Healthy lifestyle and life expectancy free of major chronic diseases at age 40 in Chinese population: a prospective cohort study

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Abstract

Background

A healthy lifestyle has been associated with a longer life expectancy (LE). However, whether it also helps achieve gains in LE free of major non-communicable diseases (NCDs) and its share of total LE in Chinese adults remains unknown.

Methods

We used data from China Kadoorie Biobank (CKB) of 451,233 adults aged 30-79 free of heart disease, stroke, cancer, chronic obstructive pulmonary disease (COPD), and asthma at baseline. Low-risk lifestyle factors included never smoking or quitting for reasons other than illness, no excessive alcohol use, being physically active, healthy eating habits, and healthy body shape. We built multistate life tables for individuals with different risk levels of lifestyle factors to calculate LE with and without diseases (cardiovascular diseases [CVDs], cancer, chronic respiratory diseases [CRDs, including COPD and asthma]) at age 40. For life table calculation, we used prevalence of lifestyle factors, transition rates, and hazard ratios (HRs) for three transitions (disease-free to disease onset, disease-free to death, and presence of disease to all-cause mortality).

Findings

During a median follow-up of 11.1 years, we documented 111,002 new CVD cases, 24,635 cancer cases, 12,506 CRD cases, and 34,740 deaths. The adjusted HRs (95% confidence intervals [CIs]) of men adopting all five versus 0-1 low-risk factors was 0.56 (0.50, 0.63), 0.40 (0.20, 0.80), and 0.64 (0.50, 0.83) for baseline to disease, baseline to death, and disease to death, respectively; the corresponding values for women were 0.69 (0.64, 0.75), 0.57 (0.34, 0.94), and 0.57 (0.47, 0.69). The LE free of the three NCDs (95%CI) at age 40 for individuals with 0-1 low-risk factor was on average 23.9 (23.2, 24.6) years for men and 24.2 (23.5, 24.9) years for women. For individuals adopting all five low-risk factors, it was 30.2 (28.8, 31.6) years for men and 28.4 (27.2, 29.6) years for women, with an increase of 6.3 (5.1, 7.5) years (men) and 4.2 (3.6, 5.4) years (women). Correspondingly, the proportion of LE free of the three NCDs to total LE increased from 73.1% to 76.3% for men and from 67.6% to 68.4% for women.

Interpretation

Our findings suggest that promoting healthy lifestyles through public health interventions could be associated with increased LE free of major NCDs and "relative compression of morbidity" in the Chinese population.

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Research in context

Evidence before this study

We searched PubMed, EMBASE, and Google Scholar for articles published from the inception of each database to May 31, 2022, using a combination of terms: ("healthy life expectancy" OR "life expectancy free of diseases" OR "disease-free life expectancy" OR "disease-free life years" OR "life expectancy without diseases") AND ("lifestyle" OR "smoking" OR "tobacco use" OR "alcohol" OR "physical activity" OR "diet" OR "BMI" OR "overweight" OR "obesity"). We implemented no restriction on study type or language. Relevant studies were also found through checking reference lists of identified articles. Available studies that assessed the relationship between lifestyle and life expectancy free of major non-communicable diseases (NCDs) were mainly performed in high-income countries and based on occupational populations or populations with high socioeconomic status and health levels. It remains unclear how much room the population-wide promotion of a healthy lifestyle could increase life expectancy free of major NCDs and its share of total life expectancy in a Chinese population with more diverse socio-demographic characteristics and from regions with different economic development levels.

Added value of this study

Life expectancy free of cardiovascular diseases, cancer, and chronic respiratory diseases at age 40 accounted for about three-quarters of the residual life expectancy in men and two-thirds in women. The estimated life expectancy free of the three NCDs for individuals with all five low-risk factors was on average 6.3 years longer in men and 4.2 years longer in women than those with 0-1 low-risk factors, accounting for a slightly higher share of the total life expectancy as well. Our study fills the evidence gap of the association between a healthy lifestyle and disease-free life expectancy in populations with less developed economies and various socioeconomic characteristics and reinforces the importance of promoting healthy lifestyles to achieve healthy aging.

Implications of all the available evidence

The present prospective cohort study of the Chinese population shows that a healthy lifestyle was associated with longer total life expectancy and a larger proportion of remaining years lived without major NCDs, achieving “relative compression of morbidity”. Further researches on the impact of other health risk factors on healthy life expectancy are also needed.

Background

Life expectancy (LE) in China has risen in the past 30 years.(1) The aging population and the widespread prevalence of health risk factors drive a rise in the burden of non-communicable diseases (NCDs). Meanwhile, advances in medicine play an important role in reducing mortality from NCDs. As a result, more and more people live with chronic conditions, such as cardiovascular diseases (CVDs), cancer, and chronic respiratory diseases (CRDs).(2) Healthy life expectancy (HLE) adds a quality-of-life dimension to the estimates of LE by dividing the expected lifespan into life years spent with and without diseases. According to the compression of morbidity hypothesis, healthy aging should manifest as a greater extension of LE free of diseases than total LE or an increase in its share of total LE.(3) Therefore, LE free of diseases can be a better indicator than total LE to monitor progress in healthy aging and the achievement of sustainable development goals.(4)

A healthy lifestyle has been associated with lower incidence risks of CVDs, cancer, and CRDs and mortality risks from these diseases,(5-7) thus being associated with a delayed onset of diseases and longer LE.(8) There is an increasing interest in understanding the net effect of a healthy lifestyle on the proportion of disease-free LE to the total LE. Available studies were mainly conducted in Western countries. Most studies focused on individual lifestyle factors or LE free of a certain ill-health state such as CVDs,(9-11) or type 2 diabetes (T2D).(12) Only three studies assessed the impact of combined lifestyle factors on LE free of several NCDs.(8, 13, 14) It remains unclear how increasing the adoption of a healthy lifestyle through public health interventions helps achieve gains in LE free of major chronic diseases and healthy aging in Chinese population.

The present study examined the impact of individual and combined lifestyle factors on the LE free of major NCDs and its share of total LE in the China Kadoorie Biobank (CKB) of 0.5 million Chinese adults. The NCDs of interest are CVDs, cancer, and CRDs (including chronic obstructive pulmonary disease [COPD] and asthma), which have posed a heavy burden on healthcare systems in China.(15)

Methods

Study design and participants

The CKB study is a nationwide population-based prospective cohort study. Details of the study design have been described elsewhere.(16) In brief, 512,725 participants

aged 30-79 years were recruited from five urban and five rural areas in the 2004-08 baseline survey. Two periodic resurveys were conducted in 2008 and 2013-14 in a random sample of about 5% surviving participants. Information collected at baseline and resurveys were recorded using a laptop-based data entry system with built-in functions to avoid missing items and minimize logic errors. All participants signed an informed consent form. Ethical approval was obtained from the Ethics Review Committee of the Chinese Center for Disease Control and Prevention (CDC; Beijing, China) and the Oxford Tropical Research Ethics Committee, University of Oxford (UK).

For the current study, we excluded participants with prevalent coronary heart disease (n=15,472), stroke (n=8,884), cancer (n=2,578), COPD (n=37,057), or asthma (n=2,806) at baseline. Reasons for exclusion were not mutually exclusive, with 4,999 participants meeting multiple exclusion criteria. Two participants with missing values for body mass index (BMI) were excluded as well, leaving 451,233 participants in the primary analysis.

Definition of low-risk lifestyle

Lifestyle-related factors were assessed by questionnaire and physical measurements at baseline. Details have been described in the Supplementary Material (appendix p1). Five modifiable lifestyle factors were compiled to create a gradient scale in our study: smoking, alcohol consumption, physical activity, dietary habits (fresh fruits, fresh vegetables, red meat, legumes, and fish), and body shape (BMI and waist circumference [WC], a reflection of balance between energy intake and energy expenditure).

The low-risk lifestyle for each factor was defined based on the Chinese dietary guidelines and related references.(8, 17, 18) For smoking, participants that reported not smoking or quitting smoking for reasons other than illness were classified as low-risk group. For alcohol consumption, the low-risk group included non-regular drinkers and daily light-to-moderate drinkers (<30 g of pure alcohol in men and <15 g in women per day).(8, 18) Former smokers quitting due to illness and former drinkers were both excluded from the low-risk group to avoid potential sick-quitter phenomenon.(19) For physical activity, we defined those who engaged in an age- (<50, 50-59, and ≥60 years) and sex-specific median or higher level of physical activity as the low-risk group.(18) For dietary habits, we derived a simple diet score based on the following criteria: eating fresh vegetables daily, eating fresh fruits daily, eating red meat 1-6 days per week, eating legumes ≥4 days per week, and eating fish

≥1 day per week. One point was scored for each criterion met, or zero. A score of 4 to 5 was classified as the low-risk group.(18) For body shape, both general and central adiposity indicators were taken into account to help distinguish between lean body mass and fat mass.(20) Participants with BMI of 18.5 to 27.9 kg/m^2 and WC of <90/85 cm for men/women were defined as low-risk.(18) The number of the low-risk lifestyle factors served as a simple score, ranging from 0 to 5, with higher scores indicating a healthier lifestyle.

Ascertainment of disease onset and deaths

Participants were followed up for disease incidence and mortality since baseline recruitment via local disease and death registries and national health insurance system, supplemented with annual active follow-up to minimize loss to follow-up. All events were coded by trained staff who were unaware of baseline information using the 10th revision of the International Classification of Diseases (ICD-10).

In the present study, CVDs and cancer were defined by codes I00-I99 and C00-C97, respectively. CRDs were defined jointly by COPD (J41-J44) and asthma (J45-J46). For T2D, we excluded cases clearly defined as insulin-dependent, malnutrition-related, or other specified diabetes (E10, E12, and E13), and defined T2D as code E11 or E14. Because the majority of the included participants were aged over 40 years, incident cases of unspecified diabetes (E14) were reasonably assumed as T2D.

Statistical analysis

We analyzed the changes in dichotomized lifestyle factors between 2004-08 baseline and 2013-14 resurvey and whether such changes differed by occurrence of any of the three non-communicable diseases (NCDs), with adjustment for age, sex, and study area, as appropriate.

To calculate life expectancies in different health states, we applied population-based multistate life table (MSLT) method, which is a demographic tool incorporating both the morbidity and mortality experience of multiple birth cohorts during a certain follow-up period.(21) We considered three states in this study: disease-free, presence of disease, and death. Possible transition directions were: (1) from disease-free to presence of disease; (2) from disease-free to death without experiencing the disease, and (3) from presence of disease to all-cause mortality. No backflows were allowed, and only the first entry into a state was considered.(8, 22) For participants who died on the same date of first disease diagnosis, we calculated the date of disease onset as the date of death minus 0.5 day in the primary analysis.

Due to the sex differences in life expectancy, we performed all analyses for men and women separately. We built MSLTs separately for CVDs, cancer, CRDs, and the combination of these three diseases, following a similar approach to previous studies.(8, 12, 23) First, we calculated the observed transition rates by dividing the number of events by the corresponding risk period of exposure in each state for every single year of age. For smoothing the observed age-specific transition rates, we applied Poisson regression with attained age as the only covariate.(23) Second, we calculated the prevalence of low-risk lifestyle factors by 5-year age (attained age) groups separately for participants with and without the diseases, assuming that the baseline assessment reflected the lifestyle within the follow-up period. Subsequently, we estimated the sex-specific hazard ratios (HRs) of the association between lifestyle factors and each transition by using separate Cox proportional hazard models with age as the time scale. When modeling the hazard of transition from presence of disease to all-cause mortality, we used the time after disease onset as the time scale, with age at disease onset as a fixed covariate.(24) The Cox model was stratified jointly by 10 study areas and age at baseline in a 5-year interval, with adjustment for education level, marital status, menopausal status (women only), and family histories of heart attack, stroke, or cancer. Lastly, transition rates of each category of lifestyle factor were calculated separately by integrating the foregoing results. To avoid unstable rates due to the limited number of events under age 40, MSLTs started at age 40 and closed at age 90 since few participants reached this age during the follow-up period.

In the sensitivity analysis, we estimated the HRs after excluding participants who experienced disease onset or died within the first two years of follow-up to minimize potential reverse causality. For participants who died on the same date of disease onset, we considered several other alternatives to repeat all analyses: (i) calculating the date of disease onset using different time intervals (0.5 and 1 year); (ii) regarding them as death without disease onset; (iii) excluding these participants. To evaluate the impact of lifestyle factors on life expectancy at different ages, we also calculated the life expectancy at ages 50 and 65.

Subgroup analyses were performed by residence (urban or rural), family history of chronic diseases (with family history of heart attack, stroke, or cancer, or none), and baseline disease status (with hypertension or diabetes, or none). Also, we repeated the primary analysis with an alternative outcome that included T2D in addition to the three diseases. In this analysis, participants with diabetes at baseline were further excluded (n=24,134).

All statistical analyses were performed using Stata (version 15.0, StataCorp). The

confidence intervals (CIs) for life expectancy was estimated using @RISK 8.1 (Palisade Corp, Ithaca, NY), with 10,000 runs of Monte Carlo simulation (parametric bootstrapping).(25) Graphs were plotted using R version 4.0.3.

Role of the funding source

The funders had no role in the study design, data collection, data analysis and interpretation, writing of the report, or the decision to submit the article for publication.

Results

Characteristics of the study population

A total of 451,233 participants were included in this study, with a mean baseline age of 51.0 ± 10.4 years and 40.2% being males. The proportion of participants adopting at least three, four, and all five low-risk lifestyle factors were 68.6%, 28.2%, and 2.0%, respectively. Overall, younger women and better-educated participants were more likely to adopt low-risk lifestyles (**Table S1**). Among 22,275 participants who participated in the 2013-14 resurvey, the risk level of lifestyle factors remained largely unchanged over the mean follow-up period of 8 years, regardless of disease occurrence in this period (**Table S2**).

During a median follow-up of 11.1 years (4.93 million person-years), we documented 111,002 new CVD cases, 24,635 cancer cases, and 12,506 CRD cases. When considering CVDs, cancer, and CRDs as a whole, the number of cases with CVDs as the first disease was 106,065. The corresponding numbers of cases for cancer and CRDs were 20,223 and 8,760, respectively (1,461 participants developed multiple concurrent diseases as the first disease). We documented 34,740 deaths; 4,710 dead did not have CVDs, cancer, or CRDs being recorded between baseline and death.

Lifestyle and transitions between states

In the multivariable-adjusted models, almost all five low-risk lifestyle factors were associated with reduced risks of developing any of the three NCDs in both men and women. Healthy body shape defined by BMI and WC showed the strongest negative association, with HRs (95% CIs) of 0.77 (0.76, 0.79) and 0.80 (0.79, 0.81) for men and women, respectively (**Figure 1**). All four low-risk lifestyle factors other than healthy body shape were associated with lower mortality risks for either transition from baseline or presence of any of the three NCDs.

When low-risk lifestyle factors were considered jointly, there were linear decreasing trends in the incidence and mortality risk with the increasing number of low-risk lifestyle factors for all three transitions (**Table 1**). The corresponding HRs (95% CIs) of per one-factor increase for men were 0.85 (0.84, 0.86), 0.86 (0.83, 0.90), and 0.90 (0.89, 0.92) for baseline to disease, baseline to death, and disease to death, respectively; the corresponding values for women were 0.88 (0.87, 0.89), 0.83 (0.78, 0.88), and 0.93 (0.91, 0.95). The gradient association persisted for analyses of disease-specific outcomes (**Table 1**). Sensitivity analyses did not alter the results substantially (**Tables S3 and S4**).

Lifestyle and LE at age 40

The Poisson regression model fitted the observed age-specific rates well for each transition in men and women (**Figure S1**). About three-quarters of the total LE at age 40 in men was free of the three NCDs, but the proportion was lower for women (**Figure S2**). All four low-risk lifestyle factors other than healthy body shape were accompanied by a parallel extension of total LE at age 40 and LE free of the three NCDs. Although the most obese participants had about the same LE as those with a BMI of 18.5-27.9 kg/m^2 and without abdominal obesity, the LE free of the three NCDs of the former was shorter by 3.9 years for men and 3.7 years for women (**Figure S3**). The proportion of LE free of the three NCDs to the total LE was also obviously lower for the most obese participants (men: 67.6%, women: 63.0%), indicating expansion of morbidity (**Figure 2**).

The joint analysis of five low-risk lifestyle factors showed that total LE and LE free of the three NCDs, as well as the proportion of LE free of the three NCDs to the total LE, increased steadily with the increasing number of low-risk lifestyle factors (**Figure 3**). Women had a shorter LE free of the three NCDs but longer total LE and LE with the three NCDs than men. Sensitivity analyses showed the robustness of the results (**Figure S4**). Similar results were observed at every age after age 40 (**Figure S2**). The LE free of the three NCDs (95%CI) at age 40 for individuals with 0-1 low-risk factor was on average 23.9 (23.2, 24.6) years (73.1% of total LE) for men and 24.2 (23.5, 24.9) years (67.6% of total LE) for women (**Figure 4**). When individuals adopted all five low-risk factors, it would reach 30.2 (28.8, 31.6) years (76.3% of total LE) for men and 28.4 (27.2, 29.6) years (68.4% of total LE) for women, with an increase of 6.3 (5.1, 7.5) years (men) and 4.2 (3.6, 5.4) years (women), respectively. When calculating LE free of the three NCDs at ages 50 and 65, the difference narrowed slightly for individuals with different numbers of low-risk lifestyle factors compared to the 0-1 reference group (**Table S5**).

In the subgroup analysis, urban residents had similar LE free of the three NCDs to rural residents but longer total LE and LE with the NCDs than rural residents (**Figure S5**). As the number of low-risk lifestyle factors increased, urban residents gained more LE free of the NCDs than rural residents. When stratified by personal medical or family history, LE free of the three NCDs was lower for participants with a family history of any chronic diseases and for participants with hypertension or diabetes, but adopting low-risk lifestyles was associated with longer LE free of the three NCDs and higher share of total LE (**Figures S6 and S7**). When we included T2D in the NCDs of interest, there was a slight decrease in LE free of the four NCDs, but the upward trend of LE free of the four NCDs persisted with the increasing number of low-risk lifestyle factors (**Figure S8**).

When each disease was analyzed individually, the LE without cancer or CRDs was longer than without CVDs (**Figure 4**). The LE without CVDs was 6.0 (4.7, 7.2) years (men) and 4.5 (3.6, 5.4) years (women) longer in participants with all five low-risk lifestyle factors compared to those with 0-1 low-risk lifestyle factor. The corresponding extended years were 6.5 (5.0, 7.8) years (men) and 4.4 (3.2, 5.5) years for LE without cancer, and 7.3 (5.7, 8.7) years (men) and 5.2 (4.2, 6.1) years (women) for LE without CRDs (**Figure 4**).

Discussion

In the present Chinese population, LE free of CVDs, cancer, and CRDs at age 40 accounted for about three-quarters of the residual LE in men and two-thirds in women. The five low-risk lifestyle factors, namely never smoking or quitting for reasons other than illness, no excessive alcohol use, being physically active, healthy eating habits, and healthy weight and shape were associated with longer LE free of the three NCDs. When individuals adopted all five low-risk factors, their estimated LE free of the three NCDs at age 40 was on average 6.3 years longer in men and 4.2 years longer in women than those with 0-1 low-risk factors. Individuals with healthier lifestyles also showed the LE free of the three NCDs accounting for a slightly higher share of the total LE than those following unhealthy lifestyle choices.

A study based on the Nurses' Health Study (NHS) and the Health Professionals Follow-Up Study (HPFS) found that the LE free of CVDs, cancer, and T2D at age 50 for individuals with 4-5 low-risk factors was on average 7.6 (95%CI: 6.8, 8.4) years longer in men and 10.7 (10.0, 11.3) years longer in women than those without any low-risk factors.(8) The corresponding proportion of the disease-free LE to the total LE also increased from 75.3% to 79.0% in men and from 74.8% to 83.6% in women.

In a pooled analysis of 12 European occupational cohorts, a healthy lifestyle was associated with an increase of LE free of T2D, coronary heart disease, stroke, cancer, asthma, and COPD at age 40 by 9.9 (6.7, 13.1) years in men and 9.4 (5.4, 13.3) years in women.(13) The above two studies were performed in occupational populations or populations with high socioeconomic status and health levels. In contrast, our study first quantified the associations of combined lifestyle factors with LE free of the major NCDs and its share of total LE in a Chinese population with diverse socio-demographic characteristics and from regions with different economic development levels. We observed that the proportion of the disease-free LE to the total LE increased with the number of low-risk factors, but the difference between healthy and the most unhealthy groups was lower than that in the study of NHS and HPFS.(8)

In the study of NHS and HPFS, a healthy lifestyle was associated with 8.6 years (for men) and 10.0 years (for women) increase in LE free of CVDs, and 6.0 years (for men) and 8.3 years (for women) increase in LE free of cancer at age 50.(8) Whereas in our study, the gains in LE free of CVD at age 50 was 5.2 years in men and 3.9 years in women; the corresponding values for LE free of cancer was 5.9 years in men and 4.3 years in women (data not shown). Possible explanations for the difference in disease-free LE gains related to a healthy lifestyle include the differences in the characteristics of the study population and the definition of low-risk lifestyle factors. In addition, other health risk factors that are important to the Chinese population are worth noting, such as environmental hazards in the living and working places, and the poor control of proximal risk factors like hypertension, dyslipidemia, and diabetes.(26)

In this study, the gain in disease-free LE, as well as its share of total LE, associated with a healthier lifestyle was bigger in men than in women. Previous studies also observed sex differences in the association between healthy lifestyle factors and disease-free LE but with inconsistent results, and the reason was unclear.(8, 12, 23) It is worth noting an important difference between urban and rural populations. The healthier lifestyle was associated with a greater increase in the disease-free LE in urban than in rural populations. The urban men showed a greater gain in disease-free LE than total LE, known as “absolute morbidity compression”.

In the analyses of individual low-risk lifestyle factors, body shape defined jointly by BMI and WC had a smaller impact on total LE but a greater impact on disease-free LE than the other four lifestyle factors, corresponding to the relatively stronger associations of body shape with disease incidence than death. The obese individuals, despite a similar total LE to those with healthy weight and shape, spent more years

living with diseases. This finding was consistent with most previous studies that used BMI as a single measure to define obesity and added to emphasize the importance of central obesity prevention for the Chinese population.(10, 14, 27)

Several strengths characterized this study. First, this study was based on a geographically spread Chinese population living in urban and rural areas. It filled the evidence gap of the association between a healthy lifestyle and disease-free LE in populations with less developed economies and various socioeconomic characteristics. Second, the nature of the CKB study in terms of its large sample size, long-term follow-up, and a large number of documented incident cases and deaths enables us to obtain robust results within a single population following the unified study protocol. Third, the CKB study collected information on morbidity and mortality in continuous time by electronic linkage with local and national surveillance systems; thus, age-specific transition rates could be estimated and treated with the time-honored methods of the multistate life table.

This study also has limitations. First, the lifestyle factors were determined at baseline and not updated during the follow-up. However, among participants attending both the baseline survey and 2013-14 resurvey (a mean follow-up period of 8 years), most of them had not changed their risk level of lifestyles, regardless of disease occurrence during this period. Additionally, using baseline lifestyle factors can also avoid possible reverse causality resulting from lifestyle change after disease onset. Second, the transition rates at every age resulted from a mixture of both the broad age range at entry and the long follow-up. Thus, cohort effects might impact our estimates. Third, the conclusion of this study was based on the premise that the lifestyle factors have a casual association with the disease of interest, which, however, could not be inferred from the present study but supported by evidence from other Mendelian randomization studies.(28-30)

The present prospective cohort study of the Chinese population shows that a healthy lifestyle was associated with longer total LE and a larger proportion of remaining years lived without major NCDs, achieving “relative compression of morbidity”. The average LE of the Chinese population has reached the level of moderately developed countries.(1) In addition to the goal of 79 years of life expectancy at birth by 2030, the blueprint of Healthy China 2030 also calls for an increase in HLE. The present study reinforces the importance of promoting healthy lifestyles in achieving this goal. Meanwhile, it is necessary to strengthen research on the impact of other health risk factors on HLE and take measures to attain absolute compression of morbidity.

Contributors

JL and LL conceived and designed the study, contributed to the interpretation of the results and critical revision of the manuscript for valuable intellectual content. LL, ZC, and JC: as the members of the CKB steering committee, designed and supervised the conduct of the whole study, obtained funding, and together with CY, YG, PP, LY, YC, HD, SB, SS, FN, acquired the CKB data. QS and YH accessed, verified and analyzed the data. QS drafted the manuscript. All authors had access to the data and have read and approved the final manuscript. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. JL and LL are the guarantors.

Declaration of interests

We declare no competing interests.

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Data sharing

Details of how to access China Kadoorie Biobank data and details of the data release schedule are available from www.ckbiobank.org/site/Data+Access.

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Table 1. Multivariable-adjusted hazard ratios (95% CIs) for each transition by the number of low-risk lifestyle factors in men and women separately.

	Number of events*	Events/PYs (/1,000)	HRs (95% CIs)					
			0-1	2	3	4	5	Per 1-factor increase
Men (n=181,544)								
Baseline → disease								
CVDs, cancer or CRDs	55,757	31.9	1.00 (Referent)	0.80 (0.78-0.81)	0.69 (0.67-0.71)	0.61 (0.59-0.63)	0.56 (0.50-0.63)	0.85 (0.84-0.86)
CVDs	44,970	25.3	1.00 (Referent)	0.80 (0.78-0.82)	0.69 (0.68-0.71)	0.63 (0.61-0.65)	0.60 (0.53-0.68)	0.85 (0.85-0.86)
Cancer	11,816	6.1	1.00 (Referent)	0.80 (0.76-0.84)	0.70 (0.67-0.74)	0.58 (0.54-0.62)	0.50 (0.38-0.64)	0.84 (0.82-0.86)
CRDs	5,956	3.1	1.00 (Referent)	0.77 (0.72-0.82)	0.63 (0.59-0.68)	0.49 (0.44-0.55)	0.29 (0.17-0.50)	0.79 (0.77-0.81)
Baseline → death†								
CVDs, cancer or CRDs	2,674	1.5	1.00 (Referent)	0.80 (0.72-0.89)	0.73 (0.65-0.81)	0.64 (0.55-0.74)	0.40 (0.20-0.80)	0.86 (0.83-0.90)
CVDs	8,394	4.7	1.00 (Referent)	0.79 (0.75-0.84)	0.68 (0.64-0.72)	0.55 (0.50-0.60)	0.43 (0.30-0.61)	0.83 (0.81-0.85)
Cancer	11,603	6.0	1.00 (Referent)	0.78 (0.74-0.82)	0.63 (0.60-0.66)	0.54 (0.50-0.58)	0.43 (0.31-0.58)	0.81 (0.79-0.82)
CRDs	17,388	9.0	1.00 (Referent)	0.79 (0.75-0.82)	0.66 (0.63-0.69)	0.55 (0.52-0.58)	0.44 (0.34-0.56)	0.82 (0.81-0.83)
Disease → death‡								
CVDs, cancer or CRDs	16,481	81.2	1.00 (Referent)	0.92 (0.88-0.96)	0.83 (0.79-0.86)	0.74 (0.69-0.78)	0.64 (0.50-0.83)	0.90 (0.89-0.92)
CVDs	10,761	62.2	1.00 (Referent)	0.88 (0.84-0.93)	0.77 (0.73-0.81)	0.69 (0.64-0.75)	0.58 (0.43-0.79)	0.88 (0.86-0.90)
Cancer	7,552	307.4	1.00 (Referent)	0.95 (0.89-1.01)	0.88 (0.82-0.94)	0.82 (0.75-0.90)	0.87 (0.61-1.25)	0.94 (0.91-0.96)
CRDs	1,767	98.7	1.00 (Referent)	0.86 (0.77-0.98)	0.73 (0.64-0.83)	0.63 (0.50-0.78)	1.00 (0.40-2.47)	0.86 (0.81-0.91)
Women (n=269,689)								
Baseline → disease								
CVDs, cancer or CRDs	77,821	29.3	1.00 (Referent)	0.93 (0.87-0.99)	0.78 (0.73-0.83)	0.69 (0.65-0.74)	0.69 (0.64-0.75)	0.88 (0.87-0.89)
CVDs	66,032	24.5	1.00 (Referent)	0.93 (0.87-1.00)	0.78 (0.73-0.83)	0.68 (0.64-0.73)	0.67 (0.62-0.73)	0.87 (0.86-0.88)
Cancer	12,819	4.4	1.00 (Referent)	0.94 (0.79-1.12)	0.87 (0.73-1.03)	0.85 (0.72-1.01)	0.85 (0.69-1.03)	0.96 (0.94-0.98)
CRDs	6,550	2.2	1.00 (Referent)	0.81 (0.70-0.94)	0.64 (0.55-0.74)	0.57 (0.49-0.67)	0.47 (0.36-0.61)	0.84 (0.81-0.86)
Baseline → death†								
CVDs, cancer or CRDs	2,036	0.8	1.00 (Referent)	0.97 (0.68-1.40)	0.81 (0.57-1.16)	0.65 (0.45-0.94)	0.57 (0.34-0.94)	0.83 (0.78-0.88)
CVDs	6,261	2.3	1.00 (Referent)	0.87 (0.70-1.07)	0.78 (0.63-0.96)	0.71 (0.58-0.88)	0.58 (0.43-0.76)	0.90 (0.87-0.93)
Cancer	9,945	3.4	1.00 (Referent)	0.75 (0.66-0.85)	0.59 (0.51-0.67)	0.45 (0.39-0.51)	0.36 (0.28-0.45)	0.77 (0.75-0.79)
CRDs	14,430	4.9	1.00 (Referent)	0.81 (0.72-0.92)	0.67 (0.60-0.76)	0.58 (0.51-0.66)	0.50 (0.41-0.59)	0.84 (0.83-0.86)

	Number of events*	Events/PYs (/1,000)	HRs (95% CIs)					
			0-1	2	3	4	5	Per 1-factor increase
Disease → death‡								
CVDs, cancer or CRDs	13,549	42.7	1.00 (Referent)	0.78 (0.69-0.88)	0.74 (0.66-0.83)	0.69 (0.62-0.78)	0.57 (0.47-0.69)	0.93 (0.91-0.95)
CVDs	9,324	34.2	1.00 (Referent)	0.76 (0.67-0.87)	0.69 (0.60-0.78)	0.59 (0.52-0.68)	0.51 (0.40-0.64)	0.87 (0.85-0.90)
Cancer	5,640	146.4	1.00 (Referent)	0.96 (0.77-1.19)	0.97 (0.78-1.20)	0.93 (0.74-1.15)	0.84 (0.63-1.11)	0.97 (0.94-1.01)
CRDs	1,155	48.9	1.00 (Referent)	0.64 (0.48-0.85)	0.66 (0.50-0.87)	0.47 (0.35-0.64)	0.35 (0.15-0.83)	0.84 (0.79-0.91)

CVDs indicate cardiovascular diseases; CRDs, chronic respiratory diseases, including chronic obstructive pulmonary disease and asthma; PYs, person-years; HR, hazard ratio; CI, confidence interval.

Multivariable models were adjusted for education (no formal school, primary school, middle school, high school, college, or university or higher), marital status (married, widowed, divorced or separated, or never married), family histories of heart attack, stroke, and cancer (presence, absence, or unknown), and menopausal status (women only) as appropriate. In the analysis of transitions from a disease state to all-cause mortality, HRs were further adjusted for age at diagnosis of corresponding diseases (years).

Low-risk lifestyle factors were defined as: never smoking or having stopped for reasons other than illness; less than daily drinking or drinking <30 g (men)/15 g (women) of pure alcohol per day (former drinkers excluded); engaging in an age- (<50 years, 50-59 years, and ≥60 years) and sex-specific median or higher level of physical activity; having at least 4 of the following dietary habits: eating fresh vegetables daily, eating fresh fruits daily, eating red meat 1-6 days per week, eating legumes ≥4 days per week, eating fish ≥1 day per week; having a BMI between 18.5 and 27.9 kg/m^2 and a waist circumference <90 cm (men)/85 cm (women).

*Number of events refers to the number of cases in each transition.

†The transition from baseline to death refers to the transition from disease-free state at baseline to death from any cause other than the concerned disease without experiencing disease onset.

‡The transition from disease to death refers to the transition from the concerned disease state to all-cause death.

Figure legends

Figure 1. Multivariable-adjusted hazard ratios (95% CIs) for each transition by individual low-risk lifestyle factors in men and women separately.
HR indicates hazard ratio; CI, confidence interval.
All five lifestyle factors were included simultaneously in the same model.
Multivariable models were adjusted for education, marital status, family histories of heart attack, stroke, and cancer, and menopausal status (women only) as appropriate.
In the analysis of transition from a disease state to all-cause mortality, HRs were further adjusted for age at diagnosis of corresponding diseases (years).
The definition of low-risk lifestyle factors was the same as in Table 1. The disease event in this analysis refers to the first occurrence of any of cardiovascular diseases, cancer, and chronic respiratory diseases (including chronic obstructive pulmonary disease and asthma). The number of events refers to the number of cases in each transition with the corresponding exposure.

Figure 2. Life expectancy at age 40 years with and without cardiovascular diseases (CVDs), cancer, and/or chronic respiratory diseases (CRDs) by levels of individual lifestyle risk factors in men and women separately.
Cigs indicate cigarettes or equivalent; BMI, body mass index; WC, waist circumference; M, men; W, women.
For compact display, the scale on the vertical axis starts from 20 years, and the parts not shown are all LE without CVDs, cancer, and CRDs. Former smokers refer to those having stopped smoking for reasons other than illness. Participants who had stopped smoking due to illness were classified as current smokers. Less than daily group included never-regular drinkers and current weekly drinkers. Former drinkers refer to those who used to drink at least once weekly but drank less than weekly at baseline. Physical activity level was categorized based on age- (<50 years, 50-59 years, and ≥60 years) and sex-specific quintile of total physical activity level. Diet score was created based on the following criteria: eating fresh vegetables daily, eating fresh fruits daily, eating red meat 1-6 days per week, eating legumes ≥4 days per week, eating fish ≥1 day per week. For each food group, the participant who met the criterion received a score of 1, and otherwise, 0.

Figure 3. Life expectancy at age 40 years with and without cardiovascular diseases (CVDs), cancer, and/or chronic respiratory diseases (CRDs) by the number of low-risk lifestyle factors in men and women separately.
The definition of low-risk lifestyle factors was the same as in Table 1.

Figure 4. Life expectancy (LE) at age 40 years without chronic diseases and life expectancy differences by the number of low-risk lifestyle factors in men and

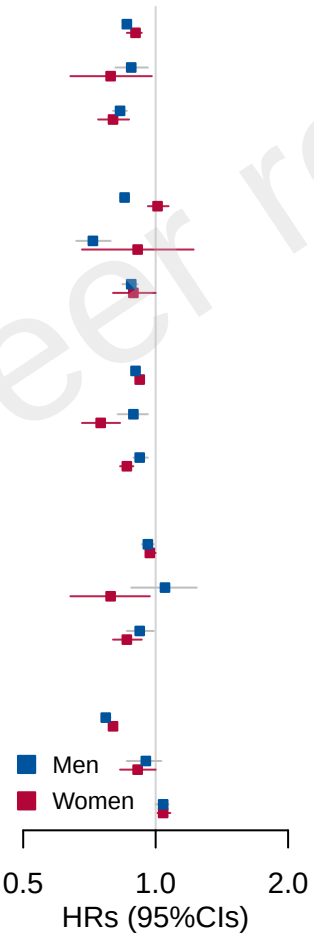
women separately.

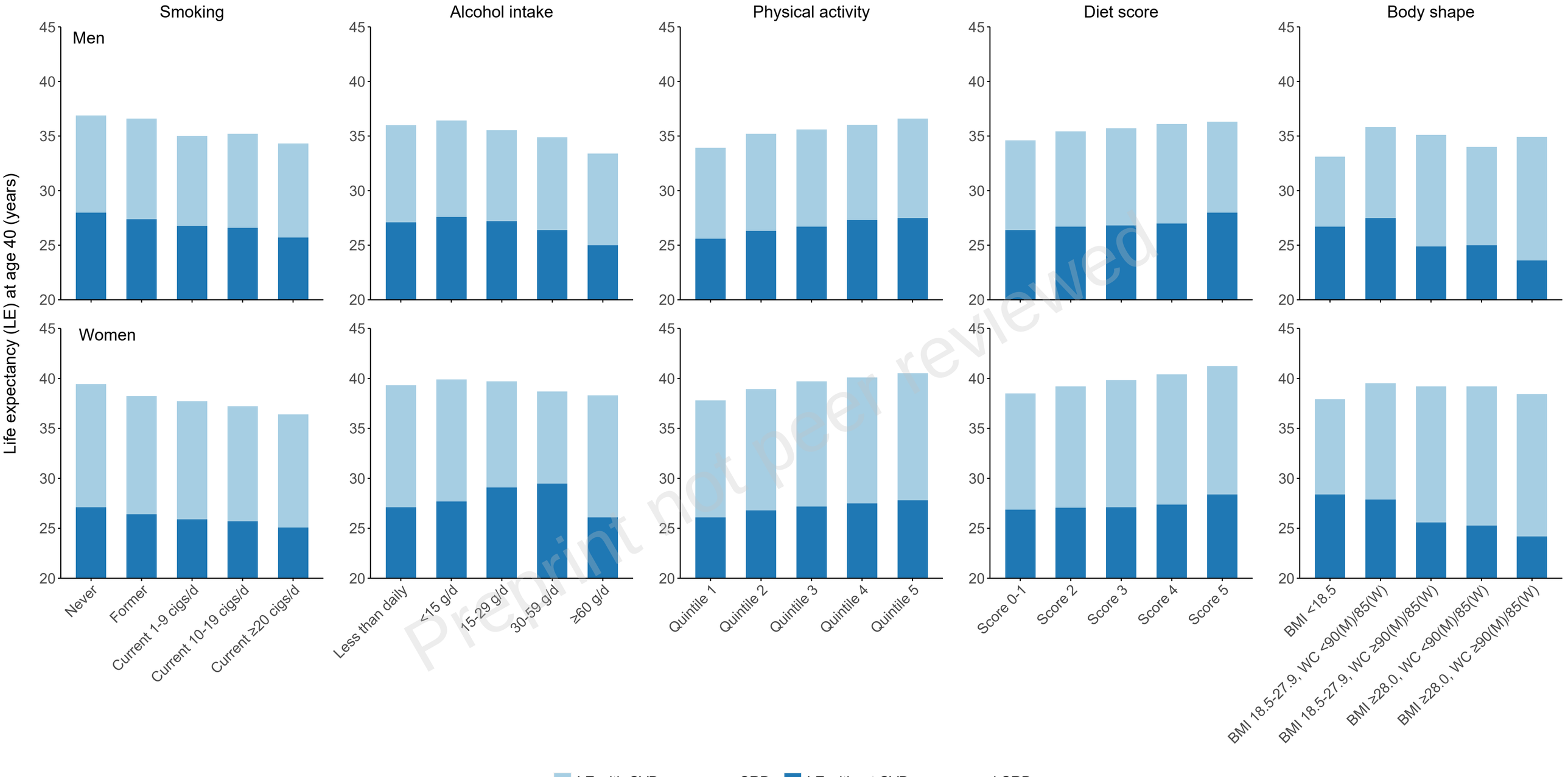
CVDs, indicate cardiovascular diseases; CRDs, chronic respiratory diseases, including chronic obstructive pulmonary disease and asthma; CI, confidence interval.

Combined diseases refer to a combination of CVDs, cancer, and CRDs, of which only the first occurrence was considered.

The definition of low-risk lifestyle factors was the same as in Table 1.

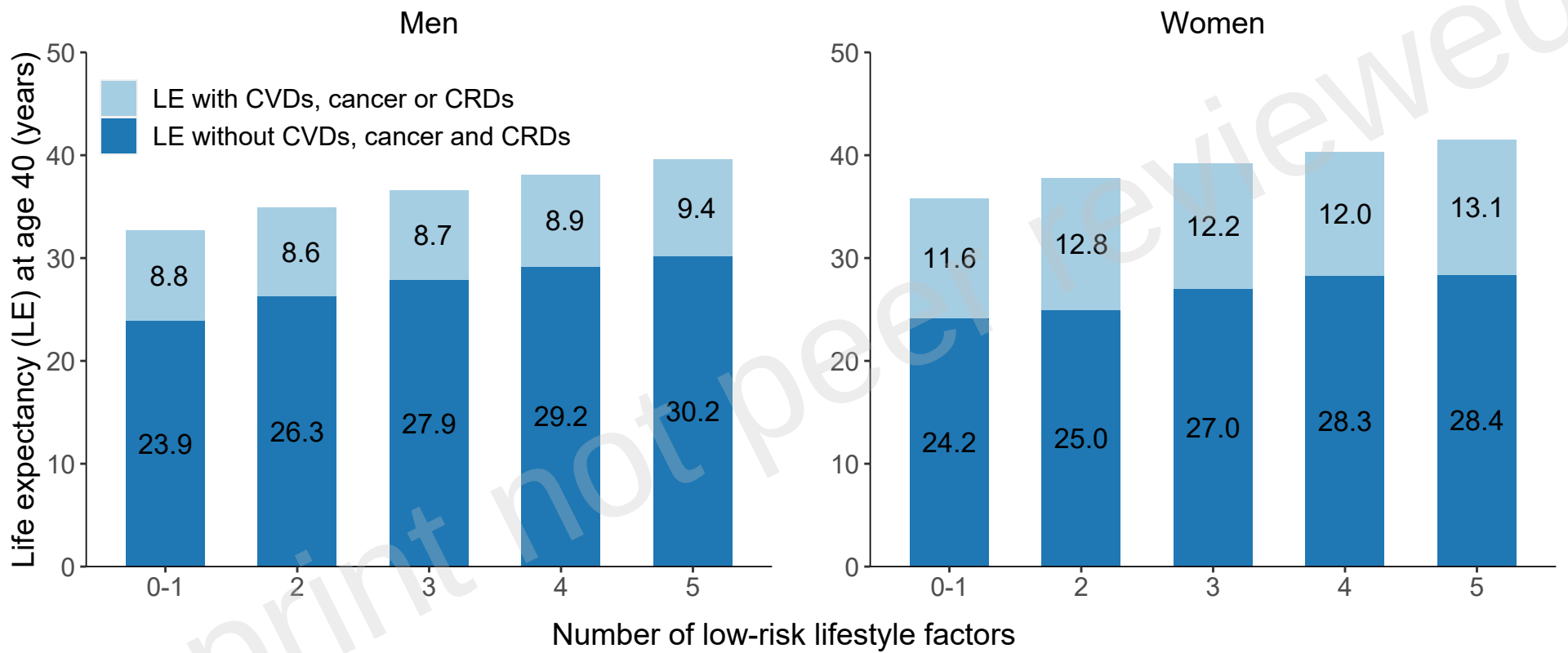
	No. of events		HRs (95%CIs)	
	Men	Women	Men	Women
Non−smoking				
Baseline −> disease	18,127	74,708	0.86 (0.85, 0.88)	0.90 (0.86, 0.93)
Baseline −> death	785	1,927	0.88 (0.81, 0.96)	0.79 (0.64, 0.98)
Disease −> death	4,823	12,683	0.83 (0.80, 0.86)	0.80 (0.74, 0.87)
Non−excessive alcohol intake				
Baseline −> disease	40,761	76,387	0.85 (0.83, 0.87)	1.01 (0.96, 1.07)
Baseline −> death	1,865	1,984	0.72 (0.66, 0.79)	0.91 (0.68, 1.22)
Disease −> death	11,631	13,219	0.88 (0.84, 0.91)	0.89 (0.80, 1.00)
Being physically active				
Baseline −> disease	24,783	33,644	0.90 (0.88, 0.91)	0.92 (0.91, 0.94)
Baseline −> death	1,316	941	0.89 (0.82, 0.96)	0.75 (0.68, 0.83)
Disease −> death	7,421	5,655	0.92 (0.89, 0.96)	0.86 (0.83, 0.89)
Healthy dietary habits				
Baseline −> disease	3,906	6,767	0.96 (0.93, 0.99)	0.97 (0.95, 1.00)
Baseline −> death	146	105	1.05 (0.88, 1.24)	0.79 (0.64, 0.97)
Disease −> death	971	811	0.92 (0.86, 0.99)	0.86 (0.80, 0.93)
Healthy body shape				
Baseline −> disease	38,032	47,570	0.77 (0.76, 0.79)	0.80 (0.79, 0.81)
Baseline −> death	2,021	1,314	0.95 (0.86, 1.03)	0.91 (0.83, 1.00)
Disease −> death	11,622	7,871	1.04 (1.00, 1.07)	1.04 (1.01, 1.08)





LE without CVDs, cancer, and CRDs / total LE (%)

Men	75.9	74.9	76.6	75.6	74.9	75.3	75.8	76.6	75.6	74.9	75.5	74.7	75.0	75.8	75.1	76.3	75.4	75.1	74.8	77.1	80.7	76.8	70.9	73.5	67.6
Women	68.8	69.1	68.7	69.1	69.0	69.0	69.4	73.3	76.2	68.1	69.0	68.9	68.5	68.6	68.6	69.9	69.1	68.1	67.8	68.9	74.9	70.6	65.3	64.5	63.0



LE without CVDs, cancer and CRDs / total LE (%)

Men	73.1	75.4	76.2	76.6	76.3	*Women*	67.6	68.1	68.9	70.2	68.4