Aging Clinical and Experimental Research
https://doi.org/10.1007/s40520-020-01552-w

ORIGINAL ARTICLE

The Great Escape. Centenarians' exceptional health

Yoram Barak[1] · Sharon Leitch[2] · Paul Glue[1]

Received: 4 March 2020 / Accepted: 1 April 2020

Abstract

Background Centenarians escapers are those who reached 100 years of age without the diagnosis of any of the common age-related diseases and exploring their characteristics will inform about successful ageing. No previous study has examined centenarians free of common chronic diseases amongst New Zealand centenarians.

Methods Retrospective observational cross-sectional review of a national dataset determining the prevalence of depression, dementia, diabetes and hypertension, smoking, physical activity and social relationships among older adults (aged 60–99 years) and centenarians. Participants were all older New Zealanders living independently in the community who completed the international Residential Assessment Instrument–Home Care (interRAI-HC) assessment during the study's 5-year period (July 2013–June 2018).

Results The assessments of 292 centenarians (mean age 101.03, SD 1.27 years) and 103,377 elderly (mean age 81.7, SD 5.7 years) were analysed. Compared to the elderly, centenarians were more likely to be female (74.7%, compared with 59.3% elderly, $p < 0.001$). Centenarians free of common chronic diseases did not differ from other centenarians on any of the analysed variables. Reduction in smoking rates and steady high rates of social engagement were associated with reaching a centenarian status free of common chronic diseases compared with older adults.

Conclusions Not smoking and being socially engaged throughout older age were associated with being a centenarian free of common chronic diseases. This study adds to our understanding the complexities of attaining exceptional longevity.

Keywords Longevity · Centenarians · InterRAI · Smoking · Escapers · Ageing

> 1963 Drama. "With its impeccably slow-building story and a cast for the ages, The Great Escape is an all-time action classic. Rotten Tomatoes 93%".

Introduction

In 1668 an extract of the anatomical account: "… written and left by the famous Dr Harvey, concerning Thomas Parre, who died in London at the age of 152 years and 9 months…" was annexed to a book, published in Latin by Dr. John Betts one of his Majesties Physicians in Ordinary, and Fellow of the London-College [1]. It was more than two centuries later that in 1886 the British Medical Journal published the first scientific "case report" of a lady centenarian describing her family history; father lived to be 100 years, lifestyle; did not have wine or spirits, sleep quality and BMI [2]. A century later, in the 1990s, research into longevity has expanded exponentially. The biopsychosocial foundations of remarkable health and longevity among centenarians is unclear. Genetic factors, certain geographical locations and life-style characteristics have all been studied in an effort to identify potential predisposing factors of exceptional longevity [3]. Centenarians may interact with environmental and lifestyle factors differently to the majority of individuals who achieve only an average lifespan. It is possible centenarians experience unique genotype-environment interactions which may inform us about ageing well through lifestyle modulation [4].

Centenarians are remarkable not only because of their prolonged life, but also because they compress morbidity until the very last moments of their lives, thus being proposed as a model of successful, extraordinary ageing [5]. In Canada researchers were unable to detect a clear overall

✉ Yoram Barak
Yoram.barak@otago.ac.nz

[1] Department of Psychological Medicine, Dunedin School of Medicine, University of Otago, PO Box 56, Dunedin, New Zealand

[2] Department of General Practice and Rural Health, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand

Published online: 02 June 2020

trend in compression or expansion of morbidity from 1994 to 2010 [6], in Spain evidence indicates expansion of morbidity [7] and in Germany and the USA compression of morbidity has been shown in ageing studies [8, 9]. In the largest prospective study to date undertaken in Denmark centenarians were hospitalized substantially less than their shorter-lived contemporaries during 27 years of follow-up reflecting that centenarians represent healthy agers [10]. However, other Danish researchers argued that: "Danish centenarians are not healthy. However, a minor proportion was identified as being cognitively intact and functioning well… " [11]. The number of centenarians has risen exponentially worldwide. In Europe centenarian ratios were highest in France, Italy and Greece, the percentage of men is 16.5% on average and 62.7% of the centenarians live in private households [12].

Lifestyle behaviours, including smoking, exercise and social contact have been studied in centenarians. Smoking is well known to cause premature morbidity and mortality [13], and is reflected by exceptionally low levels of lifetime smoking prevalence in centenarians [14]. Exercise is considered important in the preservation of good health and critical in maintaining independence in older adults [15]. Compared with octogenarians, centenarians report lower levels of social resources, and this is especially so in nursing homes compared to those living at home or in personal care facilities [16]. These factors are all relevant to the study of centenarian escapers. Centenarians as a group are reported to suffer less frequently from common chronic physical illness and are generally healthier than their former cohort members who died [17]. Only 10% of centenarians living in the community suffer from diabetes [18] and approximately half of centenarians do not experience dementia [19, 20]. It is estimated that a quarter to a third of centenarians reach age 100 with no major chronic diseases but the variation amongst centenarians is large and some centenarians have poor health and functioning upon reaching age 100 [19, 21].

In the 2003 seminal study by Evert and colleagues [21] health and disease trajectories of centenarians were first defined. The authors found that centenarians fit into three trajectories "…Survivors, Delayers, and Escapers" of which "…escapers were individuals who attained their 100th year of life without the diagnosis of common age-associated illnesses…" [21].

It is estimated there are probably 400–500 NZ centenarians currently alive (Stats New Zealand [22, 23). NZ is the first country in the world to implement the international Residential Assessment Instrument – Home Care (interRAI-HC) for all people who are being considered for access to publicly-funded community services or entry into aged residential care, providing a rich data resource for researchers. Thus, the interRAI –HC assessment is likely to capture a large proportion of community dwelling centenarians in NZ. The present study reviews interRAI data to determine the frequency of centenarians free of common chronic diseases within a large cross-sectional sample of community dwelling older adults and centenarians to describe variables associated with healthy longevity.

Methods

Participants

Participants in this study were New Zealanders aged 60 years and over who completed their first interRAI-HC assessment during the 5-year study period (July 2013–June 2018). All were living independently in the community. Only data from each patient's initial assessment was reviewed. Patient data was completely anonymised; no personal identifying data such as National Health Index number or date of birth were included. Age was that recorded at the time of assessment.

The number of centenarians in NZ has increased significantly over the last 60 years. As of 2011, there are likely to be 400–500 centenarians living in New Zealand. Of these, fewer than 40 would be aged 105 years or over [23].

Measurements

The international Residential Assessment Instrument (interRAI) is an evidence-based tool [24]. The 236-item electronically recorded assessment encompasses all aspects of an older person's life including physical, psychological and cognitive domains. Nine main items from the interRAI-HC data set were analysed in this exploration, including demographic items to describe the population, (age and gender), and items which reflected core biopsychosocial components of ageing, (diagnosis of dementia, depression, diabetes mellitus, hypertension, smoking, physical exercise and engagement in social activities).

Definitions

Smoking

Smoking status was based on the person's self-report status as follows: 0 = none; 1–2 = not in the last 3 days, but usually a daily smoker; or yes. We dichotomized smoking into "no" or "…usually or yes."

Exercise and physical activity

Activity level was based on the interRAI-HC section G, self-reported functional status, as the total hours of exercise or physical activity in the last 3 days as follows: 0 = none, 1 = less than 1 h, 2 = 1–2 h, 3 = 3–4 h and 4 = more than 4 h.

We dichotomized exercise into "none and less than an hour" or "1 to more than 4 h."

Social contact

Social engagement was defined by participating in social activities of long-standing interest as follows: 0 = never, 1 = more than 30 days ago, 2 = 8–30 days ago, 3 = 4–7 days ago and 4 = in the last 3 days. We dichotomized social contact into "never to 8–30 days ago" or "4–7 days ago and in the last 3 days."

Diagnosis

Diagnoses of dementia, depression, diabetes mellitus and hypertension were captured as recorded in the interRAI-HC section I, disease diagnoses, as follows: 0 = not present or 1–3 = primary diagnosis, diagnosis present and receiving active treatment or diagnosis present, monitored but no active treatment.

The interRAI instruments, including the RAI-HC captures disease diagnoses in two formats. First, pick lists of conditions that are relatively common in the particular care setting are available. For less common conditions, a free-text section is provided to record the name of the condition and the corresponding ICD code. Trained assessors, often nurses or social workers, use all sources of information available, including interviews with the person and family members, consultation with other clinicians, and chart review to complete all sections of the interRAI instruments, including diagnosis. It has been demonstrated that the interRAI assessment collects accurate information about disease diagnoses when compared to administrative records [25].

Free of common chronic diseases

In the present study we limited our definition to reaching 100 years of age, living in the community and being free of the aforementioned common chronic diseases. Escapers are individuals who attain their 100th year of life without any diagnosis of common age-associated illnesses [19, 21]. The cross-sectional nature of our dataset precluded evaluation of classically defined escapers, delayers and survivors.

Sex differences

We used an interactive tool for visualizing sex differences in the entire cohort. This tool allows to see calculate effect size (based on Cohen's *d*) and overlap (based on Weitzman's delta) for any comparison between males and females. It was designed to employ statistical tests that reveal the extent to which sex explains variation, rather than whether or not the sexes 'differ' and to properly characterizing the frequency distributions of scores or dependent measures, which nearly always overlap, [26].

Statistical analysis

We compared the following age cohorts: 60–69 years, 70–79, 80–89, 90–99 and over 100 years. Chi-squared analyses were used to evaluate distribution of study variables including being free of common chronic diseases by age cohort. All available data were used. Analyses were conducted in Stata 15.1 and two-sided $p < 0.05$ was considered statistically significant.

Consent and ethical review

Participants or their authorised representatives were asked whether they consented for their anonymised information to be used for research purposes at the time of their interRAI assessment; only the interRAI data from consenting participants were analysed (this was 96.8% of the total data set). Ethical approval was obtained from the University of Otago Ethics Committee and the Department of Psychological Medicine Ethics Committee.

Results

During the study period, 103,669 interRAI-HC first assessments were undertaken in NZ, representing 12.3% of the population aged 60 years and older [23]. Missing data in this dataset ranged from < 0.2% for smoking status to 7.8% for social engagement.

There are an estimated 400–500 centenarians in New Zealand [23]. It has been estimated that 50% of centenarians are living in the community [27]. There were 292 centenarians in this sample who underwent an interRAI home assessment. Thus the present sample captures the great majority of community living centenarians.

The largest age group in the present analysis was 80–89 years comprising 46.4% of the total interRAI-HC assessments, while centenarians accounted for only 0.3% of the sample. Centenarians had a mean age of 101.03 (SD 1.27 years; range 100–107) compared to 81.7 (SD 5.7) in the elderly. Female gender increased significantly with age. Women comprised 74.7% of centenarians compared to 58.6% of the elderly, ($p < 0.001$). In any age group women were more likely to be free of the common disorders herein assessed. We demonstrate a large difference and small overlap in being free of common chronic diseases status between genders ($d = 3.1$; overlap = 12.0%). Thus, men may have an advantage in becoming free of illness and eventually centenarian free of common chronic diseases.

The social engagement of participants was stable across the entire sample. Physical activity declined significantly from the age of 90. Rates of depression and diabetes declined steadily with increasing age and rates of dementia declined after the age of 80. Hypertension rates increased by nearly 30% from age 60 to 100 years of age.

Centenarian free of common chronic diseases were nearly half (47.9%) of all centenarians. They did not differ significantly from centenarian non-escapers on any of the evaluated variables.

Table 1 shows descriptive data for all participants by age decile, as well as the differences in distribution for each variable.

Figure 1 presents the number of comorbid medical disorders by age decile. It is of interest to note that "no" or "one" comorbid disorders were over-represented in centenarians.

Table 2 shows the descriptive variables distribution between centenarians free of common chronic diseases and non-escaper centenarians.

See Table 3 for gender details.

Discussion

Centenarian escapers represent not only exceptional longevity, but also uniquely healthy longevity—the epitome of compressed morbidity. This study found higher rates of centenarian free of common chronic diseases in New Zealand than reported in other countries [19, 20, 28]. One explanation is that we sampled only centenarians dwelling in the community, who are likely to be in better health compared with those living in residential care or hospital settings. Recent international studies of centenarians demonstrated that half or more of centenarians resided in nursing homes and were severely functionally impaired [28–31]. Nevertheless, for centenarians, the transition to long-term care appears to progresses more slowly than for younger comparison cohorts [32]. Thus focusing on the trajectories of health and disease in community dwelling centenarians may inform us as to the characteristics of "escapers." The findings of the present study need to be very cautiously interpreted. Centenarians—free of common chronic diseases or not—did not differ from each other on the measures we hypothesized to be related to "free of common chronic diseases status." However, compared to "younger" elderly centenarians smoked significantly less and kept a steady level of social engagement. Thus the dynamics of ageing confirm previous reports about centenarians [33].

International reports also support our findings. In a large national sample of centenarians from Portugal the great majority lived in the community with cognitive functioning relatively preserved [34]. Another similarly comprehensive assessment of very old individuals based in New York City was recently undertaken. A large proportion of the sample lived in the community and cognitive functioning was high, depression was below defined cut-off, and most participants reported positive life satisfaction [35]. In addition, a recent study based in Costa Rica also found a low prevalence of diabetes and depression in community dwelling centenarians [36].

Choice of lifestyle variables in this analysis were based on The Lancet Commissions report on dementia prevention [37]. In this study the highest physical activity groups were at the lowest risk of dementia [38, 37]. We, therefore, defined those in the highest level coded in the interRAI-HC assessment as physically active. A recent systematic review and meta-analysis for social isolation divided exposure into social contact, social participation (belonging to or taking part in community activities or organisations), and loneliness [39]. We used the interRAI codes for social contact as the prevalence of reporting social contact less than monthly as social isolation to reflect a conservative definition of social isolation [39].

Age is one of the most reliable risk factors for death; however, a recent study demonstrated that cardiorespiratory fitness is inversely associated with long-term mortality and with benefit in older patients and those with hypertension. Exercise improves health and length of life [40]. In the present study only a minority of the elderly and only a third of centenarians exercised for more than an hour in the last 3 days. Thus it is possibly lack of variability in our sample of frail older adults that resulted in our inability to link higher levels of exercise with free of common chronic diseases status.

We observed a higher proportion of males to females in centenarian free of common chronic diseases (1:2) compared with centenarian non-escapers (1:4), Table 2. Therefore, men appear to have an increased chance in becoming free of common chronic diseases if they reach 100 years, although the likelihood of this is lower than for females. It is tempting to speculate that this observation reflects the male–female health-survival paradox [41, 42]; however, it is also possible that this is a chance finding which warrants further investigation.

There are several limitations to the present study. The disease categories reported here do not correspond to those reported by Evert [21], reflecting methodological differences in diagnostic ascertainment. This community-based sample of people whose frailty necessitated undertaking an interRAI-HC assessment is likely to not represent all elderly people as detailed in our study of a similar cohort [43]. This is a highly selected group and participants free of common chronic diseases are less likely to have been herein represented. In addition, like much of the existing research we were unable to compare centenarians with appropriate controls, the nonsurviving members of their birth cohort.

Table 1 Biopsychosocial variables

Age	Number	% Female	% Non-smokers	% Exercising	% Socially Engaged	% Depression	% HTN	% Diabetes	% Dementia	%Free of illness
60+	9878	53.4	81.5	39.9	86.3	19.9	33.2	28.5	17.5	32
70+	28,629	56.6	90.9	42.6	87.3	15.3	38.9	25.6	22.8	29
80+	48,133	59.8	96.7	41.1	87.2	10.8	43.1	18.8	21.5	31
90+	16,737	66.1	98.8	36.4	86.8	6.8	43.0	12.0	15.4	39
Centenarians	292	74.7	99.7	32.2	87.0	4.8	40.0	4.4	10.3	47
Chi^2		583.1	4541.8	185.5	8.3	1357.9	416.5	1720.7	463.4	547.5
Df		4	4	4	4	4	4	4	4	4
P value		<0.001	<0.001	<0.001	NS	<0.001	<0.001	<0.001	<0.001	<0.001

Smoking: based on the interRAI-HC definition as follows: 0 = no or 1–2 = not in the last 3 days, but usually a daily smoker, or, yes

Exercising: based on the interRAI-HC total hours of exercise or physical activity in the last 3 days as follows: 0 = none and 1 = less than 1 h; 2, 3 or 4 = 1 to more than 4 h

Socially engaged: based on the interRAI-HC participation in social activities of long-standing interest as follows: 0 = never and 1 = more than 30 days ago; 2, 3 or 4 = 8–30 days ago to in the last 3 days

Diagnosis: diagnosis of dementia, depression, diabetes mellitus and hypertension were based on the interRAI-HC section I, disease diagnoses, as follows: 0 = not present or 1–3 = primary diagnosis and diagnosis present

Free of illness: no diagnosis of dementia, depression, diabetes mellitus nor hypertension

Chi^2, Df, NS = chi-square, degrees of freedom, not significant

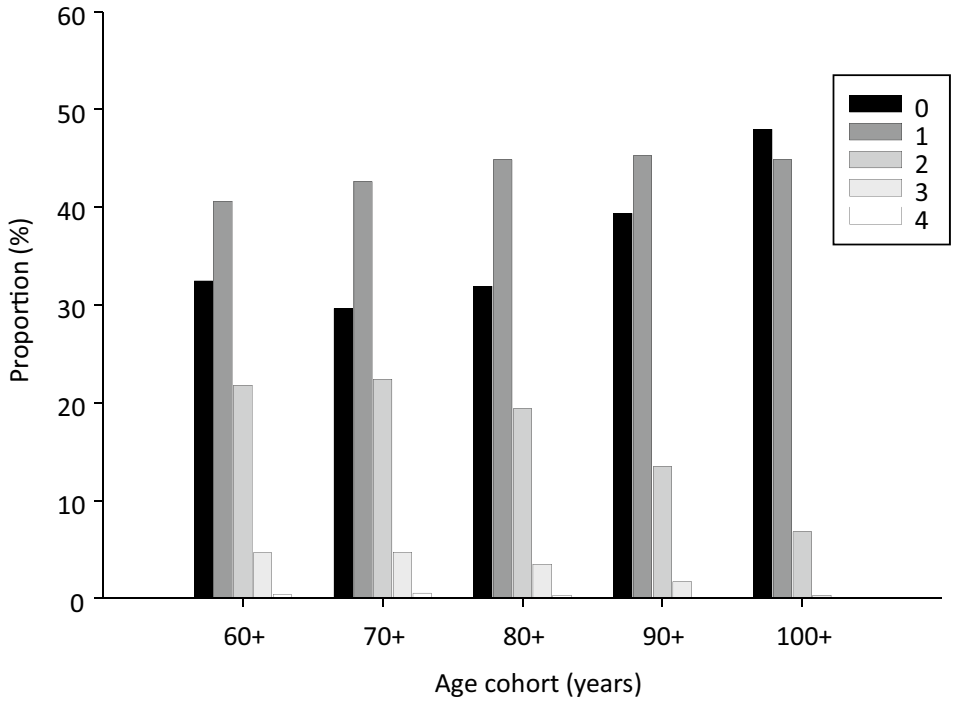

Fig. 1 Number of medical disorders by age decile. 0, 1, 2, 3, 4 = number of diagnosed medical conditions

Legend:

0, 1, 2, 3, 4 = number of diagnosed medical conditions.

Table 2 Centenarians free of common chronic diseases Biopsychosocial Variables

Centenarians' status	Number (%)	Age	Female	Non-smokers	Exercising	Socially Engaged
Free of common chronic diseases	140 (47.9)	101.2 ± 1.4	93 (66.4)	140 (100)	48 (34.3)	122 (87.1)
Non-escapers	152 (52.1)	100.9 ± 1.2	125 (82.2)	151 (99.9)	46 (30.2)	132 (86.8)

Smoking: based on the interRAI-HC definition as follows: 0 = no or 1–2 = not in the last 3 days, but usually a daily smoker, or, yes

Exercising: based on the interRAI-HC total hours of exercise or physical activity in the last 3 days as follows: 0 = none and 1 = less than 1 h; 2, 3 or 4 = 1 to more than 4 h

Socially engaged: based on the interRAI-HC participation in social activities of long-standing interest as follows: 0 = never and 1 = more than 30 days ago; 2, 3 or 4 = 8–30 days ago to in the last 3 days

Table 3 Distribution by sex and age group of the prevalence of being free of common chronic diseases

Age	Number	% Female	Free of illness	%Free of illness	%Female
60 +	9878	53.4	3142	31.8	52.8
70 +	28,629	56.6	8482	29.6	54.5
80 +	48,133	59.8	15,331	31.9	57.3
90 +	16,737	66.1	6582	39.3	61.6
Centenarians	292	74.7	140	47.9	66.4

Free of illness: no diagnosis of dementia, depression, diabetes mellitus nor hypertension

Making intracohort comparisons precludes cohort differences as a potential explanation for centenarians' health advantage at older ages [19]. Future longitudinal research may address some of these issues, as addressed by Douglas and colleagues in their detailed protocol aiming to inform characteristics of successful aging [44]. The strengths of our study include a near-complete data set for this well-defined population, and comparatively large sample size.

In conclusion, a significant minority of New Zealand centenarians are free of major chronic diseases. The trajectory

of reaching such uniquely healthy longevity seems to be associated with not smoking and maintaining steady high levels of social engagement.

Author contributions All authors designed this study, YB obtained the dataset, SL and PG completed the statistical analyses, all authors wrote the manuscript.

Funding The present study did not receive any funding.

Compliance with ethical standards

Conflict of interest The author(s) declare that they have no conflict of interest.

Ethical approval Ethical approval was obtained from the University of Otago Ethics Committee and the Department of Psychological Medicine Ethics Committee.

Statement of human and animal rights All authors had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Informed content Participants or their authorised representatives were asked whether they consented for their anonymised information to be used for research purposes at the time of their inter-RAI assessment.

References

1. Harvey (1668) An extract of the anatomical account, written and left by the famous Dr. Harvey, concerning Thomas Parre, who died in London at the age of 152 years and 9 months. In: Philosophical transactions, vol 3. The Royal Society, London, pp 886–888
2. Humphry GM (1886) Centenarians: Miss Hastings, who died aged 104. Br Med J 1:1104–1105
3. Govindaraju D, Atzmon G, Barzilai N (2015) Genetics, lifestyle and longevity: lessons from centenarians. Appl Transl Genom 4:23–32
4. Rajpathak SN, Liu Y, Ben-David O et al (2011) Lifestyle factors of people with exceptional longevity. J Am Geriatr Soc 59:1509–1512
5. Borras C, Ingles M, Mas-Bargues C et al (2020) Centenarians: an excellent example of resilience for successful ageing. Mech Ageing Dev 186:111199
6. Steensma C, Loukine L, Choi BC (2017) Evaluating compression or expansion of morbidity in Canada: trends in life expectancy and health-adjusted life expectancy from 1994 to 2010. Health Promot Chronic Dis Prev Can 37:68–76
7. Walter S, Beltran-Sanchez H, Regidor E et al (2016) No evidence of morbidity compression in Spain: a time series study based on national hospitalization records. Int J Public Health 61:729–738
8. Allen NB, Zhao L, Liu L et al (2017) Favorable cardiovascular health, compression of morbidity, and healthcare costs: forty-year follow-up of the CHA study (Chicago Heart Association Detection Project in Industry). Circulation 135:1693–1701
9. Rodriguez FS, Matschinger H, Angermeyer MC et al (2018) Compression of cognitive morbidity by higher education in individuals aged 75+ living in Germany. Int J Geriatr Psychiatry 33:1389–1396
10. Engberg H, Oksuzyan A, Jeune B et al (2009) Centenarians–a useful model for healthy aging? A 29-year follow-up of hospitalizations among 40,000 Danes born in 1905. Aging Cell 8:270–276
11. Andersen-Ranberg K, Schroll M, Jeune B (2001) Healthy centenarians do not exist, but autonomous centenarians do: a population-based study of morbidity among Danish centenarians. J Am Geriatr Soc 49:900–908
12. Teixeira L, Araujo L, Jopp D et al (2017) Centenarians in Europe. Maturitas 104:90–95
13. Christensen CH, Rostron B, Cosgrove C et al (2018) Association of cigarette, cigar, and pipe use with mortality risk in the US population. JAMA Intern Med 178:469–476
14. Cicconetti P, Tafaro L, Tedeschi G et al (2004) Smoking and survival in centenarians. Recenti Prog Med 95:187–189
15. Venturelli M, Schena F, Scarsini R et al (2013) Limitations to exercise in female centenarians: evidence that muscular efficiency tempers the impact of failing lungs. Age 35:861–870
16. Randall, Kevin G, Martin P et al (2010) Social resources and longevity: findings from the georgia centenarian study. Gerontology 56:106
17. Kheirbek RE, Fokar A, Shara N et al (2017) Characteristics and incidence of chronic illness in community-dwelling predominantly male US veteran centenarians. J Am Geriatr Soc 65:2100–2106
18. Davey A, Lele U, Elias MF et al (2012) Diabetes mellitus in centenarians. J Am Geriatr Soc 60:468–473
19. Ailshire JA, Beltran-Sanchez H, Crimmins EM (2015) Becoming centenarians: disease and functioning trajectories of older US Adults as they survive to 100. J Gerontol A Biol Sci Med Sci 70:193–201
20. Arnold J, Dai J, Nahapetyan L et al (2010) Predicting successful aging in a population-based sample of georgia centenarians. Curr Gerontol Geriatr Res. https://doi.org/10.1155/2010/989315
21. Evert J, Lawler E, Bogan H et al (2003) Morbidity profiles of centenarians: survivors, delayers, and escapers. J Gerontol A Biol Sci Med Sci 58:232–237
22. Stats New Zealand (2010) National population estimates: December 2010 quarter. https://archive.stats.govt.nz/browse_for_stats/population/estimates_and_projections/NationalPopulationEstimates_HOTPDec10qtr.aspx.
23. Stats New Zealand (2013) Census quickstats about people aged 65 and over. Statistics New Zealand. https://www.stats.govt.nz.
24. Hogeveen SE, Chen J, Hirdes JP (2017) Evaluation of data quality of interRAI assessments in home and community care. BMC Med Inform Decis Mak 17:150
25. Foebel AD, Hirdes JP, Heckman GA et al (2013) Diagnostic data for neurological conditions in interRAI assessments in home care, nursing home and mental health care settings: a validity study. BMC Health Serv Res 13:457
26. Maney DL (2016) Perils and pitfalls of reporting sex differences. Philos Trans R Soc Lond B Biol Sci 371:20150119
27. Wilkinson TJ, Sainsbury R (1998) A census-based comparison of centenarians in New Zealand with those in the United States. J Am Geriatr Soc 46:488–491
28. Richmond RL, Law J, KayLambkin F (2012) Morbidity profiles and lifetime health of Australian centenarians. Australas J Ageing 31:227–232
29. Brandao D, Ribeiro O, Afonso RM et al (2019) Regional differences in morbidity profiles and health care use in the oldest old: findings from two Centenarian Studies in Portugal. Arch Gerontol Geriatr 82:139–146
30. Tettamanti M, Marcon G (2018) Cohort profile: 'Centenari a Trieste' (CaT), a study of the health status of centenarians in a small defined area of Italy. BMJ Open 8:e019250
31. von Berenberg P, Drager D, Zahn T et al (2017) Chronic conditions and use of health care service among German centenarians. Age Ageing 46:939–945

32. Gellert P, Eggert S, Zwillich C et al (2018) Long-term care status in centenarians and younger cohorts of oldest old in the last 6 years of life: trajectories and potential mechanisms. J Am Med Dir Assoc 19:535–40.e1
33. Beltran-Sanchez H, Soneji S, Crimmins EM (2015) Past, present, and future of healthy life expectancy. Cold Spring Harb Perspect Med. https://doi.org/10.1101/cshperspect.a025957
34. Ribeiro O, Teixeira L, Araujo L et al (2016) Health profile of centenarians in Portugal: a census-based approach. Popul Health Metr 14:13
35. Jopp DS, Park MK, Lehrfeld J et al (2016) Physical, cognitive, social and mental health in near-centenarians and centenarians living in New York City: findings from the Fordham Centenarian Study. BMC Geriatr 16:1
36. Madrigal-Leer F, Martinez-Montandon A, Solis-Umana M et al (2019) Clinical, functional, mental and social profile of the Nicoya Peninsula centenarians, Costa Rica, 2017. Aging Clin Exp Res 32:313–321
37. Livingston G, Sommerlad A, Orgeta V et al (2017) Dementia prevention, intervention, and care. Lancet 390:2673–2734
38. Hamer M, Chida Y (2009) Physical activity and risk of neurodegenerative disease: a systematic review of prospective evidence. Psychol Med 39:3–11
39. Kuiper JS, Zuidersma M, Oude Voshaar RC et al (2015) Social relationships and risk of dementia: a systematic review and meta-analysis of longitudinal cohort studies. Ageing Res Rev 22:39–57
40. Mandsager K, Harb S, Cremer P et al (2018) Association of cardiorespiratory fitness with long-term mortality among adults undergoing exercise treadmill testing. JAMA Netw Open 1:e183605
41. Kingston A, Davies K, Collerton J et al (2014) The contribution of diseases to the male-female disability-survival paradox in the very old: results from the Newcastle 85+ study. PLoS One 9:e88016
42. Perls TT (2017) Male centenarians: How and why are they different from their female counterparts? J Am Geriatr Soc 65:1904–1906
43. Leitch S, Glue P, Gray AR et al (2018) Comparison of psychosocial variables associated with loneliness in centenarian vs elderly populations in New Zealand. JAMA Netw Open 1:183880
44. Douglas E, Rutherford A, Bell D (2018) Pilot study protocol to inform a future longitudinal study of ageing using linked administrative data: Healthy AGeing in Scotland (HAGIS). BMJ Open 8:e018802