ORIGINAL ARTICLE

EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Parental lifespan and the likelihood of reaching the age of 90 years in the Netherlands Cohort Study

Lloyd Brandts,[1] Frans WA van Poppel[2] and Piet A van den Brandt[1,3]

[1]GROW – School for Oncology and Developmental Biology, Department of Epidemiology, Maastricht University Medical Center, Maastricht, the Netherlands
[2]Netherlands Interdisciplinary Demographic Institute (NIDI)/ Royal Netherlands Academy of Arts and Sciences (KNAW), The Hague, the Netherlands
[3]CAPHRI – School for Public Health and Primary Care, Department of Epidemiology, Maastricht University Medical Center, Maastricht, the Netherlands

Correspondence

Dr Lloyd Brandts PhD, Maastricht University Medical Centre, Department of Epidemiology, PO Box 616, 6200 MD Maastricht, the Netherlands.
Email: lloyd.brandts@maastrichtuniversity.nl

Aim: Growing evidence suggests an association between parental longevity and lifespan of subsequent generations. We aimed to reproduce earlier findings, showing a positive association between parental longevity and offspring's longevity. Additionally, we investigated whether this is mainly driven by the maternal or paternal germline in male and female offspring.

Methods: For these analyses, data from the oldest birth cohort (1916–17) of the Netherlands Cohort Study was used. Participants filled in a baseline questionnaire in 1986 (at age 68–70 years). Follow up for vital status information until the age of 90 years (2006–07) was >99.9% complete. Multivariable-adjusted Cox regression analyses with a fixed follow-up time were based on 2368 men and 2657 women with complete parental survival data and relevant confounders to calculate risk ratios (RR) of reaching longevity.

Results: In age-adjusted models, paternal and maternal age at death were significantly positively associated with reaching 90 years in both male and female offspring. In male offspring, paternal age at death (≥90 years *vs* <80 years) showed the strongest association with survival to 90 years (RR 1.42, 95% CI 1.07–1.89), after confounder correction. In female offspring, maternal age at death (≥90 years *vs* <80 years) showed the strongest association with survival to 90 years (RR 1.20, 95% CI 1.04–1.40).

Discussion: After confounder adjustment, stronger and significant associations were observed between paternal lifespan and male offspring longevity, and maternal lifespan and female offspring longevity. Future research should investigate through which pathways a longer lifespan of parents is transmitted to their offspring. **Geriatr Gerontol Int 2021; 21: 215–221**.

Keywords: aging, cohort study, longevity, parental lifespan, survival.

Introduction

Several studies observed that parental longevity was significantly associated with the offspring's lifespan.[1–6] Furthermore, it was found that this association was primarily present for maternal longevity, and not for paternal longevity,[3,4,6] and also more pronounced in female offspring.[1,2,4]

Using data from the Netherlands Cohort Study (NLCS), we aimed to reproduce earlier findings, showing an association between parental longevity and offspring's longevity. Additionally, we aimed to investigate if these relationships differ by sex, and whether it is mainly driven by the maternal and/or paternal germline in male and female offspring separately.

Methods

Population and study design

For the present study, data from the NLCS were used. The NLCS was set up in September 1986 as a large prospective cohort study.[7] Participants born in 1916 or 1917 were selected to form the longevity cohort for the current longevity analyses in the NLCS (i.e. aged 68–70 years at baseline), as has been done before in other NLCS longevity studies.[8,9] Follow up for vital status of the longevity cohort until the age of 90 years (2006–2007) was 99.9% complete. The date of death was collected by record linkage to the "Centraal Bureau voor Geneologie" from 1986 until 1995, and the

"gemeentelijke basisadministratie voor persoonsgegevens". Seven participants were lost to follow up due to migration before reaching the age of 90 years. After exclusion of participants with missing information on both parental and maternal survival information (*n* = 946), and potential confounders (*n* = 1836), the analyses were based on 2368 men and 2657 women.

Exposure assessment

At baseline, participants completed an 11-page self-administered questionnaire on diet, lifestyle and other cancer risk factors, including information on paternal and maternal year of birth. Furthermore, they were asked in what year their mother and father had died and the cause of death. Parental age at death was computed by subtracting the year of birth from the year of death, for those parents who were deceased at baseline in 1986. Additional parental cause of death information was used to check whether the father and/or mother was still alive at baseline. Parental age at baseline was used to determine the minimum attained age for parents who were still alive at baseline in September 1986.

Statistical analysis

Reaching the age of 90 years (yes/no) was used as our main outcome variable. For the analyses, maternal and paternal age at death were categorized as: <80, 80 to <85, 85 to <90 or ≥90 years. Participants whose father and/or mother were still alive at baseline, according to cause of death information, were only included in categorical analyses if the parental age was >90 years at baseline, to avoid misclassification of the exposure. Furthermore, parental longevity was defined as having a parent who belonged to the top 10% of survivors of their birth cohort using a dichotomous variable (yes/no). The sex- and birth cohort-specific parental longevity cut-off ages were based on national Dutch population-based survival tables.[10] Parental birth cohorts ranged from 1850 to 1906, with longevity cut-off ages ranging from 83 to 88 years for fathers, and from 84 to 93 years for mothers. Parental longevity was determined for the mother (yes, no), father (yes, no) and combined (none, only father, only mother, both).

Baseline characteristics are presented by offspring survival status using the mean with standard deviation (SD) for continuous variables, and using frequencies (*n*) and percentages (%) for categorical variables. Cross-tabulations were used to examine the distribution of environmental factors according to parental survival status. Age- and multivariable-adjusted risk ratios (RR) of reaching 90 years with 95% confidence intervals (95% CI) were estimated using Cox regression models with a fixed follow-up time.[11,12] Standard errors were calculated using the robust Huber–White sandwich estimator to account for underdispersion.[13] Restricted cubic spline regression analyses were used for modeling continuous relationships between paternal and maternal age at death and the chance of reaching the age of 90 years. For these analyses, three knots were used at the 10th, 50th and 90th percentile. The median ages at death of the reference category in categorical analyses were used as a reference in continuous analyses. Some additional sensitivity analyses were carried out to assess the association between dichotomous exposure variables (parental survival to 85 years [yes/no], 90 years [yes/no] and survival to top the 10% of their birth cohort [yes/no]) and offspring survival to the age of 90 years.

Confounder selection was based on earlier studies examining parental longevity and offspring's longevity[1–4] and directed acyclic graphs, using a disjunctive cause criterion approach.[14]

Confounders used for these analyses included: cigarette smoking status (never smoker/former smoker/current smoker), number of cigarettes smoked per day (continuous; centered), cigarette smoking duration (in years; continuous; centered), alcohol consumption (<0.1, ≥0.1–5, >5–15, >15–30 and >30 g/day), non-occupational physical activity (≤30, >30–60, >60–90, >90 min/day), total energy intake (kcal; continuous), body mass index at baseline (<18.5, ≥18.5–<25, ≥25–<30 and ≥30 kg/m^2), educational level (primary/lower vocational education, junior/senior high school and higher vocational/university), marital status (never married/married/divorced/widowed), number of (selected) diseases at baseline and, depending on the exposure, mutually adjusted for paternal or maternal survival. Selected diseases at baseline included hypertension, heart attack, angina pectoris, stroke, any type of cancer excluding skin cancer, asthma, chronic bronchitis and diabetes. All analyses were carried out with Stata 15.0 (2017; Statacorp, College Station, TX, USA).

Results

Survival to the age of 90 years was more common in women (35.0%) compared with men (17.1%; Table 1). In men, those who survived to the age of 90 years were more often a never smoker (15.8% *vs* 8.9%), had a higher average non-occupational physical activity level (85.0 *vs* 72.4 min/day), more often had a higher vocational or university degree (25.3% *vs* 17.2%) and were more often married (90.4% *vs* 87.6%) compared with those who died before the age of 90 years. In women, we observed similar patterns, except for physical activity levels, which were comparable for both survivors and non-survivors (56.0 *vs* 55.9 min/day; Table 1).

In male offspring, paternal age at death showed a significantly positive association with survival to the age of 90 years in both age-adjusted (*P*-trend = 0.002) and multivariable-adjusted analyses (*P*-trend = 0.011; Table 2). In multivariable-adjusted analyses, men whose father died after the age of 90 years had a significantly higher chance of reaching the age of 90 years themselves (RR 1.42, 95% CI 1.07–1.89) compared with those whose father died before the age of 80 years. Compared with maternal age at death <80 years, maternal age at death ≥90 years was significantly positively associated with male offspring survival to 90 years in the age-adjusted model (RR 1.32, 95% CI 1.01–1.72), but not in the multivariable-adjusted model (RR 1.15, 95% CI 0.87–1.51). A significantly increased chance of reaching the age of 90 years was observed when only the father reached longevity (RR 1.30, 95% CI 1.02–1.65), and a somewhat weaker non-significantly increased chance when only the mother reached longevity (RR 1.16, 95% CI 0.88–1.42) compared with those of which none of the parents reached longevity. Having both parents reaching longevity was not associated with an increased chance of reaching the age of 90 years for male offspring (RR 1.04, 95% CI 0.63–1.73).

In female offspring, increasing paternal age at death was significantly positively associated with reaching longevity in the age-adjusted model (*P*-trend = 0.007), but not in the multivariable-adjusted model (*P*-trend = 0.069; Table 2). Although not significant, paternal age at death ≥90 years pointed toward a positive association (RR 1.16, 95% CI 0.97–1.38) with offspring longevity in the multivariable-adjusted model compared with paternal age at death <80 years (Table 2). Maternal age at death was significantly positively associated with reaching the age of 90 years in both the age-adjusted (*P*-trend <0.001) and the multivariable-adjusted model (*P*-trend = 0.003). In multivariable-adjusted analyses, women whose mother had died after the age of 90 years had a significantly higher chance of reaching the age of 90 years (RR 1.20,

Table 1 Baseline characteristics of the cohort members overall and by survival status in a birth cohort of 1916–17 in the Netherlands Cohort Study on diet and cancer (1986–2007)

	Men		Women	
	Survived to 90 years	Died before age 90 years	Survived to 90 years	Died before age 90 years
n (%)	404 (17.1)	1964 (82.9)	929 (35.0)	1728 (65.0)
Year of birth (%)				
1916	23.5	22.9	23.5	22.5
1917	76.5	77.1	76.5	77.5
Smoking status (%)				
Never smoker	15.8	8.9	74.5	69.2
Former smoker	56.2	50.5	15.3	16.2
Current smoker	28.0	40.6	10.2	14.6
Body mass index, kg/m^2 (mean ± SD)	24.7 ± 2.5	24.9 ± 2.7	24.9 ± 3.1	25.1 ± 3.7
Physical activity, min/day (mean ± SD)	85.0 ± 73.2	72.4 ± 59.5	56.0 ± 46.6	55.9 ± 50.0
Alcohol consumption, g/day (mean ± SD)	14.1 ± 14.8	13.8 ± 15.8	4.9 ± 8.2	4.7 ± 8.8
Total energy intake, kcal (mean ± SD)	2120 ± 469	2034 ± 448	1667 ± 369	1643 ± 368
Educational level (%)				
Primary/lower vocational	40.4	45.5	53.0	58.5
Junior/senior high school	34.4	37.4	37.7	33.3
Higher vocational/university	25.3	17.2	9.4	8.2
Marital status (%)				
Married	90.4	87.6	59.3	56.3
Widow(er)	5.0	7.2	28.1	29.5
Divorced	2.0	2.1	3.3	3.2
Never married	2.7	3.2	9.3	11.1

95% CI 1.04–1.40) compared with those whose mother died before the age of 80 years. Non-significant positive associations were observed with reaching the age of 90 years, for only father, only mother or both parents reaching longevity (Table 2).

For the total population, in multivariable-adjusted analyses, paternal age at death (P-trend = 0.003) and maternal age at death (P-trend = 0.001) were both significantly positively associated with reaching longevity in age-adjusted and multivariable-adjusted analyses, respectively. No statistically significant interaction was observed by sex in the multivariable adjusted analyses for the relationship of paternal age at death (P-interaction = 0.468), maternal age at death (P-interaction = 0.859) and parental longevity (P-interaction = 0.728) with reaching offspring longevity.

Restricted cubic spline analyses showed a positive association between paternal and maternal age at death and reaching age 90 years in both male and female offspring (Fig. 1). All figures showed a gradually increasing slope from the age of death ≥73 years, with steeper and statistically significant slopes observed for paternal age at death in men, and maternal age at death in women.

Discussion

In the present large prospective cohort study, we observed that parental survival to age ≥80 years pointed toward an increasing likelihood of reaching the age of 90 years in both male and female offspring compared with parental age at death <80 years, in age-adjusted analyses. After further adjustment for offspring environmental factors and disease history, paternal survival in male offspring and maternal survival in female offspring in particular

were still significantly positively associated with an increased likelihood of reaching the age of 90 years.

Several studies have investigated the parent–offspring heritability of longevity with varying study designs and results. Most studies used cross-sectional analyses comparing multiple cohorts or cases with younger controls using historical genealogical data,[15–17] as summarized by van den Berg et al.[18] Of these, parental lifespan showed positive associations with offspring lifespan in all 12 studies investigating this relationship.[18] When examining patterns of inheritance, most evidence was observed for the presence of a mother–daughter longevity relationship (positive association, n = 13; no association, n = 3), and least evidence for a father–daughter relationship (positive association, n = 6; no association, n = 10).[18]

Similar to the present study, several studies have used a prospective cohort design to study the parent–offspring longevity relationship.[1–5] Three studies observed no significant association between parental age and death and male offspring longevity after confounder adjustment.[1,2,4] In analyses from the Honolulu Heart Program, a significant association was observed between maternal age at death ≥80 years and male offspring survival to 90 years (OR 1.84, 95% CI 1.37–2.47) and 100 years (OR 2.26, 95% CI 1.04–4.90), respectively, but not for paternal age at death.[3] However, the effect estimates were not shown.[3]

Regarding female offspring, in the personnes agées QUID study, women had a significantly increased chance of reaching the age of 90 years if their mother had reached the age of 85 years compared with maternal age at death between 65–79 years.[4] No association was observed with paternal age at death. In analyses from the Women's Health Initiative, both maternal and paternal age at death ≥90 years were significantly associated with an

Table 2 Age- and multivariable-adjusted risk ratios for reaching longevity according to parental survival in a birth cohort of 1916–17 in the Netherlands Cohort Study (1986–2007)

	median	*n*	Survival	Age-adjusted	Multivariable-adjusted[†]
				RR (95% CI)	RR (95% CI)
Male offspring					
Paternal age at death					
<80 years	69	1392	208	Reference	Reference
80–84 years	82	404	78	1.29 (1.02–1.64)	1.28 (1.01–1.62)
85–89 years	87	298	55	1.23 (0.94–1.62)	1.16 (0.89–1.52)
≥90 years	92	213	48	1.51 (1.14–2.00)	1.42 (1.07–1.89)
P-trend				0.002	0.011
Maternal age at death					
<80 years	69	1233	183	Reference	Reference
80–84 years	82	405	78	1.30 (1.02–1.65)	1.19 (0.94–1.51)
85–89 years	87	365	72	1.33 (1.04–1.70)	1.25 (0.97–1.60)
≥90 years	92	297	58	1.32 (1.01–1.72)	1.15 (0.87–1.51)
P-trend				0.007	0.112
Parental longevity (top 10% of birth cohort)					
None		1551	242	Reference	Reference
Only father		334	69	1.33 (1.04–1.69)	1.30 (1.02–1.65)
Only mother		254	49	1.24 (0.94–1.63)	1.16 (0.88–1.42)
Both		68	13	1.22 (0.74–2.02)	1.04 (0.63–1.73)
Female offspring					
Paternal age at death					
<80 years	69	1653	549	Reference	Reference
80–84 years	82	423	157	1.12 (0.97–1.29)	1.10 (0.95–1.27)
85–89 years	87	304	115	1.14 (0.97–1.34)	1.07 (0.92–1.26)
≥90 years	92	216	88	1.23 (1.03–1.46)	1.16 (0.97–1.38)
P-trend				0.007	0.069
Maternal age at death					
<80 years	68	1365	435	Reference	Reference
80–84 years	82	487	175	1.13 (0.98–1.30)	1.11 (0.96–1.28)
85–89 years	87	397	157	1.24 (1.07–1.43)	1.19 (1.03–1.37)
≥90 years	93	323	136	1.32 (1.14–1.53)	1.20 (1.04–1.40)
P-trend				<0.001	0.003
Parental longevity (top 10% of birth cohort)					
None		1803	606	Reference	Reference
Only father		334	128	1.14 (0.98–1.33)	1.11 (0.96–1.29)
Only mother		290	114	1.17 (1.00–1.37)	1.11 (0.95–1.29)
Both		64	27	1.25 (0.94–1.68)	1.10 (0.34–1.47)
Total population					
Paternal age at death					
<80 years		3045	757	Reference	Reference
80–84 years		827	235	1.17 (1.03–1.32)	1.14 (1.01–1.29)
85–89 years		602	170	1.16 (1.01–1.34)	1.10 (0.96–1.26)
≥90 years		429	136	1.31 (1.13–1.52)	1.23 (1.06–1.43)
P-trend				<0.001	0.003
P-interaction (sex)				0.539	0.468
Maternal age at death					
<80 years		2598	618	Reference	Reference
80–84 years		892	253	1.18 (1.04–1.33)	1.14 (1.01–1.29)
85–89 years		762	229	1.27 (1.12–1.43)	1.21 (1.06–1.37)
≥90 years		620	194	1.32 (1.16–1.51)	1.19 (1.04–1.36)
P-trend				<0.001	0.001
P-interaction (sex)				0.767	0.859
Parental longevity (top 10% of birth cohort)					
None		3355	848	Reference	Reference
Only father		668	197	1.20 (1.05–1.36)	1.17 (1.03–1.32)

(*Continues*)

Table 2 Continued

	median	*n*	Survival	Male offspring Age-adjusted	Multivariable-adjusted[†]
				RR (95% CI)	RR (95% CI)
Only mother		544	163	1.19 (1.04–1.36)	1.12 (0.98–1.29)
Both		132	40	1.24 (0.96–1.61)	1.08 (0.84–1.39)
P-interaction (sex)				0.763	0.728

[†]Model adjusted for cigarette smoking status (never, former, current), cigarette smoking quantity (continuous, centered), cigarette smoking duration (continuous, centered), non-occupational physical activity (≤30 min, >30–60, >60–90, >90 min/day), body mass index (<18.5, ≥18.5–<25, ≥25–<30 and ≥30 kg/m^2), alcohol consumption (<0.1, ≥0.1–5, >5–15, >15–30 and >30 g/day), educational level (primary/lower vocational education, junior/senior high school and higher vocational/university), total energy intake (kcal; continuous), marital status (never married, married, widowed, divorced), number of (selected) diseases at baseline (0, 1, 2, ≥3) and mutually adjusted for paternal or maternal survival.
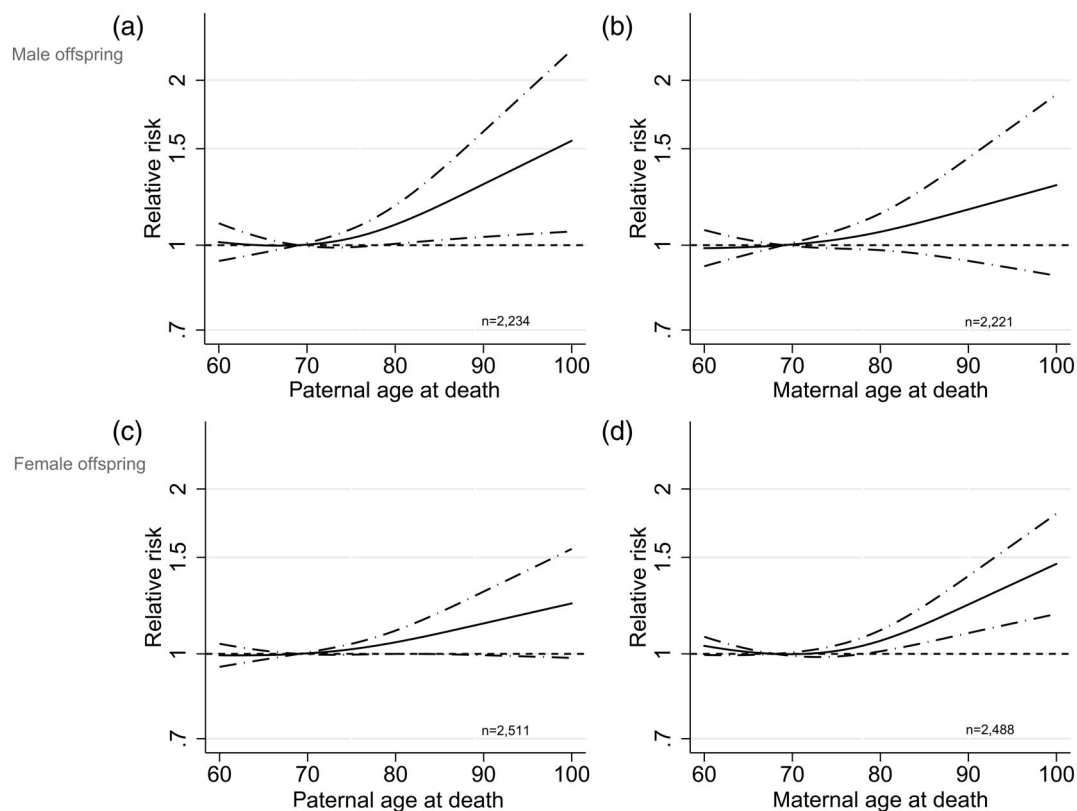

Figure 1 Non-parametric regression curve for the association between paternal and maternal age at death, and the chance of reaching 90 years in men and women. Solid line represents point estimate and dashed lines represent 95% confidence intervals. All models were adjusted for age (years), cigarette smoking status (never, former, current), cigarette smoking quantity (continuous, centered), cigarette smoking duration (continuous, centered), non-occupational physical activity (≤30 min, >30–60, >60–90, >90 min/day), body mass index (<18.5, ≥18.5–<25, ≥25–<30 and ≥30 kg/m^2), alcohol consumption (<0.1, ≥0.1–5, >5–15, >15–30 and >30 g/day), educational level (primary/lower vocational education, junior/senior high school and higher vocational/university), total energy intake (kcal; continuous), marital status (never married, married, widowed, divorced), number of (selected) diseases at baseline (0, 1, 2, ≥3) and mutually adjusted for paternal or maternal survival. (a) *P*-nonlinearity = 0.069. (b) *P*-nonlinearity = 0.418. (c) *P*-nonlinearity = 0.236. (d) *P*-nonlinearity = 0.001.

increased odds of reaching the age of 90 years compared with maternal or paternal survival to age 70–79 years.[5]

To increase statistical power, additional analyses were carried out in which men and women were combined. In these analyses, maternal age at death and paternal age at death were significantly positively associated with offspring reaching longevity. Furthermore, the test for interaction was not statistically significant, which might indicate that the relationship of

paternal and maternal survival with reaching longevity is similar in both sexes.

Based on the existing literature and the results of our age-adjusted analyses, an older age at death of the parents seems to increase the likelihood of reaching old age in offspring. However, the observed relationship between parental longevity and offspring longevity is probably no direct causal relationship. The survival advantage of parents is most likely transferred to their offspring by
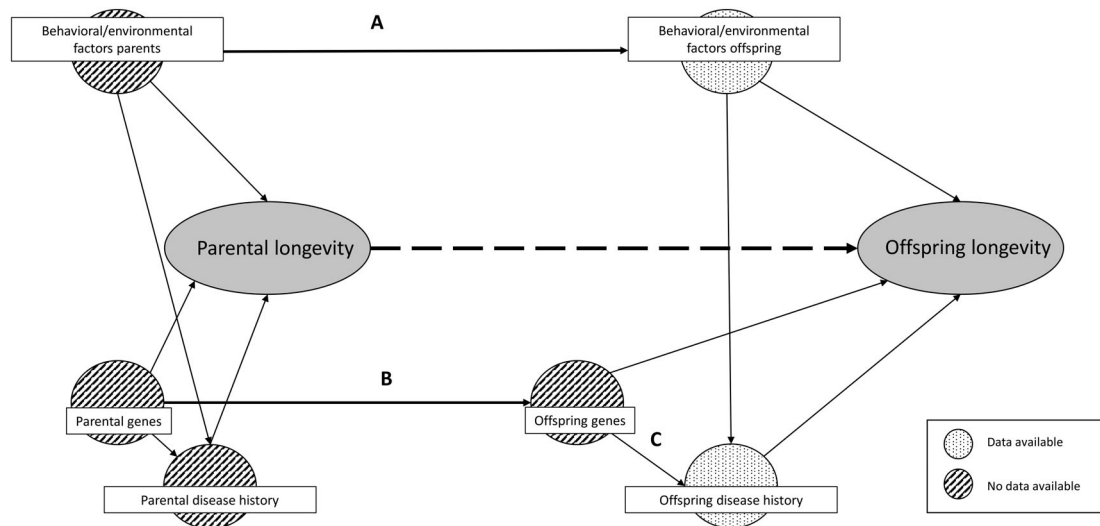
Figure 2 A simplified conceptual representation of the relationship between parental longevity and offspring longevity.

a combined effect of behavioral, environmental and genetic influences, as proposed in Figure 2. Health conditions, such as blood pressure and diabetes, seem to cluster within families.[19,20] Furthermore, it has been suggested that offspring whose parents have an unfavorable lifestyle characteristic, such as smoking or obesity, have a higher chance of having this unfavorable lifestyle characteristic themselves.[21,22] When adjusting for several offspring behavioral/environmental factors and history of (selected) diseases, the causal explanation by a common behavior/environment (pathway A) and a common vulnerability for disease (pathway C) becomes partially blocked. In these analyses, we observed that the father–son and mother–daughter longevity relationship showed somewhat stronger and significant effect estimates compared with the effect estimates of the mother–son and father–daughter longevity relationship. This could imply that genetic or residual confounding factors of the "A" and "C" pathway have a more prominent role in the heritability of old age survival between fathers and sons, and mothers and daughters. Based on earlier studies, it is estimated that approximately 20–30% of human longevity can be attributed to genetic factors,[23,24] of which single-nucleotide polymorphisms in the apolipoprotein E gene and the forkhead box O3A gene are the most important genetic alterations associated with longevity.[24,25]

In contrast to the current study, other prospective cohort studies observed no significant father–son longevity relationship; however, no effect estimates were shown.[3,4] Among the aforementioned genealogical studies, eight observed a father–son longevity association, whereas an equal number (*n* = 8) observed no association. Therefore, more studies are required to investigate whether the present findings can be replicated in other cohorts as well.

More consistent evidence exists for a mother–daughter longevity relationship.[4,5,18] The consistent sex-specific findings between mother and daughter could hint toward an important role of variations in inherited mitochondrial DNA (mtDNA) in the process of reaching longevity, which is transmitted through the maternal germline only.[26] Several studies have found an association between longevity and mtDNA variants of haplogroup J in several European countries,[27–29] and with mtDNA variant haplogroup D in Japan .[30] In these studies, it was observed that these haplogroups were more common among centenarians than in

ethnically matched younger controls. However, these findings could not be replicated in other geographical populations, which indicates that the effect of certain mtDNA variations depends on the individual-specific genetic background.[31]

In analyses of the Framingham study, an increased odds of reaching the age of 75 years was observed per one parent increase in survival to 75 years.[1] In the Iowa-established populations for epidemiological study of the elderly study, women were more likely to reach the age of 97 years when one or both parents survived to the age of 85 years compared with none of the parents surviving to 85 years.[2] In the Women's Health Initiative (WHI) trial, both parents surviving to 90 years was associated with an increased odds of reaching 90 years in female offspring.[5] We did not observe an additional increased chance of reaching 90 years when both parents reached longevity in both men and women. A similar relationship was observed in analyses where men and women were combined. However, the absolute number of participants of which both parents reached longevity was very small, which makes it difficult to draw any conclusions based on this finding. We also observed a notably higher percentage of current smokers in these specific groups, which might have also altered the present results (Table S1).

The current analyses confirm the hypothesis that the chance of reaching longevity is related to parental lifespan. However, the causal explanation for this relationship remains unclear. Future studies should explore potential pathways through which longevity can be passed on by earlier generations.

Strength of the present study were the prospective study design, which limited the risk for selection and information bias, and the detailed information collected on confounding factors. Furthermore, the study population was very homogenous with respect to age, making confounding by age unlikely.

There were some limitations to the present study. First, the men and women included for our analyses had already survived to an advanced age, which might have led to survivorship bias. Second, only limited information on parental vital status was available for participants with missing data on parental age at death, including those whose parents were still alive at baseline. Because these parents most likely survived to older ages, this might have led to a higher dropout rate of participants whose parents survived to

advanced ages. Finally, all causes of death of the parents and offspring were taken into account for these analyses, instead of natural causes of death only. These biases might have led to an underestimation of the true relationship between parental lifespan and offspring lifespan.

In conclusion, we observed that paternal age at death was significantly positively associated with reaching the age of 90 years in men, and maternal age at death was significantly positively associated with reaching the age of 90 years in women. Weaker, non-significantly, positive associations were observed between maternal age at death and reaching 90 years in male offspring, and between paternal age at death and reaching 90 years in female offspring. Regarding parental longevity, paternal longevity showed the strongest association with reaching the age of 90 years in male offspring.

Acknowledgements

Disclosure statement

The authors declare no conflict of interest.

References

1 Goldberg RJ, Larson M, Levy D. Factors associated with survival to 75 years of age in middle-aged men and women. The Framingham study. *Arch Intern Med* 1996; **156**: 505–509.

2 Dutta A, Henley W, Lang I *et al*. Predictors of extraordinary survival in the Iowa established populations for epidemiologic study of the elderly: cohort follow-up to "extinction". *J Am Geriatr Soc* 2011; **59**: 963–971.

3 Rantanen T, Masaki K, He Q, Ross GW, Willcox BJ, White L. Midlife muscle strength and human longevity up to age 100 years: a 44-year prospective study among a decedent cohort. *Age* 2012; **34**: 563–570.

4 Edjolo A, Helmer C, Barberger-Gateau P, Dartigues JF, Maubaret C, Peres K. Becoming a nonagenarian: factors associated with survival up to 90 years old in 70+ men and women. Results from the PAQUID longitudinal cohort. *J Nutr Health Aging* 2013; **17**: 881–892.

5 Shadyab AH, Manson JE, Li W *et al*. Parental longevity predicts healthy ageing among women. *Age Ageing* 2018; **47**: 853–860.

6 van den Berg N, Rodriguez-Girondo M, de Craen AJ, Houwing-Duistermaat JJ, Beekman M, Slagboom PE. Longevity around the turn of the 20th century: life-long sustained survival advantage for parents of today's nonagenarians. *J Gerontol A Biol Sci Med Sci* 2018; **73**: 1295–1302.

7 van den Brandt PA, Goldbohm RA, van't Veer P, Volovics A, Hermus RJ, Sturmans F. A large-scale prospective cohort study on diet and cancer in The Netherlands. *J Clin Epidemiol* 1990; **43**: 285–295.

8 Brandts L, van den Brandt PA. Sex-specific associations between smoking habits and reaching longevity: Netherlands cohort study. *Geriatr Gerontol Int* 2018; **18**: 1249–1258.

9 Brandts L, van den Brandt PA. Body size, non-occupational physical activity and the chance of reaching longevity in men and women: findings from The Netherlands cohort study. *J Epidemiol Community Health* 2019; **73**: 239–249.

10 Statistics Netherlands (CBS). *Levensverwachting; geslacht, geboortegeneratie*. Voorburg: *Centraal Bureau voor de Statistiek*. opendata.cbs.nl, 2019.

11 Nijem K, Kristensen P, Al-Khatib A, Bjertness E. Application of different statistical methods to estimate relative risk for self-reported health complaints among shoe factory workers exposed to organic solvents and plastic compounds. *Norsk Epidemiologi* 2005; **15**.

12 Breslow N. Covariance analysis of censored survival data. *Biometrics* 1974; **30**: 89–99.

13 Barros AJ, Hirakata VN. Alternatives for logistic regression in cross-sectional studies: an empirical comparison of models that directly estimate the prevalence ratio. *BMC Med Res Methodol* 2003; **3**: 21.

14 VanderWeele TJ, Shpitser I. A new criterion for confounder selection. *Biometrics* 2011; **67**: 1406–1413.

15 Piraino P, Muller S, Cilliers J, Fourie J. The transmission of longevity across generations: the case of the settler cape Colony. *Research in Social Stratification and Mobility* 2014; **35**: 105–119.

16 Gavrilov LA, Gavrilova NS. Biodemographic study of familial determinants of human longevity. *Population* 2001; **13**: 197–221.

17 Salaris L, Tedesco N, Poulain M. Familial transmission of human longevity: a population-based study in an inland village of Sardinia (Italy), 1850–2010. *Vienna Yearb Popul Res* 2013; **11**: 325–349.

18 van den Berg N, Beekman M, Smith KR, Janssens A, Slagboom PE. Historical demography and longevity genetics: back to the future. *Ageing Res Rev* 2017; **38**: 28–39.

19 Scott LJ, Mohlke KL, Bonnycastle LL *et al*. A genome-wide association study of type 2 diabetes in Finns detects multiple susceptibility variants. *Science* 2007; **316**: 1341–1345.

20 Newton-Cheh C, Johnson T, Gateva V *et al*. Genome-wide association study identifies eight loci associated with blood pressure. *Nat Genet* 2009; **41**: 666–676.

21 Tobacco and Genetics Consortium. Genome-wide meta-analyses identify multiple loci associated with smoking behavior. *Nature genetics* 2010; **42**: 441–447.

22 Justice AE, Winkler TW, Feitosa MF *et al*. Genome-wide meta-analysis of 241 258 adults accounting for smoking behaviour identifies novel loci for obesity traits. *Nat Commun* 2017; **8**: 14977–14977.

23 Murabito JM, Yuan R, Lunetta KL. The search for longevity and healthy aging genes: insights from epidemiological studies and samples of long-lived individuals. *J Gerontol A Biol Sci Med Sci* 2012; **67**: 470–479.

24 Costa D, Scognamiglio M, Fiorito C, Benincasa G, Napoli C. Genetic background, epigenetic factors and dietary interventions which influence human longevity. *Biogerontology* 2019; **20**: 1–22.

25 Revelas M, Thalamuthu A, Oldmeadow C *et al*. Review and meta-analysis of genetic polymorphisms associated with exceptional human longevity. *Mech Age Develop* 2018; **175**: 24–34.

26 Vandenbroucke JP. Maternal inheritance of longevity. *Lancet* 1998; **351**: 1064.

27 De Benedictis G, Rose G, Carrieri G *et al*. Mitochondrial DNA inherited variants are associated with successful aging and longevity in humans. *FASEB J* 1999; **13**: 1532–1536.

28 Ross OA, McCormack R, Curran MD *et al*. Mitochondrial DNA polymorphism: its role in longevity of the Irish population. *Exp Gerontol* 2001; **36**: 1161–1178.

29 Niemi AK, Hervonen A, Hurme M, Karhunen PJ, Jylha M, Majamaa K. Mitochondrial DNA polymorphisms associated with longevity in a Finnish population. *Hum Genet* 2003; **112**: 29–33.

30 Tanaka M, Gong J-S, Zhang J, Yoneda M, Yagi K. Mitochondrial genotype associated with longevity. *Lancet* 1998; **351**: 185–186.

31 Sevini F, Giuliani C, Vianello D *et al*. mtDNA mutations in human aging and longevity: controversies and new perspectives opened by high-throughput technologies. *Exp Gerontol* 2014; **56**: 234–244.

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1 Baseline characteristics of the cohort members by survival status of parents in a birth cohort of 1916–17; Netherlands Cohort Study on diet and cancer (1986–2007).