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Mixed evidence for the compression of morbidity hypothesis for smoking elimination—a systematic literature review

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Background: There is debate around the composition of life years gained from smoking elimination. The aim of this study was to conduct a systematic review of the literature to synthesize existing evidence on the effect of smoking status on health expectancy and to examine whether smoking elimination leads to compression of morbidity. **Methods:** Five databases were systematically searched for peer-reviewed articles. Studies that presented quantitative estimates of health expectancy for smokers and non-/never-smokers were eligible for inclusion. Studies were searched, selected and reviewed by two reviewers who extracted the relevant data and assessed the risk of bias of the included articles independently. **Results:** The search identified 2491 unique records, whereof 20 articles were eligible for inclusion (including 26 cohorts). The indicators used to measure health included disability/activity limitations (n=9), health-related quality of life (EQ-5D) (n=2), weighted disabilities (n=1), self-rated health (n=9), chronic diseases (n=6), cardiovascular diseases (n=4) and cognitive impairment (n=1). Available evidence showed consistently that non-/never-smokers experience more healthy life years throughout their lives than smokers. Findings were inconsistent on the effect of smoking on the absolute number of unhealthy life years. Findings concerning the time proportionally spent unhealthy were less heterogeneous: nearly all included articles reported that non-/never-smokers experience relatively less unhealthy life years (e.g. relative compression of morbidity). **Conclusions:** Support for the relative compression of morbidity due to smoking elimination was evident. Further research is needed into the absolute compression of morbidity hypothesis since current evidence is mixed, and methodology of studies needs to be harmonized.

Introduction

Worldwide life expectancies are increasing, which is partly the result of new medical possibilities. We live longer, but the burden of non-communicable diseases (NCD) has never been higher. NCDs are currently the leading cause of deaths worldwide.[1] The majority of these NCDs may be the consequence of modifiable lifestyle risk factors, such as smoking, physical inactivity, excessive alcohol consumption and poor diet.[2] The exact influence of prevention of lifestyle risk factors on longevity and health, including the number of life years spent in good or impaired health, remains unclear. This is in particular the case for smoking.

The past decade can be described as a public health success story in terms of smoking prevalence reduction. Joint efforts have led to substantial decreases in tobacco consumption worldwide. However, smoking is still considered as a major public health threat and this is recognized by several initiatives that aim to combat this threat. A main initiative is the world's first public health treaty: the World Health Organization (WHO) Framework Convention for Tobacco Control, which is as of 2016 ratified by 180 parties.[3] Strengthening its implementation is also mentioned in the United Nations' Sustainable Development Goals.[4] Another explicit goal set by the WHO involves the 25×25 NCDs targets, which include lowering tobacco use by 30% between 2010 and 2025.[5]

There is a debate around the composition of life years gained from smoking elimination. A reduction in smoking prevalence leads to higher life expectancies because of the effect of smoking on mortality through fatal diseases.[1] However, smoking also has an effect on morbidity through a wide range of both fatal and non-fatal diseases.[6] Which effect is stronger, the morbidity or mortality effect, will determine how these life years are spent. A reduction in smoking prevalence may lead to either a compression of morbidity,[7] an expansion of morbidity,[8] or a dynamic equilibrium,[9] implying, respectively, that less smoking leads to fewer years lived with morbidity, more years lived with morbidity, or to a shift from more severe to less severe morbidity. The third theory, a dynamic equilibrium, has never been formally defined. Morbidity and disability here not binary but are more considered as processes and therefore often proposed as the 'intermediate' scenario between the other two theories.[10] Hence, in this study, we merely focus on the first two theories. Consequences on morbidity can be examined as absolute and relative effects.[11] The absolute effects reflect the change of number of years lived unhealthily. When this change is interpreted as a percentage change, we consider the consequences as relative effects.[12] On the individual level, distinguishing between the absolute and relative effects are not *per se* of an added value. However, the absolute and relative changes are both relevant to capture and estimate changes in population health.

The increased efforts that are undertaken to lower smoking prevalence's emphasize the need to understand the impact of smoking elimination on population health. This study aims to conduct a systematic literature review in order to synthesize existing knowledge on the effect of smoking status on health expectancy. Health expectancy is a measure that reflects the total life expectancy split in

years lived in good health and years lived in poor health (in absolute terms and as proportion of total lifetime)[10,13] and thus allows us to assess whether non-smokers experience a compression of morbidity or expansion of morbidity when health expectancies are compared with smokers.

Methods

Search strategy

Four databases were systematically searched for peer-reviewed studies from inception up to July 2018: Embase.com (since 1971), Medline ALL via Ovid (since 1946) Web of Science Core Collection (since 1975), Cochrane Central Register of Trials via Wiley (since 1992). An additional search was performed in Google Scholar. This search engine could help in retrieving articles that have not been published yet or had no relevant search terms in their title and abstract. The search equation combined search terms (using thesaurus terms when available combined with terms in title and/or abstract) for 'smoking' and 'health status indicators'. We adopted a broad search strategy to cover a wide spectrum of articles. The search strategy was set up together with a librarian. The complete search strategies for all databases can be found in Supplementary file S1.

Eligibility criteria

We included articles based on the following eligibility criteria:

(1) The article focuses on smoking and health expectancy.
(2) The article estimates health expectancy for smokers and non-smokers, either prospectively or retrospectively.
(3) The article focuses on a sample that aims to be representative for the general population.
(4) The article is written in English.
(5) The article is not a conference abstract, letter, note or editorial.

Health status indicators can range from objective measures (e.g. disease status) to subjective measures (e.g. self-perceived health). We did not limit inclusion by a certain type of health status indicator.

Selection strategy

Two researchers screened the retrieved articles. The predefined eligibility criteria guided the decision process for inclusion and exclusion. When the information provided in the titles and abstracts were insufficient for a decision, a brief screening of the full-text took place to decide whether the article was eligible for inclusion. Differences in screening results, among the two researchers, were discussed and resolved by dialogue. When no consensus could be achieved, a third researcher was consulted to judge. Study selection was conducted in Endnote X6.

Data extraction

Extraction forms were developed to assist in the harmonization of the extracted data. Extracted data included the following information: operationalization of exposure and outcome variables, study population characteristics, applied method to estimate health expectancy and the health expectancies. Two main approaches for the estimation of health expectancy exist, which can be applied either on cross-sectional or longitudinal data.[14] Prevalence-based life tables, also known as Sullivan's Method, is applied on cross-sectional data.[15] The other approach uses multiple measurements and is based on incidence rather than prevalence and often relies on the multi-state life tables.[16] The risk of bias was assessed with a quality assessment tool for observational cohort and cross-sectional studies (Supplementary files S2 and S3).

Data analysis

The study selection was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (figure 1).[17] For all studies it was evaluated whether a compression or expansion of morbidity (both in relative and absolute terms) occurred by comparing the findings between non-/never-smokers and current smokers.[11] An absolute expansion of morbidity indicates an increase in the number of unhealthy life years for non-/never-smokers. This may lead to either an increase or decrease in the proportion of life spent in poor health for non-/never-smokers: relative compression or expansion of morbidity.

Results

Study search

Figure 1 shows the PRISMA flow diagram of the screening process. In total, 2488 unique records were identified and screened. We excluded 2367 articles based on title and abstract. Thus, the full-text of 121 articles were assessed of which, we excluded 101 articles most of including no relevant outcomes. Moreover, one study reported health expectancies where the unhealthy and healthy life years did not add up to the total life expectancy. It was decided to exclude this article due to inadequate results. This resulted in 20 included articles. Some articles reported health expectancies for multiple population cohorts: in total health expectancies for 26 population cohorts were reported. The quality assessment (Newcastle—Ottawa quality assessment), independently conducted by two researchers, showed that the majority of the articles were of sufficient quality (scoring at least five out of the eight stars). One article[18] showed some reason for concern with scoring three stars because the study did not control for factors in the analysis.

Study characteristics

Table 1 provides characteristics of the included articles ($N = 20$), listed by cohort ($N = 26$). The first column in table 1 attaches a number to each cohort. These numbers will be used for reference in the rest of this article. Data collection of the population cohorts occurred between 1948 and 2014. Sample sizes varied from 1759 up to 42 516 respondents. Smoking status was defined in various manners, namely in two categories [(ever)smokers, non-/never-smokers]; three categories (current smokers, former smokers and never-smokers); or four categories (heavy smokers, moderate smokers, former smokers and never-smokers). The studies that applied a dichotomous definition for smoking status could still vary by group composition due to the categorization of former smokers. The indicators for health involved disability/activity of daily living limitations ($n = 9$), health-related quality of life (EQ-5D) ($n = 2$), disability weights ($n = 1$), self-rated health (SRH) ($n = 9$), chronic diseases ($n = 6$), cardiovascular diseases ($n = 4$) and cognitive impairment ($n = 1$). Some studies estimated health expectancies for different indicators for health, e.g. for both SRH and chronic diseases. The majority of the studies ($n = 11$) used a longitudinal approach by applying a multi-state (Markov) transition model. The Sullivan approach (cross-sectional data) was the other main applied method ($n = 6$). More novel methods were applied by Van Baal et al.[19] and Mehta and Myrskylä.[20]The former adopted a dynamic population model (RIVM chronic disease model) whereas the latter applied a matrix population model (an extension of the multi-state technique).

Compression of morbidity hypothesis

In order to assess the occurrence of compression of morbidity, we compared the unhealthy life years between non-/never-smokers and current smokers. Supplementary file S4 shows the health expectancies (unhealthy life years + healthy life years = life expectancy) of

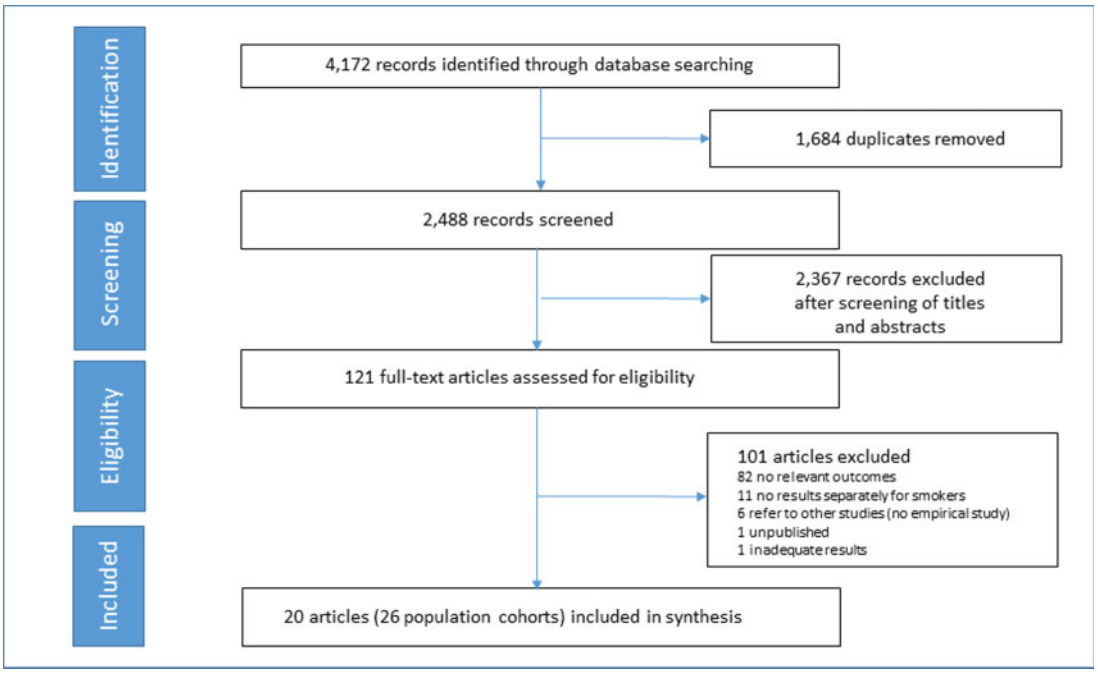

Figure 1 Flow diagram

the included articles. Table 2 shows the answers on the question whether a compression of morbidity was observed in the health expectancies. The different starting ages for the health expectancy estimations are also included in the table. The heterogeneity in the data (different health indicators, different starting ages, different smoking definitions and further stratification) hampered direct comparisons between studies. Nonetheless, we grouped the health indicators into three categories (disability, SRH and longstanding illness) in order to structure the findings and gain insights.

The results for the absolute compression of morbidity hypothesis are diffuse: approximately half of the studies reported an absolute compression of morbidity. This means that non-/never-smokers spent less time in poor health. Yet, this also indicates that approximately half of the studies found that non-/never-smokers spent a longer time in poor health than current, moderate and heavy smokers (absolute expansion of morbidity). This last finding was mostly found in studies that applied disability as an indicator for health. Most of the studies reported a relative compression of morbidity [except cohorts #7, #8, #26 (women), #11 (men), #19 (only from 80 years), #1]. The studies that did not report a relative compression of morbidity (and thus found a relative expansion of morbidity) were prevalent in all three health categories. Further, a finding was that all studies reported that non-/never-smokers have more healthy life years compared to smokers.

Health expectancies—disability

Figure 2 shows the health expectancies of the studies that are listed under the disability category in table 2. The studies #6, #8, #9 and #25 are not included in this figure because they are further stratified (#8) or have the EQ-5D or disability weights as health indicator. This figure is only reported for this measure due to the great variability between the studies. The numbers in the bars indicate the healthy and unhealthy life years.

For men, the differences in unhealthy life years between non-/never-smokers and current smokers varied between −0.3 years and +1.3 years. Most studies ($n = 8$) found more unhealthy life years for non-/never-smokers, indicating an absolute expansion of morbidity. For example, in cohort #12 it was found that non-/never-smokers would have 4.6 unhealthy life years, while current smokers would only have 3.8 unhealthy life years. The relative differences are hard to observe from this figure, but these can be found in Supplementary file S4. Most studies show a relative compression of morbidity, except cohorts #7 and #11.

For women, the same pattern was observed. However, the differences in the number of unhealthy life years between non-/never-smokers and current smokers were larger, ranging from -1.1 years to 2.4 years. For instance, in cohort #2, it was estimated that smokers would have 13.4 unhealthy life years while non-/never-smokers would have 15.8 unhealthy life years. A relative compression of morbidity was also found for women in most studies, except in the cohorts #7 and #26. Moreover, figure 2 shows that women have on average a higher total life expectancy and more unhealthy life years compared to men.

Discussion

While health expectancies are central in the debate related to quantity vs. quality of life, a relatively small number of studies have investigated the health expectancies for smokers and non-/never-smokers. This systematic review extracted 20 articles from the 2488 unique retrieved records. Within these 20 articles, a total of 26 cohorts were studied. Our collected evidence showed consistently that non-/never-smokers spent more years in good health throughout their lives than smokers. In contrast, findings were inconsistent regarding the effect smoking has on the absolute number of unhealthy life years. Estimates for unhealthy life years were diffuse for all applied health indicators. Approximately half of the studies found an absolute compression of morbidity for non-/never-smokers compared to smokers. As such, the other half of the studies reported an absolute expansion of morbidity, which is a finding that deserves attention in this discussion. Findings concerning the time proportionally spent unhealthy were less heterogeneous: nearly all included articles reported relative compression of unhealthy life years for non-/never-smokers compared to smokers. Caution in drawing universal conclusions of our findings is required because of the heterogeneity in the studies.

Chronic diseases mostly have an onset earlier in life than disabilities, however, the mortality effect of chronic diseases is reduced nowadays. Hence, life years after the onset of chronic diseases are likely to exceed life years after the onset of disabilities. Smokers may not reach the average age at which severe disabilities [e.g. Activities

Table 1 Characteristics included articles, listed by cohort

# Cohort	Country of study	Time period[a]	Sample size[b]	Smoking status definitions	Health indicator	Estimation technique	Reference
1. DYNOPTA	Australia	1990–2006	8111	Non-smokers (never-smokers and former smokers), current smokers	Cognitive impairment (MMSE examination)	Multi-state life table	(Anstey et al.)[21]
2. NPHS	Canada	1994–96	8009	Non-smokers (never smoked, stopped more than 5 years ago, or always only occasional), smokers (daily, occasional but formerly daily, or former who had stopped within the prior 5 years)	Activity limitations and dependency (preparing meals, personal care, get about the house)	Multi-state life table	(Belanger et al.)[22]
3. DANCOS	Denmark	1991, 1994	5811	Never-smokers, former smokers, moderate smokers (1–14 g tob. p/d), heavy smokers (>14 g tob. p/d)	SRH, longstanding illness	Sullivan's method	(Brønnum-Hansen and Juel)[23]
4. DANCOS	Denmark	2000	16 690	Never-smokers, former smokers, moderate smokers (1–14 g tob. p/d), heavy smokers (>14 g tob. p/d)	SRH	Sullivan's method	(Brønnum-Hansen and Juel)[24]
5. DANCOS	Denmark	2000	16 690	Never-smokers, moderate smokers (1–14 g tob. p/d), heavy smokers (>14 g tob. p/d)	SRH	Sullivan's method	Bronnum-Hansen and Juel[25]
6. DANCOS	Denmark	2000	12 524	Never-smokers, former smokers, moderate smokers (1–14 cig p/d), heavy smokers (>14 cig p/d)	EQ-5D (report general subjective health; report numbers of their physically unhealthy days, mentally unhealthy days and days with activity limitation during the past 30 days), Danish values	Sullivan's method	(Brønnum-Hansen et al.)[26]
7. EPESE	USA	1981–89	8604	Never-smokers, former smokers, current smokers (note: in most analyses past and current as single group)	Activities of daily living (walking across a small room, transferring from bed to chair, bathing, dressing, eating, grooming and using the toilet)	Multi-state life table	(Ferrucci et al.)[27]
8. EPESE	USA	1981–89	3673	Never-smokers, former smokers, never-smokers	Activities of daily living (walking across a small room, transferring from bed to chair, bathing, dressing, eating, grooming and using the toilet)	Multi-state life table	(Izmirlian et al.)[28]
9. BRFSS	USA	1993–2009	n.s.	Non-smokers (never-smokers and former smokers), current smokers (at least 100 cig in entire life; now smoking)	EQ-5D (report general subjective health; report numbers of their physically unhealthy days, mentally unhealthy days and days with activity limitation during the past 30 days)	Multi-state life table	(Jia et al.)[18]
10. POLS	The Netherlands	1997, 1999	6446	Never-smokers, former smokers, current smokers	Disability (to walk up and down the stairs, walk outside, enter/leave the house, sit down/get up from a chair, move around on the same floor, get in/out of bed,	Sullivan's method	(Klijs et al.)[29]

(continued)

Table 1 Continued

# Cohort	Country of study	Time period[a]	Sample size[b]	Smoking status definitions	Health indicator	Estimation technique	Reference
					eat/drink, get dressed/undressed, wash face/hands and wash completely)		
11. ECHP	Western Europe[c]	1998–2001	66 331	Never-smokers, daily smokers	Disability (hampered in daily activities by any physical or mental health problem, illness or disability)	Multi-state life table	(Majer et al.)[30]
12. HRS	USA	1998–2012	14 804	Never-smokers, ever smokers	Katz activities of daily living (walking, bathing, dressing, toileting, feeding)	Matrix population model (extension of multi-state technique)	(Mehta and Myrskylä)[20]
13. GLOBE & LSOA	The Netherlands and USA	1991–95 1984–90	5107 3270	Non-smokers, current smokers	Disability (living in an institution or indicated that they needed help or were unable to perform without any difficulty one or more activities of daily life)	Multi-state life table	(Nusselder et al.)[31]
14. The Framingham Heart Study	USA	1948–89	4634	Never-smokers, former smokers, current smokers	First incidental or fatal cardiovascular disease (and death)	Multi-state life table	(Nusselder et al.)[32]
15. RCPH	Denmark	1982–94	1759	Never-smokers, former smokers, current smokers	First incidental or fatal cardiovascular disease (and death)	Multi-state life table	(O'Doherty et al.)[33]
16. ESTHER	Germany	2000–10	8482				
17. Tromso	Norway	1994–2001	9179				
18. HRS	USA	1992–2000	12 652	Never-smokers, former smokers, moderate smokers, heavy smokers	SRH	Multivariate linear regression (AUC)	(Østbye and Taylor)[34]
19. AHEAD	USA	1993–2000	8124	Never-smokers, former smokers, current smokers			
20. HRS & AHEAD	USA	1992–2004	16 176	Never-smokers, former smokers, current smokers	Katz activities of daily living (walking, bathing, dressing, toileting, feeding)	Multi-state life table	(Reuser et al.)[35]
21. ELSA	UK	2002–13	8805	Non-smokers (never-smokers and former smokers), current smokers	Selft-rated health, longstanding illness	Multi-state life table	(Stenholm et al.)[36]
22. FPS	Finland	1997–2013	42 516				
23. GAZEL	France	1996–2014	14 931				
24. SLOSH	Sweden	2006–14	8118				
25. Multiple sources[d]	The Netherlands	n.s.	n.s.	Non-smokers (never-smokers and former smokers), current smokers	Coupling disease prevalence rates to disability weights available from the Dutch burden of disease study	Dynamic population model (extension of multi-state technique)	(Van Baal et al.)[19]
26. BHIS	Belgium	1997, 2001, 2004	17 148	Never-smokers, daily smokers	Activities of daily living; mobility limitations (transferring in-and-out of bed or chair, dressing, washing hands and face, feeding and using the toilet; or inability to walk without stopping for ≤200 m)	Sullivan's method	(Yokota et al.)[37]

a: Time period included in article.
b: At baseline; n.s. = not stated.
c: Nine countries: Finland, Denmark, Ireland, Austria, Belgium, Greece, Italy, Spain and Portugal.
d: Different sources were used: Dutch Burden of Disease Study, GP registrations, national registries and population surveys (STIVORO, POLS).

of daily living (ADL)] become relevant, which might explain the reported relative small differences in unhealthy life years between non-/never-smokers and smokers. Some included articles analyzed SRH and chronic diseases for the same study population (cohorts #3, #21, #22, #23 and #24). In the majority of these cohorts the largest differences between smokers and non-/never-smokers were found for health expectancies estimated with SRH. Three of the studies reported that male smokers had less years with chronic

Table 2 Compression of morbidity hypothesis overview included articles

#[a]	Health indicator		Compression of morbidity?					
			NS–CS		NS–MS		NS–HS	
			Absolute	Relative	Absolute	Relative	Absolute	Relative
			Disability					
7.[b,c]	ADL	M	65: No	65: No	NA	NA	NA	NA
		F	65: No	65: No	NA	NA	NA	NA
8.[c]	ADL	M	65: No	65: No	NA	NA	NA	NA
			70: No	70: No	NA	NA	NA	NA
			75: No	75: No	NA	NA	NA	NA
			80: No	80: No	NA	NA	NA	NA
			85: No	85: No	NA	NA	NA	NA
	Low educated		90: No	90: No	NA	NA	NA	NA
		F	65: No	65: No	NA	NA	NA	NA
			70: No	70: No	NA	NA	NA	NA
			75: No	75: No	NA	NA	NA	NA
			80: No	80: No	NA	NA	NA	NA
			85: No	85: No	NA	NA	NA	NA
			90: No	90: No	NA	NA	NA	NA
	ADL	M	65: No	65: No	NA	NA	NA	NA
			70: No	70: No	NA	NA	NA	NA
			75: No	75: No	NA	NA	NA	NA
			80: No	80: No	NA	NA	NA	NA
			85: No	85: No	NA	NA	NA	NA
	High educated		90: No	90: No	NA	NA	NA	NA
		F	65: No	65: No	NA	NA	NA	NA
			70: No	70: No	NA	NA	NA	NA
			75: No	75: No	NA	NA	NA	NA
			80: No	80: No	NA	NA	NA	NA
			85: No	85: No	NA	NA	NA	NA
			90: No	90: No	NA	NA	NA	NA
26.	ADL & mobility limitations	M	15: No	15: Yes	NA	NA	NA	NA
		F	15: No	15: No	NA	NA	NA	NA
12.	Katz ADL	M	50: No	50: Yes	NA	NA	NA	NA
		F	50: No	50: Yes	NA	NA	NA	NA
20.[c]	Katz ADL	M	55: No	55: Yes	NA	NA	NA	NA
		F	55: No	55: Yes	NA	NA	NA	NA
2.	ADL & dependency	M	45: No	45: Yes	NA	NA	NA	NA
		F	45: No	45: Yes	NA	NA	NA	NA
6.[c]	EQ-5D	M	NA	NA	25: Yes	25: Yes	25: Yes	25: Yes
		F	NA	NA	25: Yes	25: Yes	25: Yes	25: Yes
9.	EQ-5D	M	18: Yes	18: Yes	NA	NA	NA	NA
		F	18: Yes	18: Yes	NA	NA	NA	NA
10.[c]	Disability	M	55: No	55: Yes	NA	NA	NA	NA
		F	55: Equal	55: Yes	NA	NA	NA	NA
11.[d]	Disability	M	16: No	16: No	NA	NA	NA	NA
		F	16: Yes	16: Yes	NA	NA	NA	NA
13.	Disability	M	30: Yes	30: Yes	NA	NA	NA	NA
			70: Yes	70: Yes	NA	NA	NA	NA
		F	30: Yes	30: Yes	NA	NA	NA	n.a
			70: Yes	70: Yes	NA	NA	NA	NA
25.	Disability weights	M	20: Yes	20: Yes	NA	NA	NA	NA
			40: Yes	40: Yes	NA	NA	NA	NA
			60: Yes	60: Yes	NA	NA	NA	NA
		F	20: No	20: Yes	NA	NA	NA	NA
			40: No	40: Yes	NA	NA	NA	NA
			60: Yes	60: Yes	NA	NA	NA	NA
SRH								
18.[c]	SRH	M	50: No	50: Yes	NA	NA	NA	NA
			55: No	55: Yes	NA	NA	NA	NA
			60: Yes	60: Yes	NA	NA	NA	NA
		F	50: Yes	50: Yes	NA	NA	NA	NA
			55: No	55: Yes	NA	NA	NA	NA
			60: No	60: Yes	NA	NA	NA	NA
19.[c]	SRH	M	70: No	70: Yes	NA	NA	NA	NA
			75: Yes	75: Yes	NA	NA	NA	NA
			80: No	80: No	NA	NA	NA	NA
		F	70: Equal	70: Yes	NA	NA	NA	NA
			75: Yes	75: Yes	NA	NA	NA	NA
			80: No	80: No	NA	NA	NA	NA
21.	SRH	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
22.	SRH	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA

(continued)

Table 2 Continued

#[a]	Health indicator		Compression of morbidity?					
			NS–CS		NS–MS		NS–HS	
			Absolute	Relative	Absolute	Relative	Absolute	Relative
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
23.	SRH	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
24.	SRH	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
3.[c]	SRH	M	NA	NA	20: Yes	20: Yes	20: Yes	20: Yes
			NA	NA	65: Yes	65: Yes	65: Yes	65: Yes
		F	NA	NA	20: Yes	20: Yes	20: Yes	20: Yes
			NA	NA	65: No	65: Yes	65: Yes	65: Yes
4.[c]	SRH	M	NA	NA	30: Yes	30: Yes	30: Yes	30: Yes
		F	NA	NA	30: Yes	30: Yes	30: Yes	30: Yes
5.[b]	SRH	M	NA	NA	30: Yes	30: Yes	30: Yes	30: Yes
		F	NA	NA	30: Yes	30: Yes	30: Yes	30: Yes
Longstanding illness								
21.	Longstanding illness	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
22.	Longstanding illness	M	50–75: No	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
23.	Longstanding illness	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
24.	Longstanding illness	M	50–75: Yes	50–75: Yes	NA	NA	NA	NA
		F	50–75: Yes	50–75: Yes	NA	NA	NA	NA
3.[c]	Longstanding illness	M	NA	NA	20: No	20: No	20: Yes	20: Yes
			NA	NA	65: No	65: No	65: No	65: Yes
		F	NA	NA	20: No	20: No	20: Yes	20: Yes
			NA	NA	65: No	65: No	65: Equal	65: Yes
4.[c]	Longstanding illness	M	NA	NA	30: No	30: Yes	30: Yes	30: Yes
		F	NA	NA	30: No	30: Yes	30: No	30: No
1.	Cognitive impairment	M	65: No	65: No	NA	NA	NA	NA
		F	65: No	65: No	NA	NA	NA	NA
14.[c]	Cardiovascular disease	M	50: No	50: Yes	NA	NA	NA	NA
		F	50: No	50: Yes	NA	NA	NA	NA
15.[c]	Cardiovascular disease	M	50: No	50: Yes	NA	NA	NA	NA
		F	50: No	50: Yes	NA	NA	NA	NA
16.[c]	Cardiovascular disease	M	50: Yes	50: Yes	NA	NA	NA	NA
		F	50: Yes	50: Yes	NA	NA	NA	NA
17.[c]	Cardiovascular disease	M	50: Yes	50: Yes	NA	NA	NA	NA
		F	50: Yes	50: Yes	NA	NA	NA	NA

a: Corresponds with the cohort # in table 1.
b: Middle educational level.
c: Reports former smokers separately.
d: Normal body weight. NS, non/never-smoker; CS, current smoker; MS, moderate smoker; HS, heavy smoker; M, male; F, female.

diseases, while none of these studies reported that male smokers had less years in poor SRH. Put differently, health expectancy measured with SRH resulted in fewer healthy life years and more unhealthy life years for smokers compared to health expectancy estimated with chronic diseases. This could be because chronic diseases are stronger associated with mortality than SRH. Further, one study in our review had cognitive impairments as an indicator for health and reported absolute and relative expansion of morbidity for non-smokers. This health measure deviates from the other included health indicators but is an important health indicator in an aging population. Hence, the effect of smoking elimination on this health indicator is worth further exploring.

From a methodological perspective, studies differed considerably. Firstly, remaining health expectancies were estimated from a variety of ages. Health expectancy estimations from an older age (e.g. 65 years) are likely to underestimate the effect of smoking since premature deaths and early onset of reduced health are not captured. In total, eleven cohorts estimated health expectancy with a start age of 65 years and higher of which, seven cohorts reported absolute expansion of morbidity and five cohorts a relative expansion of morbidity. Secondly, various categorizations for smoking were applied. Respondents belonging to a never/non-smoking group could differ from studies with a category for former smokers. Thirdly, estimation methods for health expectancy were characterized by the Sullivan's method or the multi-state life table method. The multi-state life table method provides a richer analysis, but for health expectancy estimations, it is suggested that Sullivan's method is easier to implement and needs less assumptions.[38] Fourthly, studies used different methods to measure health status. Questionnaires, interviews, health care professionals and other sources were used.

Strengths and limitations

The discussed variety of methods hampered comparability and interpretation of the results. A meta-analysis was therefore not possible. Health expectancy as a measure for population health has become a standard. A call for adopting a homogeneous measure of health expectancy has frequently been made.[39] A strength of this systematic review was the applied search strategy, which was comprehensive and covered a variety of databases and the consultation of experts. This creates confidence that we reached the most relevant published articles. All retrieved articles were independently double screened, and the data were extracted independently.

Figure 2 Overview health expectancies based on disability measure

Conclusion

When a reduction in smoking prevalence delays both death and ill health, relative and absolute time spent unhealthily may still increase.[40] Relative compression of morbidity due to smoking elimination was found in most of the studies. Further research is needed to examine the effect of smoking elimination on the absolute number of years spent unhealthily since findings were mixed in all health categories. The health indicators for health expectancy should be more streamlined in future research to synthesize and understand the implications of smoking elimination on population health better.

The support found in approximately half of the studies for absolute expansion of morbidity for non-/never-smokers raises questions concerning the related consequences for public health. When society will be smoke-free, health expectancies change and thus the environment need to adapt accordingly to cope with this change. Health systems might be in need for specific adaptations in order to deal with people spending more years unhealthily. For instance, disease management programs with a particular focus on the most common NCDs will become more important.[41]

Supplementary data

Supplementary data are available at *EURPUB* online.

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Conflicts of interest: None declared.

Key points

- While health expectancies are central in the debate related to quantity versus quality of life, a relatively small number of studies have investigated the health expectancies for smokers and non-/never-smokers.
- Relative compression of morbidity was found for non-/never-smokers in most of the studies, absolute expansion of morbidity was found in approximately half of the studies.
- In order to estimate the effect of smoking elimination on population health more precisely it is important that research on this subject is harmonized in terms of methodology.
- When society will be smoke-free, health expectancies change and thus health systems need to adapt accordingly to cope with this change.

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