interval, 1960-2010

	Deaths N (%), by time interval											
Age-group	**1960-1964**	**1965-1969**	**1970-1974**	**1975-1979**	**1980-1984**	**1985-1989**	**1990-1994**	**1995-1999**	**2000-2004**	**2005-2009**	**2010**	**Total**
Under 15 years	69 (65.1)	48 (42.9)	29 (30.5)	20 (14.4)	8 (9.6)	17 (11.4)	13 (12.3)	10 (7.8)	5 (4.1)	2 (2.0)	1 (6.3)	222 (19.2)
15 - <45 years	9 (8.5)	6 (5.4)	19 (20.0)	28 (20.1)	16 (19.3)	31 (20.8)	32 (30.2)	46 (35.9)	50 (40.7)	40 (40.4)	2 (12.5)	279 (24.1)
45 years and over	28 (26.4)	58 (51.8)	47 (49.5)	91 (65.5)	59 (71.1)	101 (67.8)	61 (57.6)	72 (56.3)	68 (55.3)	57 (57.6)	13 (81.3)	655 (56.7)
Total	**106 (100)**	**112 (100)**	**95 (100)**	**139 (100)**	**83 (100)**	**149 (100)**	**106 (100)**	**128 (100)**	**123 (100)**	**99 (100)**	**16 (100)**	**1,156 (100)**

Note: 5-yearly time intervals are presented except for the single year of 2010; people who started dialysis are included among deaths

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No.(s) [Paragraph No.(s)]
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3[1-9]
Objectives	3	State specific objectives, including any prespecified hypotheses	3[1]
Methods			
Study design	4	Present key elements of study design early in the paper	4[6]-5[5]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4[6]-5[5]
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4[4] 5[5]
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4[5]-5[4]
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4[5]-5[4]
Bias	9	Describe any efforts to address potential sources of bias	5[1-3] 7[3-4] 8[1,3]
Study size	10	Explain how the study size was arrived at	4[5]-5[3]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	4[5]-5[4]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5[3]
		(*b*) Describe any methods used to examine subgroups and interactions	5[4]
		(*c*) Explain how missing data were addressed	
		We believe that the ascertainment of deaths overall is as good as it can be. We have accessed the original sources for this information (4[5]). There are no published government estimates prior to 1985. From 1985, our ascertainment compares favourably with that of government agencies (8[3]). Subjects included are those with available death data, plus age at death or age-group and natural or unnatural cause of death classification.	

		As a more detailed description of the cause of death was not consistently documented until after 1985 we restricted analyses by cause of death to 1985-2010. Additionally, as census data also became available from that time, death rates were calculated in the same time period.	
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	-
		(*e*) Describe any sensitivity analyses	

Continued on next page

Results			**Page No.(s) [Paragraph No.(s)]**
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6[1-2]
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6[1-5] Figures 1 & 2
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	7[3]-8[2]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8[3]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8[4]-9[3]

Generalisability	21	Discuss the generalisability (external validity) of the study results	9[1]
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11[3]

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Transformation of mortality in a remote Australian Aboriginal community: a retrospective observational study

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Transformation of mortality in a remote Australian Aboriginal community: a retrospective observational study

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Abstract

Objectives To describe trends in ages and causes of deaths in a remote-living Australian Aboriginal group over a recent 50 year period.

Design A retrospective observational study, from 1960 to 2010, of deaths and people starting dialysis, using data from local clinic, parish, dialysis and birthweight registers.

Setting A remote island community in the Top End of Australia's Northern Territory, where a Catholic Mission was established in 1911. The estimated Aboriginal population was about 800 in 1960 and 2,260 in 2011.

Participants All Aboriginal residents of this community whose deaths had been recorded.

Outcome measures Annual frequencies and rates of terminal events (deaths and dialysis starts) by age-group and cause of death.

Results In all, and against a background of high rates of low birthweight, 223 deaths in infants and children and 934 deaths in adults (age ≥15 years) were recorded; 88% were of natural causes. Most deaths in the 1960s were in infants and children. However, these fell dramatically, across the birthweight spectrum, while adult deaths progressively increased. The leading causes of adult natural deaths were chronic lung disease, cardiovascular disease and, more recently, renal failure, and rates were increased two-fold in those of low birthweight. However, rates of natural adult deaths have been falling briskly since 1986, most markedly among people of age 45+ years. The population is increasing and its age structure is maturing.

Conclusions The changes in death profiles, the expression of the Barker hypothesis and the ongoing increases in adult life expectancy, reflect epidemiologic and health transitions of astonishing rapidity. These probably flow from advances in public health policy and health care delivery, as well as improved inter-sectoral services, which are all to be celebrated. Other remote communities in Australia are experiencing the same phenomena, and similar events are well advanced in many developing countries.

Strengths and limitations of this study

- The broad sweep and historical depth of this study, the unique data sources and the integration of clinical and demographic information have allowed delineation of the profound and recent transformation of mortality not previously appreciated in the Australian Aboriginal setting.
- It is inevitable that we have failed to capture some deaths in the past, which probably resulted in understatement of the magnitude of this transition. In some recorded natural deaths the assignments were approximate and the contribution of multiple causes was underestimated.

Background

Recent literature describes a rapid shift in patterns and causes of death in most countries and regions. Infant and childhood deaths have decreased, life expectancy has increased,[1] and more deaths in adults are associated with non-communicable chronic diseases.[2] Here we describe such a transition in a remote-living Aboriginal Australian group over the last 51 years.

The Tiwi people live in three major communities (and several smaller ones) on Bathurst and Melville Islands off the coast of the Northern Territory, about 90 km by sea from Darwin (Figure 1). They lived in relative isolation for perhaps 7,000 to 15,000 years, and consider themselves distinct from mainland Aboriginal people, with their own unique origins, language, and customs.[3]

In 1911, a Catholic mission was established by the Missionaries of the Sacred Heart (MSC), led by Father Francis Xavier Gsell.[4] Changes followed in lifestyle (from nomadic hunter gatherers to living in fixed dwellings), in diet (from food from the bush and sea to depot supplies of less perishable, high caloric density food, of flour, fat, meat and sugar), in family and community structures (from polygamy and networks of carers within extended families to monogamy), and in the establishment of dormitories, schools and clinics. Transition has been especially accelerated since World War 2. Cigarettes were widely introduced around this time (anecdotal evidence). The 1967 referendum formally recognised Aboriginal people in Australia[5] and they were thenceforth included as residents in the national census. Legal access to alcohol began around that time. The first social club, serving alcohol, was opened in the largest Tiwi community in 1967.

Some early insights into remote-living Aboriginal people in the NT are provided by Ellen Kettle, the first Rural Survey Sister in the NT, who pioneered mobile health work in isolated areas and established health records for individuals, and by Dr John Hargrave, the first Aboriginal Health Officer, who personally examined members of many communities in 1957/1958. Both advanced understanding of Aboriginal health and development of services and policy. They described endemic conditions (yaws, malaria, infestations, trachoma), imported conditions like leprosy, syphilis (arguably), tuberculosis, measles, small pox and influenza. They documented florid malnutrition and frank starvation, high infant and maternal mortality and conspicuously low birthweight. They then described, over time, dramatic reductions in infant mortality, the appearance of alcohol related disorders, and of occasional overweight and obesity, as well as the emergence of non-communicable chronic diseases.[6,7]

These phenomena occurred against a background of continuous improvements in remote Aboriginal health services, including management of infections and infestations, immunisations, better obstetric services, better maternal and child care, and cancer surveillance. Chronic non-communicable diseases, predominantly type 2 diabetes,

cardiovascular disease, chronic lung disease and chronic kidney disease now dominate the adult health profile and are the focus of most of health service provision for remote-living Australian Aboriginal adults.[8]

Clinical services were established by the mission, starting as first aid facilities on the beach at Nguiu (now Wurrumiyanga) on Bathurst Island. These eventually evolved into a clinic and local hospital, run by the Sisters of the Order of Our Lady of Sacred Heart (OLSH), with additional clinics in the Melville Island communities of Milikapiti and Pirlangimpi. Medical records were established for individuals, along with clinic-based registers for births and deaths. Doctors from Darwin eventually provided backup support. More recently, there have been resident doctors for intermittent periods. Local hospital beds were closed in the early 1990s, and all persons needing hospital admission were thenceforth streamed to the Royal Darwin Hospital, transported by small plane. Responsibility for clinical services was transferred from the mission to the NT government in the early/mid-1990s.

Anthropologist Charles Hart enumerated a Tiwi population of 1,062 in 1928.[3] Dr John Hargrave estimated the Tiwi population at about 800 to 900 in 1957, compatible with a 1954 Commonwealth Government estimate of 920.[9,10] Regular government census estimates have been published every five years since 1986.

Traditionally, Tiwi people have only occasionally transmigrated, usually for purposes of intermarriage according to tribal edicts. The destinations of people who travel, and the movements and locations of community members, are known by all. Deaths of people who die out of community (usually in Darwin or while visiting other communities) are documented in their medical records on in their "home" community clinic and added to the death register.

Death rates in the Tiwi community, along with those in Aboriginal people in Arnhem Land, have among been the highest in Australia: in the 1990s, with age-standardisation, they were six times those of the Australian mainstream.[11] This generally reflects the much younger age of Tiwi people at death. Cases of kidney failure began to attract attention in the 1980s; [12] for several decades Tiwi people had the highest rates of renal failure yet described, and the first hemodialysis unit in a remote Aboriginal location was established in Wurrumiyanga on Bathurst Island in the late 1990s. High renal failure rates have followed in other remote communities. The characteristics and speculative causes of the renal disease have been described extensively.[12,13,14] We have previously described the high rates of low birthweight in this community and the risk exacerbations for natural deaths in infants, children and young adults associated with low birthweight.[15,16]

Aims and objectives

To describe trends in mortality over more than fifty years in a remote Aboriginal community in the Northern Territory (NT) of Australia.

Methods

Data sources were the written logs of deaths maintained by the clinics, dialysis unit records of NT Renal Services, and in this staunchly Catholic community, records maintained by the parish priests of all funerals and burials. We report recorded deaths over the 51 year period from 1960 to 2010, beginning when clinic recording of details of death (age, date and explanation) was becoming more systematic.

One thousand, one hundred and ninety deaths were ascertained, and with exclusion of 34 who lacked a recorded cause of death, date of birth or date of death, 1,156 were included in analyses. Amongst them, some details were sometimes still lacking. Eighty five of 1,017 people (8.4%) who died as adults (at ≥15 years of age) of natural causes, did not have a precise cause of death recorded: they were described as natural deaths of unknown cause. Deaths of misadventure had been clearly documented. Deaths in those age <15 years had clear natural or non-natural death assignments.

Age was documented or age group was inferred for the 1,156 deaths. Analyses were conducted using broad age-groups, rather than a single year of age. Sixteen death records lacked a date of birth but did have date of death and cause of death – based on cause of death, clinical judgement and local knowledge they were assigned an age of 50 years, which put them into the category of the oldest adults (≥45 years). Five did not have date of birth but did have date of death and cause of death had been recorded as old age. They were assigned an age of death of 60 years, which also put them into the category of the oldest adults (≥45 years).

Starting in the 1980s, maintenance dialysis has been available to Tiwi persons with end-stage renal disease; numbers of patients starting treatment increased steadily until apparently stabilising at about 6 persons a year in the early 2000s. In this study, initiation of dialysis is considered a natural (renal) death, occurring when dialysis began, because without that treatment all participants would have died shortly thereafter. There was no additional assignment of date or cause of death when they finally expired.

Description of cause of death became more detailed over time. In the early years the only discrimination for some deaths was of natural versus unnatural causes, while, in later years, there was more detailed narrative on cause(s) and associations of death. In the early years, deaths in people over 60 years of age often received a causal assignment of “old age” or “debility”, but with time “disease or organ-specific” assignments increased for them as well. In some recorded natural deaths the assignments were approximate and the contribution of multiple causes was underestimated. Cause of death was assigned by clinic directors and always took into account the previous health profile of each deceased person. In the context of sometimes sparse clinical detail, and conforming to the methodology for the Global Burden of Disease study, we derived and assigned a principal cause of death only.

Unnatural deaths, or deaths of misadventure, included those due to vehicular accidents, drownings, fire (burns and smoke inhalation), homicide, suicide, poisonings, jelly fish stings,

crocodile and shark attacks etc. We defined the main categories of natural deaths as cardiovascular (heart attack, congestive heart failure, ischemic heart disease, coronary artery disease and stroke), respiratory (chronic lung disease, chronic obstructive airways disease, chronic bronchitis, bronchiectasis, pneumonia), renal (death with terminal renal failure, and also, after 1985, institution of dialysis in people with terminal renal failure), various other causes (eg sepsis, liver failure, lupus, cancer etc.), and debility or old age. When there was uncertainty about deaths or persons, data were checked with several senior community members, who had lived through much of the study interval and had known most community members.

Analyses were conducted using Stata 14 (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP). Numbers and rates of deaths were calculated by age-group and cause of death. Five-year moving averages were created using the tssmooth package. Mortality rates, per 100,000 population, could be calculated only since 1986, the first year of the subsequent quinquennial national census that specifically enumerated Aboriginal Tiwi people. Total population estimates were also taken from census figures.[17]

Results

Among the 1,156 deaths, 222 (19.2 %) were in infants and children (<1 years and 1 to <15 years respectively), and 934 (78·5%) were deaths of adults (at ages ≥15 years). Twenty-five (11·3%) deaths of infants and children were deaths of misadventure and 197 (88·7%) were of natural causes. Among adults, 114 (12·2%) of deaths were due to misadventure and 820 (87·8%) were natural deaths.

Figure 2 shows numbers of all deaths by major cause group (natural and misadventure), age-group and interval (frequencies are tabulated in Supplementary Table 1). Early on, most deaths were in infants and children. These fell rapidly at first, then more slowly. The main categories of death in infants and children were diarrhoea, respiratory disease and failure to thrive, with some cases of sudden infant death, and a few congenital abnormalities.[15] In 1973, a house fire killed six siblings, making a major contribution to deaths of misadventure in this group.

As infant and childhood deaths fell, numbers of deaths of adults increased. Many of these have been among young adults (ages 15 to <45 years) with high numbers of both natural death and deaths of misadventure. The latter include motor vehicle accidents, drownings, homicide, and suicide; there were 50 suicides (50% of deaths of misadventure) between 1985 and 2010, of which 47 (94%) were among males.

Since 1975 most deaths are in people of ≥45 years, and most of these are of natural causes. The numbers have not perceptibly increased since the early 1990s. Only 13 (2.5%) of these older adult deaths were due to misadventure.

Figure 3 shows the trends in natural deaths in adults over time, by primary causal assignment. Numbers peaked in the later 1980s but have since had an indeterminate or falling trend. Through the mid-1980s there were substantial numbers of natural deaths with no further details and deaths with assignments of "old age" or debility", but there have been more "organ-system" assignments since the early 1990s. Among specific assignments, cardiovascular deaths, and cancer/liver/other deaths were represented over the continuum, while pulmonary (respiratory) deaths became prominent but more recently have been decreasing. Renal deaths become prominent in the 1980s; there were 25 renal deaths in the 1980s, 42 in the 1990s and 52 from 2000 to 2009, constituting 14·7, 24·1 and 31·7% of all natural deaths in those intervals.

Figures 4 A-C show the smoothed estimated rates of natural deaths by age-group since 1986.[17] Rates of death in infants and children have fallen remarkably (4A). There was an early increase in death rates among young adults (4A), followed by a progressive decline since the mid-1990s. Death rates of people age ≥45 years have markedly declined, at least until the last few years of the observation interval (4B). The net effect of all these changes is a decrease overall death rates of the entire population.

These trends are further summarised in Table 1, which shows the rates of natural deaths by age-group in the first and last 5-year blocks of the observation interval. Death rates of infants and children fell by 88.9 %, those of young adults fell by 23·5%, while of people age ≥45 years fell by 65·1%. For the population as a whole, rates of natural death fell by 51.6 %.

Figures 5 A-D show that the population age structure has changed over <40 years to include higher numbers and proportions of young and middle age adults.[17,18] In addition, the size of the total population has increased by 85%.

Discussion

This is the most complete description of deaths in any indigenous Australian community. It shows a profound change in patterns, rates and causes of death over a 51 year interval. Infant and childhood deaths have fallen dramatically; now most people die as adults (≥15 years), and of natural causes. Furthermore, in the last 25 years, rates of natural deaths of adults have been falling. The population is increasing and is progressively ageing.

With continued improvements in prevention and treatment of infectious diseases, adult deaths are increasingly due to non-communicable diseases, with chronic lung disease, cardiovascular disease and renal disease making the greatest contribution. These chronic diseases have usually overlapped and been co-contributors to death, although this is obscured by our use of mutually exclusive categories of primary cause of adult death. Among specific assignments, cardiovascular deaths, and cancer/liver/other deaths etc. have been represented over several decades, while pulmonary deaths became prominent in the 1970s, but have decreased since the early 1990s. Kidney failure has become prominent since the 1980s, and is now the single leading assignment.

The still excessive (although improving) rates of natural deaths are compatible with the "Barker hypothesis", which proposes that survivors of lower birthweights have accentuated susceptibility to chronic diseases and premature natural death in adult life.[15,16,19] We have shown that the dramatic reductions in early life mortality have been experienced across the birthweight spectrum, so that, against a background of seriously low birthweights, large cohorts of underweight infants, who were previously at greatest risk for early death, have now survived to adult life. As adults, they have enhanced susceptibility to chronic disease, as the hypothesis proposes and as we have demonstrated.[15,20,21] Through 2010, rates of natural adult deaths before the age of 41, in Tiwi people of low birthweight, were twice that of those with higher birthweights, with the greatest accentuation of risk being for pulmonary deaths, a 6-fold increase.[16]

The continued evolution of the chronic disease rates and patterns and rates over time is probably influenced by improving birthweights, changing age structure among adults, improved prevention, screening and management of chronic disease and changes in competing causes of deaths. With reductions in deaths from pulmonary disease and postponement of cardiovascular deaths, flowing from a secular increase in birthweights,[13] and from better medical management, coexisting nephropathy has more opportunity to pursue its more leisurely course to renal failure.[22] We have published extensively on the expression, course and biopsy representation of the underlying renal disease.[12] It is clearly multideterminant with risk enhanced by low birthweights, inflammation and infection, episodes of post-streptococcal glomerulo nephritis and higher BMIs and diabetes in adult life.[23,24]

Availability and use of the clinic-based death records and the supporting parish burial records sets this study apart. The NT-wide government register of deaths dates only back to the mid-1980s, and in that register, community assignment has sometimes been incomplete. Moreover, government records do not capture the full burden of renal failure, due to deficient documentation of a renal cause of death, both in people receiving renal replacement therapy (RRT), and in those dying of renal failure without receiving RRT.[14,25] Our composite definition of "renal deaths" as the start of RRT and a renal death without RRT more fully reveals the burden of renal failure disease. That approach is necessary for monitoring, prevention and intervention strategies, especially in the context of the burden and costs of RRT.[13,26] Furthermore, it is the only way that kidney failure rates can be compared with populations in other countries for whom RRT is not widely available.

Our data also reveal an excess of deaths by misadventure in young adults in more recent years. Such deaths, often alcohol or drug-fuelled, are prominent among young Aboriginal adults nationwide, and are of grave concern.[27,28]

Limitations include the fact that some Tiwi deaths were probably not captured in our data sources. This is more likely in the earlier years, so that that the earlier numbers and rates of

deaths, as well as the subsequent fall in deaths, have probably been understated. Moreover, from 1985 to 2009, the government agencies recorded 18% fewer deaths for the Tiwi community than we have recorded, with under-identification varying from 10 to 30% over five consecutive 5 years intervals (In an email from Y Zhao, (yuejen.zhao@nt.gov.au) 2016 Oct 24). An additional limitation is assignment of a single category of cause of death, whereas natural deaths in adults have multiple causes and associated conditions; the coexistence of cardiovascular risk and lung disease, and of renal disease with cardiovascular disease are well recognised. However, the use of a single underlying cause of death is dictated by the detail of the source data. It is also the approach employed until recently for the mortality component of the study of Global Burden of Disease.

Is it credible that about half the deaths in Tiwi people in the 1960s were in subjects less than 15 years of age? The World Health Organization estimated that, in 1955, fully 40% of global deaths were in children age <5 years, so presumably an even greater proportion were deaths of people <15 year old).[29] Furthermore, analyses of skeletal remains of some premodern cultures have suggested that up to 68% of deaths occurred people <15 years old (Chamberlain cited in Roser, 2006).[1,30] Hart's comment that, around 1928, five of 15 bestowed wives (females promised in marriage to specific Tiwi community members), died before puberty, supports a high childhood mortality.[3]

Other Aboriginal groups in remote areas of Australia over the same intervals have undoubtedly experienced similar transitions. NT government agencies have described similar trends in early life mortality since 1967, and improvements in natural death rates overall since the late 1980s (Figures 6 and 7).[31] In the Shire of Broome, Western Australia, Gracey et al. described excessive levels of Aboriginal infant and childhood infection and under-nutrition in the 1970s and 1980s and increasing deaths by misadventure in young Aboriginal adults between 1971 and 1994.[32] Our findings are also consistent with events in many other countries and regions. Figure 8 shows the fall in early life mortality since 1960, which is most dramatic in disadvantaged populations like Yemen, Afghanistan, Bangladesh and Nepal,[33] while Figure 9 shows the simultaneous increase in life expectancy at birth, again most marked in disadvantaged settings.[34] Our Tiwi data show that the improvement in life expectancy is a function of reduced early life morality as well as increasing adult longevity.

Gratifying as these reductions in adult death rates are, further improvements can still be anticipated. Birthweights continue to increase, so that accentuated chronic disease risk from that source should decline. In addition adult health services continue to improve, especially in prevention, screening and management of chronic disease,[8] and rates of smoking are falling.[35] Current challenges in all of remote Aboriginal Australia, however, include high rates of obesity,[36] poor diet, especially sugar excess,[37] drug use, alcohol abuse,

and foetal alcohol syndrome,[7] and rates of interpersonal violence, as well as of suicide and accidents, remain high.

These changes described in the manuscript are especially welcome news for the Tiwi Aboriginal people, whose mortality rates have been the worst in Australia,[11] and for remote-living Aboriginal people more broadly. They represent triumphs of inter-sectoral improvements, public health policy and health care more broadly, which are to be celebrated. Health care providers and policy makers should be comforted to see such large scale progress demonstrated through an historical perspective, and encouraged in their resolve for ongoing improvements in preventative health care.[8] Better education, skills training, employment opportunities, empowerment and socioeconomic status must also be unflaggingly supported. More broadly, this information should moderate the negative discourse which has pervaded the Aboriginal health literature.

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Contributors: WH conceived and designed this work, collected data, directed data analyses, interpreted the findings and wrote the manuscript. BMcL conducted field work, and performed data collection and data preparation. SM prepared data, performed analyses and contributed to interpretation, produced figures and tables, and coordinated preparation and editing of the manuscript. All authors had full access to all of the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. All authors reviewed, revised and approved the manuscript.

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Transparency: The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Ethical approval: Human Research Ethics Committee of the Northern Territory Department of health and Community Services and Menzies School of Health Research (91/20, 94/02 and 03/51); The University of Queensland (2004000028).

Provenance and peer review: Not commissioned; externally peer reviewed.

Data sharing statement: Grouped, de-identified data can be requested from the Corresponding Author, Wendy E Hoy (w.hoy@uq.edu.au).

Table 1. Mean (95%CI) natural death rate per 100,000 population by five-year intervals and age-group

Time interval	<15 years	15-44 years	45+ years	All ages
1986-1990	547.4 (406, 689)	426.3 (240, 613)	8065.4 (6778, 9353)	1480.7 (1240,1721)
2006-2010	60.5 (0, 202)	326.3 (140, 513)	2815.2 (1528, 4103)	716.8 (476,957)

Note: The mean of aggregate natural deaths over years 2001-2010 is used for deaths of those <15 years of age.

Sources: 1986-2011 census data, Australian Bureau of Statistics (Catalogues: 1987, #2460.0; 2012,#2002.0).[17]

Figure 1. The Tiwi Islands, Northern Territory, Australia
Note: Wurrumiyanga was formerly named Nguiu.
Source: Adapted from Google Map data. The Tiwi Islands. Google; ©2017 [cited 2017 Jan 10]. Available from: https://www.google.com.au/maps/@-12.2087082,130.7314414,8.75z

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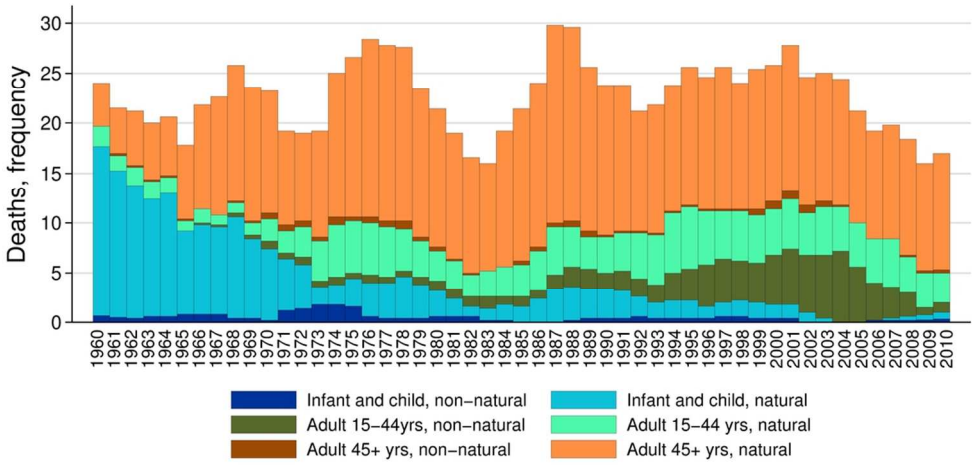

Figure 2. Numbers of Tiwi deaths by age-group and broad cause of death, 1960-2010
Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among natural deaths.

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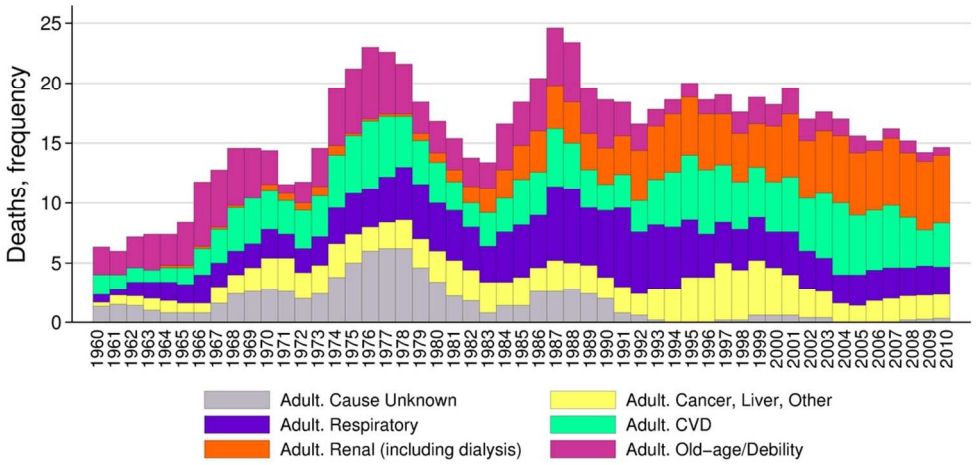

Figure 3. Numbers of Tiwi natural adult deaths by age-group and cause of death, 1960-2010
Note: A five-year rolling average of frequencies is presented; people who have started dialysis are included among renal deaths.

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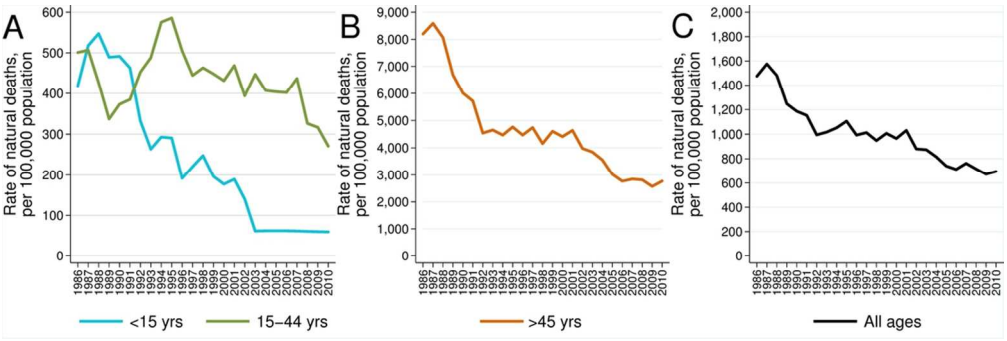

Figures 4 A-C. Tiwi rates of natural death per 100,000 population by age-group, 1986-2010
Note: The figure presents a five-year rolling average of natural death rates by age-group: <15 and 15-45 years (A); ≥45 years (B); all ages (C). People who started dialysis are included among natural deaths. The low rates of death depicted for those <15 years from 2003 to 2010 are each based upon the average of the very small number of events (four) that occurred between 2001 and 2010.

Sources of 1986-2010 population data: quinquennial Census estimates (Australian Bureau of Statistics Catalogues: 1987, #2460.0; 1993, #2730.7; 2000, #70609; 2007, #2001.0; 2002, #2002.0; 2012, #2002.0);17

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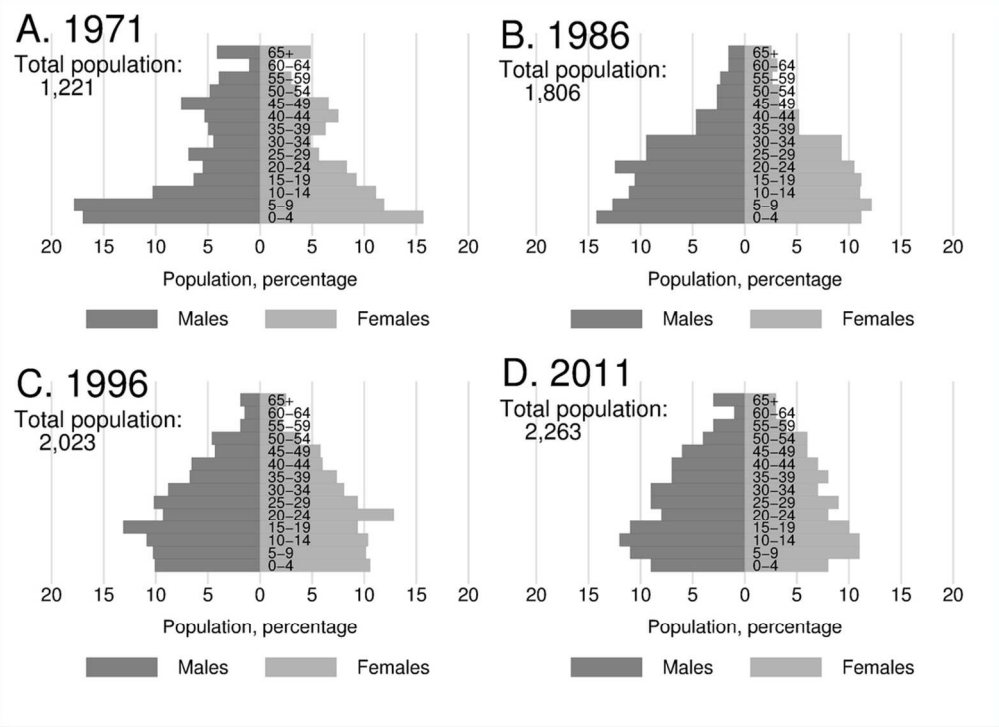

Figures 5 A-D. Age distribution of the Tiwi population at four time-points, by sex, 1971-2011
Note: The figure presents population pyramids and total population for 1971 (A); 1986 (B); 1996 (C); 2011 (D).
Sources: A, cited in Peterson, 1988;18 B-D, census data, Australian Bureau of Statistics (Catalogues: 1987, #2460.0; 2000, #70609; 2012,#2002.0).17

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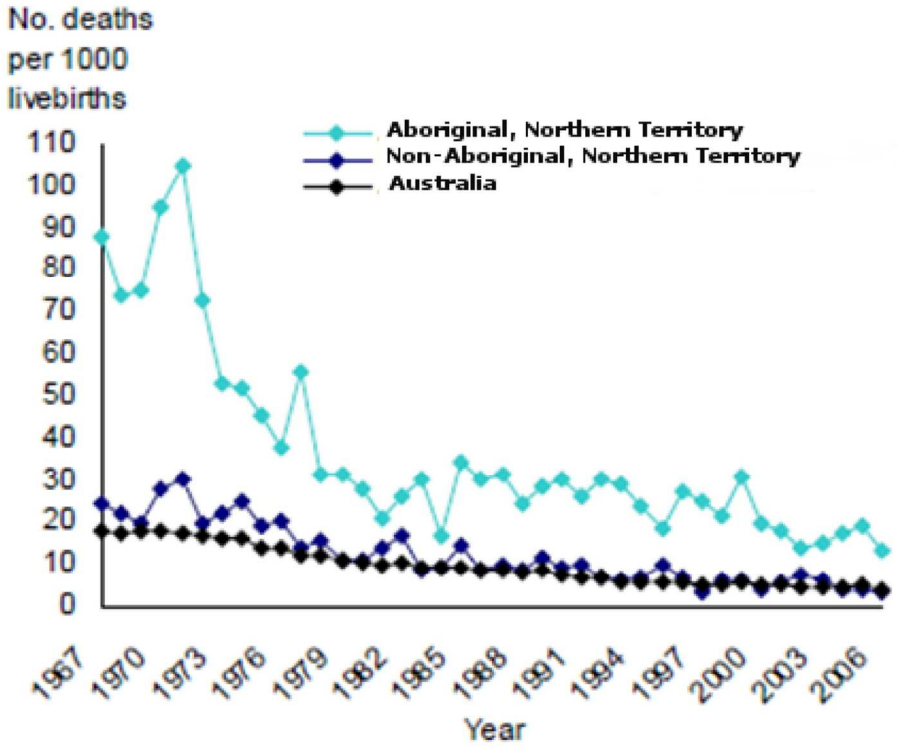

Figure 6. Infant mortality, Northern Territory and Australia, 1967-2007
Source: Northern Territory Department of Health, 2011.31

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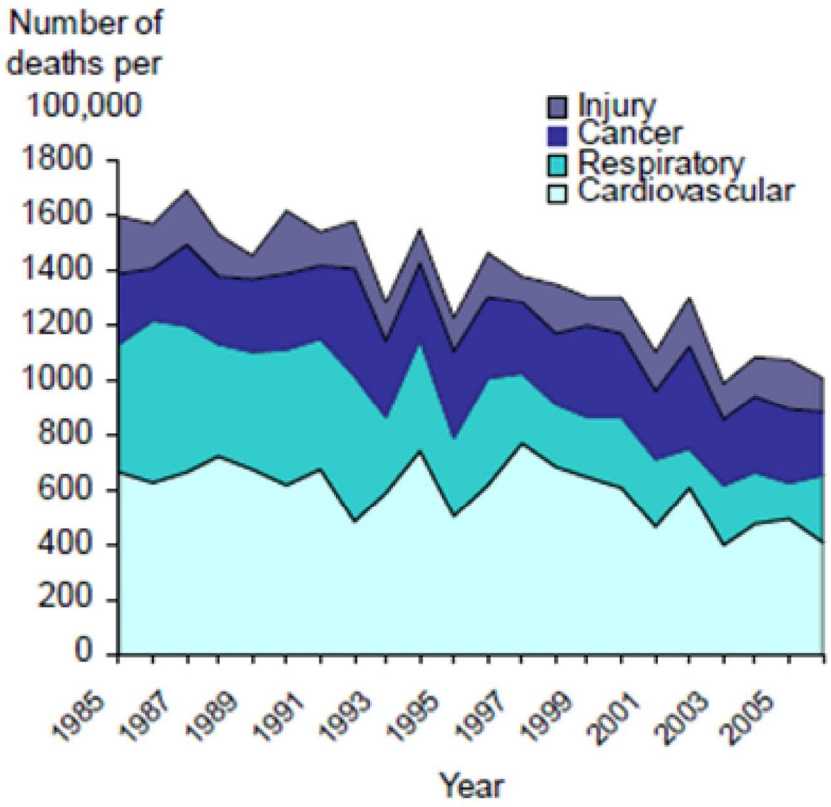

Figure 7. Leading causes of death in the Aboriginal population of the Northern Territory: 1985-2006
Source: Northern Territory Department of Health, 2011.31

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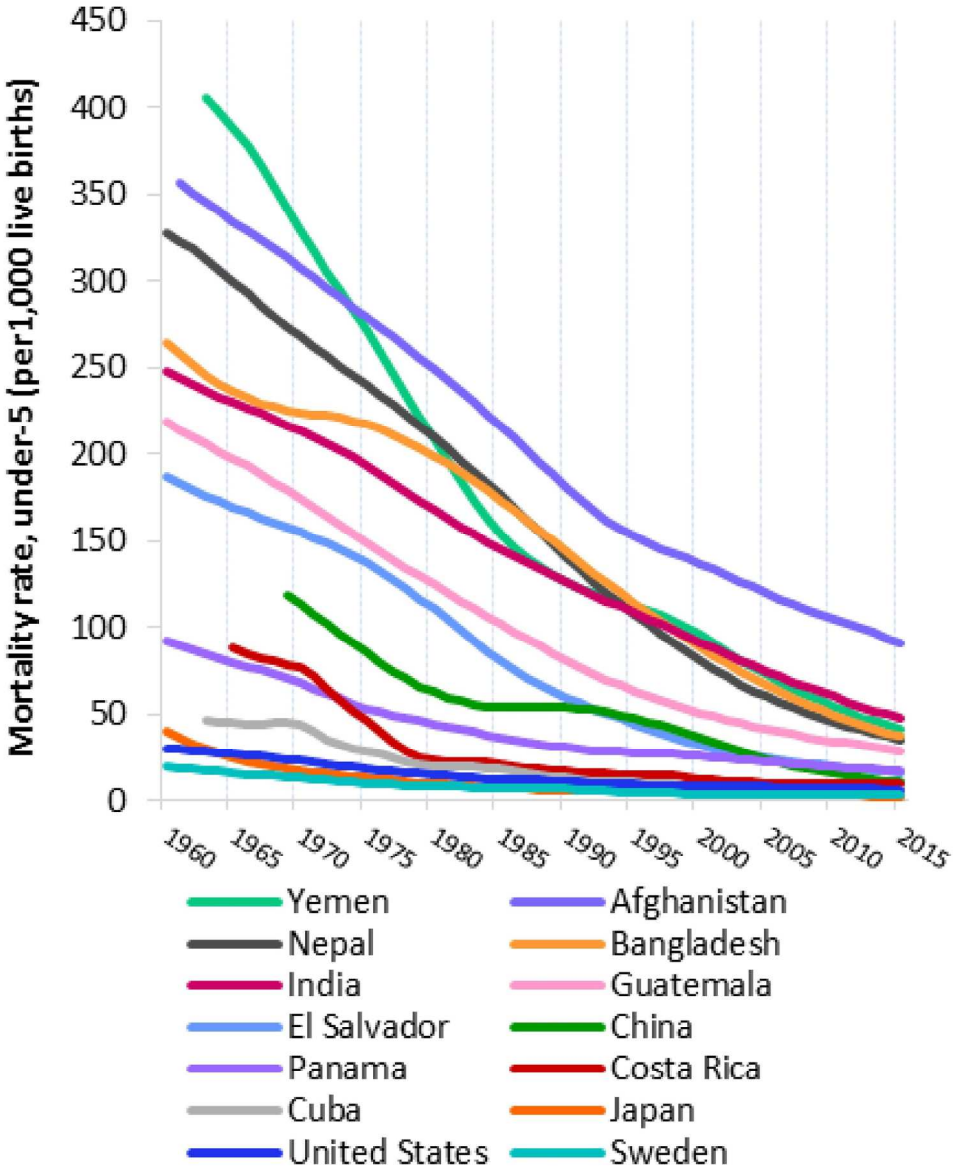

Figure 8. Under-five mortality rates for selected countries, 1960-2015
Source: adapted from UNICEF Global Database, 2015.33

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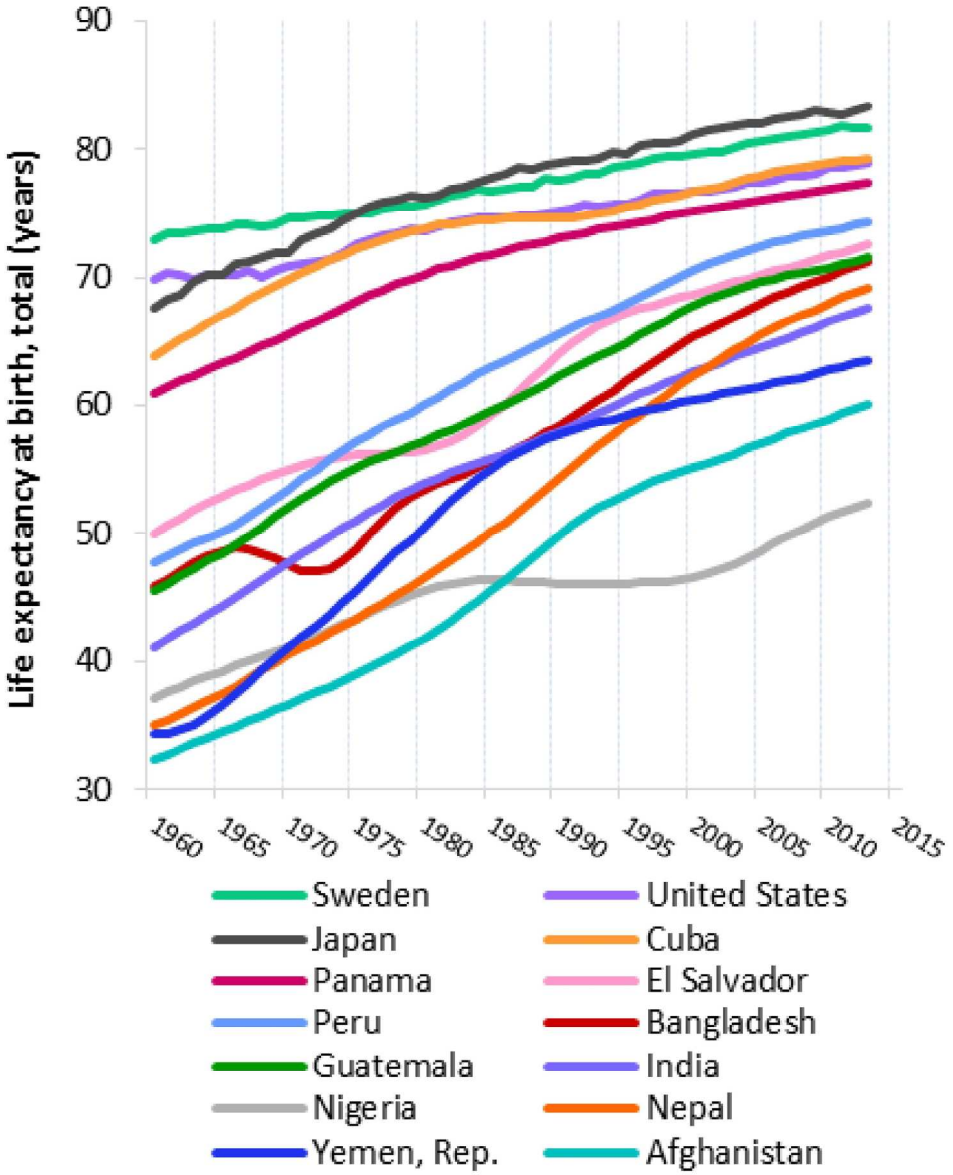

Figure 9. Life expectancy at birth for selected countries, 1960-2013
Source: adapted from The World Bank, 2016.34
Source notes: Derived from male and female life expectancy at birth from sources such as: United Nations Population Division; World Population Prospects; United Nations Statistical Division. Population and Vital Statistics Report (various years); Census reports and other statistical publications from national statistical offices; Eurostat: Demographic Statistics; Secretariat of the Pacific Community: Statistics and Demography Programme; and U.S. Census Bureau: International Database.

189x223mm (300 x 300 DPI)

Supplementary Table 1. Frequencies of Tiwi deaths by age-group and time interval, 1960-2010

	Deaths N (%), by time interval											
Age-group	**1960-1964**	**1965-1969**	**1970-1974**	**1975-1979**	**1980-1984**	**1985-1989**	**1990-1994**	**1995-1999**	**2000-2004**	**2005-2009**	**2010**	**Total**
Under 15 years	69 (65.1)	48 (42.9)	29 (30.5)	20 (14.4)	8 (9.6)	17 (11.4)	13 (12.3)	10 (7.8)	5 (4.1)	2 (2.0)	1 (6.3)	222 (19.2)
15 - <45 years	9 (8.5)	6 (5.4)	19 (20.0)	28 (20.1)	16 (19.3)	31 (20.8)	32 (30.2)	46 (35.9)	50 (40.7)	40 (40.4)	2 (12.5)	279 (24.1)
45 years and over	28 (26.4)	58 (51.8)	47 (49.5)	91 (65.5)	59 (71.1)	101 (67.8)	61 (57.6)	72 (56.3)	68 (55.3)	57 (57.6)	13 (81.3)	655 (56.7)
Total	**106 (100)**	**112 (100)**	**95 (100)**	**139 (100)**	**83 (100)**	**149 (100)**	**106 (100)**	**128 (100)**	**123 (100)**	**99 (100)**	**16 (100)**	**1,156 (100)**

Note: 5-yearly time intervals are presented except for the single year of 2010; people who started dialysis are included among deaths

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No.(s) [Paragraph No.(s)]
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3[1-9]
Objectives	3	State specific objectives, including any prespecified hypotheses	3[1]
Methods			
Study design	4	Present key elements of study design early in the paper	4[6]-5[5]
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4[6]-5[5]
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4[4] 5[5]
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4[5]-5[4]
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4[5]-5[4]
Bias	9	Describe any efforts to address potential sources of bias	5[1-3] 7[3-4] 8[1,3]
Study size	10	Explain how the study size was arrived at	4[5]-5[3]
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	4[5]-5[4]
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5[3]
		(*b*) Describe any methods used to examine subgroups and interactions	5[4]
		(*c*) Explain how missing data were addressed	
		We believe that the ascertainment of deaths overall is as good as it can be. We have accessed the original sources for this information (4[5]). There are no published government estimates prior to 1985. From 1985, our ascertainment compares favourably with that of government agencies (8[3]). Subjects included are those with available death data, plus age at death or age-group and natural or unnatural cause of death classification.	

		As a more detailed description of the cause of death was not consistently documented until after 1985 we restricted analyses by cause of death to 1985-2010. Additionally, as census data also became available from that time, death rates were calculated in the same time period.	
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	-
		(*e*) Describe any sensitivity analyses	

Continued on next page

Results			**Page No.(s) [Paragraph No.(s)]**
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6[1-2]
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6[1-5] Figures 1 & 2
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	7[3]-8[2]
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8[3]
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8[4]-9[3]

Generalisability	21	Discuss the generalisability (external validity) of the study results	9[1]
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11[3]

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.