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LE BOUDEC Joana

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Smoking cessation and the incidence of pre-diabetes and type 2 diabetes: a cohort study

THESE

préparée sous la direction du Professeur Jacques Cornuz
sous la co-direction de la Dre Carole Clair
(avec la collaboration du Professeur associé Pedro Marques-Vidal)

et présentée à la Faculté de biologie et de médecine de
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par

Joana LE BOUDEC

Médecin diplômé de la Confédération Suisse
Originaire de Bâle (BS)

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Résumé en Français

Incidence de pré-diabète et diabète de type 2 à l'arrêt du tabac : une étude de cohorte

Le tabagisme est associé à un risque augmenté de développer un diabète de type 2. Arrêter de fumer devrait donc diminuer le risqué de diabète. Seulement, les études concernant le risque métabolique à l'arrêt du tabac sont discordantes.

Par ailleurs, les effets métaboliques du tabac et de l'arrêt du tabac diffèrent probablement selon le sexe, avec notamment un effet différent du tabac sur la santé des femmes, et une prise pondérale plus importante à l'arrêt que chez les hommes. Notre étude vise à évaluer le risque métabolique à l'arrêt du tabac, chez les femmes et les homes séparément.

Nous avons utilisé les données de l'étude de cohorte prospective *CoLaus,* qui évalue différents facteurs de risque cardiovasculaire chez des sujets choisis de manière aléatoire, dans la population Lausannoise entre 35 et 75 ans, suivis sur 5.5 ans en moyenne. Parmi ceux avec une glycémie à jeun normale au départ, nous avons divisé les participants en quatre groupes selon leur statut tabagique : non fumeurs, personnes ayant arrêté de fumer depuis plus de 5 ans, celles ayant arrêté depuis moins de 5 ans, et fumeurs actifs. Nous avons mesuré les incidences de glycémie à jeun altérée (5.6-6.99 mmol/l) et de diabète (glycémie à jeun ≥ 7 mmol/l et/ou traitement pour le diabète) durant le période de suivi, stratifiées par sexe. Puis le risque d'incidence de glycémie altérée et de diabète a été calculé avec trois niveaux d'ajustement pour les facteurs confondants pour un risque métabolique.

Nous avons inclus 3166 participants, dont 63% de femmes. Au total, 26.3% étaient fumeurs, 6.5% ex-fumeurs depuis moins de 5 ans et 23.5% ex-fumeurs depuis plus de 5 ans. Durant le suivi, 1311 (41.4%) personnes ont développé une glycémie à jeun altérée (33.6% des femmes, 54.7% des homes), et 47 (1.5%) ont développé un diabète (1.1% des femmes, 2.1% des hommes). Les personnes ayant arrêté de fumer n'avait pas de risque significativement plus élevé de développer une glycémie à jeun altérée ou un diabète que les fumeurs, après ajustement pour l'âge, l'éducation, l'hypercholestérolémie, la prise d'alcool, l'activité physique, la prise de poids, le BMI initial et le BMI d'arrivée dans les différents modèles d'ajustement. L'analyse de l'interaction du sexe avec ces résultats est également négative.

Les analyses de sensibilité ont montré que l'exclusion des personnes ayant changé de statut tabagique durant le suivi ne changeait pas ces résultats. Nous avons refait les analyses en incluant les participants ayant une glycémie altérée au début du suivi, mais le risque d'incidence de diabète n'est pas plus élevé chez les ex-fumeurs que chez les fumeurs non plus dans cette population. Sur demande d'un reviewer, nous avons également refait les analyses avec la glycémie en continue (valeurs de base et valeurs à 5.5 ans), et la glycémie moyenne n'était pas différente par groupe de tabagisme.

En conclusion, dans cette population européenne d'âge moyen, avec une prévalence basse d'obésité et une prise de poids modérée durant le suivi, nous n'avons pas trouvé de risque significativement plus élevé de développer un diabète en arrêtant de fumer, et ce pour les deux sexes. L'arrêt du tabac doit donc être encouragé chez toutes les fumeuses et tous les fumeurs.

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Smoking cessation and the incidence of pre-diabetes and type 2 diabetes: a cohort study

Joana Le Boudec [a,*], Pedro Marques-Vidal [b], Jacques Cornuz [a], Carole Clair [a]

[a] Department of Ambulatory Care and Community Medicine, Lausanne University Hospital, Lausanne, Switzerland
[b] Institute of Social and Preventive Medicine, Lausanne University Hospital, Lausanne, Switzerland

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ABSTRACT

Aims: Smoking cessation has been suggested to increase the short-term risk of type 2 diabetes mellitus (T2DM). This study aimed at assessing the association between smoking cessation and incidence of T2DM and impaired fasting glucose (IFG).
Methods: Data from participants in the CoLaus study, Switzerland, aged 35–75 at baseline and followed for 5.5 years were used. Participants were classified as smokers, recent (≤5 years), long-term (>5 years) quitters, and non-smokers at baseline. Outcomes were IFG (fasting serum glucose (FSG) 5.6–6.99 mmol/l) and T2DM (FSG ≥7.0 mmol/l and/or treatment) at follow up.
Results: 3,166 participants (63% women) had normal baseline FSG, of whom 26.7% were smokers, 6.5% recent quitters, and 23.5% long-term quitters. During follow-up 1,311 participants (41.4%) developed IFG (33.6% women, 54.7% men) and 47 (1.5%) developed T2DM (1.1% women, 2.1% men). Former smokers did not have statistically significant increased odds of IFG compared with smokers after adjustment for age, education, physical activity, hypercholesterolemia, hypertension and alcohol intake, with OR of 1.29 [95% confidence interval 0.94–1.76] for recent quitters and 1.03 [0.84–1.27] for long-term quitters. Former smokers did not have significant increased odds of T2DM compared with smokers with multivariable-adjusted OR of 1.53 [0.58–4.00] for recent quitters and 0.64 [0.27–1.48] for long-term quitters. Adjustment for body-mass index and waist circumference attenuated the association between recent quitting and IFG (OR 1.07 [0.78–1.48]) and T2DM (OR 1.28 [0.48–3.40].
Conclusion: In this middle-aged population, smoking cessation was not associated with an increased risk of IFG or T2DM.

1. Introduction

Smoking is as an established risk factor for type 2 diabetes (T2DM) (Athyros, Katsiki, Doumas, Karagiannis, & Mikhailidis, 2013; Willi, Bodenmann, Ghali, Faris, & Cornuz, 2007) and increases the risk of micro- and macro-vascular complications (Clair, Cohen, Eichler, Selby, & Rigotti, 2015; Eliasson, 2003; Turner et al., 1998). The increased risk is due to different mechanisms: smoking is toxic on the pancreatic beta cells (Hartwig et al., 2000), acts on inflammatory pathways (Arnson, Shoenfeld, & Amital, 2010), induces oxidative stress, and favours central obesity (Chiolero, Faeh, Paccaud, & Cornuz, 2008) and insulin resistance (Eliasson, 2003; Facchini, Hollenbeck, Jeppesen, Chen, & Reaven, 1992). As a consequence, to quit smoking should reverse or at least lower this increased metabolic risk. However, the reversible character of the pro-diabetogenic effects of smoking has not yet been proven. Besides, smoking cessation is associated in most cases with weight gain (Aubin, Farley, Lycett, Lahmek, & Aveyard, 2012), which is a known risk factor for T2DM. Weight gain is also an important barrier to smoking cessation in many smokers (Luostarinen et al., 2013).

Studies on metabolic risk after smoking cessation show controversial results. A meta-analysis estimated that the risk of developing T2DM for ex-smokers was not as high as that of smokers, but was still 23% higher relatively to non smokers (Willi et al., 2007). The incidence of T2DM after smoking cessation has been investigated in six prospective studies (Hur et al., 2007; Luo et al., 2013; Oba et al., 2012; Wannamethee, Shaper, & Perry, 2001; Will, Galuska, Ford, Mokdad, & Calle, 2001; Yeh, Duncan, Schmidt, Wang, & Brancati, 2010) and all showed an increased risk compared with never smoking in the first years following smoking cessation.

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* Corresponding author at: Policlinique Médicale Universitaire, Rue du Bugnon 44, 1011, Lausanne, Switzerland. Tel.: +41 76 471 62 50; fax: +41 21 314 61 06.
E-mail address: joana.leboudec@gmail.com (J. Le Boudec).

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The development of metabolic risk goes through a continuum from normoglycemia to impaired fasting glucose (IFG), a pre-diabetic state, and T2DM. IFG is the key state in which life style measures are effective to prevent disease (Orozco et al., 2008). Only few studies considered the risk of developing impaired fasting glucose following a smoking quit attempt and most focused on established T2DM.

Furthermore gender/sex disparities might exist concerning metabolic risk after smoking cessation. Studies suggest that women might gain more weight at smoking cessation (Flegal, Troiano, Pamuk, Kuczmarski, & Campbell, 1995) and the effect of smoking on their health also differs from men (Chiolero et al., 2008; Tanko & Christiansen, 2004).

Our study aimed at assessing whether the incidence of T2DM as well as IFG increases after smoking cessation in a middle-aged European population and test for an interaction with gender.

2. Subjects, material and methods

2.1. CoLaus study

Data from a Swiss prospective observational cohort study (CoLaus) were used. The CoLaus study has been accepted by the Ethics Committee of the Canton de Vaud. The sampling procedure of the CoLaus study has been described previously (Firmann et al., 2008). Recruitment began in June 2003 and ended in May 2006. The following inclusion criteria were applied: (i) written informed consent; (ii) age 35–75 years; (iii) willingness to take part in the examination and to have a blood sample drawn. Participation rate was 41% and 6,733 participants (3,544 women and 3,189 men) were recruited. A follow up interview at 5.5 years was completed in 2012.

2.2. Participants

For the present study, 5,064 participants who completed follow-up were selected. Ninety of them (0.8%) were further excluded because of missing data for smoking status, fasting serum glucose (FSG), treatment for T2DM, body-mass index (BMI) or waist circumference at baseline or follow up. Participants with T2DM (n = 278) or IFG (n = 1530) at baseline were also excluded, leaving 3,166 participants with FSG ≤5.6 mmol/l and no treatment for T2DM.

2.3. Variables

2.3.1. Impaired fasting glucose and T2DM

The primary outcomes were the cumulative 5.5-year incidences of IFG and of T2DM. Serum glucose was measured at baseline and 5.5-year follow-up from blood samples drawn after an 8-hour fasting. T2DM was defined as FSG ≥7 mmol/l or presence of an oral anti-diabetic or insulin treatment. IFG was defined as FSG between 5.60 and 6.99 mmol/l and no treatment for T2DM.

2.3.2. Smoking status

Smoking status and years since quitting were self-reported. Participants were categorised in four groups: current smokers if they reported smoking ≥1 cigarette/day or ≥1 pipe or cigar/day at baseline; recent quitters if they reported quitting smoking ≤5 years before baseline; long-term quitters if they reported quitting >5 years before baseline, and as never smokers otherwise. We considered pipe and cigar smoking as equivalent to cigarette smoking because they represented a minority of smokers (7%) and because all types of tobacco combustion are harmful (Katsiki, Papadopoulou, Fachantidou, & Mikhailidis, 2013).

Exposure of interest was smoking cessation > 5 years or ≤ 5 years before baseline, with smokers as the control group.

2.3.3. Other variables

BMI was calculated based on weight and height measured at baseline. Waist circumference was measured at a level midway between the lower rib margin and the iliac crest.

Baseline BMI (kg/m^2) and weight gain during follow up (weight at follow up minus weight at baseline in kilograms) was calculated in women and men.

We defined participants as physically active if they exercised at least 20 minutes of leisure time physical activity per week (Ponte et al., 2013; Stringhini et al., 2012). Alcohol consumption was defined as reported standard units consumed per week. High level of education was defined as having completed at least secondary school (>9 years of school) (Firmann et al., 2008). As participants were included from an urban area, they were mainly with middle to high socio-economic status. Hypercholesterolemia was defined as LDL cholesterol ≥4·1 mmol/l or taking a lipid lowering treatment; hypertension was defined as a systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg and/or taking an antihypertensive drug treatment.

2.4. Statistical analysis

2.4.1. Basis analysis

Statistical analysis was conducted using Stata version 12·0 (StataCorp, College Station, Texas). Descriptive results were presented as number of participants (percentage) or as mean ± standard deviation. Between-group comparisons were performed using Student t-test for continuous variables and Fischer's exact test for proportions.

Analyses were stratified by sex. The associations between smoking status and incidences of IFG and T2DM were assessed separately. We used logistic regressions to estimate the odds ratio (ORs) and 95% confidence intervals (CI) of developing IFG or T2DM in recent quitters, long-term quitters and never smokers compared with smokers. Three levels of adjustment were performed: age only (model 1); age, education, leisure-time physical activity, alcohol consumption, hypercholesterolemia, and hypertension (model 2), and all variables in model 2 plus BMI, and waist circumference (model 3). We adjusted for waist circumference and BMI in a separate model because they might be mediators rather than confounders in the relationship between smoking cessation and development of IFG or T2DM.

Finally, we tested the interaction for sex in the association between smoking status and IFG or T2DM incidence using an interaction term in the fully adjusted non-stratified model.

A two-sided p-value <0.05 was considered as statistically significant.

2.4.2. Sensitivity analyses

We tested whether participants with inconsistent smoking status during the 5.5 years of follow-up influenced results. These participants (n = 343, 10.8%) were excluded, and the association between smoking status and IFG or T2DM by smoking status was assessed in the remaining 2823 (89.2%) participants using the fully adjusted model (model 3). We also repeated the analyses without excluding participants with IFG at baseline (n = 1,530, 30.8%). This was done to test whether selecting participants with normal FSG introduced a bias towards T2DM resistant smokers and ex-smokers.

We also adjusted the multivariate analysis to weight change defined as weight at follow up minus weight at baseline (model 4).

Finally, in post-hoc analyses we analysed the change in glycaemia as a continuous variable between baseline and follow up in each smoking category by Wilcoxon Ranksum test and between categories by Kruskall Wallis test.

3. Results

3.1. Subjects

The baseline characteristics of the participants free from IFG and T2DM are summarized in Table 1. There were 63% of women, mean age was 50.7 years and the majority had a high educational level. There were 846 smokers (26.7%), 207 recent quitters (6.5%), 743

long-term quitters (23.5%) and 1370 never smokers (43.3%). Men presented significantly higher levels of cardiovascular risk factors and were more frequently current or former smokers than women.

3.2. Weight gain during follow-up

Weight gain during follow up according to smoking status can be found in Table 2. Overall, women gained slightly less weight than men over the 5.5 years of follow-up with a median of 1.2 kg (interquartile range (IQR) −0.9 to 3.7) compared with 1.6 kg (IQR −0.8 to 4.2) in men ($p = 0.048$). Among women, recent quitters gained the most weight with a median of 1.6 kg, followed by smokers (1.5 kg), long-term quitters (1.3 kg) and never smokers (1.1 kg). Among men, smokers gained the most weight with a median of 2 kg, followed by never smokers (1.5 kg), long term quitters (1.4 kg), and recent quitters (1.3 kg).

3.3. Association between smoking status and incidence of IFG or T2DM

During follow-up, 1,311 participants (41.4%) developed IFG and 47 (1.5%) T2DM. The unadjusted cumulative incidences of IFG and T2DM according to baseline smoking status, stratified by sex are shown in Fig. 1. Women had a lower cumulative incidence of IFG than men (33.6% versus 54.7%, $p < 0.001$). Similarly women also had a lower incidence of T2DM than men (1.1% versus 2.1%, $p = 0.032$).

The results of the minimal-adjusted and multivariable-adjusted analyses of the associations between incidence of IFG or T2DM and smoking status are summarized in Table 3. No statistically significant association was found between smoking and the incidence of IFG or T2DM. Former smokers did not have statistically significant increased odds of IFG compared with smokers, with multivariable-adjusted OR, adjusted for age, education, physical activity, hypercholesterolemia, hypertension and alcohol intake, of 1.29 [0.94–1.76] for recent quitters and 1.03 [0.84–1.27] for long-term quitters. Further adjustment for body-mass index and waist circumference attenuated the association for recent quitters (OR 1.07 [0.78–1.48]) and to a lesser extent for long-term quitters (OR 0.96 [0.78–1.19]). Similarly, former smokers did not have statistically significant increased odds of T2DM compared with smokers with multivariable-adjusted OR of 1.53 [0.58–4.00] for recent quitters and 0.64 [0.27–1.48] for long-term quitters. Further adjustment for body-mass index and waist circumference attenuated the association for recent quitters (OR 1.28 [0.48–3.40]). The sex × smoking status interaction was non-significant.

3.4. Sensitivity analyses

The analyses were repeated using the fully adjusted model after excluding participants who changed their smoking status during follow-up: 204 (10.2%) women and 139 (11.8%) men. Again, no significant association was found between the incidence of IFG or T2DM and smoking status but the association was somewhat stronger for recent quitters (Supplementary Table 1).

A second sensitivity analysis was performed using the fully adjusted model 3 and including 1,530 participants with IFG at baseline (and who initially excluded in the main analyses, total $N = 4696$). Never smokers had a significantly lower likelihood of developing T2DM compared with smokers (OR 0.67 [0.49–0.94]), while recent quitters and long-term quitters did not have statistically different odds of developing T2DM compared with smokers.

The adjustment for weight change between baseline and follow up did not change the main results, as there was no significant increase in IFG and T2DM incidence after smoking cessation when adjusted for this factor either (Table 3, model 4).

Finally analysis of change in glycaemia between baseline and follow-up showed no statistically significant difference ($p = 0.16$) between smokers and those who had stopped smoking or never smoked (Supplementary Table 2).

4. Discussion

In this study, we found no significant association between smoking cessation and the incidence of IFG or T2DM. On average men were at higher metabolic risk at baseline and also gained more weight during follow up than women, but there was no interaction between sex and metabolic risk after smoking cessation.

4.1. Smoking cessation and risk of T2DM

In a meta-analysis including 25 cohort studies not specifically designed to assess the relationship between smoking cessation and the incidence of T2DM, former smokers had on average a lower risk of developing T2DM compared with current smokers on the long term (Willi et al., 2007).

Nevertheless, six studies specifically designed to assess T2DM after smoking cessation showed an increased risk in the short term after cessation compared with never smoking (Hur et al., 2007; Luo et al., 2013; Oba et al., 2012; Will et al., 2001; Yeh et al., 2010); Will et al. showed an increased risk of T2DM in the first ten years after smoking

Table 1
Baseline characteristics of 3166 participants with normal FSG at baseline.[a]

	Total N = 3166	Women N = 1993	Men N = 1173	p value
Mean age at baseline, years	507 ± 02	51.5 ± 105	49·3 ± 102	<0001
Higher educational level (secondary school or university)	1579 (49·9)	945 (47·4)	634 (54·1)	<0001
BMI at baseline, kg/m^2	24·6 ± 01	24·1 ± 4·1	255 ± 34	<0001
Waist circumference at baseline, cm	849 ± 02	804 ± 106	92·6 ± 9·9	<0001
Hypercholesterolemia[b]	705 (22·3)	381 (19·1)	324 (27·6)	<0001
Low HDL (<1.03 mmol/l)	469 (14·8)	124 (6·2)	345 (29·4)	<0001
Hypertension[c]	808 (25.5)	447 (22·4)	361 (30.8)	<0001
Alcohol consumption, standard units/week	56 ± 01	3.7 ± 5·1	8·8 ± 10.0	<0001
Higher leisure time physical activity (≥20 min/week)	2124 (67·1)	1330 (66·7)	794 (67·7)	060
Positive family history of diabetes	622 (19·6)	417 (209)	205 (17·5)	006
Baseline cardiovascular disease[d]	131 (4·1)	74 (40)	57 (5·3)	006
Smoking status				<0001
Never smokers	1370 (433)	932 (46·8)	438 (37·3)	
Long term quitters (>5 years)	743 (235)	454 (22·8)	289 (24·6)	
Recent quitters (≤5 years)	207 (65)	111 (56)	96 (8·2)	
Smokers	846 (267)	496 (249)	350 (29·8)	

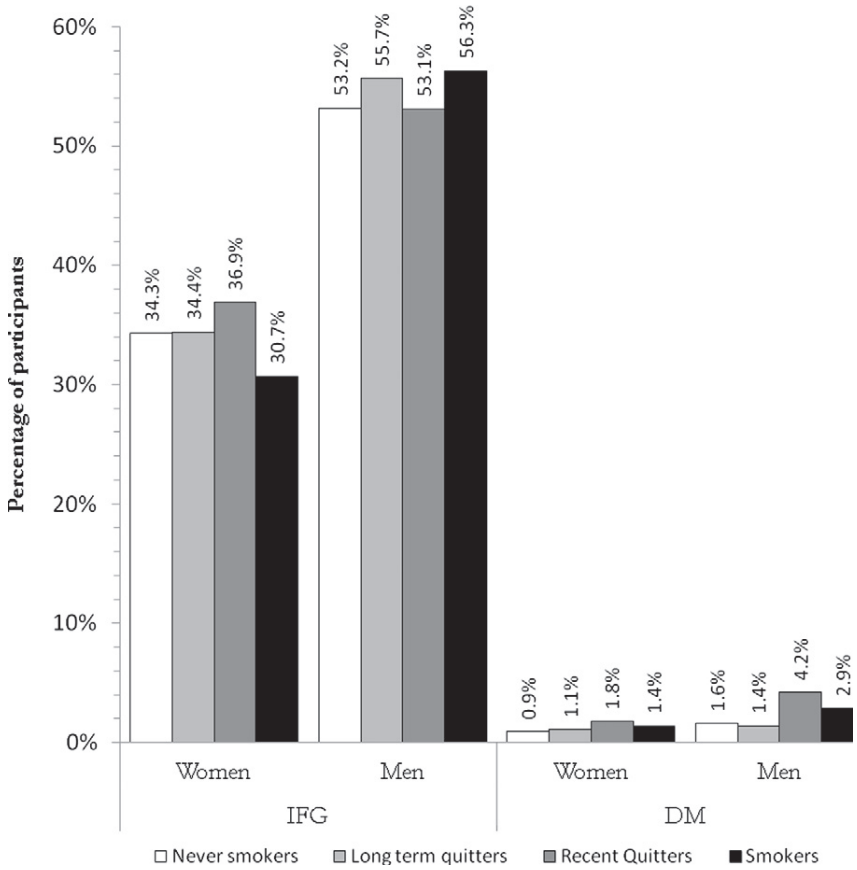
[a] Results are expressed as number of subjects (percentage) or as means ± standard deviation.
[b] Defined as LDL >4·1 mmol/l or hypolipidemic treatment.
[c] Defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg and/or antihypertensive drug treatment.
[d] Defined as coronary heart disease present at baseline. BMI: body mass index.

Table 2
Body mass index at baseline and weight gain between baseline and follow up according to baseline smoking status.

	Total		Women		Men		P-value***
	BMI*	Weight gain**	BMI*	Weight gain**	BMI*	Weight gain**	
Never smokers	24·7 ± 0.4	1.2 (−0.8 to 3.7)	24·4 ± 4.2	1.1 (−0.9 to 3.4)	25·2 ± 3.4	1.5 (−0.7 to 4·1)	0.047
Long term quitters	24.9 ± 0.6	1.3 (−0.9 to 3.4)	24.2 ± 4·1	1.3 (−0.9 to 3.4)	25·9 ± 3·6	1.4 (−1.1 to 3.4)	0.682
Recent quitters	25·2 ± 0.9	1.5 (−1 to 4.7)	24.3 ± 3·6	1.6 (−1.0 to 4.9)	26·2 ± 3·1	1.3 (−0.7 to 4·6)	0.940
Smokers	24·1 ± 0.5	1.7 (−1 to 4.7)	23.2 ± 4.0	1.5 (−1.0 to 4·5)	25·4 ± 3.3	2·0 (−0.9 to 4.9)	0.185
All subjects	24·6 ± 0.1	1.3 (−0.9 to 3.9)	24·1 ± 4·1	1.2 (−0.9 to 3.7)	25.5 ± 3.4	1.6 (−0.8 to 4.2)	0.048

BMI = body-mass index, SD = standard deviation, IQR = interquartile range.
* Mean+/−SD, kg/m^2.
** Median (IQR), kg.
*** p-value for differences in weight gain between men and women using Wilcoxon Ranksum test.

cessation for men and in the first five years for women in a US population (Will et al., 2001). No specific data were given regarding weight gain. Wannamathee and colleagues reported a higher risk of T2DM for smokers who had quit for less than five years compared with British smokers who continued to smoke (Wannamethee et al., 2001). In this study participants gained between 3.2 and 4.3 kg and recent quitters gained more weight than continuing smokers and long-term quitters (4.3 vs. 3.8 vs. 3.2 kg). In Korea, Hur et al. reported a significantly increased risk of T2DM for men who had quit for two to four years compared with non-smokers (Hur et al., 2007). No specific data were given regarding weight gain. In 2010 Yeh et al. showed an increased risk of T2DM in American men and women in the first six years after smoking cessation compared with smokers (Yeh et al., 2010). Recent quitters gained significantly more weight (3.8 kg) compared to continuing smokers (0.6 kg) and longer term quitters (1.2 kg). In Japan, Oba showed an increased risk of T2DM among male former smokers who had quit for less than five years compared with never smokers but former smokers who had quit for longer than five years did not have an increased risk (Oba et al., 2012). Recent quitters gained more weight (1.3 kg) than continuing smokers (0.2 kg) and long-term quitters (0.2 kg). In this same study among women, the risk of T2DM was increased to a greater extent, and for all former smokers, even those who had quit for a longer period. A recent study, conducted in the US among women, also showed an increased risk of



IFG, Impaired fasting glucose (Fasting serum glucose 5·60 - 6·99 mmol/l and no treatment for diabetes)

DM = type 2 diabetes (Fasting serum glucose ≥ 7mmol/l and/or treatment)

Fig. 1. Unadjusted five years incidence of IFG and T2DM according to baseline smoking status, stratified by gender.

Table 3
Multivariate analysis of the associations between incidences of IFG and T2DM and smoking status.

	Smokers	Recent quitters	Long-term quitters	Never smokers
IFG (N = 3,166)	N = 846	N = 207	N = 743	N = 1370
No. of events	349	92	317	553
Model 1	1	1.20 (0.88–1.64)	0.94 (0.77–1.11)	0.93 (0.78–1.12)
Model 2	1	1.29 (0.94–1.76)	1.03 (0.84–1.27)	1.08 (0.90–1.30)
Model 3	1	1.07 (0.78–1.48)	0.96 (0.78–1.19)	1.05 (0.87–1··27)
Model 4	1	1.12 (0.80–1.55)	0.97 (0.78–1.21)	1.09 (0.90–1.32)
T2DM (N = 3,166)	N = 846	N = 207	N = 743	N = 1370
No. of events	17	6	9	15
Model 1	1	1.50 (0.58–3.87)	0.56 (0.24–1.27)	0.53 (0.26–1.06)
Model 2	1	1.53 (0.58–4.00)	0.64 (0.27–1.48)	0.58 (0.28–1.21)
Model 3	1	1.28 (0.48–3.40)	0.57 (0.24–1.38)	0.57 (0.27–1.20)
Model 4	1	1.33 (0.50–3·53)	0.57 (0.24–1.34)	0.57 (0.27–1.19)

Results are expressed as odds ratio (OR) and 95% confidence interval relative to current smokers. Statistical analysis by logistic regression. Model 1: adjusted for age. Model 2: adjusted for age, education, physical activity, hypercholesterolemia, hypertension and alcohol intake. Model 3: adjusted for age, education, physical activity, hypercholesterolemia, hypertension, alcohol intake, *body mass index and waist circumference*. Model 4: adjusted for age, education, physical activity, hypercholesterolemia, hypertension, alcohol intake, body mass index, waist circumference and *weight gain*.

T2DM in the first ten years after quitting (Luo et al., 2013). In this study recent quitters gained more weight (2·9 kg) than all other groups (0.3–0.5 kg). All these studies used never smokers as the reference group and none compared directly quitters with continuing smokers. None of these studies specifically tested the risk for IFG development.

Our study does not confirm these findings. Several hypotheses can explain the discrepancy. First, weight gain after smoking cessation was rather limited in our cohort particularly among recent quitters. This may explain the lower incidence of T2DM and IFG after smoking cessation compared with other cohorts. Surprisingly, recent quitters did not gain more weight than the continuing smokers in our study. In most studies described earlier, recent quitters gained more weight over time than continuing smokers (with differences in weight gain ranging from 0.5 to 3.2 kg) and this might in part explain the lack of association between smoking cessation and T2DM or IFG in our study.

Second, the association between smoking cessation and T2DM probably draws an inverse U-shaped curve (Clair & Cornuz, 2010) with an increased risk of T2DM in the short term, followed by a decrease after several years of abstinence. Based on the six prospective studies, it takes between two to ten years for a former smoker to have a risk of T2DM similar to that of someone who has never smoked. In our population, recent quitters had quit for 2·6 years but former smokers were abstinent for 19·5 years on average. We might have measured the incidence of T2DM at a moment when the risk was already decreasing, explaining the absence of positive association for former smokers.

Another hypothesis is that the population we followed might not be comparable to that of the other studies. Our sample was rather homogenous, including an urban population with middle to high socio economic status. Our population had a standard prevalence of T2DM for Europe (5.6%), but great differences between men and women for IFG and T2DM incidence and a low prevalence of obesity (12%). Indeed, in Europe there is an estimated prevalence of 6% of diabetes (in adults, type 1 and 2 together) as compared with 11.1% in North America (Whiting, Guariguata, Weil, & Shaw, 2011), and the prevalence of obesity in Europe is around 10–30% (Anonymous, 2010) as compared with 34.9% in the US (Ogden, Carroll, Kit, & Flegal, 2014). These particularities have to be taken into account, and our results cannot be generalized to other populations.

Supplementary analyses showed that change in glycaemia was similar in the different smoking categories. This strengthens our results and the hypothesis that higher weight gain in quitters than in smokers might explain the increased risk of diabetes after smoking cessation found in other studies.

Our study speaks against an increase in metabolic risk after smoking cessation, in an urban normal weight European setting with overall low weight gain.

4.2. Limitations and strengths

The study has a number of limitations that need to be acknowledged. First, since this is an observational prospective study, associations were measured but there is no proof that they are causal. Some potential confounders such as diet were not included in our models. Second, variables were measured at baseline and five-year follow-up only. Smoking habits might have changed during this period. However we conducted a sensitivity analysis excluding participants with inconstant smoking behaviour over follow-up, which showed no significant influence on the analyses. Additionally, other studies have used similar timeframes and found valid results (Clair et al., 2013; Oba et al., 2012; Wannamethee et al., 2001). Third, smoking status and duration of smoking abstinence were self-reported. There might be a difference between the actual duration of smoking abstinence and the reported years, and we had no biological validation of smoking abstinence. People usually remember well when they quit smoking and self-reported smoking status is considered as trustworthy in this kind of population (Patrick et al., 1994). Another limitation is the exclusion of participants with pre-diabetes at baseline. We therefore conducted another sensitivity analysis, in which we included people with IFG at baseline. We observed a significantly lower risk of T2DM in never smokers. We might have underestimated the increased risk in smokers and ex-smokers by selecting only baseline participants with normal glycaemia. This has to be taken into account when generalizing our results to global population. Furthermore, the number of events is quite low in our population, especially the incidence of new T2DM. As observed by the large confidence intervals for the incidence of T2DM in multivariate analysis (Table 3), lack of power might explain the non-significant results. Finally we have used impaired fasting glucose and not impaired glucose tolerance because only a minority of participants had an oral glucose tolerance test. Impaired glucose tolerance test is a better predictor for cardiovascular disease than impaired fasting glucose (Nathan et al., 2007).

Several strengths deserve to be mentioned. Our study is based on prospective data, representative of real life conditions. We used data from an initial population of over 5,000 participants followed over a 5.5-year period and randomly selected. The sample we studied is representative of an urban middle-aged population of European decent. Numerous life styles, as well as anthropometric and biologic variables, were reliably collected, allowing for an extensive adjustment for potential confounders. We have especially been able to measure fasting serum glucose levels, which is a major strength of this study.

5. Conclusion and implication

In an urban population of European decent, smoking cessation is not associated with an increased risk of pre-diabetes or T2DM, compared with smoking continuation or not smoking. Health professionals should strongly recommend smoking cessation with focus on limiting weight gain after quitting.

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