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Nationwide indoor smoking ban and impact on smoking behaviour and lung function: a two-population natural experiment

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ABSTRACT

Introduction Many countries have implemented indoor smoking bans over the past two decades. Although smoking bans have been shown to reduce cardiovascular outcomes, little is known about their impact on respiratory health. This study investigated the impact of a nationwide indoor smoking ban on smoking behaviour and lung function.

Methods We used repeated cross-sectional data from two large cohorts of the general population comprising 31 807 Swiss and 62 093 Danish adults. We compared associations between smoking ban and smoking prevalence and prebronchodilator lung function trends in Denmark (indoor smoking ban introduced in 2007) and Switzerland (indoor smoking ban introduced in 2010) from 2005 to 2010 using a quasi-experimental study design. We performed difference-in-difference analyses with linear regression models adjusted for age, sex, weight and height.

Results Denmark had a stronger decrease in active smokers compared with Switzerland. Also, forced expiratory volume in the first second was higher in Danish adults than in Swiss adults: 26 mL (95% CI 2.4 to 49) 1 year, 88 mL (65 to 112) 2 years, and 74 mL (51 to 98) 3 years after smoking ban implementation. Correspondingly, forced vital capacity was higher in Danish adults compared with Swiss adults (80 mL (50 to 109) after 1 year and 126 mL (97 to 155) after two and 3 years). Improvements were observed in both never-smokers and ever-smokers, most pronounced in ever-smokers.

Conclusions Nationwide indoor smoking ban is associated with less smoking and improved lung function in the general population. Implementing an indoor smoking ban can improve lung function by influencing smoking behaviour and reducing secondhand smoke.

Key messages

What is already know on this topic

⇒ Nationwide indoor smoking bans have a beneficial impact on cardiovascular disease and smoking-related mortality, but the impact on respiratory health and smoking prevalence is less clear.

What this study adds

⇒ This study shows that a nationwide indoor smoking ban has a positive impact on lung function and smoking prevalence in the general population, as evidenced by a stronger decrease in active smokers and better lung function in the Danish population up to 3 years after the Danish smoking ban implementation compared with the Swiss population that was not exposed to such a ban within the study period.

How this study might affect research, practice or policy

⇒ This is one of the first quasi-experimental studies in the field of respiratory public health and an example for illustrating key assumptions of the difference-in-difference approach, one of the most commonly used approaches for causal inference when randomised trials are not possible. Our findings can be used as a guidance for policymakers to make evidence-based decisions related to respiratory health in the general population.

INTRODUCTION

Secondhand tobacco smoke is a mixture of smoke from the burning tip of a tobacco product and smoke exhaled by an active smoker.[1] Work and public places such as restaurants, bars and shopping malls have historically been major sources of secondhand smoke exposure. Exposure to secondhand tobacco smoke is linked to several adverse health outcomes such as cardiovascular diseases, lower respiratory tract infections and lung cancer.[2–4] The probability of being exposed to tobacco smoke is high, considering that smoking prevalence was around 20% worldwide and 27% in Europe among people aged 15 years or older in 2015.[5] Hence, the vast majority of countries have enacted nationwide indoor smoking bans in the last two decades that prohibit smoking in work and public places. However, the benefits of such bans on public health are difficult to measure. Nonetheless, previous studies have shown that nationwide smoking bans seem to reduce hospital admissions due to cardiovascular disease,[2 6 7] and countries that have implemented such bans report lower incidence of lung cancer, reduced asthma admission rates and a lower risk of respiratory diseases.[4 8]

Only few previous studies have shown that exposure to secondhand tobacco smoke is directly

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linked to lung function with inconsistent result.[9–12] Most of these studies included hospitality workers as study participants and were based on an uncontrolled before-and-after study design, either with cohort follow-up or repeated cross-sectional surveys.[13–17] However, temporal trends cannot be controlled in the before-and-after study design that may bias a potential causal relationship between intervention and outcome, but instead a quasi-experimental study design may offer a solution for this.[18 19] A quasi-experimental study design is an empirical interventional study design that can estimate the impact of a certain intervention in a given population without random assignment, and, hence, shares several advantages with traditional experimental studies and randomised controlled trials.[20]

In the present study, we investigated the association between nationwide indoor smoking ban and lung function in two general populations using a quasi-experimental study design. We hypothesised that a nationwide indoor smoking ban is associated with less smoking and improved lung function.

METHODS

Study design and populations

We chose a quasi-experimental study design to estimate the impact of a nationwide indoor smoking ban implementation on lung function and smoking behaviour. The quasi-experimental study design compares the exposure-outcome associations between an intervention and a control group, but the group allocation is not randomised. We compared lung function and smoking behaviour trends between Denmark and Switzerland. Denmark introduced a nationwide indoor smoking ban 3 years earlier than Switzerland, thereby providing an ideal framework to approximate the causal relationship by comparing the outcomes of a group exposed to a policy (Denmark) with the outcomes of a group not exposed to the policy (Switzerland). We used repeated cross-sectional data obtained from new independent individuals each year between 2005 and 2010 from two large population-based cohorts to evaluate changes in lung function and smoking behaviour associated with the nationwide indoor smoking ban implementation: the Copenhagen General Population Study and the Swiss LuftiBus Cohort.[21 22]

Exposure group: Denmark

The Copenhagen General Population Study is a prospective population-based cohort initiated in 2003 with ongoing enrolment. So far, more than 100 000 individuals have been randomly selected and invited from the Danish Civil Registration System to reflect the adult Danish general population. All participants completed a comprehensive questionnaire, underwent a physical examination including spirometry and gave blood for biochemical and genetic analyses. Additional data for each individual are available through nationwide health registries on hospitalisations and mortality. Individuals participating between 2005 and 2010 were used to form the exposure group. Since Denmark passed the nationwide Smoke-Free Environment Act on 6 June 2007 (Act number 512), which prohibits smoking in indoor workplaces, institutions and schools for children and adults, public places (eg, hotel rooms and public transportation) and hospitality establishments (eg, restaurants and bars), the Copenhagen General Population Study provides appropriate preban and postban spirometry data.[23]

Control group: Switzerland

Spirometry data from the control group were derived from the Swiss LuftiBus Cohort. LuftiBus is a health promotion campaign conducted by the Zurich Lung Association in Switzerland, a not-for-profit health organisation.[24] The campaign included a bus that travelled throughout Switzerland in the period between 1993 and 2012 providing health information and offering spirometry to the general population. Spirometry data from 85 789 individuals were collected during this time period. Information on smoking, height and weight was also collected during the LuftiBus assessment. Since Switzerland implemented a nationwide indoor smoking ban on 1 May 2010, ie, 3 years later than Denmark, individuals participating in the LuftiBus between 2005 and 2010 were used to form the control group.

Lung function outcome measurement

Prebronchodilator measurements of forced expiratory volume in the first second (FEV_1) and forced vital capacity (FVC) were used as lung function outcomes in both the Copenhagen General Population Study and the Swiss LuftiBus Cohort. Spirometry was performed with the ndd Medical Technologies EasyOne Spirometer in the Copenhagen General Population Study and the VIASYS SensorMedics Vmax ENCORE 20c in the Swiss LuftiBus Cohort.

In the Copenhagen General Population Study, spirometry use has undergone a rigorous validation process before, including regular calibrations.[25] Spirometry was performed in a standing position without the use of a noseclip under strict instructions from a healthcare professional in accordance with the internal standard operating procedures. A valid spirometry performance was based on at least two measurements differing by less than 5%, each with acceptable quality criteria. Only the highest measurement for FEV_1 and FVC was used.

In the Swiss LuftiBus Cohort, technicians calibrated the device daily and were trained at least two times a year. After receiving oral instructions from the technicians, participants performed spirometry while sitting with a straight back and their neck in a neutral position without the use of a noseclip in accordance with the American Thoracic Society/European Respiratory Society recommendations.[26 27] A minimum of two acceptable measurements out of a maximum of eight were required for a valid spirometry performance. Only the highest measurement for FEV_1 and FVC was used.

Statistical analysis

We compared trends in smoking status between exposed (Denmark) and control (Switzerland) groups in the preban and postban period to identify changes in smoking behaviour. We performed difference-in-difference (DID) analyses to investigate the change in FEV_1 and FVC trends before and after the ban in the exposed group to the change in the outcome in the control group.[20] The DID analyses were performed with linear regression models and adjusted for age, sex, weight and height and SEs were clustered at the country level. The DID estimate is the interaction term between time and group in the regression model and can, therefore, be used to compare trends in an outcome over multiple time periods. We also used the probability of being an ex-smoker, current and never-smoker as outcomes in the DID analyses to assess if smoking ban was associated with an increased smoking cessation rate in the study population.

The year 2006 was the reference year since it immediately preceded the year of policy implementation in Denmark. Outcomes were measured at different time points before and after the ban, and we, therefore, estimated the DID for multiple time points. The main assumption for DID is that of parallel trends in outcomes between exposure and control group before

Table 1 Baseline characteristics of the exposed (DK) and control group (CH) averaged over 2005 and 2006 prior to nationwide indoor smoking ban implementation in Denmark

	Exposed group (DK) n=21 045	Control group (CH) n=12 223
Women	10 840 (52)	6372 (52)
Age, mean	61±13	51±17
Smoking status		
Never-smokers	7935 (38)	6402 (52)
Ex-smokers	8337 (40)	2938 (24)
Current smokers	4773 (23)	2876 (24)
Height, cm	171±9.4	170±9.5
Weight, kg	77±15	71±14
FEV_1, mL	2840±897	3176±975
FVC, mL	3669±1067	4092±1183

Data are presented as n (%) or mean±SD.
CH, Switzerland; DK, Denmark; FEV_1, forced expiratory volume in first second; FVC, forced vital capacity.

the ban implementation.[20] The model assumes that in absence of implementation, the postban trend would have remained unchanged between exposure and control group. Testing for parallel trends before implementation provides evidence of residual confounding over time that would bias the estimates. We provide graphical evidence for fulfilment of this assumption by plotting the mean outcomes by group and time period. We stratified the DID analyses by sex and smoking status rather than including them as covariates in our models to identify modifying effects on the smoking ban and lung function association. Furthermore, we performed subgroup analyses with only never-smokers to investigate if associations are more likely a result of change in smoking behaviour or a reduction of secondhand smoke exposure. To assess the robustness of our results, we used outcomes that should not be affected by the smoking ban policy, that is, height and weight. We chose height as a time-independent and weight as a time-dependent factor since they were available in both cohorts. We studied trends and calculated DID estimates for both outcomes. All statistical analyses were conducted in R V.4.0.4.[28]

RESULTS

Thirty one thousand eight-hundred and seven participants from Switzerland and 62 093 from Denmark aged ≥20 years were enrolled in this study between 2005 and 2010 (online supplemental table S1). At baseline between 2005 to 2006 prior to the nationwide indoor smoking ban implementation in Denmark, Danish individuals were older (61 years vs 51 years), more often ex-smokers (40% vs 24%) and had a lower lung function (FEV_1 2840 mL and FVC 3669 mL vs FEV_1 3176 mL and FVC 4092 mL) compared with Swiss individuals (table 1). Otherwise, we found no noteworthy differences. In total, there were 407 missing values (0.4%) in smoking behaviour, these cases had to be excluded from the analyses.

Trends in smoking prevalence

The prevalence of current smokers was decreasing for both countries and sexes between 2005 and 2010 after the nationwide smoking ban implementation (figure 1 and online supplemental table S2). The decrease was larger in the exposed group compared with the control group. The prevalence of ex-smokers increased in the female Danish population compared with the female Swiss population. The prevalence of never-smokers was consistently higher in the control than in the exposed group between 2005 and 2010 (online supplemental figure S1 and table S2).

In the DID analyses, we found an increasing probability of being an ex-smoker after the smoking ban implementation in women (table 2 and online supplemental figure S2). Compared with the reference year 2006, the probability increased to 6.8% (95% CI 4.0 to 9.6) in the year of smoking ban implementation, 3.3% (0.5 to 6.1) after 1 year, 5.4% (2.5 to 8.2) after 2 and

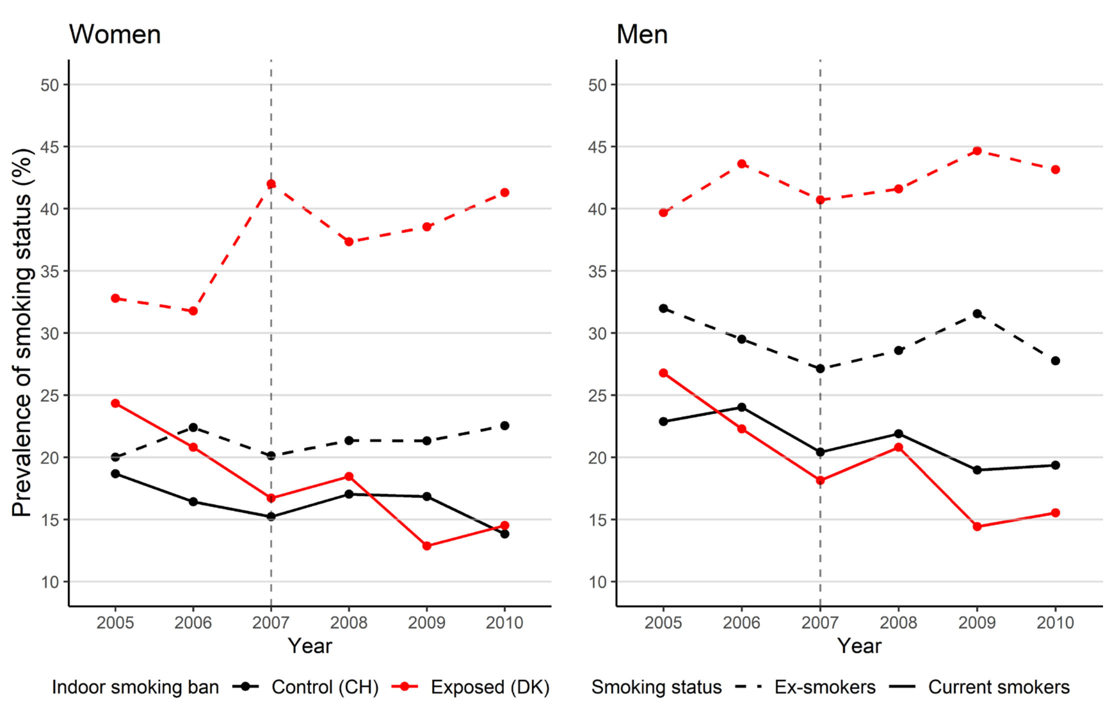

Figure 1 Trends in smoking status between exposed (DK) and control group (CH) from 2005 to 2010. CH, Switzerland; DK, Denmark.

Table 2 Difference-in-difference estimates and 95% CIs for being an ex-, current and never-smoker from 2005 to 2010, stratified by sex (corresponding, online supplemental figure S2–S4)

	Probability in Denmark compared with Switzerland in year 2006 Absolute difference in % (95% CI)					
	Ex-smoker		Current smoker		Never-smoker	
Year	Women	Men	Women	Men	Women	Men
2005	1.4 (−1.3 to 4.0)	−6.2 (−9.1 to −3.3)	1.1 (−1.3 to 3.6)	5.4 (2.6 to 8.1)	−2.4 (−5.5 to 0.6)	0.8 (−2.3 to 3.9)
2006	ref.	ref.	ref.	ref.	ref.	ref.
2007	6.8 (4.0 to 9.6)	0.5 (−2.6 to 3.7)	−5.2 (−7.7 to −2.7)	−2.5 (−5.4 to 0.4)	−1.4 (−4.6 to 1.8)	2.0 (−1.4 to 5.5)
2008	3.3 (0.5 to 6.1)	−1.2 (−4.2 to 1.9)	−3.5 (−6.0 to −1.0)	0.5 (−2.4 to 3.4)	0.3 (−2.9 to 3.5)	0.6 (−2.7 to 3.9)
2009	5.4 (2.5 to 8.2)	−0.3 (−3.4 to 2.8)	−7.8 (−10 to −5.4)	−1.5 (−4.3 to 1.3)	2.6 (−0.7 to 5.8)	1.8 (−1.6 to 5.1)
2010	6.9 (4.1 to 9.8)	2.4 (−0.6 to 5.5)	−3.9 (−6.3 to −1.5)	−1.7 (−4.4 to 1.1)	−3.0 (−6.2 to 0.2)	−0.7 (−4.0 to 2.6)

The estimates in the table show the probability of being an ex-, current or never-smoker in Denmark from 2005 to 2010 in women and men compared with Switzerland in year 2006. For example, the probability of being an ex-smoker was 6.9% higher 3 years after the smoking ban implementation in 2010 for the Danish female population compared with the Swiss female population.
Ref, reference.

6.9% (4.1 to 9.8) after 3 years in the exposed group. We did not observe a similar increase in male participants.

Accordingly, the probability of being a current smoker decreased in the female but not in the male population by −5.2% (95% CI −7.7 to –2.7) in the year of smoking ban implementation, −3.5% (−6.1 to −1.0) after 1 year, −7.8% (−10 to −5.4) after 2 and −3.9% (−6.3 to −1.5) after 3 years in the exposed group compared with the reference year 2006 (table 2 and online supplemental figure S3). The probability of being a never-smoker did not change after the smoking ban implementation between the two populations (table 2 and online supplemental figure S4).

Trends in lung function

Trends in FEV_1 and FVC were almost parallel between the exposed and control group in the preban period from 2005 to 2007 (figure 2 and online supplemental table S3). We observed changes in trends with implementation of the nationwide smoking ban from 2007 and onwards. As expected, trends in height and weight were parallel in the preban and postban period, and the 95% CIs did not overlap in any of the years between the two groups.

Compared with the control group, FEV_1 in the exposed group was higher: 26 mL (95% CI 2.4 to 49) after 1 year, 88 mL (65 to 112) after 2 years and 74 mL (51 to 98) after 3 years of smoking ban implementation (figure 3 and online supplemental table S4). Correspondingly, FVC was also higher: 80 mL (50 to 109) after 2 years and 126 mL (97 to 155) after 3 years of smoking ban implementation.

Subgroup analyses

For never-smokers, FEV_1 was highest with 65 mL (95% CI 33 to 97) after 2 years and remained constant after 3 years of smoking ban implementation (figure 4 and online supplemental table S5). FVC changed from 66 mL (26 to 106) after 2 years to 99 mL (59 to 139) after 3 years. The DID estimate was higher for current and ex-smokers than for never-smokers but with overlapping CIs (figure 4 and online supplemental table S5). FEV_1 was 97 mL (62 to 132) after 2 years and FVC 143 mL (101 to 186) after 3 years in current and ex-smokers. For women, FEV_1 and FVC were highest 3 years after smoking ban implementation with 81 mL (95% CI 55 to 108) and 133 mL (99 to 166), respectively (online supplemental figure S5 and table S6). For men, FEV_1 was highest 2 years and FVC 3 years after smoking ban implementation with 112 mL (73 to 151) and 110 mL (64 to 157), respectively.

Sensitivity analyses

As expected, we could not see a clear pattern for change in height and weight between exposed and control group after nationwide smoking ban implementation. Height changed by −0.3 cm (95% CI −0.6 to −0.002) after 1 year, 0.5 cm (0.2 to 0.8) after 2 years and 0.1 cm (−0.2 to 0.4) after 3 years of implementation in the exposed group (online supplemental figure S6 and table S7). Correspondingly, weight changed by 1.0 kg (0.4 to 1.5), 0.6 kg (−0.02 to 1.1) and −0.7 kg (−1.2 to −0.1), respectively.

DISCUSSION

In this two-population natural experiment, we found that population FEV_1 and FVC increased in Denmark, the country that implemented a nationwide indoor smoking ban compared with Switzerland that did not. FEV_1 and FVC were also increased in the subpopulation of never-smokers, indicating an improved lung function through reduced secondhand smoke exposure. Since FEV_1 and FVC differences tended to be even larger for ex-smokers and current smokers than for never-smokers, our findings suggest both a direct impact through smoking cessation and an indirect impact through reduced secondhand smoke exposure. The probability of being an ex-smoker increased and the probability of being a current smoker decreased in Denmark in the year of the ban implementation and thereafter in women but not in men. This is one of the first studies to provide evidence for a positive association between indoor smoking ban and respiratory health in the general population using a quasi-experimental approach.

Mechanistically, the improved lung function in ex-smokers and current smokers is likely explained in part by the observed increased smoking cessation in exposed versus control population. However, the subgroup analyses within never-smokers

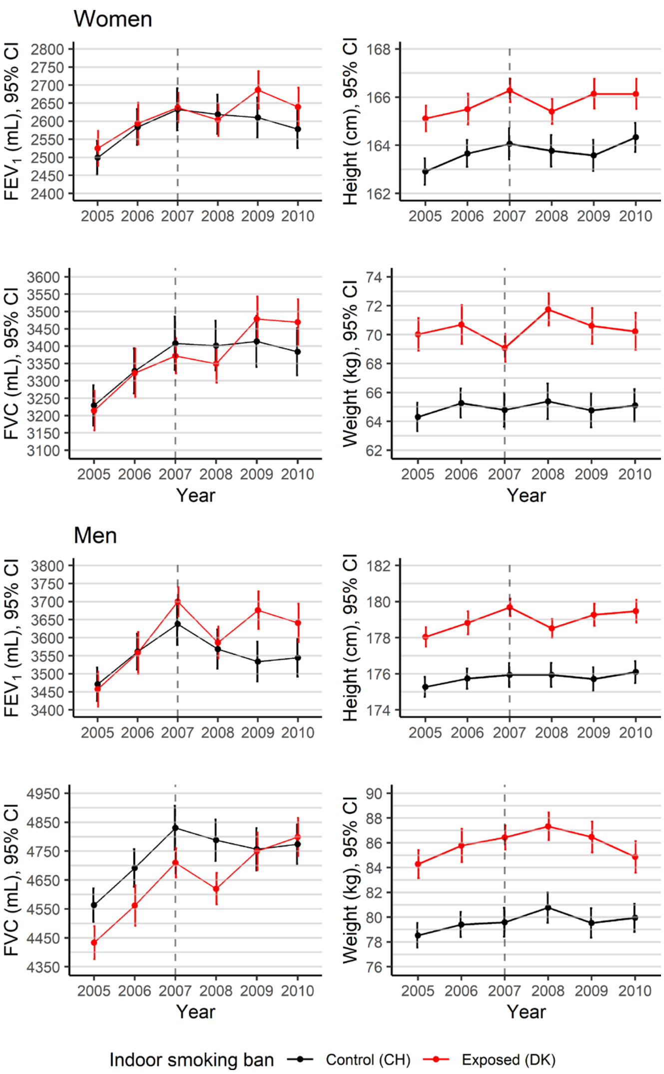

Figure 2 Trends in age-standardised FEV_1, FVC, height, and weight between exposed (DK) and control group (CH) according to sex and 95% confidence intervals (CIs). CH, Switzerland; DK, Denmark; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity.

indicate that changes in lung function may not be due to changes in smoking behaviour (eg, smoking cessation) but rather due to a reduced exposure to secondhand smoke. A positive influence of reduced exposure to secondhand smoke likely will affect both never-smokers and ever-smokers.

Two systematic reviews have shown that evidence for an association between indoor smoking ban and lung function is scarce and inconsistent. In a Cochrane Review from 2016, two out of four studies reported improved lung function after an indoor smoking ban[11 15 29]; however, all four studies were based on an uncontrolled before-and-after study design and included small samples of hospitality workers (n ranging from 71 to 105). In another systematic review from 2017, eight out of nine studies were based on small samples of hospitality workers (n ranging from 53 to 198) and one study was based on healthy miners.[12] Six out of these nine studies reported positive effects of smoking bans on lung function: the pooled meta-analysis resulted in a net difference in FEV_1 of 100 mL (95% CI −40 to 240) (three studies included) and in FVC of 190 mL (130 to 250) (two studies included). Based on these systematic reviews and our extensive literature search, we could not find any study that estimated the association of indoor smoking ban on lung function based on the general population and using a quasi-experimental study design.

We found that the mean difference in FEV_1 was 88 mL higher after 2 years and in FVC 126 mL after 3 years of smoking ban implementation. These changes may have significant repercussions for public health as several large observational studies have shown a strong association of lung function with mortality in community-based cohorts.[30 31] In a prospective, international, community-based cohort study including 126 359 adults, the largest population burden was associated with mildly to moderately reduced FEV_1.[30] Therefore, even a reduction of mildly to moderately impaired FEV_1 may have a great impact on health, in particular, on mortality and cardiovascular diseases.[30]

Our study has several limitations. One could argue that a potential limitation is that there was no random allocation of study participants to the exposed or control group. However, such an experiment would be unethical as smoking is known to be harmful. Thus, the best approach is to use a quasi-experimental study design to derive potential causal relationships. As our assumptions were met and results seemed robust, we believe our results to be valid. Another potential limitation is that there were no longitudinal lung function data available, which would have allowed a pre–post comparison within the same individuals. However, the DID method considers changes over time within a group as well as relative to a control group. Although the Danish and the Swiss cohorts are similar in terms of key characteristics,

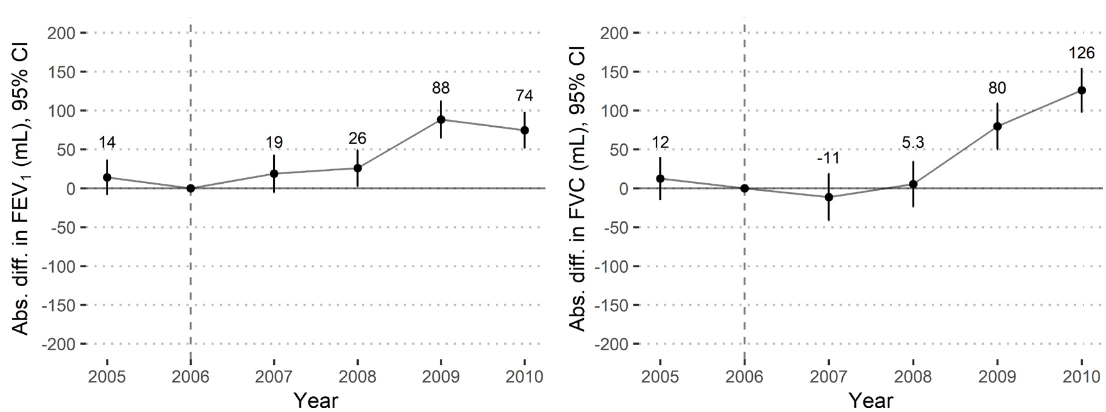

Figure 3 Age-standardised difference-in-difference for FEV_1 and FVC from 2005 to 2010 and 95% CIs. The dotted line represents the reference year: 1 year prior the smoking ban implementation in the exposed group. Analyses were adjusted for age, sex, weight, and height and standard errors were clustered at the country level. Abs. diff., absolute difference; FEV_1, forced expiratory volume in first second; FVC, forced vital capacity.

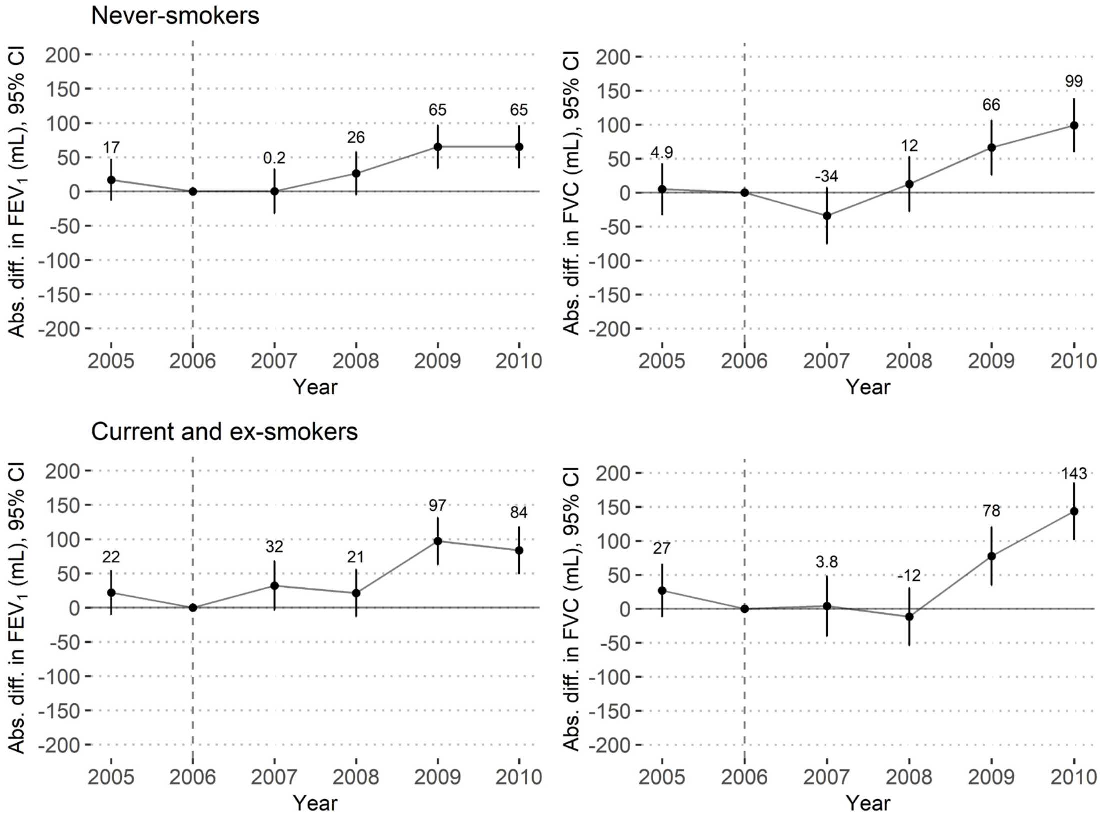

Figure 4 Age-standardised difference-in-differences estimates for FEV_1 and FVC from 2005 to 2010 among never- and ever-smokers and 95% CIs. The dotted line represents the reference year: 1 year prior the smoking ban implementation in the exposed group. Analyses were adjusted for age, sex, weight, and height and standard errors were clustered at the country level. Abs. diff., absolute difference; FEV_1, forced expiratory volume in first second; FVC, forced vital capacity.

we cannot fully rule out that other important cohort differences, such as comorbidities, may have confounded our study results.

The quasi-experimental study design is the major strength of this study. The comparison with an appropriate control group provides suggestive evidence for a causal relationship between smoking ban and lung function changes. The risk that changes in outcomes are a result of natural temporal trends or unmeasured events that occurred in the same time period is minimised in controlled study designs compared with the uncontrolled before-and-after study design. The greatest challenge of DID analyses is finding an appropriate control group that meets the parallel trend assumption. We show that trends in outcomes were almost parallel in the preban period and that our findings were unlikely to be a result of unobserved trends. We presented DID estimates at multiple time points, which allows the effect to be described up to 3 years after the smoking ban implementation. In the sensitivity analyses, we showed that other outcomes (ie, height and weight) were unaffected by the smoking ban implementation, which supports the assumption that changes in lung function were a result of the smoking ban. Results from quasi-experiments have higher external validity than those from traditional experimental studies because the inclusion of participants is less restrictive.[18] Therefore, we are confident to say that the results of this study likely can be generalised to a general population with similar exposure patterns.

In conclusion, we found that nationwide indoor smoking ban is associated with less smoking and improved lung function in the general population. Implementing an indoor smoking ban can improve lung function by influencing smoking behaviour and reducing secondhand smoke.

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Contributors SA and MAP had full access to all data in the study and had final responsibility for the decision to submit for publication. Study concept and design: AS, YÇ, MSB, BGN, AT, SA and MAP. AT provided data of the LuftiBus Cohort. Statistical analyses: SA, MSB, AS. Interpretation of the data: AS, YÇ, MSB, BGN, SA and MAP. Drafting the manuscript: AS and YÇ. Revision of the manuscript for important intellectual content: AS, YÇ, MSB, BGN, AT, SA, AT and MAP. MAP is responsible for the overall content as guarantor.

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Competing interests YÇ reports personal fees from Boehringer Ingelheim, AstraZeneca, and Sanofi Genzyme outside of the submitted work. MSB reports grants from the European Commission's H2020 and EiT Health programmes outside of the submitted work.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by The Herlev and Gentofte Hospital and a Danish ethical committee (approval number: H-KF-01-144/01) and the Ethics Committee of the Canton of Zurich in Switzerland (BASEC-Nr. 2017-01804). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement The Swiss data are available from the corresponding author MAP (miloalan.puhan@uzh.ch) upon reasonable request. The Danish data are available from SA (shoaib.afzal@regionh.dk) upon reasonable request. However, according to national Danish laws, only summary-level data (as reported herein) and scripts can be shared.

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