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Consumption of individual saturated fatty acids and the risk of myocardial infarction in a UK and a Danish cohort

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ABSTRACT

Background: The effect of individual saturated fatty acids (SFAs) on serum cholesterol levels depends on their carbon-chain length. Whether the association with myocardial infarction (MI) also differs across individual SFAs is unclear. We examined the association between consumption of individual SFAs, differing in chain lengths ranging from 4 through 18 carbons, and risk of MI.

Methods: We used data from 22,050 and 53,375 participants from EPIC-Norfolk (UK) and EPIC-Denmark, respectively. Baseline SFA intakes were assessed through validated, country-specific food frequency questionnaires. Cox regression analysis was used to estimate associations between intakes of individual SFAs and MI risk, for each cohort separately.

Results: During median follow-up times of 18.8 years in EPIC-Norfolk and 13.6 years in Denmark, respectively, 1204 and 2260 MI events occurred. Mean (±SD) total SFA intake was 13.3 (±3.5) en% in EPIC-Norfolk, and 12.5 (±2.6) en% in EPIC-Denmark. After multivariable adjustment, intakes of C12:0 (lauric acid) and C14:0 (myristic acid) inversely associated with MI risk in EPIC-Denmark (HR upper versus lowest quintile: 0.80 (95%CI: 0.66, 0.96) for both SFAs). Intakes in the third and fourth quintiles of C4:0–C10:0 also associated with lower MI risk in EPIC-Denmark. Moreover, substitution of C16:0 (palmitic acid) and C18:0 (stearic acid) with plant proteins resulted in a reduction of MI risk in EPIC-Denmark (HR per 1 energy%: 0.86 (95%CI: 0.78, 0.95) and 0.87 (95%CI: 0.79, 0.96) respectively). No such associations were found in EPIC-Norfolk.

Conclusion: The results from the present study suggest that the association between SFA and MI risk depends on the carbon chain-length of the SFA.

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1. Introduction

Limiting the intake of dietary saturated fatty acids (SFAs) is an important component of the dietary recommendations for the prevention of coronary heart disease (CHD) [1–4]. A high intake of SFAs, compared with carbohydrates is associated with higher serum LDL cholesterol concentrations [5], which is an established risk factor for CHD. However, the link between SFAs and CHD has been heavily debated for years now, because of inconsistent results from observational cohort studies [6–9].

One of the proposed explanations for the inconsistent findings in meta-analyses of these cohort studies is that the association between SFAs and CHD differs across types of SFAs, based on their carbon-atom chain lengths. A recent meta-analysis of 52 controlled trials showed that the effect of dietary SFA on serum cholesterol levels in humans differed depending on the carbon-chain length [5]. Compared to carbohydrates, lauric acid (C12:0), myristic acid (C14:0) and palmitic acid (C16:0) increased LDL and HDL cholesterol, C12:0 improved the total to HDL cholesterol ratio, and stearic acid (C18:0) had neutral effects [5]. This suggests not all SFA may be equally harmful with respect to CHD development. Approaching SFAs as a whole in observational studies may therefore have obscured the association with CHD risk.

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Four previous prospective cohort studies [10–13] indeed observed differential associations with CHD when individual SFAs were separated in the analyses, but their findings are inconsistent. In the Nurses’ Health Study (NHS) [10,13] and the Health Professional Follow-up Study (HPFS) [13], SFAs with chain lengths of 12 or more carbons were associated with a higher CHD risk. In the Rotterdam study, C16:0 was associated with an increased risk [12]. In the EPIC-NL cohort, the SFAs with chain lengths up to 10 carbons, as well as the odd-chain SFAs, pentadecylic acid (C15:0) and margaric acid (C17:0), were associated with a lower CHD risk [11].

Addressing the associations of individual SFAs with CHD risk in other populations will yield more insight into if and how individual SFAs associate with CHD risk. Therefore, the objective of this study was to investigate the association between individual SFAs and MI risk in a UK and a Danish cohort.

2. Methods

2.1. Study population

For the present study, we used data from EPIC-Norfolk (European Investigation into Cancer and Nutrition-Norfolk cohort), and from the Danish Diet, Cancer and Health cohort (further referred to as EPIC-Denmark). Both cohorts are part of the international multicentre EPIC study [14]. Detailed descriptions of the design and rationale of both cohorts can be found elsewhere [15,16]. In brief, the recruitment of both cohorts took place between 1993 and 1997. Participants for EPIC-Norfolk were recruited through 35 participating General Practices in the rural areas of Norfolk and markers as well as the city of Norwich, in the United Kingdom [15]. A total of 25,639 men and women, aged 40 through 74 years, were enrolled in the study. Participants for EPIC-Denmark were selected from the Copenhagen and Aarhus areas in Denmark, and were identified through the Civil Registration System (CPR) [16]. Selection criteria were being born in Denmark, being between 50 and 64 years of age, and being free of cancer. A total of 57,053 men and women were enrolled.

All participants gave written informed consent before enrolment into the study, and ethical approval for the studies was obtained from the Norfolk and Norwich Hospital Ethics Committee (EPIC-Norfolk) and from the relevant Scientific Committees and the Danish Data Protection Agency (EPIC-Denmark).

We included participants who had a history of cancer (n = 1435 in EPIC-Norfolk; n = 574 in EPIC-Denmark), a history of cardiovascular disease (EPIC-Norfolk, n = 1045) or myocardial infarction (EPIC-Denmark, n = 900), had missing or incomplete dietary data (n = 547; n = 91), reported implausible energy intakes compared to their estimated basal metabolic rate (n = 266; n = 554), or had missing data on co-variables (n = 296; n = 1559), leaving 22,050 and 53,375 participants for analysis in EPIC-Norfolk and EPIC-Denmark, respectively.

2.2. Dietary assessment

Baseline dietary data were obtained through validated, country specific Food Frequency Questionnaires (FFQs), that allowed the participants to specify the food consumption frequency during the preceding year [17,18]. For each participant, the daily intakes of macro- and micronutrients were calculated using FETA [19], based on McCance & Widdowson’s food composition tables [20]–[29] (Norfolk) or the software program FoodCalc [30] (EPIC-Denmark). Data on individual fatty acid intake were calculated based on the fatty acids supplement to the McCance & Widdowson’s The Composition of Foods [31], or McCance and Widdowson’s The Composition of Foods integrated dataset (CoF IDS) [32], and on the Danish food composition tables from 1996 [33].

The FFQs were both previously validated [34–36] against weighed records. The Norfolk FFQ was not validated for its ability to measure saturated fat, but for total fat, the correlation coefficient was 0.55 in women [34]. For the Danish FFQ, the correlation coefficients were 0.67 (men) and 0.68 (women) for total fat intake, and 0.46 (men) and 0.39 (women) for saturated fat intake [36].

For the present analyses, the intakes of individual saturated fatty acids (SFAs), and of all other macronutrients were expressed as percentages of total energy intake (en%). For both cohorts, we summed the intakes of butyric acid (C4:0) through capric acid (C10:0), because of very low intakes and because they are all derived from dairy food sources. For the same reasons, the intakes of C15:0 and C17:0 were also summed in EPIC-Norfolk. In EPIC-Denmark, C15:0 was analysed individually because no data on C17:0 intake were available. C12:0 through C14:0 and C12:0 through C18:0 were also analysed combined to facilitate comparison with a previous study [13]. Furthermore, for the Danish cohort, trans fatty acids intake was available only from ruminant sources, and was therefore left out of the analyses.

2.3. Outcome assessment

Information on vital status was obtained by flagging the participants for death certification at the United Kingdom Office of National Statistics (EPIC-Norfolk), and through linkage with The Danish National Patient Register [37] and The Danish Register of Causes of Death [38] (EPIC-Denmark). Information on hospital admissions in Norfolk and Denmark was obtained through linkage with the Norfolk Health Authority database (ENCORE), and the Danish National Patient Register, respectively.

The cause of death or hospital admission were coded according to the ninth revision of the International Classification of Diseases (ICD) for Norfolk, and according to the eight and tenth ICD revisions for Denmark. The outcome of interest in the present study was incident myocardial infarction (MI). This included both fatal and non-fatal events classified with codes 410–410.09 (ICD-8 and ICD-9) and I21.0–I21.9 (ICD-10). In the Danish cohort also stroke and cardiac arrest cases (ICD-8 code: 427.27, and ICD-10 codes: 146.0–146.9) were included if the arrest was considered to be of cardiac origin after validation. Follow up was up until 31 March 2015 (EPIC-Norfolk), and 31 December 2009 (EPIC-Denmark). Follow-up rates were (very close to) 100% for both cohorts.

2.4. Assessment of other variables

Information on baseline non-dietary factors, including medical history, medication use, smoking status, alcohol use, education level and physical activity level, was obtained through general questionnaires. Smoking status was defined as never, former and current. Education level was categorized as none, 0 level, A level, and having a degree (Norfolk), or, according to the number of years one attended school: 0–7 years, 8–10 years, >10 years (Denmark). Alcohol intake, as obtained from the FFQ, was expressed according to the following categories: none, 0–5, 5–15, 15–30, 30–45, and ≥45 g/d. Physical activity level was obtained using a validated questionnaire and expressed according to the Cambridge Physical Activity Index [39] into the following categories: active, moderately active, moderate or not active, and inactive.

Height, weight and waist circumference were measured at the physical examination. Body mass index (BMI) was calculated as weight divided by height squared (kg/m²), and divided into the following categories: <18.5, 18.5–23, 23–25, 25–30, 30–35, and ≥35 kg/m². Hypertension was defined as diastolic blood pressure > 90 mm/Hg, systolic blood pressure > 140 mm/Hg [40], use of antihypertensive medication or self-reported high blood pressure (UK), or self-reported hypertension (Denmark; yes/no/don’t know).

Hypercholesterolemia was defined as total cholesterol >6.5 mmol/L [41] or use of lipid lowering drugs at baseline (UK), or self-reported medical treatment or history hypercholesterolemia (Denmark; yes/no/don’t know). Postmenopausal status was defined as having no cycle for >5 years (UK) or self-reported natural or surgical menopause (Denmark), and coded as yes/no/male. Hormone replacement therapy was categorized into current, former and never (UK), or use of hormones for menopause (Denmark; yes/no).

2.5. Data analysis

2.5.1. Main analysis

All analyses were performed separately per cohort. SFA intakes were dived into cohort specific quintiles. We calculated Pearson correlations for SFA intakes. We used Cox proportional Hazard regression analysis to calculate Hazard Ratios (HR) with 95% confidence intervals (CI) for the associations of SFAs with MI risk. In model 1, we adjusted HRs for age (continuous), sex (male/female), total energy intake (kcal, excluding alcohol), BMI (categories), education level (categories), physical activity level (categories), smoking status (categories), hypertension (UK yes/no; Denmark yes/no/don’t know), alcohol intake (categories), use of post-menopausal hormones (UK current/former/never; Denmark yes/no), and in the UK, therapeutic wax use (yes/no) and family history of MI (yes/no). In model 2, we additionally adjusted for intakes of PUFA (en%), protein (en%), the sum of all other SFAs (en%), and trans fatty acids (UK only; en%). In model 3, we additionally adjusted for hypercholesterolemia (UK yes/no; Denmark yes/no/don’t know) as possible intermediate of the relationship between SFA intake and MI risk [45]. We also adjusted for body mass index (UK; underweight or normal weight, overweight, obese) in comparison with previous work [13]. P for trend was calculated by linearly including quartile specific median FA intake in the model. We examined the possibly non-linear relationships non-parametrically with restricted cubic splines [42], after limiting the analysis to participants from the SFA intake percentile 1 to 99. Tests for non-linearity used the likelihood ratio test, comparing the model with the only linear term to the model with the linear and the cubic spline terms.

2.5.2. Additional analyses

Results for the main analysis (model 2) from the two cohorts were pooled with a random effects model. Additionally, we performed isocaloric substitution modelling by adjusting for co-variables in model 1, plus total energy (en%, excluding alcohol), and energy (en%) from PUFA, MUFA, protein (subdivided in plant and other protein), carbohydrates (UK; subdivided in starch carbohydrates and other carbohydrates) and SFA intakes. By leaving the intake of a particular SFA of interest out of the model, regression coefficients of other macronutrients could be interpreted as the effect of isocalorically replacing the SFA intake not in the model. We reported substitution with PUFA, MUFA, plant protein and starch carbohydrates (UK) or total carbohydrates (Denmark).

To investigate if food sources of the SFA intakes contributed to the observed associations, we investigated the association between SFA from meat and total dairy and MI in both cohorts, and between SFA from cakes and cookies, cheese, hard fats and soft fats and MI in the UK cohort, after adjustment for co-variables in model 2.

We tested for possible interactions in our main analyses, for age, sex, BMI, physical activity and smoking by including an interaction term between the co-variable and SFA intakes to adjustment model 2. If this interaction term was statistically significant, stratified analyses were presented for this co-variable.
3. Results

3.1. Population characteristics

The mean (±SD) intakes per day of total SFA were 13.3 (±3.5) en%, and 12.5 (±2.6) en% in EPIC-Norfolk and EPIC-Denmark, respectively.

### Table 1

Baseline characteristics across quintiles of total SFA intake (en%) in EPIC-Norfolk.

<table>
<thead>
<tr>
<th>Total SFA, en%</th>
<th>Q1 (±1)</th>
<th>Q2 (±0.5)</th>
<th>Q3 (±0.4)</th>
<th>Q4 (±0.6)</th>
<th>Q5 (±2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n)</td>
<td>4410</td>
<td>4410</td>
<td>4410</td>
<td>4410</td>
<td>4410</td>
</tr>
<tr>
<td>Age, y</td>
<td>58.3 (±8.7)</td>
<td>58.5 (±9.2)</td>
<td>58.4 (±9.3)</td>
<td>58.6 (±9.5)</td>
<td>59.7 (±9.4)</td>
</tr>
<tr>
<td>Male (%)</td>
<td>42</td>
<td>48</td>
<td>50</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.5 (±4.0)</td>
<td>26.4 (±3.9)</td>
<td>26.3 (±3.8)</td>
<td>26.3 (±3.9)</td>
<td>26.0 (±3.9)</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>86.6 (±12.2)</td>
<td>87.8 (±12.2)</td>
<td>88.0 (±12.2)</td>
<td>88.9 (±12.5)</td>
<td>88.8 (±12.4)</td>
</tr>
<tr>
<td>Education level (%)</td>
<td>None</td>
<td>33</td>
<td>35</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td>Degree</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Current smoker (%)</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>Physically inactive (%)</td>
<td>26</td>
<td>28</td>
<td>29</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Physically active (%)</td>
<td>20</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>134.7 (±11.3)</td>
<td>135.4 (±11.2)</td>
<td>135.0 (±11.1)</td>
<td>135.3 (±11.2)</td>
<td>135.6 (±11.2)</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>82.5 (±11.2)</td>
<td>82.5 (±11.1)</td>
<td>82.5 (±11.1)</td>
<td>82.8 (±11.2)</td>
<td>82.7 (±11.2)</td>
</tr>
<tr>
<td>Hypertensiona (%)</td>
<td>15</td>
<td>15</td>
<td>13</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Total cholesterol, mmol/L</td>
<td>6.1 (±1.2)</td>
<td>6.1 (±1.2)</td>
<td>6.2 (±1.2)</td>
<td>6.2 (±1.1)</td>
<td>6.3 (±1.2)</td>
</tr>
<tr>
<td>HDL-cholesterol, mmol/L</td>
<td>1.5 (±0.3)</td>
<td>1.4 (±0.4)</td>
<td>1.4 (±0.4)</td>
<td>1.4 (±0.4)</td>
<td>1.3 (±0.4)</td>
</tr>
<tr>
<td>LDL-cholesterol, mmol/L</td>
<td>3.9 (±1)</td>
<td>3.9 (±1)</td>
<td>4.0 (±1)</td>
<td>4.0 (±1)</td>
<td>4.1 (±1)</td>
</tr>
<tr>
<td>Triglycerides, mmol/L</td>
<td>1.7 (±1.1)</td>
<td>1.8 (±1.1)</td>
<td>1.8 (±1.1)</td>
<td>1.8 (±1.1)</td>
<td>1.8 (±1.1)</td>
</tr>
<tr>
<td>Hypercholesterolemia (%)</td>
<td>34</td>
<td>31</td>
<td>33</td>
<td>32</td>
<td>35</td>
</tr>
<tr>
<td>Diabetes mellitus (%)</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Family history of MI (%)</td>
<td>39</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>Postmenopausal (% among women)</td>
<td>36</td>
<td>33</td>
<td>32</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>HRT use (% among women)</td>
<td>24</td>
<td>23</td>
<td>21</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Current</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Former</td>
<td>58</td>
<td>53</td>
<td>47</td>
<td>42</td>
<td>37</td>
</tr>
<tr>
<td>Supplement use (%)</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Energy, kcal</td>
<td>1877 (±502)</td>
<td>1987 (±555)</td>
<td>2087 (±581)</td>
<td>2155 (±617)</td>
<td>2229 (±642)</td>
</tr>
<tr>
<td>Fat, en%</td>
<td>25.7 (±4.1)</td>
<td>30.9 (±3.1)</td>
<td>33.6 (±3.1)</td>
<td>36.1 (±3.3)</td>
<td>39.7 (±4.0)</td>
</tr>
<tr>
<td>Trans fatty acids, en%</td>
<td>1.0 (±0.4)</td>
<td>1.0 (±0.4)</td>
<td>1.1 (±0.5)</td>
<td>1.7 (±0.5)</td>
<td>1.9 (±0.6)</td>
</tr>
<tr>
<td>Carbohydrates, en%</td>
<td>55.4 (±6.9)</td>
<td>52.2 (±5.6)</td>
<td>50.3 (±5.3)</td>
<td>48.5 (±5.2)</td>
<td>45.5 (±5.5)</td>
</tr>
<tr>
<td>Energy from SFA, en%</td>
<td>C14:0, en%</td>
<td>0.3 (0.2–0.5)</td>
<td>0.4 (0.3–0.5)</td>
<td>0.5 (0.4–0.5)</td>
<td>0.5 (0.4–0.6)</td>
</tr>
<tr>
<td>Energy from MUFA, en%</td>
<td>C18:0, en%</td>
<td>6.6 (6.4–6.9)</td>
<td>7.4 (7.1–7.7)</td>
<td>8.0 (7.6–8.6)</td>
<td>8.6 (8.1–9.2)</td>
</tr>
<tr>
<td>Energy from PUFA, en%</td>
<td>C16:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
</tr>
<tr>
<td>HRT use (% among women)</td>
<td>0.7 (0.6–0.8)</td>
<td>0.7 (0.6–0.8)</td>
<td>0.7 (0.6–0.8)</td>
<td>0.7 (0.6–0.8)</td>
<td>0.7 (0.6–0.8)</td>
</tr>
<tr>
<td>C18:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
<td>1.5 (1.2–2.4)</td>
</tr>
<tr>
<td>C16:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
<td>1.5 (1.2–2.4)</td>
</tr>
<tr>
<td>C18:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
<td>1.5 (1.2–2.4)</td>
</tr>
<tr>
<td>C18:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
<td>1.5 (1.2–2.4)</td>
</tr>
<tr>
<td>C18:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
<td>1.5 (1.2–2.4)</td>
</tr>
<tr>
<td>C18:0, en%</td>
<td>2.2 (1.9–2.4)</td>
<td>2.0 (1.7–2.4)</td>
<td>1.9 (1.6–2.4)</td>
<td>1.7 (1.4–2.4)</td>
<td>1.5 (1.2–2.4)</td>
</tr>
</tbody>
</table>

All values are means (±SD) or median (quartile 1–quartile 4), unless indicated otherwise.

a Defined as diastolic blood pressure <90 mm/Hg, systolic blood pressure > 140 mm/Hg, use of antihypertensive medication or self-reported high blood pressure.

b Defined as total cholesterol >6.5 mmol/L or use of lipid-lowering drugs at baseline.

In both cohorts the majority of SFA was represented by C16:0 (~52%), C18:0 (~22%) and C14:0 (~10%) (Supplemental Fig. 1). High correlations were observed for C4:0–C10:0 with C14:0, and with C15:0. Also, correlations between C16:0 and C18:0 were high (Supplemental Table 1).

Participants (in both cohorts) with higher intakes of energy from total SFA, as well as from all the individual SFAs (data not shown), were more often male, had a lower BMI, were less educated, more often a smoker, and less physically active. Moreover, higher intakes of SFA were associated with higher intakes of total energy, MUFA, trans-fat, and lower intakes of carbohydrates, fibre, vitamin C, and alcohol (Tables 1 and 2).

### 3.2. Association between individual SFAs and MI risk

During median follow-up times of 18.8 (IQR 17.4, 20.2) years in the UK and the 13.6 (IQR 12.9, 14.3) years in Denmark, respectively, 1204 (5.5%) and 2260 (4.2%) MI events occurred.
3.2.1. EPIC-Norfolk

After multivariable adjustment for lifestyle and dietary factors, a higher intake of the sum of C4:0–C10:0 (Q5 0.85, 95%CI 0.63, 1.14), C14:0 (Q5 0.78, 95%CI 0.58, 1.09), the sum of C15:0 and C17:0 (Q5 0.78, 95%CI 0.58, 1.06) and C18:0 (Q5 0.79, 95%CI 0.56, 1.13) were weakly associated with lower MI risk, but none of these associations were significant (Table 3). Further adjusting for hypercholesterolemia and menopausal status in model 3 did not affect associations (Table 3). Restricting follow-up to the first eight years strengthened the associations for the sum of C15:0 and C17:0 (Q5 0.57, 95% 0.34, 0.97), but otherwise did not change results. Excluding the first two years of follow-up, excluding lipid lowering drugs, adjusting for TC/HDL ratio (Supplemental Table 2), or adjusting for baseline diabetes (data not shown), did not change the conclusions. No evidence of a non-linear association between C4:0–C10:0 or C12:0–C18:0 and MI was found (Supplemental Figs. 2 and 3). There were no interactions for the intakes of C4:0–C10:0 and C12–C18:0 with sex, age, smoking, or BMI, whereas interaction by physical activity was suggested (p = 0.01) for intake of C12:0–C18:0, although no meaningful differences were found in stratified analyses (Supplemental Table 3).

In isocaloric substitution analyses (Table 4 and Supplemental Table 4 – latter shows median intakes per SFA –), no statistically significant associations were found with MI risk. Additional adjustment for hypercholesterolemia and menopausal status did not change the results of the substitution analyses (data now shown).

Intakes of SFA from dairy, meat, cakes and cookies, cheese, soft fats or hard fats were not associated with MI risk (Supplemental Table 5).

3.2.2. EPIC-Denmark

The multivariable adjusted HRs for the association of C4:0–C10:0 with MI risk in EPIC-Denmark, suggested an inverse association in especially quintile 3 and 4 when compared to quintile 1 (Q3 0.87, 95% CI 0.75, 1.00; Q4 0.81, 95% CI 0.69, 0.94) (Table 3). This non-linear association persisted (p for non-linearity 0.04) after excluding the lowest and highest intake percentile of C4:0–C10:0 intake (Supplemental Fig. 2). Other individual SFAs that associated with a lower risk of MI incidence were C12:0 (Q5 0.80, 95% CI 0.66, 0.96), C14:0 (Q5 0.80, 95% CI 0.66, 0.96), and the sum of C12:0 and C14:0 (Table 3). No evidence for a non-linear relationship between intake of the sum of C12:0 to C18:0 and MI incidence was found (Supplemental Fig. 3). The interaction term for physical activity was borderline significant (p = 0.05) for the analysis of C12:0 to C18:0, but stratified analyses suggested similar associations across physical activity groups (Supplemental Table 3). We did not observe evidence for interaction by sex, age, smoking, or BMI for C12:0 to C18:0, nor for any interaction in the analysis of C4:0 to C10:0. Adjusting for possible intermediates in model 3 did not alter conclusions (Table 3), nor did restricting follow-up to the first eight years, excluding the first two years of follow-up (Supplemental Table 2), or adjusting for baseline diabetes (data not shown).

Isocaloric substitution modelling of the sum of C12:0 to C14:0 (median intake 1.8 en%/day), C16:0 (7.4 en%/day), C18:0 (3.2 en%/day)...

---

**Table 2**

Baseline characteristics across quintiles of total SFA intake (en%) in the Danish Diet Cancer and Health cohort.

<table>
<thead>
<tr>
<th>Total SFA, en%</th>
<th>Q1 (±1.2)</th>
<th>Q2 (±0.4)</th>
<th>Q3 (±0.4)</th>
<th>Q4 (±0.4)</th>
<th>Q5 (±1.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n)</td>
<td>10,675</td>
<td>10,675</td>
<td>10,675</td>
<td>10,675</td>
<td>10,675</td>
</tr>
<tr>
<td>Age, years (mean ± SD)</td>
<td>56.5 (±4.3)</td>
<td>56.5 (±4.3)</td>
<td>56.6 (±4.4)</td>
<td>56.7 (±4.4)</td>
<td>56.9 (±4.4)</td>
</tr>
<tr>
<td>Male (%)</td>
<td>42</td>
<td>42</td>
<td>49</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.2 (±3.9)</td>
<td>26.2 (±4.7)</td>
<td>26.0 (±4.7)</td>
<td>25.9 (±4.1)</td>
<td>25.7 (±4.2)</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>88.1 (±12.4)</td>
<td>88.9 (±12.6)</td>
<td>88.7 (±12.4)</td>
<td>88.6 (±12.6)</td>
<td>88.4 (±13.1)</td>
</tr>
</tbody>
</table>
|ыма of MI risk in a UK and a Danish cohort, Int J Cardiol (2018),https://doi.org/10.1016/j.ijcard.2018.10.064 Please cite this article as: J. Praagman, et al., Consumption of individual saturated fatty acids and the risk of myocardial infarction in a UK and a Danish cohort, Int J Cardiol (2018), https://doi.org/10.1016/j.ijcard.2018.10.064
Table 3
Hazard ratios (95%CI) for the associations between individual SFAs (in quintiles) and MI risk.a

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>P for trend</th>
<th>P for non-linearity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sum of C14:0–C16:0</strong></td>
<td><strong>EPIC-Norfolk</strong></td>
<td><strong>EPIC-Denmark</strong></td>
<td><strong>EPIC-Norfolk</strong></td>
<td><strong>EPIC-Denmark</strong></td>
<td><strong>EPIC-Denmark</strong></td>
<td><strong>EPIC-Norfolk</strong></td>
<td><strong>EPIC-Denmark</strong></td>
</tr>
<tr>
<td></td>
<td>HR (95%CI)</td>
<td>HR (95%CI)</td>
<td>HR (95%CI)</td>
<td>HR (95%CI)</td>
<td>HR (95%CI)</td>
<td>HR (95%CI)</td>
<td>HR (95%CI)</td>
</tr>
<tr>
<td>Median intake (IQR)</td>
<td>0.3 (0.2–0.4)</td>
<td>0.2 (0.2–0.3)</td>
<td>0.8 (0.7–0.9)</td>
<td>0.8 (0.7–0.9)</td>
<td>0.8 (0.7–0.9)</td>
<td>0.8 (0.7–0.9)</td>
<td>0.8 (0.7–0.9)</td>
</tr>
<tr>
<td>Cases/subjects (n)</td>
<td>235/4410</td>
<td>210/4410</td>
<td>265/4410</td>
<td>436/10675</td>
<td>396/10675</td>
<td>210/4410</td>
<td>436/10675</td>
</tr>
<tr>
<td>Model 1 Ref</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Model 2 Ref</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.98</td>
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<td>0.99</td>
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<tr>
<td>Model 3 Ref</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.99</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(continued on next page)
and the sum of C12:0 to C18:0 (12.5 en%/day), by MUFA, PUFA, carbohydrates or plant protein, suggested that substituting any of these SFAs by plant protein was inversely associated with MI incidence, although this was not statistically significant for the sum of C12:0 and C14:0 (Table 4, Supplemental Table 4). Additional adjustment for hypercholesterolemia and menopausal status did not change the results of the substitution analyses (data now shown).

A higher intake of SFA from meat was associated with a higher risk of MI incidence (HR per 1 en% 1.08, 95%CI 1.04, 1.12; Supplemental Table 5).

3.2.3. Pooled results

We pooled results from the main analysis (model 2) between EPIC-Norfolk and EPIC-Denmark. An inverse association was observed for C14:0 (Q5 0.81, 95%CI 0.67, 0.97), the sum of C12:0 and C14:0, and the sum of C15:0 and C17:0 (Q5 0.83, 95%CI 0.70–0.98) with MI incidence risk. For the intake of C4:0 to C10:0, pooled analysis yielded a HR of 0.82 (95%CI 0.72, 0.93) in quintile 4, and a HR of 0.88 (95%CI 0.76, 1.03) in quintile 5. Substantial heterogeneity (in terms of I²) was observed when pooling results for C12:0, C18:0 and the sum of C12:0 to C18:0 (Table 5).

4. Discussion

In the present study of two separate cohorts from the UK and Denmark, a higher consumption of C12:0 and C14:0 associated with a lower MI risk in Denmark. Intakes in the third and fourth quintile of C4:0–C10:0 also associated to lower MI risk in Denmark. Other individual SFAs were not associated with MI. In substitution analyses, substituting C16:0 and C18:0 with plant protein associated with lower risk of MI in Denmark. No associations were found in the UK cohort. Differences in results between Denmark and the UK may have occurred due to differences in underlying food sources and dietary patterns (e.g. intake of SFA from total dairy and meat was higher in Denmark compared to the UK) or lifestyles (e.g. the Danish cohort smoked more often and was more physically active than the UK cohort), or differences in confounder definitions and availability (e.g. trans fat intake was only available for the UK cohort). Also, differences in samples size may explain why we only found statistically significant associations in EPIC-Denmark (n = 53,375), and not in EPIC-Norfolk (n = 22,050). By pooling results of the two studies we intended to increase our ability to find associations, and thereby further clarify which individual SFAs associate with MI risk. However, these analyses should be interpreted with caution because of the above described heterogeneity, which was
also reflected by the high level of heterogeneity ($I^2$ values) for some of the pooled fatty acid analyses (e.g. C12:0, C16:0).

Second, we used baseline measures of SFA intake only, whereas the US cohorts used repeated measures of diet. It is conceivable that dietary intakes change over time [13], and that repeated dietary measures probably yield a more accurate measure of SFA intake during follow-up, which might be another explanation for the divergent findings. However, sensitivity analysis with a shortened follow-up time in our study did not yield materially different results, compared to the original analyses.

Third, differences in adjustment of dietary factors could impact the interpretation of the results. For example in our main analyses, we adjusted for intakes of energy, remaining SFAs, PUFAs, proteins and trans fatty acids (latter UK only), whereas the most recent US study of Zong et al. adjusted for energy intake only [13]. In additional substitution analyses that did take these macronutrients into account, findings from the present study and of Zong et al. were more comparable, although some differences remain. In the present study, we found that substituting C16:0 and C18:0, and C12:0–C18:0 (which to a large extent are C16:0 and C18:0) with plant protein associated with lower risk of MI in Denmark, supporting previous reports that defining the substituting macronutrient is of importance in the relationship of SFAs with MI. In line with this, Zong et al. found inverse associations of replacing C16:0 and C12:0–C18:0 with plant proteins, but not for C18:0. [13]. Zong et al. [13] also found inverse associations for substituting C16:0 and C12:0–C18:0 with PUFA and whole grain carbohydrates, whereas we did not. This may be due to lack of our ability to disentangle between types of PUFAs and because we investigated total or starch carbohydrates instead of whole grain carbohydrates in our study.

Regarding the non-linear association of C4:0–C10:0 with MI we found, we should be careful with interpreting these results as non-linear because the intake range was very low, with average intakes around 1.5 energy% associating to lower MI risk and of around 2.0 energy% not. There is no (biological) explanation for why intakes of C10:0 of slightly higher than 1.5 energy% are less protective for MI risk than of around 2.0 energy%.
to be an inverse or neutral association between MI or CHD risk and the shorter chain and odd chain SFAs (C4:0–C10:0, C12:0, C14:0, C15:0, and C17:0) and a harmful or neutral association of the longer-chain SFAs (C16:0 and C18:0) as evident from substitution analyses on replacement of C16:0 and C18:0 with plant protein. These observations could reflect a difference in the underlying dietary pattern, e.g. the difference in consumption of dairy versus meat, but could also reflect actual differences of SFAs effects on CHD risk markers. Because of the high correlations between the SFAs, observational cohort studies alone will not suffice in answering the question whether individual SFAs have different associations with MI or CHD. Also in our study, high correlations between several SFA subtypes exist, what made it unclear whether the observed associations in our study pertain to all these SFAs, or represent the association of one of them. At present, controlled trials have been conducted for C12:0 and C14:0, but not for C4:0–C10:0 or C15:0 and C17:0. C12 and C14:0 were shown to increase serum LDL-cholesterol as compared to carbohydrates [5], but had little (C14:0) or beneficial (C12:0) effects on the ratio of total: HDL cholesterol, which is considered to be a stronger CHD risk predictor than LDL-cholesterol levels alone [47]. This could explain why in our study and previous studies [10–12], C12:0 and C14:0 were not harmfully associated with risk of MI or CHD.

Strengths of this study are the large sample sizes of the included cohorts, with a long follow-up time and a large number of MI endpoints. Also, the extensive assessment of population characteristics at baseline allowed us to adjust the observed associations for many potential confounders. Furthermore, because both cohorts are part of the international EPIC cohort, they have a similar recruitment period (between 1993 and 1997). Limitations of this study are that we had no or limited longitudinal EPIC cohort, they have a similar recruitment period (between 1993 and 1997). Whether this difference is caused by the SFAs as such, by the differences in underlying dietary pattern, or by residual confounding in observational studies is unclear, and cannot be solved using observational evidence alone, therefore for further examination of the effects of the short-to medium-chain SFAs on MI risk, evidence from interventional studies is needed.

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Conflicts of interest

JP is financially supported by a restricted Research Grant from Unilever Research and Development, Vlaardingen, the Netherlands; YTvDs and IS report grants from Unilever Research and Development, Vlaardingen, the Netherlands. None of the other authors declares a conflict of interest.

Appendix A. Supplementary data

Supplementary data can be found at https://doi.org/10.1016/j.jjcard.2018.10.064.

References


