



**Long-term prediction of major coronary or ischemic stroke event in a low-incidence European population: model development and evaluation of clinical utility**

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Manuscripts

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4 **Long-term prediction of major coronary or ischemic stroke event in a low-incidence**  
5 **European population: model development and evaluation of clinical utility**  
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9 **Short Title: Clinical utility of long-term CVD risk prediction in primary prevention**  
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51 prevention  
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## ARTICLE SUMMARY

### Article focus

- Primary prevention of cardiovascular disease (CVD) has been recently moved towards the concepts of “lifetime” and “long-term” risk, especially in young subjects and women.
- There is no long-term risk prediction model available for European populations; in addition, the evaluation of the clinical benefit of long-term prediction has not been provided so far.
- We aim to develop a 20-year risk score equation in a northern Italian population of men and women considered at low incidence of major cardiovascular events; and to evaluate the clinical utility of the model for risk stratification in primary CVD prevention program.

### Key Messages

- In our population, the 20-year risk model had satisfactory discrimination ability as compared to short-term risk prediction. The importance of long-term prediction for early identification of young subjects and women at increased likelihood of event during their remaining lifespan is confirmed.
- Risk stratification based on the predicted 20-year risk had a better clinical Net Benefit with respect to a stratification based on the number of risk factors, in men and women.
- In both genders, the optimal treatment allocation based on 20-year risk can be determined according to different public health strategies, i.e. either to reduce the fraction of events potentially un-prevented or to avoid un-necessary treatment.

### Strengths and limitations of this study

- Our sample comprises subjects drawn from a representative northern Italian population, with a satisfactory participation rate. We also mention the high-quality of follow-up

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4 procedures, including case ascertainment for non-fatal events and a consistent event  
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6 validation according to MONICA criteria over the whole follow-up period.  
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- 29 ■ Our 20-year risk prediction model is the first attempt to characterize long-term risk of  
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31 first coronary or ischemic stroke event in a low-incidence European population. To allow  
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33 applying our equation to different populations, as Supplementary Material we provide the  
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35 baseline survival term as well as the calibration slope. However, an external validation  
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37 study might be desirable. We also remind that our underlying population is characterized  
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39 by high levels of industrialization and urbanization, with one of the highest average  
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41 incomes in Italy. Caution is therefore required before generalizing our findings to  
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43 different contexts.  
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## ABSTRACT

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**Objective.** To develop a long-term prediction model of first major cardiovascular event and to assess its clinical utility in a low-incidence European population.

**Setting.** Four independent population-based cohorts enrolled between 1986 and 1993 in Northern Italy.

**Participants and methods.** N=5,247 35-69 years old men and women free of cardiovascular disease at baseline. Absolute 20-year risk of first fatal or non-fatal coronary or ischemic stroke event (MONICA validated) was estimated from gender-specific Cox models.

**Main outcome measures.** Model discrimination (Area Under the ROC-Curve, AUC). “High-risk” subjects were defined based on several threshold values for the 20-year predicted risk. Clinical utility was defined in terms of fraction of missed events (events among those

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4 considered at low-risk) and unnecessary treatment (false: true positives ratio). A Net Benefit  
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6 curve was also provided.  
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9 **Results.** Kaplan-Meier 20-year risk was 16.1% in men (315 events) and 6.1% in women (123  
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11 events). Model discrimination (AUC=0.737 in men, 0.801 in women) did not change  
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13 significantly as compared to 10-year prediction time interval. In men, with respect to risk  
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15 stratification based on the number of risk factors, a 20% predicted risk cut-off would miss  
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17 less events (36% vs. 50%) and reduce unnecessary treatment (false: true positive ratio: 2.2 vs.  
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19 3.0); the Net Benefit was higher over the whole range of threshold values. Similar  
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21 considerations hold for women.  
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25 **Conclusions.** Long-term prediction has good discrimination ability and is clinically useful for  
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27 risk stratification in primary prevention. A clinical utility analysis is recommended to identify  
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29 the optimal stratification according to different public health goals.  
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## INTRODUCTION

Current European and American guidelines for primary prevention of major coronary and stroke events recommend the use of a multivariable risk prediction method to identify high risk subjects [1, 2]. Several risk scores are available in different US [3, 4] and European [5] populations of middle-aged adults, including the Italian one [6], to estimate the risk of first fatal and non-fatal cardiovascular event over a 10 year time interval. Primary prevention however has been recently moved towards the concepts of “lifetime” [7] and “long-term” risks [8], motivated also by the increasing life expectancy in western Countries. To this extent, 10-year risk prediction models are inadequate to distinguish between those at both low short-term and long-term risks, and those at low short-term but at elevated long-term risk due to the presence of non-optimal risk factors levels [9-11]. In the Framingham Study population, an unfavorable risk factor profile led to an increased 30-year risk of first cardiovascular event, independently on the age at the risk factors assessment [10]. In a representative sample of the Italian population, about 80% of individuals classified at low 10-year risk had increased lifetime risk according to US definition ( $\geq 40\%$ ), potentially leading to a consistent number of un-prevented events that might have been prevented if lifetime risk had been considered [11]. This group was largely composed of women and young subjects, suggesting that long-term prediction models for risk stratification may be even more beneficial in populations at low incidence of cardiovascular disease [12]. To this extent, the development of a specific long-term risk prediction should be preferred with respect to re-calibration of risk models derived in high-incidence countries [13]. However, extending the range of risk prediction is not a straightforward operation. Although several studies have shown that a single measurement of risk factor is predictive of future events after 30 plus years [10, 14], behavioral changes and risk factors modification may affect model

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4 discrimination. High-quality follow-up data, with a consistent event definition and validation  
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6 over-time, are also required. Finally, subjects' stratification in risk categories is often based  
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8 on arbitrary cut-points of absolute risk [15] which may show no benefit in clinical practice  
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10 [16]. The evaluation of the clinical benefit of long-term prediction by means of some  
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12 standard measure [17] has not been provided so far and is therefore required [8].

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14 The aim of the present paper is to develop a 20-year risk score equation in a European  
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16 population of men and women considered at low incidence of major cardiovascular events. In  
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18 addition to standard model calibration and discrimination tools, we evaluate the clinical  
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20 utility of the model for risk stratification.  
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## 24 **METHODS**

### 25 **Study population**

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27 The Brianza population comprises residents in 173 municipalities in the area between Milan  
28  
29 and the Swiss border, Northern Italy. The CAMUNI study includes four independent  
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31 population surveys carried out between 1986 and 1994 as part of either the WHO-MONICA  
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33 Project[3 surveys; 18] or the PAMELA study [19]. Participation rates were 70.1%, 67.2%,  
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35 and 70.8% for the three MONICA surveys, respectively, and 64% for the PAMELA Study,  
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37 with no differences between men and women. Both the baseline screening and the follow-up  
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39 for all the surveys were approved by the ethical committee of the Monza Hospital.  
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### 44 **Baseline assessment of risk factors**

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46 Cardiovascular risk factors were collected at baseline strictly adhering to the standardized  
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48 procedures and quality standards of the WHO-MONICA Project [20]. Height and weight  
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50 were measured on subjects without shoes and wearing light clothing. Trained technicians  
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52 collected blood pressure at right arm on subjects in sitting position and at rest, using a  
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54 standard mercury sphygmomanometer equipped with two side cuff bladders, for normal and  
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4 obese subjects. Systolic and diastolic blood pressure were assessed twice, at 5 minutes apart,  
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6 recording the first and fifth phase of the Korotkoff sounds. The study variable for systolic  
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8 blood pressure is the average of the two measurements. Venous blood specimens were taken  
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10 from the ante-cubital vein on fasting subjects (12 hours or more). Serum total cholesterol,  
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12 HDL-cholesterol and blood glucose were determined using the enzymatic methods; HDL-  
13  
14 cholesterol fraction was separated using the Phosphotungstate-Mg<sup>++</sup> method [20]. A  
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16 standardized interview was administered to participants by trained interviewers. Information  
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18 on the use of anti-hypertensive treatment in the last two weeks was dichotomised as yes/no;  
19  
20 similarly, cigarette smoking habit was dichotomised as current versus past/never smokers.  
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22 Diabetes mellitus was defined using self-reported diagnoses, information on insulin and oral  
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24 hypoglycaemic treatments and fasting blood glucose exceeding 7 mmol/L (126 mg/dl). The  
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26 presence at baseline of a previous history of MI, unstable angina pectoris, cardiac  
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28 revascularization or stroke was defined based on self-reported information.  
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### 33 **Study endpoint and follow-up procedures**

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35 The study endpoint is defined as the occurrence of first major coronary event (myocardial  
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37 infarction, acute coronary syndrome and coronary revascularization) as well as for first  
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39 ischemic stroke or carotid endarterectomy, fatal and non-fatal [13]. Data completeness for  
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41 fatal events was assured through a systematic collection of death certificates provided by  
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43 local health units; vital status and death certificates were available for 99% of the subjects.  
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45 Suspected out-of-hospital deaths were investigated through interview of relatives. Suspected  
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47 hospitalized coronary (discharge code ICD-IX 410 or 411 and ICD-IX CM 36.0-9 for  
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49 coronary revascularization) and stroke events (ICD-IX 430-432, 434, 436; ICD-IX CM  
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51 38.01-39.22 or 39.50-39.52 with at least one 430-438 as discharge code, for carotid  
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53 endarterectomy) were identified through deterministic and probabilistic record linkages with  
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4 regional hospital discharge databases, obtaining a satisfactory performance in case finding, as  
5 reported [18, 21]. All acute events were investigated and validated according to the MONICA  
6 diagnostic criteria [20]; the ischemic subtype for stroke was attributed after review of the  
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8 available clinical information.  
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### 11 12 13 **Statistical analysis**

14 The CUORE Project 10-year risk equation for the Italian population [6, 18] constituted the  
15 base for the development of the 20-year risk prediction model. We considered gender-  
16 specific Cox regression models with age, total cholesterol, HDL-cholesterol, systolic blood  
17 pressure, anti-hypertensive treatment, cigarette smoking and diabetes. After a preliminary  
18 check on linearity, total- and HDL-cholesterol were included in the model as categorical  
19 variables in four standard classes [4, 22]. The interaction between systolic blood pressure and  
20 anti-hypertensive treatment was not statistically significant (p-value 0.84 in men and 0.12 in  
21 women, respectively). Finally, no violations in the proportional hazard assumption were  
22 observed using a standard test for time-dependent variables.  
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25 Model calibration was assessed through the Grønnesby-Bogan goodness-of-fit test [23]. The  
26 Area Under the ROC-curve (AUC), as well as sensitivity and specificity in the top and  
27 bottom predicted risk quintiles, were computed taking censorship into account [24].  
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30 Correction for over-optimism and confidence intervals for the AUC were obtained through  
31 1000 bootstrapped samples [25]. To assess the hypothesis of a loss in discrimination ability  
32 due to a longer prediction period, we estimated the 10-year predicted probability of event in  
33 our database, using the same set of risk factors but with shorter follow-up period, i.e. up to  
34 the end of 2002 for all the subjects. We then compared the AUC of both models, by  
35 considering bootstrapped confidence intervals for the difference in the betas.  
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4 To assess the clinical utility of the long-term model for risk stratification, we considered two  
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6 different public health goals. One is to decrease the number of events occurring among those  
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8 considered at “low-risk”. If we assume that a subject classified at “high risk” will be targeted  
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10 for prevention (either lifestyle intervention or treatment), any event occurring outside this  
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12 category is “not-identified” or “missed” by the prevention strategy. The second strategy aims  
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14 instead to reduce un-necessary treatment, by decreasing the number of non-events among  
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16 those considered at “high-risk”. Under the two scenarios, “high-risk” subjects are defined as  
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18 those with predicted risk above a certain cut-off value. Clinical utility is defined in terms of  
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20 *i)* fraction of “missed” events; *ii)* probability of event among those classified at high risk; and  
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22 *iii)* false positive/true positive ratio, for several threshold values in the 20-year predicted risk.  
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24 We also provide a decision curve analysis based on the net benefit: Net Benefit = (true  
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26 positives - w\*false positives)/n, where n is the sample size and the weight w represents the  
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28 ratio between the harm of un-necessary treatment and the harm of missing a case at that given  
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30 value of predicted risk [17]. All the analyses were conducted using the SAS software 9.2.  
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## 35 RESULTS

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37 N=5,426 (2,703 men) subjects were enrolled in the age range 35-69 years. N=205 subjects  
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39 (3.8%; n=14 events) had at least one missing data; we considered data imputation (R  
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41 *transcan* function, [26]) and excluded only those with missing values in more than 4  
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43 covariates of interest (n=6 men and n=3 women). Finally n=120 men and n=45 women with a  
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45 positive history of CVD at baseline were also excluded, reducing the sample size to 2,574  
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47 men and 2,673 women.  
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51 Baseline characteristics of the study population, by gender, are shown in **Table 1**. During a  
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53 median follow-up time of 15 years (interquartile range: 12-20), we observed 315 first CVD  
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4 events in men (233 coronary events) and 123 in women (n=85 coronary events). The Kaplan-  
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6 Meier estimate for 20-year risk was 16.1% and 6.1% in men and women, respectively.  
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### 9 **Model development**

10 The beta-coefficients for the 20-year risk prediction model, as well as the baseline survival  
11 term and the calibration slope [25], are provided in the Supplementary Material (**Table S1**).  
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14 All the risk factors were statistically significant, except for anti-hypertensive treatment,  
15 though its point estimate reflected a 30% increase in hazard in both men and women; the  
16 variable was retained in the model for comparability with the short-term CUORE model [6].  
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18 There were no significant differences in the set of beta estimates for the 20-year model as  
19 compared to those from the 10-year risk model for the risk factors in the model (data not  
20 shown). The model calibration was satisfactory, in men (Grønnesby-Bogan goodness-of-fit  
21 chi-square 6.7, p-value 0.67) and in women (chi-square 9.6, p-value 0.38).  
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31 We found no statistically significant difference in the overall discrimination ability between  
32 long- and short-term prediction models, in men (0.736 vs. 0.731) and in women (0.801 vs.  
33 0.816; **Table 2**). Only 5% of 20-year events in men occurred among subjects with a predicted  
34 risk below the 20<sup>th</sup> percentile (bottom quintile); the corresponding figure in women is 2%.  
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38 The relative risk of event for being above the 80<sup>th</sup> percentile vs. below the 20<sup>th</sup> percentile of  
39 20-year risk was 9.5 (i.e. 35.1/3.7) in men and 22.4 (i.e. 20.2/0.9) in women. Finally, the  
40 value of the 80<sup>th</sup> percentile for 20-year risk was more than twice as high than the similar  
41 percentile for 10-year risk in men (26.8 vs. 10.8) and more than three times as high in women  
42 (10.1 vs. 3.0). A similar consideration holds for the 20<sup>th</sup> percentile of risk or the median  
43 value.  
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### 52 **Clinical utility**

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4 **Table 3a** and **Table 3b** describe strategies for the identification of high-risk subjects, based  
5 on predicted 20-year risk, in men and women respectively. A cut-off value of 10% twenty  
6 year risk in men would result in a 9% of “missed” events (i.e. events among those with  
7 predicted risk below the cut-point), with a probability of event of 23% and one true positive  
8 for every 3.4 false positive subjects (**Table 3a**). In the second scenario, by choosing the 20%  
9 twenty year risk threshold value, the fraction of missed events was 36%. Note that about 30%  
10 of events occurred for a predicted 20-year risk between 20% and 30%. Finally, using the  
11 number of risk factors to define high risk subjects would result in a higher fraction of missed  
12 events, with no changes in specificity or in the prevalence of subjects considered at high risk.  
13 Among women, a cut-off value of 2% would result in a 5% of missed events, with a  
14 probability of event of 9% and a true positive for every 10.1 false positive women (**Table**  
15 **3b**). In the second scenario, the probability of event among those with absolute risk greater  
16 than 10% was 20.4%, with a true positive for every 3.9 false positive subjects. However, the  
17 fraction of missed events would be 32%; this number can be reduced by lowering the cut-off  
18 value to 8%. By considering at high risk those with 2 or more risk factor would result in a  
19 higher fraction of missed events, with no gain in specificity or in the probability of event in  
20 the group. **Figure 1** illustrates the decision curve analysis based on the Net Benefit [17], for  
21 men (left) and women (right). The figure suggests a greater net benefit for the predicted risk  
22 with respect to the number of risk factors over the whole range of values, thus generalizing  
23 the findings from Table 3a and Table 3b.

## 48 DISCUSSION

49 In this paper we present the 20-year prediction model of first major coronary or ischemic  
50 stroke event in a Northern Italian population of men and women aged 35 to 69 years at  
51 baseline. To our knowledge, this is the first long-term prediction model in a low-incidence,  
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4 European population. The discrimination ability of the long-term model did not significantly  
5 drop with respect to a 10-year risk prediction model derived on the same population. Risk  
6 stratification based on the predicted 20-year risk can be modulated according to different  
7 prevention aims, i.e. either to reduce the fraction of events potentially un-prevented or to  
8 avoid un-necessary treatment. Under both scenarios, the predicted 20-year risk showed an  
9 overall better Net Benefit with respect to a risk stratification based on the number of risk  
10 factors.  
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12 Our data confirmed previous findings on predictiveness of a single measurement of risk  
13 factors on long-term CVD risk, in the Italian [27] as well as in other populations [10, 14].  
14 Event discrimination for the 20-year risk prediction model did not change significantly from  
15 10-year's, although in women it decreased from 0.814 to 0.801. In the Framingham Offspring  
16 Study updating the baseline measurement of blood pressure and lipids with a later assessment  
17 poorly affected model discrimination and reclassification [28] and cardiometabolic risk  
18 factors clustering has been found to be quite stable over time [29].  
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20 As in the Framingham population, in our study the long-term predicted risk was more than  
21 simply  $n$ -times the short-term risk prediction [10]. In addition in the age range 35 to 49  
22 years, the long-term predicted risk in subjects with 1 or more non-optimal or elevated risk  
23 factors (defined as in [7]) was 3-times the short-term risk in men, and 4-times in women (see  
24 **Figure S1** in the Supplementary Material). This conveys the importance of long-term  
25 prediction for early identification of young subjects and women at increased likelihood of  
26 event during their remaining lifespan. We observed in our data a modest net reclassification  
27 improvement (computed as in [24]) for the 20-year risk prediction model over the re-  
28 calibrated 10-year risk, in men (1.8%) and in women (4.5%). The net reclassification  
29 increased when we considered subjects with a low 10-year predicted risk but a cluster of 2 or  
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4 more risk factors (5.4% and 7.6% in men and women, respectively; data not shown).  
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7 Subjects' stratification is often based on arbitrarily-chosen thresholds of predicted risk [15],  
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9 which may limit the clinical utility of risk prediction models [16]. We considered two  
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11 strategies for the identification of "high-risk" subjects with contrasting goals, either to  
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13 decrease the fraction of missed events or to decrease un-necessary treatment. These can be  
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15 implemented by choosing threshold values for the predicted risk driven by either sensitivity  
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17 or by specificity, respectively. Despite the lowering costs of statin treatment with respect to  
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19 the costs of one un-prevented event, the high sensitivity scenario might not be cost-effective  
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21 [30]. These two scenarios might be combined to adopt a more complex risk stratification, as  
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23 often present in clinical practice [1-2, 12]. For instance, if we consider at "low-risk" the 36%  
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25 of men with 20-year absolute risk less than 10%, the fraction of missed events would be 9%,  
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27 i.e. 31 first events in 20 years. About 31% of men with absolute risk between 10% and 20%  
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29 could be addressed for lifestyle modification or treatment according to the presence of  
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31 specific risk factors; this category accounts for about 20% of cases. Finally, the 33% of men  
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33 with predicted risk above the 20% could be targeted with treatment intervention; they account  
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35 for 68% of events, and out of 3.2 treated men, one is a case. A similar stratification can be  
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37 provided for women, with different threshold values reflecting gender-specific underlying  
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39 risk as for the cardiovascular age assessment [15].  
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44 Among the study strengths and limitations, our sample comprises subjects drawn from a  
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46 representative northern Italian population, with a satisfactory participation rate. The  
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48 underlying population is characterized by high levels of industrialization and urbanization,  
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50 with one of the highest average incomes in Italy. As Supplementary Material we provide the  
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52 baseline survival term as well as a calibration slope [25] to allow applying our equation to  
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54 different contexts. However, a validation study in a different population might be desirable to  
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investigate the generalizability of our findings. We also mention a high-quality of follow-up procedures, including case ascertainment for non-fatal events [21] and a consistent event validation according to MONICA criteria, resulting in a Standardized Incidence Rate for the study cohorts above 1 over the whole follow-up period [18]. Finally, the study endpoint reflects the clinical need to treat the “global” ischemic risk of a given patient, and not its separate components [3].

In conclusions, we provide a model to predict long-term risk of first major ischemic cardiovascular event in a low-incidence population. Risk stratification based on long-term risk can be clinically useful, especially for young subjects and women. A clinical utility analysis is required to identify the optimal stratification, according to different public health goals.

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### **Competing Interests**

None.

### **Contributors**

Conception and design: MMF, GM, GC and GV. All authors interpreted the data and critically reviewed the paper. Statistical analyses: GV, WC. GV drafted the manuscript and is the guarantor. All authors have read and approved the final version of the manuscript.

### **Data sharing**

There is no additional data available



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## Tables and figures

**Table 1.** Baseline characteristics (mean (SD) or %) of the study population and number of incident events, by gender. Men and women, 35-69 years old, CVD-free at baseline.

	Men (n=2574)	Women (n=2673)
Age (years)	50.8 (9.1)	50.3 (9)
Years of schooling	8.5 (4.2)	7.3 (3.4)
Total Cholesterol (mmol/L)	5.8 (1.1)	5.8 (1.1)
HDL-Cholesterol (mmol/L)	1.3 (0.3)	1.6 (0.4)
Body Mass Index (Kg/m <sup>2</sup> )	26.2 (3.5)	25.6 (4.7)
Systolic Blood Pressure (mmHg)	134.8 (19.3)	131.6 (20.2)
Diastolic Blood Pressure (mmHg)	85.9 (10.6)	82.8 (10.8)
Anti-hypertensive treatment (%)	11.8	16.0
Fasting plasma glucose (mmol/L)	5.4 (1.3)	5.1 (1.2)
Diabetes (%)	6.7	4.0
Current smoker (%)	37.1	19.6
Incident coronary event (n)	233	85
Incident ischemic strokes (n)	99	43
Incident CVD event (n)	315	123
20-year absolute risk of CVD <sup>^</sup>	16.1	6.1

<sup>^</sup>: Kaplan-Meier estimate.

**Table 2.** Discrimination ability for the 10-year and the 20-year risk prediction models. Men and women, 35-69 years old, CVD-free at baseline

	Men		Women	
	10-year risk	20-year risk	10-year risk	20-year risk
<b>AUC (95% CI)</b>	0.731 (0.702; 0.761)	0.737 (0.713; 0.764)	0.814 (0.779; 0.853)	0.801 (0.771; 0.833)
<b>Subjects with predicted risk below the 20th percentile</b>				
20th percentile of risk	2.3	6.3	0.3	1.1
Fraction of events* (%)	4.4	5.1	1.4	2.0
Probability of event in the group^ (%)	0.8	3.7	0.2	0.9
<b>Subjects with predicted risk above the 80th percentile</b>				
80th percentile of risk	10.8	26.8	3.0	10.1
Sensitivity* (%)	49.9	45.6	68.7	62.0
Specificity (%)	82.4	85.5	81.1	83.1
Probability of event in the group^ (%)	19.4	35.1	7.5	20.2

The Area Under the ROC-curve (AUC) was estimated taking censorship into account, and adjusting for over-optimism (n=1000 bootstrap).  
\*: Probability of belonging to the group, given that the subject is a case. ^: Kaplan-Meier estimate of the probability of event in the group.

**Table 3a.** Identification of high risk subjects based on the 20-year risk prediction model with respect to the number of risk factors, according to strategies aiming to *i*) reducing the fraction of missed events; and *ii*) reducing un-necessary treatment. Men, 35-69 years old, CVD-free at baseline

	Subjects at high risk		Fraction of missed events (%)	Specificity (%)	Probability of event* (%)	FP/TP Ratio
	n	%				
<b>Strategy a: reduce the fraction of missed events</b>						
All subjects	2574	100.0	0.0	-	16.1	5.2
1+ Major Risk Factor <sup>#</sup>	1842	71.6	13.7	32.5	19.5	4.1
20-year absolute risk > 10%	1645	63.9	9.1	41.2	22.9	3.4
20-year absolute risk > 15%	1169	45.4	22.1	60.9	27.7	2.6
<b>Strategy b: reduce un-necessary treatment</b>						
2+ Major Risk Factors <sup>#</sup>	828	32.2	50.4	73.6	24.9	3.0
20-year absolute risk > 20%	841	32.7	35.7	73.7	31.7	2.2
20-year absolute risk > 30%	415	16.1	62.6	88.9	37.4	1.7

“Missed” events are events occurring among subjects not classified at “high risk”, i.e. with 20-year absolute risk (or a number of risk factors) below the cut-off point.

\*: Kaplan-Meier estimate of the probability of event in the group (positive predicted value).

FP = Number of False Positives; TP = Number of True Positives

<sup>#</sup>: total cholesterol > 240 mg/dl; HDL-cholesterol < 40 [men] or < 50 [women] mg/dl; systolic blood pressure > 160 mmHg; smoking; diabetes

**Table 3b.** Identification of high risk subjects based on the 20-year risk prediction model with respect to the number of risk factors, according to strategies aiming to *i*) reducing the fraction of missed events; and *ii*) reducing un-necessary treatment. Women, 35-69 years old, CVD-free at baseline

	Subjects at high risk		Fraction of missed events (%)	Specificity (%)	Probability of event* (%)	FP/TP Ratio
	n	%				
<b>Strategy a: reduce the fraction of missed events</b>						
All subjects	2673	100.0	0.0	-	6.1	15.3
1+ Major Risk Factor <sup>#</sup>	1654	61.9	17.7	40.1	8.2	11.3
20-year absolute risk > 2%	1733	64.8	4.5	37.4	9.0	10.1
20-year absolute risk > 5%	1067	39.9	14.7	63.2	13.1	6.6
<b>Strategy b: reduce un-necessary treatment</b>						
2+ Major Risk Factors <sup>#</sup>	640	23.9	42.3	79.5	14.8	5.8
20-year absolute risk > 8%	698	26.1	22.7	77.1	18.2	4.5
20-year absolute risk > 10%	545	20.4	32.1	82.7	20.4	3.9

“Missed” events are events occurring among subjects not classified at “high risk”, i.e. with 20-year absolute risk (or a number of risk factors) below the cut-off point.

\*: Kaplan-Meier estimate of the probability of event in the group (positive predicted value).

FP = Number of False Positives; TP = Number of True Positives

#: total cholesterol > 240 mg/dl; HDL-cholesterol < 40 [men] or < 50 [women] mg/dl; systolic blood pressure > 160 mmHg; smoking; diabetes

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5 **Figure 1:** Decision curve for the 20-year risk prediction model in the CAMUNI population, Northern Italy.  
6 Men (left) and women (right), 35 to 69 years old, free of CVD at baseline.  
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35 Net Benefit:  $(TP - w * FP) / n$ , where TP = True Positive; FP = False Positive;  $w = (\text{Absolute risk threshold}) / (1 - (\text{Absolute risk threshold}))$ ; n=sample size  
36 Number of risk factors: total cholesterol >240 mg/dl; HDL-cholesterol <40 [men] or <50 [women] mg/dl; systolic blood pressure >160 mmHg; smoking; diabetes  
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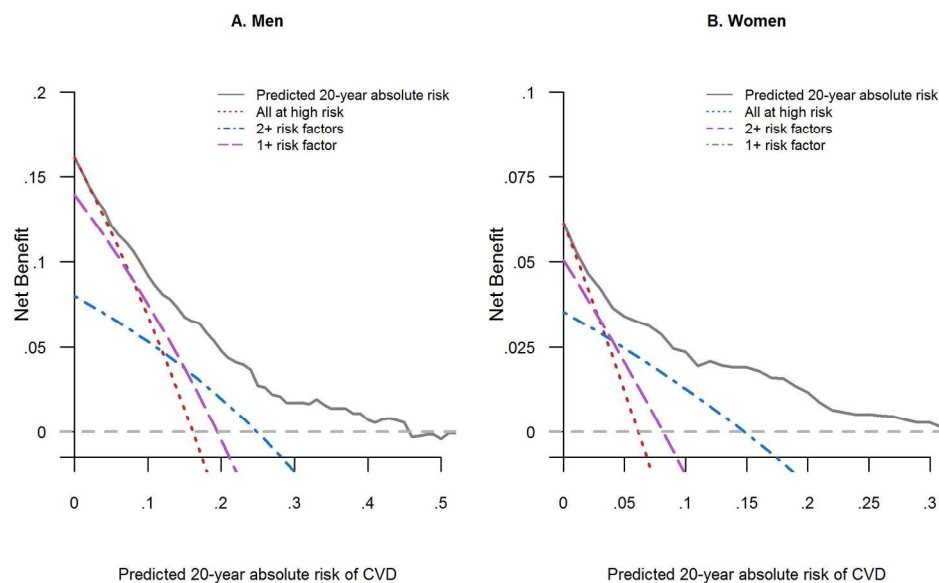


Figure 1: Decision curve for the 20-year risk prediction model in the CAMUNI population, Northern Italy. Men (left) and women (right), 35 to 69 years old, free of CVD at baseline.

Net Benefit:  $(TP - w \cdot FP) / n$ , where TP = True Positive; FP = False Positive;  $w = (\text{Absolute risk threshold}) / (1 - \text{Absolute risk threshold})$ ;  $n = \text{sample size}$

Number of risk factors: total cholesterol >240 mg/dl; HDL-cholesterol <40 [men] or <50 [women] mg/dl; systolic blood pressure >160 mmHg; smoking; diabetes

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only



## Supplementary material

**Table S1:** Beta-coefficients, standard errors and baseline survival for the 20-year risk prediction model in Northern Italy. Men and women, 35 to 69 years old, free of CVD at baseline.

	Men			Women		
	Beta	SE	p-value	Beta	SE	p-value
<b>Age (years)</b>	0.058	0.008	<.0001	0.084	0.014	<.0001
<b>Total Cholesterol<sup>^</sup></b>						
200-240 mg/dl	0.388	0.161		0.553	0.287	
240-280 mg/dl	0.690	0.167	<.0001	0.607	0.310	0.027
> 280 mg/dl	0.923	0.198		0.996	0.328	
<b>HDL-Cholesterol<sup>°</sup></b>						
<45 mg/dl	0.403	0.160		0.804	0.250	
45-50 mg/dl	0.367	0.186	0.013	0.364	0.309	0.015
50-60 mg/dl	0.024	0.177		0.261	0.225	
<b>Systolic Blood Pressure (mmHg)</b>	0.011	0.003	0.0003	0.015	0.005	0.001
<b>Anti-hypertensive treatment (yes/no)</b>	0.247	0.154	0.11	0.267	0.209	0.20
<b>Smoking (yes/no)</b>	0.521	0.117	<.0001	0.994	0.216	<.0001
<b>Diabetes (yes/no)</b>	0.744	0.163	<.0001	1.020	0.249	<.0001
<b>Baseline 20-year survival (<math>S_0(20)</math>)*</b>		0.94168			0.98502	
<b>G(<math>\mu</math>)</b>		4.35638			6.20915	
<b>Calibration Slope</b>		0.948			0.937	

SE = Standard Error. <sup>^</sup>: reference group: total cholesterol  $\leq$  200 mg/dl. <sup>°</sup>: reference group: HDL-cholesterol  $>$  60 mg/dl. \*: at the mean value for continuous RFs, and at the reference class for categorical variables. 20-year risk:  $1 - S_0(20)^{\exp(\sum \beta X - G(\mu))}$ .

Calibration slope: correction term that could be used in different population to shrink the beta-coefficients. See reference[25] for more details.

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**Figure S1:** Distribution of predicted 10-year and 20-year risk of first major CVD event, according to the number of risk factors. Men (left) and women (right), 35 to 49 years old, free of CVD at baseline.

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Risk factors stratification derived from Lloyd-Jones [7].  
All optimal: total cholesterol <180 mg/dl, HDL-Cholesterol  $\geq$  40 mg/dl [men] or  $\geq$  50 mg/dl [women], blood pressure <120/80 mmHg, non smoker, non diabetic;  
1+ non-optimal: total cholesterol 180 to 199 mg/dl, systolic blood pressure 120 to 139 mmHg, diastolic blood pressure 80 to 89 mmHg, non smoker, non diabetic  
1+ elevated: total cholesterol 200 to 239 mg/dl, systolic blood pressure 140 to 159 mmHg, diastolic blood pressure 90 to 99 mmHg, non smoker, non diabetic  
Major risk factor: total cholesterol  $\geq$ 240 mg/dl, HDL-Cholesterol <40 mg/dl [men] or <50 mg/dl [women], systolic blood pressure  $\geq$ 160 mmHg or treatment, diastolic blood pressure  $\geq$ 100 mmHg, smoker, or diabetic

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**Supplementary material for the paper:**

**Long-term prediction of major coronary or ischemic stroke event in a low-incidence European population: model development and evaluation of clinical utility.**

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Actions
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	The study setting is clearly stated in the abstract.
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Done
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	See the introduction section at pages 3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	See page 4, end of introduction section
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	See the Methods section (pages 4-7)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Relevant information on cohorts setting, location and periods of recruitment are provided in the paragraphs "Study population" (page 4), "Baseline assessment of risk factors" (page 4) and "Study endpoint and follow-up procedures" (page 5).
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	See the paragraphs "Study population" (page 4) and "Study endpoint and follow-up procedures" (page 5).
		(b) For matched studies, give matching criteria and number of exposed and unexposed	Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	See the paragraph "Statistical analysis", page 6-7
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	See paragraphs "Baseline assessment of risk factors" (page 4), and "Statistical analysis" (page 6-7). Exposure group: not applicable for this analysis.
Bias	9	Describe any efforts to address potential sources of bias	See the Methods section.
Study size	10	Explain how the study size was arrived at	See the first period in the "Results" section (page 7)
Quantitative	11	Explain how quantitative variables were	See the "Statistical Analysis" paragraph

1	variables		handled in the analyses. If applicable, (page 6)
2			describe which groupings were chosen and
3			why
4	Statistical methods	12	
5			(a) Describe all statistical methods, including See the “Statistical Analysis” paragraph
6			those used to control for confounding (page 6)
7			(b) Describe any methods used to examine See the “Statistical Analysis” paragraph
8			subgroups and interactions (page 6)
9			(c) Explain how missing data were addressed See the first line in the “Results” section
10			(page 7)
11			(d) If applicable, explain how loss to follow- See the “Statistical Analysis” paragraph
12			up was addressed (page 6) for details on the survival analysis
13			techniques
14			(e) Describe any sensitivity analyses Not applicable
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17	<b>Results</b>		
18	Participants	13*	
19			(a) Report numbers of individuals at each Participation rates are reported in the
20			stage of study—eg numbers potentially paragraph “Study population” (page 4).
21			eligible, examined for eligibility, confirmed Exposure group: not applicable for this
22			eligible, included in the study, completing analysis.
23			follow-up, and analysed
24			(b) Give reasons for non-participation at each Not applicable
25			stage
26			(c) Consider use of a flow diagram Not applicable
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28	Descriptive data	14*	
29			(a) Give characteristics of study participants See Table 1. Exposure group: not
30			(eg demographic, clinical, social) and applicable for this analysis.
31			information on exposures and potential
32			confounders
33			(b) Indicate number of participants with See the “Results” section, first period
34			missing data for each variable of interest (page 7). Exposure group: not applicable
35			for this analysis.
36			(c) Summarise follow-up time (eg, average “Results” section, second period (page 7).
37			and total amount) Exposure group: not applicable for this
38			analysis..
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40	Outcome data	15*	
41			Report numbers of outcome events or Number of events, by type, are reported in
42			summary measures over time Table 1. Exposure group: not applicable
43			for this analysis.
44	Main results	16	
45			(a) Give unadjusted estimates and, if The study model is reported in Table S1,
46			applicable, confounder-adjusted estimates and supplementary material; the analysis is
47			their precision (eg, 95% confidence interval). multivariable by nature.
48			Make clear which confounders were adjusted
49			for and why they were included
50			(b) Report category boundaries when Not applicable
51			continuous variables were categorized
52			(c) If relevant, consider translating estimates Not applicable
53			of relative risk into absolute risk for a
54			meaningful time period
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56	Other analyses	17	
57			Report other analyses done—eg analyses of Not applicable
58			subgroups and interactions, and sensitivity
59			analyses
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<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	See the first part of the Discussion section, page 9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Study limitations are reported and discussed at pages 11-12.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Done
Generalisability	21	Discuss the generalisability (external validity) of the study results	See pages 11-12
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Source of funding is reported at page 12.

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.



**Long-term prediction of major coronary or ischemic stroke event in a low-incidence Southern European population: model development and evaluation of clinical utility**

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Manuscripts

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4 **Long-term prediction of major coronary or ischemic stroke event in a low-incidence**  
5 **Southern European population: model development and evaluation of clinical utility**  
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9 **Short Title: Clinical utility of long-term CVD risk prediction in primary prevention**  
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51 prevention  
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## ABSTRACT

**Objective.** To develop a long-term prediction model of first major cardiovascular event and to assess its clinical utility in a low-incidence European population.

**Setting.** Four independent population-based cohorts enrolled between 1986 and 1993 in Northern Italy.

**Participants and methods.** N=5,247 35-69 years old men and women free of cardiovascular disease at baseline. Absolute 20-year risk of first fatal or non-fatal coronary or ischemic stroke event (MONICA validated) was estimated from gender-specific Cox models.

**Main outcome measures.** Model discrimination (Area Under the ROC-Curve, AUC). “High-risk” subjects were defined based on several threshold values for the 20-year predicted risk. Clinical utility was defined in terms of fraction of missed events (events among those considered at low-risk) and unnecessary treatment (false:true positives ratio). A Net Benefit curve was also provided.

**Results.** Kaplan-Meier 20-year risk was 16.1% in men (315 events) and 6.1% in women (123 events). Model discrimination (AUC=0.737 in men, 0.801 in women) did not change significantly as compared to 10-year prediction time interval. In men, with respect to risk stratification based on the number of risk factors, a 20% predicted risk cut-off would miss less events (36% vs. 50%) and reduce unnecessary treatment (false:true positive ratio: 2.2 vs. 3.0); the Net Benefit was higher over the whole range of threshold values. Similar considerations hold for women.

**Conclusions.** Long-term prediction has good discrimination ability and is clinically useful for risk stratification in primary prevention. A clinical utility analysis is recommended to identify the optimal stratification according to different public health goals.



## ARTICLE SUMMARY

### Article focus

- Primary prevention of cardiovascular disease (CVD) has been recently moved towards the concepts of “lifetime” and “long-term” risk, especially in young subjects and women.
- There is no long-term risk prediction model available for low-incidence Southern European populations; in addition, the evaluation of the clinical benefit of long-term prediction has not been provided so far.
- We aim to develop a 20-year risk score equation in a northern Italian population of men and women considered at low incidence of major cardiovascular events; and to evaluate the clinical utility of the model for risk stratification in primary CVD prevention program.

### Key Messages

- In our population, the 20-year risk model had satisfactory discrimination ability as compared to short-term risk prediction. The importance of long-term prediction for early identification of young subjects and women at increased likelihood of event during their remaining lifespan is confirmed.
- Risk stratification based on the predicted 20-year risk had a better clinical Net Benefit with respect to a stratification based on the number of risk factors, in men and women.
- In both genders, the optimal treatment allocation based on 20-year risk can be determined according to different public health strategies, i.e. either to reduce the fraction of events potentially un-prevented or to avoid un-necessary treatment.

### Strengths and limitations of this study

- Our sample comprises subjects drawn from a representative northern Italian population, with a satisfactory participation rate. We also mention the high-quality of follow-up

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4 procedures, including case ascertainment for non-fatal events and a consistent event  
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6 validation according to MONICA criteria over the whole follow-up period.  
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- Our 20-year risk prediction model is the first attempt to characterize long-term risk of first coronary or ischemic stroke event in a low-incidence European population. A limitation of our study is the lack of a formal external validation, although we provide a cross-validation analysis. We also remind that our underlying population is characterized by high levels of industrialization and urbanization, with one of the highest average incomes in Italy. Caution is therefore required before generalizing our findings to different contexts.

## INTRODUCTION

Current European and American guidelines for primary prevention of major coronary and stroke events recommend the use of a multivariable risk prediction method to identify high risk subjects [1, 2]. Several risk scores are available in different US [3, 4] and European [5] populations of middle-aged adults, including the Italian one [6], to estimate the risk of first fatal and non-fatal cardiovascular event over a 10 year time interval. Primary prevention however has been recently moved towards the concepts of “lifetime” [7] and “long-term” risks [8], motivated also by the increasing life expectancy in western Countries. To this extent, 10-year risk prediction models are inadequate to distinguish between those at both low short-term and long-term risks, and those at low short-term but at elevated long-term risk due to the presence of non-optimal risk factors levels [9-11]. In the Framingham Study population, an unfavorable risk factor profile led to an increased 30-year risk of first cardiovascular event, independently on the age at the risk factors assessment [10]. In a

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4 representative sample of the Italian population, about 80% of individuals classified at low 10-  
5 year risk had increased lifetime risk according to US definition ( $\geq 40\%$ ), potentially leading  
6 to a consistent number of un-prevented events that might have been prevented if lifetime risk  
7 had been considered [11]. This group was largely composed of women and young subjects,  
8 suggesting that long-term prediction models for risk stratification may be even more  
9 beneficial in populations at low incidence of cardiovascular disease [12]. To this extent, the  
10 development of a specific long-term risk prediction should be preferred with respect to re-  
11 calibration of risk models derived in high-incidence countries [13]. However, extending the  
12 range of risk prediction is not a straightforward operation. Although several studies have  
13 shown that a single measurement of risk factor is predictive of future events after 30 plus  
14 years [10, 14], behavioral changes and risk factors modification may affect model  
15 discrimination. High-quality follow-up data, with a consistent event definition and validation  
16 over-time, are also required. Finally, subjects' stratification in risk categories is often based  
17 on arbitrary cut-points of absolute risk [15] which may show no benefit in clinical practice  
18 [16]. The evaluation of the clinical benefit of long-term prediction by means of some  
19 standard measure [17] has not been provided so far and is therefore required [8].

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The aim of the present paper is to develop a 20-year risk score equation in a European population of men and women considered at low incidence of major cardiovascular events. In addition to standard model calibration and discrimination tools, we evaluate the clinical utility of the model for risk stratification.

## METHODS

### Study population

The Brianza population comprises residents in 173 municipalities in the area between Milan and the Swiss border, Northern Italy. The CAMUNI study includes four independent

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4 population surveys carried out between 1986 and 1994 as part of either the WHO-MONICA  
5 Project [3 surveys; 18] or the PAMELA study [19]. Participation rates were 70.1%, 67.2%,  
6 and 70.8% for the three MONICA surveys, respectively, and 64% for the PAMELA Study,  
7 with no differences between men and women. Both the baseline screening and the follow-up  
8 for all the surveys were approved by the ethical committee of the Monza Hospital.

### 15 **Baseline assessment of risk factors**

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17 Cardiovascular risk factors were collected at baseline strictly adhering to the standardized  
18 procedures and quality standards of the WHO-MONICA Project [20]. Height and weight  
19 were measured on subjects without shoes and wearing light clothing. Trained technicians  
20 collected blood pressure at right arm on subjects in sitting position and at rest, using a  
21 standard mercury sphygmomanometer equipped with two side cuff bladders, for normal and  
22 obese subjects. Systolic and diastolic blood pressure were assessed twice, at 5 minutes apart,  
23 recording the first and fifth phase of the Korotkoff sounds. The study variable for systolic  
24 blood pressure is the average of the two measurements. Venous blood specimens were taken  
25 from the ante-cubital vein on fasting subjects (12 hours or more). Serum total cholesterol,  
26 HDL-cholesterol and blood glucose were determined using the enzymatic methods; HDL-  
27 cholesterol fraction was separated using the Phosphotungstate-Mg<sup>++</sup> method [20]. A  
28 standardized interview was administered to participants by trained interviewers. Information  
29 on the use of anti-hypertensive treatment in the last two weeks was dichotomised as yes/no;  
30 similarly, cigarette smoking habit was dichotomised as current versus past/never smokers.  
31 Diabetes mellitus was defined using self-reported diagnoses, information on insulin and oral  
32 hypoglycaemic treatments and fasting blood glucose exceeding 7 mmol/L (126 mg/dl). The  
33 presence at baseline of a previous history of MI, unstable angina pectoris, cardiac  
34 revascularization or stroke was defined based on self-reported information.  
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### Study endpoint and follow-up procedures

The study endpoint is defined as the occurrence of first major coronary event (myocardial infarction, acute coronary syndrome and coronary revascularization) as well as for first ischemic stroke or carotid endarterectomy, fatal and non-fatal [13]. Data completeness for fatal events was assured through a systematic collection of death certificates provided by local health units; vital status and death certificates were available for 99% of the subjects. Suspected out-of-hospital deaths were investigated through interview of relatives. Suspected hospitalized coronary (discharge code ICD-IX 410 or 411 and ICD-IX CM 36.0-9 for coronary revascularization) and stroke events (ICD-IX 430-432, 434, 436; ICD-IX CM 38.01-39.22 or 39.50-39.52 with at least one 430-438 as discharge code, for carotid endarterectomy) were identified through deterministic and probabilistic record linkages with regional hospital discharge databases, obtaining a satisfactory performance in case finding, as reported [18, 21]. All acute events were investigated and validated according to the MONICA diagnostic criteria [20]; the ischemic subtype for stroke was attributed after review of the available clinical information.

### Statistical analysis

Our 20-year risk prediction model is based on gender-specific Cox regression models with age, total cholesterol, HDL-cholesterol, systolic blood pressure, anti-hypertensive treatment, cigarette smoking and diabetes. These predictors are core risk factors included in the CUORE Project [6, 13] as well as in other 10-year risk equations [3, 4]. After a preliminary check on linearity, total- and HDL-cholesterol were included in the model as categorical variables in four standard classes [4, 22]. The interaction between systolic blood pressure and anti-hypertensive treatment was not statistically significant (p-value 0.84 in men and 0.12 in women, respectively). There was no evidence of any cohort effect in the full model, in men

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4 (3 df test p-value: 0.2) nor in women (p-value: 0.5). Finally, no violations in the proportional  
5 hazard assumption were observed using a standard test for time-dependent variables.  
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9 Model calibration was assessed through the Grønnesby-Bogan goodness-of-fit test [23]. The  
10 Area Under the ROC-curve (AUC), as well as sensitivity and specificity in the top and  
11 bottom predicted risk quintiles, were computed taking censorship into account [24].  
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13 Correction for over-optimism and confidence intervals for the AUC were obtained through  
14 1000 bootstrapped samples [25]. To assess the hypothesis of a loss in discrimination ability  
15 due to a longer prediction period, we estimated the 10-year predicted probability of event in  
16 our database, using the same set of risk factors but with shorter follow-up period, i.e. up to  
17 the end of 2002 for all the subjects (number of events: 234 in men, 79 in women). We then  
18 compared the AUC of the two models by looking at their respective bootstrapped confidence  
19 intervals. To assess the clinical utility of the long-term model for risk stratification, we  
20 considered two different public health goals. One is to decrease the number of events  
21 occurring among those considered at “low-risk”. If we assume that a subject classified at  
22 “high risk” will be targeted for prevention (either lifestyle intervention or treatment), any  
23 event occurring outside this category is “not-identified” or “missed” by the prevention  
24 strategy. The second strategy aims instead to reduce un-necessary treatment, by decreasing  
25 the number of non-events among those considered at “high-risk”. Under the two scenarios,  
26 “high-risk” subjects are defined as those with predicted risk above a certain cut-off value.  
27 Clinical utility is defined in terms of *i*) fraction of “missed” events; *ii*) probability of event  
28 among those classified at high risk; and *iii*) false positive/true positive ratio, for several  
29 threshold values in the 20-year predicted risk. We also provide a decision curve analysis  
30 based on the net benefit:  $\text{Net Benefit} = (\text{true positives} - w \cdot \text{false positives})/n$ , where  $n$  is the  
31 sample size and the weight  $w$  represents the ratio between the harm of un-necessary treatment  
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4 and the harm of missing a case at that given value of predicted risk [17]. All the analyses  
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6 were conducted using the SAS software 9.2.  
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## 8 9 **RESULTS**

10 N=5,426 (2,703 men) subjects were enrolled in the age range 35-69 years. N=205 subjects  
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12 (3.8%; n=14 events) had at least one missing data; we considered data imputation (R  
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14 *transcan* function, [26]) and excluded only those with missing values in more than 4  
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16 covariates of interest (n=6 men and n=3 women). Finally n=120 men and n=45 women with a  
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18 positive history of CVD at baseline were also excluded, reducing the sample size to 2,574  
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20 men and 2,673 women.  
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24 Baseline characteristics of the study population, by gender, are shown in **Table 1**. During a  
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26 median follow-up time of 15 years (interquartile range: 12-20), we observed 315 first CVD  
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28 events in men (233 coronary events) and 123 in women (n=85 coronary events). The Kaplan-  
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30 Meier estimate for 20-year risk was 16.1% and 6.1% in men and women, respectively.  
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### 33 **Model development**

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35 The beta-coefficients for the 20-year risk prediction model, as well as the baseline survival  
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37 term and the calibration slope [25], are provided in the Supplementary Material (**Table S1**).  
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39 All the risk factors were statistically significant, except for anti-hypertensive treatment,  
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41 though its point estimate reflected a 30% increase in hazard in both men and women; the  
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43 variable was retained in the model for comparability with the short-term CUORE model [6].  
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45 There were no significant differences in the set of beta estimates for the 20-year model as  
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47 compared to those from the 10-year risk model for the risk factors in the model (data not  
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49 shown). The model calibration was satisfactory, in men (Grønnesby-Bogan goodness-of-fit  
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51 chi-square 6.7, p-value 0.67) and in women (chi-square 9.6, p-value 0.38); calibration plots  
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53 are available as supplementary material (**Figure S1**)  
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4 We found no statistically significant difference in the overall discrimination ability between  
5 long- and short-term prediction models, in men (0.736 vs. 0.731) and in women (0.801 vs.  
6 0.816; **Table 2**). Only 5% of 20-year events in men occurred among subjects with a predicted  
7 risk below the 20<sup>th</sup> percentile (bottom fifth); the corresponding figure in women is 2%. The  
8 relative risk of event for being above the 80<sup>th</sup> percentile vs. below the 20<sup>th</sup> percentile of 20-  
9 year risk was 9.5 (i.e. 35.1/3.7) in men and 22.4 (i.e. 20.2/0.9) in women. Finally, the value of  
10 the 80<sup>th</sup> percentile for 20-year risk was more than twice as high than the similar percentile for  
11 10-year risk in men (26.8 vs. 10.8) and more than three times as high in women (10.1 vs.  
12 3.0). A similar consideration holds for the 20<sup>th</sup> percentile of risk or the median value.

### 23 **Clinical utility**

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25 **Table 3a** and **Table 3b** describe strategies for the identification of high-risk subjects, based  
26 on predicted 20-year risk, in men and women respectively. A cut-off value of 10% twenty  
27 year risk in men would result in a 9% of “missed” events (i.e. events among those with  
28 predicted risk below the cut-point), with a probability of event of 23% and one true positive  
29 for every 3.4 false positive subjects (**Table 3a**). In the second scenario, by choosing the 20%  
30 twenty year risk threshold value, the fraction of missed events was 36%. Note that about 30%  
31 of events occurred for a predicted 20-year risk between 20% and 30%. Finally, using the  
32 number of risk factors to define high risk subjects would result in a higher fraction of missed  
33 events, with no changes in specificity or in the prevalence of subjects considered at high risk.  
34 Among women, a cut-off value of 2% would result in a 5% of missed events, with a  
35 probability of event of 9% and a true positive for every 10.1 false positive women (**Table**  
36 **3b**). In the second scenario, the probability of event among those with absolute risk greater  
37 than 10% was 20.4%, with a true positive for every 3.9 false positive subjects. However, the  
38 fraction of missed events would be 32%; this number can be reduced by lowering the cut-off  
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4 value to 8%. By considering at high risk those with 2 or more risk factor would result in a  
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6 higher fraction of missed events, with no gain in specificity or in the probability of event in  
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8 the group. **Figure 1** illustrates the decision curve analysis based on the Net Benefit [17], for  
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10 men (left) and women (right). The figure suggests a greater net benefit for the predicted risk  
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12 with respect to the number of risk factors over the whole range of values, thus generalizing  
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14 the findings from Table 3a and Table 3b.  
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## 17 **DISCUSSION**

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19 In this paper we present the 20-year prediction model of first major coronary or ischemic  
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21 stroke event in a Northern Italian population of men and women aged 35 to 69 years at  
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23 baseline. To our knowledge, this is the first long-term prediction model in a low-incidence,  
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25 European population. The discrimination ability of the long-term model did not significantly  
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27 drop with respect to a 10-year risk prediction model derived on the same population. Risk  
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29 stratification based on the predicted 20-year risk can be modulated according to different  
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31 prevention aims, i.e. either to reduce the fraction of events potentially un-prevented or to  
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33 avoid un-necessary treatment. Under both scenarios, the predicted 20-year risk showed an  
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35 overall better Net Benefit with respect to a risk stratification based on the number of risk  
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37 factors.  
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41 Our data confirmed previous findings on predictiveness of a single measurement of risk  
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43 factors on long-term CVD risk, in the Italian [27] as well as in other populations [10, 14].  
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45 Event discrimination for the 20-year risk prediction model did not change significantly from  
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47 10-year's, although in women it decreased from 0.814 to 0.801. In the Framingham Offspring  
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49 Study updating the baseline measurement of blood pressure and lipids with a later assessment  
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51 poorly affected model discrimination and reclassification [28] and cardiometabolic risk  
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53 factors clustering has been found to be quite stable over time [29].  
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4 As in the Framingham population, in our study the long-term predicted risk was more than  
5 simply  $n$ -times the short-term risk prediction [10]. In addition in the age range 35 to 49  
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8 years, the long-term predicted risk in subjects with 1 or more non-optimal or elevated risk  
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10 factors (defined as in [7]) was 3-times the short-term risk in men, and 4-times in women (see  
11 **Figure S2** in the Supplementary Material). This conveys the importance of long-term  
12 prediction for early identification of young subjects and women at increased likelihood of  
13 event during their remaining lifespan. We observed in our data a modest net reclassification  
14 improvement (computed as in [24]) for the 20-year risk prediction model over the re-  
15 calibrated 10-year risk, in men (1.8%) and in women (4.5%). The net reclassification  
16 increased when we considered subjects with a low 10-year predicted risk but a cluster of 2 or  
17 more risk factors (5.4% and 7.6% in men and women, respectively; data not shown).  
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19 Subjects' stratification is often based on arbitrarily-chosen thresholds of predicted risk [15],  
20 which may limit the clinical utility of risk prediction models [16]. We considered two  
21 strategies for the identification of "high-risk" subjects with contrasting goals, either to  
22 decrease the fraction of missed events or to decrease un-necessary treatment. These can be  
23 implemented by choosing threshold values for the predicted risk driven by either sensitivity  
24 or by specificity, respectively. Despite the lowering costs of statin treatment with respect to  
25 the costs of one un-prevented event, the high sensitivity scenario was not cost-effective over  
26 a 10-year period [30]. These two scenarios might be combined to adopt a more complex risk  
27 stratification, as often present in clinical practice [1-2, 12]. For instance, if we consider at  
28 "low-risk" the 36% of men with 20-year absolute risk less than 10%, the fraction of missed  
29 events would be 9%, i.e. 31 first events in 20 years. About 31% of men with absolute risk  
30 between 10% and 20% could be addressed for lifestyle modification or treatment according  
31 to the presence of specific risk factors; this category accounts for about 20% of cases. Finally,  
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4 the 33% of men with predicted risk above the 20% could be targeted with treatment  
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6 intervention; they account for 68% of events, and out of 3.2 treated men, one is a case. A  
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8 similar stratification can be provided for women, with different threshold values reflecting  
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10 gender-specific underlying risk as for the cardiovascular age assessment [15].  
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13 Among the study strengths and limitations, our sample comprises subjects drawn from a  
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15 representative northern Italian population, with a satisfactory participation rate. The  
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17 underlying population is characterized by high levels of industrialization and urbanization,  
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19 with one of the highest average incomes in Italy. A major limitation is the lack of an external  
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21 validation. External validation for long-term prediction models is in general an issue [10]; we  
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23 provide the over-optimism adjusted AUC as well as the calibration slope [25] to allow  
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25 applying our equation to different contexts (see Supplementary Material). We also mention a  
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27 high-quality of follow-up procedures, including case ascertainment for non-fatal events [21]  
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29 and a consistent event validation according to MONICA criteria, resulting in a Standardized  
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31 Incidence Rate for the study cohorts above 1 over the whole follow-up period [18]. Finally,  
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33 the study endpoint reflects the clinical need to treat the “global” ischemic risk of a given  
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35 patient, and not its separate components [3].  
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40 In conclusions, we provide a model to predict long-term risk of first major ischemic  
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42 cardiovascular event in a low-incidence population. Risk stratification based on long-term  
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44 risk can be clinically useful, especially for young subjects and women. A clinical utility  
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46 analysis is required to identify the optimal stratification, according to different public health  
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48 goals.  
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**Competing Interests**

None.

**Contributors**

Conception and design: MMF, GM, GC and GV. All authors interpreted the data and critically reviewed the paper. Statistical analyses: GV, WC. GV drafted the manuscript and is the guarantor. All authors have read and approved the final version of the manuscript.

**Data sharing**

There is no additional data available.

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## Tables and figures

**Table 1.** Baseline characteristics (mean (SD) or %) of the study population and number of incident events, by gender. Men and women, 35-69 years old, CVD-free at baseline.

	Men (n=2574)	Women (n=2673)
Age (years)	50.8 (9.1)	50.3 (9)
Years of schooling	8.5 (4.2)	7.3 (3.4)
Total Cholesterol (mmol/L)	5.8 (1.1)	5.8 (1.1)
HDL-Cholesterol (mmol/L)	1.3 (0.3)	1.6 (0.4)
Body Mass Index (Kg/m <sup>2</sup> )	26.2 (3.5)	25.6 (4.7)
Systolic Blood Pressure (mmHg)	134.8 (19.3)	131.6 (20.2)
Diastolic Blood Pressure (mmHg)	85.9 (10.6)	82.8 (10.8)
Anti-hypertensive treatment (%)	11.8	16.0
Fasting plasma glucose (mmol/L)	5.4 (1.3)	5.1 (1.2)
Diabetes (%)	6.7	4.0
Current smoker (%)	37.1	19.6
Incident coronary event (n)	233	85
Incident ischemic strokes (n)	99	43
Incident CVD event (n)	315	123
20-year absolute risk of CVD <sup>^</sup>	16.1	6.1

<sup>^</sup>: Kaplan-Meier estimate.



**Table 2.** Discrimination ability for the 10-year and the 20-year risk prediction models. Men and women, 35-69 years old, CVD-free at baseline

	Men		Women	
	10-year risk	20-year risk	10-year risk	20-year risk
<b>AUC (95% CI)</b>	0.731 (0.702; 0.761)	0.737 (0.713; 0.764)	0.814 (0.779; 0.853)	0.801 (0.771; 0.833)
<b>Subjects with predicted risk below the 20th percentile</b>				
20th percentile of risk	2.3	6.3	0.3	1.1
Fraction of events* (%)	4.4	5.1	1.4	2.0
Probability of event in the group^ (%)	0.8	3.7	0.2	0.9
<b>Subjects with predicted risk above the 80th percentile</b>				
80th percentile of risk	10.8	26.8	3.0	10.1
Sensitivity* (%)	49.9	45.6	68.7	62.0
Specificity (%)	82.4	85.5	81.1	83.1
Probability of event in the group^ (%)	19.4	35.1	7.5	20.2

The Area Under the ROC-curve (AUC) was estimated taking censorship into account, and adjusting for over-optimism (n=1000 bootstrap).  
\*: Probability of belonging to the group, given that the subject is a case. ^: Kaplan-Meier estimate of the probability of event in the group.

**Table 3a.** Identification of high risk subjects based on the 20-year risk prediction model with respect to the number of risk factors, according to strategies aiming to *i*) reducing the fraction of missed events; and *ii*) reducing un-necessary treatment. Men, 35-69 years old, CVD-free at baseline

	Subjects at high risk		Fraction of missed events (%)	Specificity (%)	Probability of event* (%)	FP/TP Ratio
	n	%				
<b>Strategy a: reduce the fraction of missed events</b>						
All subjects	2574	100.0	0.0	-	16.1	5.2
1+ Major Risk Factor <sup>#</sup>	1842	71.6	13.7	32.5	19.5	4.1
20-year absolute risk > 10%	1645	63.9	9.1	41.2	22.9	3.4
20-year absolute risk > 15%	1169	45.4	22.1	60.9	27.7	2.6
<b>Strategy b: reduce un-necessary treatment</b>						
2+ Major Risk Factors <sup>#</sup>	828	32.2	50.4	73.6	24.9	3.0
20-year absolute risk > 20%	841	32.7	35.7	73.7	31.7	2.2
20-year absolute risk > 30%	415	16.1	62.6	88.9	37.4	1.7

“Missed” events are events occurring among subjects not classified at “high risk”, i.e. with 20-year absolute risk (or a number of risk factors) below the cut-off point.

\*: Kaplan-Meier estimate of the probability of event in the group (positive predicted value).

FP = Number of False Positives; TP = Number of True Positives

<sup>#</sup>: total cholesterol > 240 mg/dl; HDL-cholesterol < 40 [men] or < 50 [women] mg/dl; systolic blood pressure > 160 mmHg; smoking; diabetes

**Table 3b.** Identification of high risk subjects based on the 20-year risk prediction model with respect to the number of risk factors, according to strategies aiming to *i*) reducing the fraction of missed events; and *ii*) reducing un-necessary treatment. Women, 35-69 years old, CVD-free at baseline

	Subjects at high risk		Fraction of missed events (%)	Specificity (%)	Probability of event* (%)	FP/TP Ratio
	n	%				
<b>Strategy a: reduce the fraction of missed events</b>						
All subjects	2673	100.0	0.0	-	6.1	15.3
1+ Major Risk Factor <sup>#</sup>	1654	61.9	17.7	40.1	8.2	11.3
20-year absolute risk > 2%	1733	64.8	4.5	37.4	9.0	10.1
20-year absolute risk > 5%	1067	39.9	14.7	63.2	13.1	6.6
<b>Strategy b: reduce un-necessary treatment</b>						
2+ Major Risk Factors <sup>#</sup>	640	23.9	42.3	79.5	14.8	5.8
20-year absolute risk > 8%	698	26.1	22.7	77.1	18.2	4.5
20-year absolute risk > 10%	545	20.4	32.1	82.7	20.4	3.9

“Missed” events are events occurring among subjects not classified at “high risk”, i.e. with 20-year absolute risk (or a number of risk factors) below the cut-off point.

\*: Kaplan-Meier estimate of the probability of event in the group (positive predicted value).

FP = Number of False Positives; TP = Number of True Positives

#: total cholesterol > 240 mg/dl; HDL-cholesterol < 40 [men] or < 50 [women] mg/dl; systolic blood pressure > 160 mmHg; smoking; diabetes

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5 **Figure 1:** Decision curve for the 20-year risk prediction model in the CAMUNI population, Northern Italy.  
6 Men (left) and women (right), 35 to 69 years old, free of CVD at baseline.  
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40 Net Benefit:  $(TP - w * FP) / n$ , where TP = True Positive; FP = False Positive;  $w = (\text{Absolute risk threshold}) / (1 - (\text{Absolute risk threshold}))$ ;  $n = \text{sample size}$   
41 Number of risk factors: total cholesterol >240 mg/dl; HDL-cholesterol <40 [men] or <50 [women] mg/dl; systolic blood pressure >160 mmHg; smoking; diabetes  
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46 For peer review only - <http://bmjopen.bmj.com/site/about/guidelines.xhtml>  
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8 **Long-term prediction of major coronary or ischemic stroke event in a low-incidence**

9 **Southern European population: model development and evaluation of clinical utility**

Comment [g1]: Added. See reviewer 1, comment #1

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11 **Short Title: Clinical utility of long-term CVD risk prediction in primary prevention**

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47 **Key words:** long-term risk, prediction, cardiovascular disease, clinical utility, primary  
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## ABSTRACT

**Objective.** To develop a long-term prediction model of first major cardiovascular event and to assess its clinical utility in a low-incidence European population.

**Setting.** Four independent population-based cohorts enrolled between 1986 and 1993 in Northern Italy.

**Participants and methods.** N=5,247 35-69 years old men and women free of cardiovascular disease at baseline. Absolute 20-year risk of first fatal or non-fatal coronary or ischemic stroke event (MONICA validated) was estimated from gender-specific Cox models.

**Main outcome measures.** Model discrimination (Area Under the ROC-Curve, AUC). “High-risk” subjects were defined based on several threshold values for the 20-year predicted risk. Clinical utility was defined in terms of fraction of missed events (events among those considered at low-risk) and unnecessary treatment (false:true positives ratio). A Net Benefit curve was also provided.

**Results.** Kaplan-Meier 20-year risk was 16.1% in men (315 events) and 6.1% in women (123 events). Model discrimination (AUC=0.737 in men, 0.801 in women) did not change significantly as compared to 10-year prediction time interval. In men, with respect to risk stratification based on the number of risk factors, a 20% predicted risk cut-off would miss less events (36% vs. 50%) and reduce unnecessary treatment (false:true positive ratio: 2.2 vs. 3.0); the Net Benefit was higher over the whole range of threshold values. Similar considerations hold for women.

**Conclusions.** Long-term prediction has good discrimination ability and is clinically useful for risk stratification in primary prevention. A clinical utility analysis is recommended to identify the optimal stratification according to different public health goals.

## INTRODUCTION

Current European and American guidelines for primary prevention of major coronary and stroke events recommend the use of a multivariable risk prediction method to identify high risk subjects [1, 2]. Several risk scores are available in different US [3, 4] and European [5] populations of middle-aged adults, including the Italian one [6], to estimate the risk of first fatal and non-fatal cardiovascular event over a 10 year time interval. Primary prevention however has been recently moved towards the concepts of “lifetime” [7] and “long-term” risks [8], motivated also by the increasing life expectancy in western Countries. To this extent, 10-year risk prediction models are inadequate to distinguish between those at both low short-term and long-term risks, and those at low short-term but at elevated long-term risk due to the presence of non-optimal risk factors levels [9-11]. In the Framingham Study population, an unfavorable risk factor profile led to an increased 30-year risk of first cardiovascular event, independently on the age at the risk factors assessment [10]. In a representative sample of the Italian population, about 80% of individuals classified at low 10-year risk had increased lifetime risk according to US definition ( $\geq 40\%$ ), potentially leading to a consistent number of un-prevented events that might have been prevented if lifetime risk had been considered [11]. This group was largely composed of women and young subjects, suggesting that long-term prediction models for risk stratification may be even more beneficial in populations at low incidence of cardiovascular disease [12]. To this extent, the development of a specific long-term risk prediction should be preferred with respect to re-calibration of risk models derived in high-incidence countries [13]. However, extending the range of risk prediction is not a straightforward operation. Although several studies have shown that a single measurement of risk factor is predictive of future events after 30 plus years [10, 14], behavioral changes and risk factors modification may affect model

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8 discrimination. High-quality follow-up data, with a consistent event definition and validation  
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10 over-time, are also required. Finally, subjects' stratification in risk categories is often based  
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12 on arbitrary cut-points of absolute risk [15] which may show no benefit in clinical practice  
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14 [16]. The evaluation of the clinical benefit of long-term prediction by means of some  
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16 standard measure [17] has not been provided so far and is therefore required [8].

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18 The aim of the present paper is to develop a 20-year risk score equation in a European  
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20 population of men and women considered at low incidence of major cardiovascular events. In  
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22 addition to standard model calibration and discrimination tools, we evaluate the clinical  
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24 utility of the model for risk stratification.

## 25 **METHODS**

### 26 **Study population**

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28 The Brianza population comprises residents in 173 municipalities in the area between Milan  
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30 and the Swiss border, Northern Italy. The CAMUNI study includes four independent  
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32 population surveys carried out between 1986 and 1994 as part of either the WHO-MONICA  
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34 Project [3 surveys; 18] or the PAMELA study [19]. Participation rates were 70.1%, 67.2%,  
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36 and 70.8% for the three MONICA surveys, respectively, and 64% for the PAMELA Study,  
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38 with no differences between men and women. Both the baseline screening and the follow-up  
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40 for all the surveys were approved by the ethical committee of the Monza Hospital.

### 41 **Baseline assessment of risk factors**

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43 Cardiovascular risk factors were collected at baseline strictly adhering to the standardized  
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45 procedures and quality standards of the WHO-MONICA Project [20]. Height and weight  
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47 were measured on subjects without shoes and wearing light clothing. Trained technicians  
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49 collected blood pressure at right arm on subjects in sitting position and at rest, using a  
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51 standard mercury sphygmomanometer equipped with two side cuff bladders, for normal and  
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8 obese subjects. Systolic and diastolic blood pressure were assessed twice, at 5 minutes apart,  
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10 recording the first and fifth phase of the Korotkoff sounds. The study variable for systolic  
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12 blood pressure is the average of the two measurements. Venous blood specimens were taken  
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14 from the ante-cubital vein on fasting subjects (12 hours or more). Serum total cholesterol,  
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16 HDL-cholesterol and blood glucose were determined using the enzymatic methods; HDL-  
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18 cholesterol fraction was separated using the Phosphotungstate-Mg<sup>++</sup> method [20]. A  
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20 standardized interview was administered to participants by trained interviewers. Information  
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22 on the use of anti-hypertensive treatment in the last two weeks was dichotomised as yes/no;  
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24 similarly, cigarette smoking habit was dichotomised as current versus past/never smokers.  
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26 Diabetes mellitus was defined using self-reported diagnoses, information on insulin and oral  
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28 hypoglycaemic treatments and fasting blood glucose exceeding 7 mmol/L (126 mg/dl). The  
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30 presence at baseline of a previous history of MI, unstable angina pectoris, cardiac  
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32 revascularization or stroke was defined based on self-reported information.

### 33 **Study endpoint and follow-up procedures**

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35 The study endpoint is defined as the occurrence of first major coronary event (myocardial  
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37 infarction, acute coronary syndrome and coronary revascularization) as well as for first  
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39 ischemic stroke or carotid endarterectomy, fatal and non-fatal [13]. Data completeness for  
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41 fatal events was assured through a systematic collection of death certificates provided by  
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43 local health units; vital status and death certificates were available for 99% of the subjects.  
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45 Suspected out-of-hospital deaths were investigated through interview of relatives. Suspected  
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47 hospitalized coronary (discharge code ICD-IX 410 or 411 and ICD-IX CM 36.0-9 for  
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49 coronary revascularization) and stroke events (ICD-IX 430-432, 434, 436; ICD-IX CM  
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51 38.01-39.22 or 39.50-39.52 with at least one 430-438 as discharge code, for carotid  
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53 endarterectomy) were identified through deterministic and probabilistic record linkages with  
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regional hospital discharge databases, obtaining a satisfactory performance in case finding, as reported [18, 21]. All acute events were investigated and validated according to the MONICA diagnostic criteria [20]; the ischemic subtype for stroke was attributed after review of the available clinical information.

### Statistical analysis

The CUORE Project 10 year risk equation for the Italian population [6, 18] constituted the base for the development of the 20 year risk prediction model. Our 20-year risk prediction model is based on We considered gender-specific Cox regression models with age, total cholesterol, HDL-cholesterol, systolic blood pressure, anti-hypertensive treatment, cigarette smoking and diabetes. These predictors are core risk factors included in the CUORE Project [6, 13] as well as in other 10-year risk equations [3, 4]. After a preliminary check on linearity, total- and HDL-cholesterol were included in the model as categorical variables in four standard classes [4, 22]. The interaction between systolic blood pressure and anti-hypertensive treatment was not statistically significant (p-value 0.84 in men and 0.12 in women, respectively). There was no evidence of any cohort effect in the full model, in men (3 df test p-value: 0.2) nor in women (p-value: 0.5). Finally, no violations in the proportional hazard assumption were observed using a standard test for time-dependent variables. Model calibration was assessed through the Grønnesby-Bogan goodness-of-fit test [23]. The Area Under the ROC-curve (AUC), as well as sensitivity and specificity in the top and bottom predicted risk quintiles, were computed taking censorship into account [24]. Correction for over-optimism and confidence intervals for the AUC were obtained through 1000 bootstrapped samples [25]. To assess the hypothesis of a loss in discrimination ability due to a longer prediction period, we estimated the 10-year predicted probability of event in our database, using the same set of risk factors but with shorter follow-up period, i.e. up to

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8 the end of 2002 for all the subjects (number of events: 234 in men, 79 in women). We then  
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10 compared the AUC of both models, by considering bootstrapped confidence intervals for the  
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12 difference in the betas. We then compared the AUC of the two models by looking at their  
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14 respective bootstrapped confidence intervals.

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Comment [G6]: Rewording of this sentence below; reviewer 1, comment #9

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16 To assess the clinical utility of the long-term model for risk stratification, we considered two  
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18 different public health goals. One is to decrease the number of events occurring among those  
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20 considered at “low-risk”. If we assume that a subject classified at “high risk” will be targeted  
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22 for prevention (either lifestyle intervention or treatment), any event occurring outside this  
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24 category is “not-identified” or “missed” by the prevention strategy. The second strategy aims  
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26 instead to reduce un-necessary treatment, by decreasing the number of non-events among  
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28 those considered at “high-risk”. Under the two scenarios, “high-risk” subjects are defined as  
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30 those with predicted risk above a certain cut-off value. Clinical utility is defined in terms of  
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32 *i)* fraction of “missed” events; *ii)* probability of event among those classified at high risk; and  
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34 *iii)* false positive/true positive ratio, for several threshold values in the 20-year predicted risk.  
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36 We also provide a decision curve analysis based on the net benefit: Net Benefit = (true  
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38 positives - w\*false positives)/n, where n is the sample size and the weight w represents the  
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40 ratio between the harm of un-necessary treatment and the harm of missing a case at that given  
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42 value of predicted risk [17]. All the analyses were conducted using the SAS software 9.2.

## 43 RESULTS

44 N=5,426 (2,703 men) subjects were enrolled in the age range 35-69 years. N=205 subjects  
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46 (3.8%; n=14 events) had at least one missing data; we considered data imputation (R  
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48 *transcan* function, [26]) and excluded only those with missing values in more than 4  
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50 covariates of interest (n=6 men and n=3 women). Finally n=120 men and n=45 women with a  
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8 positive history of CVD at baseline were also excluded, reducing the sample size to 2,574  
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10 men and 2,673 women.

11 Baseline characteristics of the study population, by gender, are shown in **Table 1**. During a  
12 median follow-up time of 15 years (interquartile range: 12-20), we observed 315 first CVD  
13 events in men (233 coronary events) and 123 in women (n=85 coronary events). The Kaplan-  
14 Meier estimate for 20-year risk was 16.1% and 6.1% in men and women, respectively.  
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### 19 **Model development**

20 The beta-coefficients for the 20-year risk prediction model, as well as the baseline survival  
21 term and the calibration slope [25], are provided in the Supplementary Material (**Table S1**).  
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24 All the risk factors were statistically significant, except for anti-hypertensive treatment,  
25 though its point estimate reflected a 30% increase in hazard in both men and women; the  
26 variable was retained in the model for comparability with the short-term CUORE model [6].  
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30 There were no significant differences in the set of beta estimates for the 20-year model as  
31 compared to those from the 10-year risk model for the risk factors in the model (data not  
32 shown). The model calibration was satisfactory, in men (Grønnesby-Bogan goodness-of-fit  
33 chi-square 6.7, p-value 0.67) and in women (chi-square 9.6, p-value 0.38); **calibration plots**  
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39 **are available as supplementary material (Figure S1)**;

**Comment [G7]:** Added; reviewer 1, comment #8

40 We found no statistically significant difference in the overall discrimination ability between  
41 long- and short-term prediction models, in men (0.736 vs. 0.731) and in women (0.801 vs.  
42 0.816; **Table 2**). Only 5% of 20-year events in men occurred among subjects with a predicted  
43 risk below the 20<sup>th</sup> percentile (bottom **quintile fifth**); the corresponding figure in women is  
44 2%. The relative risk of event for being above the 80<sup>th</sup> percentile vs. below the 20<sup>th</sup> percentile  
45 of 20-year risk was 9.5 (i.e. 35.1/3.7) in men and 22.4 (i.e. 20.2/0.9) in women. Finally, the  
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60 value of the 80<sup>th</sup> percentile for 20-year risk was more than twice as high than the similar

**Comment [g8]:** Reviewer 1, comment #7

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8 percentile for 10-year risk in men (26.8 vs. 10.8) and more than three times as high in women  
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10 (10.1 vs. 3.0). A similar consideration holds for the 20<sup>th</sup> percentile of risk or the median  
11  
12 value.

### 13 **Clinical utility**

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15 **Table 3a** and **Table 3b** describe strategies for the identification of high-risk subjects, based  
16  
17 on predicted 20-year risk, in men and women respectively. A cut-off value of 10% twenty  
18  
19 year risk in men would result in a 9% of “missed” events (i.e. events among those with  
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21 predicted risk below the cut-point), with a probability of event of 23% and one true positive  
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23 for every 3.4 false positive subjects (**Table 3a**). In the second scenario, by choosing the 20%  
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25 twenty year risk threshold value, the fraction of missed events was 36%. Note that about 30%  
26  
27 of events occurred for a predicted 20-year risk between 20% and 30%. Finally, using the  
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29 number of risk factors to define high risk subjects would result in a higher fraction of missed  
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31 events, with no changes in specificity or in the prevalence of subjects considered at high risk.  
32  
33 Among women, a cut-off value of 2% would result in a 5% of missed events, with a  
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35 probability of event of 9% and a true positive for every 10.1 false positive women (**Table**  
36  
37 **3b**). In the second scenario, the probability of event among those with absolute risk greater  
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39 than 10% was 20.4%, with a true positive for every 3.9 false positive subjects. However, the  
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41 fraction of missed events would be 32%; this number can be reduced by lowering the cut-off  
42  
43 value to 8%. By considering at high risk those with 2 or more risk factor would result in a  
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45 higher fraction of missed events, with no gain in specificity or in the probability of event in  
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47 the group. **Figure 1** illustrates the decision curve analysis based on the Net Benefit [17], for  
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49 men (left) and women (right). The figure suggests a greater net benefit for the predicted risk  
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51 with respect to the number of risk factors over the whole range of values, thus generalizing  
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53 the findings from Table 3a and Table 3b.  
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## DISCUSSION

In this paper we present the 20-year prediction model of first major coronary or ischemic stroke event in a Northern Italian population of men and women aged 35 to 69 years at baseline. To our knowledge, this is the first long-term prediction model in a low-incidence, European population. The discrimination ability of the long-term model did not significantly drop with respect to a 10-year risk prediction model derived on the same population. Risk stratification based on the predicted 20-year risk can be modulated according to different prevention aims, i.e. either to reduce the fraction of events potentially un-prevented or to avoid un-necessary treatment. Under both scenarios, the predicted 20-year risk showed an overall better Net Benefit with respect to a risk stratification based on the number of risk factors.

Our data confirmed previous findings on predictiveness of a single measurement of risk factors on long-term CVD risk, in the Italian [27] as well as in other populations [10, 14]. Event discrimination for the 20-year risk prediction model did not change significantly from 10-year's, although in women it decreased from 0.814 to 0.801. In the Framingham Offspring Study updating the baseline measurement of blood pressure and lipids with a later assessment poorly affected model discrimination and reclassification [28] and cardiometabolic risk factors clustering has been found to be quite stable over time [29].

As in the Framingham population, in our study the long-term predicted risk was more than simply  $n$ -times the short-term risk prediction [10]. In addition in the age range 35 to 49 years, the long-term predicted risk in subjects with 1 or more non-optimal or elevated risk factors (defined as in [7]) was 3-times the short-term risk in men, and 4-times in women (see

Figure S12 in the Supplementary Material). This conveys the importance of long-term prediction for early identification of young subjects and women at increased likelihood of

**Comment [g9]:** Calibration plot has been added as Figure S1, and this became Figure S2

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8 event during their remaining lifespan. We observed in our data a modest net reclassification  
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10 improvement (computed as in [24]) for the 20-year risk prediction model over the re-  
11  
12 calibrated 10-year risk, in men (1.8%) and in women (4.5%). The net reclassification  
13  
14 increased when we considered subjects with a low 10-year predicted risk but a cluster of 2 or  
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16 more risk factors (5.4% and 7.6% in men and women, respectively; data not shown).  
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18 Subjects' stratification is often based on arbitrarily-chosen thresholds of predicted risk [15],  
19  
20 which may limit the clinical utility of risk prediction models [16]. We considered two  
21  
22 strategies for the identification of "high-risk" subjects with contrasting goals, either to  
23  
24 decrease the fraction of missed events or to decrease un-necessary treatment. These can be  
25  
26 implemented by choosing threshold values for the predicted risk driven by either sensitivity  
27  
28 or by specificity, respectively. Despite the lowering costs of statin treatment with respect to  
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30 the costs of one un-prevented event, the high sensitivity scenario was not cost-effective over  
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32 a 10-year period [30]. might not be cost-effective [30]. These two scenarios might be  
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34 combined to adopt a more complex risk stratification, as often present in clinical practice [1-  
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36 2, 12]. For instance, if we consider at "low-risk" the 36% of men with 20-year absolute risk  
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38 less than 10%, the fraction of missed events would be 9%, i.e. 31 first events in 20 years.  
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40 About 31% of men with absolute risk between 10% and 20% could be addressed for lifestyle  
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42 modification or treatment according to the presence of specific risk factors; this category  
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44 accounts for about 20% of cases. Finally, the 33% of men with predicted risk above the 20%  
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46 could be targeted with treatment intervention; they account for 68% of events, and out of 3.2  
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48 treated men, one is a case. A similar stratification can be provided for women, with different  
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50 threshold values reflecting gender-specific underlying risk as for the cardiovascular age  
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52 assessment [15].  
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Comment [G10]: Modified. See reviewer 2, comment #3



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8 Among the study strengths and limitations, our sample comprises subjects drawn from a  
9 representative northern Italian population, with a satisfactory participation rate. The  
10 underlying population is characterized by high levels of industrialization and urbanization,  
11 with one of the highest average incomes in Italy. [A major limitation is the lack of an external](#)  
12 [validation. External validation for long-term prediction models is in general an issue \[10\]; we](#)  
13 [provide the over-optimism adjusted AUC as well as the , although we provide As](#)  
14 [Supplementary Material we provide the baseline survival term as well as a calibration slope](#)  
15 [\[25\] to allow applying our equation to different contexts \(see Supplementary Material\).](#)  
16 [However, a validation study in a different population might be desirable to investigate the](#)  
17 [generalizability of our findings.](#) We also mention a high-quality of follow-up procedures,  
18 including case ascertainment for non-fatal events [21] and a consistent event validation  
19 according to MONICA criteria, resulting in a Standardized Incidence Rate for the study  
20 cohorts above 1 over the whole follow-up period [18]. Finally, the study endpoint reflects the  
21 clinical need to treat the “global” ischemic risk of a given patient, and not its separate  
22 components [3].  
23  
24 In conclusions, we provide a model to predict long-term risk of first major ischemic  
25 cardiovascular event in a low-incidence population. Risk stratification based on long-term  
26 risk can be clinically useful, especially for young subjects and women. A clinical utility  
27 analysis is required to identify the optimal stratification, according to different public health  
28 goals.  
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## 48 Funding

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**Comment [G11]:** Modified; see reviewer 2, comment #5

**Comment [G12]:** Deleted; see reviewer #2, comment #5



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8 This work was supported by grants from the Health Administration of Regione Lombardia  
9  
10 [grant number 10800/2009], as part of the Osservatorio Epidemiologico Cardiovascolare  
11  
12 Regionale Lombardo.

### 13 **Competing Interests**

14  
15 None.

### 16 **Contributors**

17  
18 Conception and design: MMF, GM, GC and GV. All authors interpreted the data and  
19  
20 critically reviewed the paper. Statistical analyses: GV, WC. GV drafted the manuscript and is  
21  
22 the guarantor. All authors have read and approved the final version of the manuscript.  
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### 25 **Data sharing**

26  
27 There is no additional data available  
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## 29 **ARTICLE SUMMARY**

### 30 **Article focus**

- 31  
32
- 33 ▪ Primary prevention of cardiovascular disease (CVD) has been recently moved towards  
34 the concepts of “lifetime” and “long-term” risk, especially in young subjects and women.
  - 35  
36 ▪ There is no long-term risk prediction model available for low-incidence Southern  
37  
38 European populations; in addition, the evaluation of the clinical benefit of long-term  
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40 prediction has not been provided so far.
  - 41  
42 ▪ We aim to develop a 20-year risk score equation in a northern Italian population of men  
43  
44 and women considered at low incidence of major cardiovascular events; and to evaluate  
45  
46 the clinical utility of the model for risk stratification in primary CVD prevention program.  
47

### 48 **Key Messages**

- 49
- 50 ▪ In our population, the 20-year risk model had satisfactory discrimination ability as  
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52 compared to short-term risk prediction. The importance of long-term prediction for early  
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8 identification of young subjects and women at increased likelihood of event during their  
9 remaining lifespan is confirmed.

- 10  
11 ▪ Risk stratification based on the predicted 20-year risk had a better clinical Net Benefit  
12 with respect to a stratification based on the number of risk factors, in men and women.
- 13  
14 ▪ In both genders, the optimal treatment allocation based on 20-year risk can be determined  
15 according to different public health strategies, i.e. either to reduce the fraction of events  
16 potentially un-prevented or to avoid un-necessary treatment.

### 17 18 19 20 21 22 **Strengths and limitations of this study**

- 23  
24 ▪ Our sample comprises subjects drawn from a representative northern Italian population,  
25 with a satisfactory participation rate. We also mention the high-quality of follow-up  
26 procedures, including case ascertainment for non-fatal events and a consistent event  
27 validation according to MONICA criteria over the whole follow-up period.
- 28  
29 ▪ Our 20-year risk prediction model is the first attempt to characterize long-term risk of  
30 first coronary or ischemic stroke event in a low-incidence European population. [A](#)  
31  
32 [limitation of our study is the lack of a formal external validation, although we provide a](#)  
33 [cross-validation analysis. To allow applying our equation to different populations, as](#)  
34 [Supplementary Material we provide the baseline survival term as well as the calibration](#)  
35 [slope. However, an external validation study might be desirable.](#) We also remind that our  
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37 underlying population is characterized by high levels of industrialization and  
38 urbanization, with one of the highest average incomes in Italy. Caution is therefore  
39 required before generalizing our findings to different contexts.  
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**Comment [G13]:** Added; see reviewer 2, comment #5

**Comment [G14]:** Deleted; see reviewer 2, comment #5

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8 **Tables and figures**

9 **Table 1.** Baseline characteristics (mean (SD) or %) of the study population and number of incident events, by gender.  
10 Men and women, 35-69 years old, CVD-free at baseline.  
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	Men (n=2574)	Women (n=2673)
14 Age (years)	50.8 (9.1)	50.3 (9)
15 Years of schooling	8.5 (4.2)	7.3 (3.4)
16 Total Cholesterol (mmol/L)	5.8 (1.1)	5.8 (1.1)
17 HDL-Cholesterol (mmol/L)	1.3 (0.3)	1.6 (0.4)
18 Body Mass Index (Kg/m <sup>2</sup> )	26.2 (3.5)	25.6 (4.7)
19 Systolic Blood Pressure (mmHg)	134.8 (19.3)	131.6 (20.2)
20 Diastolic Blood Pressure (mmHg)	85.9 (10.6)	82.8 (10.8)
21 Anti-hypertensive treatment (%)	11.8	16.0
22 Fasting plasma glucose (mmol/L)	5.4 (1.3)	5.1 (1.2)
23 Diabetes (%)	6.7	4.0
24 Current smoker (%)	37.1	19.6
25 Incident coronary event (n)	233	85
26 Incident ischemic strokes (n)	99	43
27 Incident CVD event (n)	315	123
28 20-year absolute risk of CVD <sup>^</sup>	16.1	6.1

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37 <sup>^</sup>: Kaplan-Meier estimate.  
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**Table 2.** Discrimination ability for the 10-year and the 20-year risk prediction models. Men and women, 35-69 years old, CVD-free at baseline

	Men		Women	
	10-year risk	20-year risk	10-year risk	20-year risk
<b>AUC (95% CI)</b>	0.731 (0.702; 0.761)	0.737 (0.713; 0.764)	0.814 (0.779; 0.853)	0.801 (0.771; 0.833)
<b>Subjects with predicted risk below the 20th percentile</b>				
20th percentile of risk	2.3	6.3	0.3	1.1
Fraction of events* (%)	4.4	5.1	1.4	2.0
Probability of event in the group^ (%)	0.8	3.7	0.2	0.9
<b>Subjects with predicted risk above the 80th percentile</b>				
80th percentile of risk	10.8	26.8	3.0	10.1
Sensitivity* (%)	49.9	45.6	68.7	62.0
Specificity (%)	82.4	85.5	81.1	83.1
Probability of event in the group^ (%)	19.4	35.1	7.5	20.2

The Area Under the ROC-curve (AUC) was estimated taking censorship into account, and adjusting for over-optimism (n=1000 bootstrap).  
\*: Probability of belonging to the group, given that the subject is a case. ^: Kaplan-Meier estimate of the probability of event in the group.

**Table 3a.** Identification of high risk subjects based on the 20-year risk prediction model with respect to the number of risk factors, according to strategies aiming to *i)* reducing the fraction of missed events; and *ii)* reducing un-necessary treatment. Men, 35-69 years old, CVD-free at baseline

	Subjects at high risk		Fraction of missed events (%)	Specificity (%)	Probability of event* (%)	FP/TP Ratio
	n	%				
<b>Strategy a: reduce the fraction of missed events</b>						
All subjects	2574	100.0	0.0	-	16.1	5.2
1+ Major Risk Factor <sup>#</sup>	1842	71.6	13.7	32.5	19.5	4.1
20-year absolute risk > 10%	1645	63.9	9.1	41.2	22.9	3.4
20-year absolute risk > 15%	1169	45.4	22.1	60.9	27.7	2.6
<b>Strategy b: reduce un-necessary treatment</b>						
2+ Major Risk Factors <sup>#</sup>	828	32.2	50.4	73.6	24.9	3.0
20-year absolute risk > 20%	841	32.7	35.7	73.7	31.7	2.2
20-year absolute risk > 30%	415	16.1	62.6	88.9	37.4	1.7

“Missed” events are events occurring among subjects not classified at “high risk”, i.e. with 20-year absolute risk (or a number of risk factors) below the cut-off point.

\*: Kaplan-Meier estimate of the probability of event in the group (positive predicted value).

FP = Number of False Positives; TP = Number of True Positives

<sup>#</sup>: total cholesterol > 240 mg/dl; HDL-cholesterol < 40 [men] or < 50 [women] mg/dl; systolic blood pressure > 160 mmHg; smoking; diabetes



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**Table 3b.** Identification of high risk subjects based on the 20-year risk prediction model with respect to the number of risk factors, according to strategies aiming to *i)* reducing the fraction of missed events; and *ii)* reducing un-necessary treatment. Women, 35-69 years old, CVD-free at baseline

	Subjects at high risk		Fraction of missed events (%)	Specificity (%)	Probability of event* (%)	FP/TP Ratio
	n	%				
<b>Strategy a: reduce the fraction of missed events</b>						
All subjects	2673	100.0	0.0	-	6.1	15.3
1+ Major Risk Factor <sup>#</sup>	1654	61.9	17.7	40.1	8.2	11.3
20-year absolute risk > 2%	1733	64.8	4.5	37.4	9.0	10.1
20-year absolute risk > 5%	1067	39.9	14.7	63.2	13.1	6.6
<b>Strategy b: reduce un-necessary treatment</b>						
2+ Major Risk Factors <sup>#</sup>	640	23.9	42.3	79.5	14.8	5.8
20-year absolute risk > 8%	698	26.1	22.7	77.1	18.2	4.5
20-year absolute risk > 10%	545	20.4	32.1	82.7	20.4	3.9

“Missed” events are events occurring among subjects not classified at “high risk”, i.e. with 20-year absolute risk (or a number of risk factors) below the cut-off point.  
 \*: Kaplan-Meier estimate of the probability of event in the group (positive predicted value).  
 FP = Number of False Positives; TP = Number of True Positives  
 #: total cholesterol > 240 mg/dl; HDL-cholesterol < 40 [men] or < 50 [women] mg/dl; systolic blood pressure > 160 mmHg; smoking; diabetes

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8 **Figure 1:** Decision curve for the 20-year risk prediction model in the CAMUNI population, Northern Italy.  
9 Men (left) and women (right), 35 to 69 years old, free of CVD at baseline.  
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37 Net Benefit:  $(TP - w * FP) / n$ , where TP = True Positive; FP = False Positive;  $w = (\text{Absolute risk threshold}) / (1 - (\text{Absolute risk threshold}))$ ; n=sample size  
38 Number of risk factors: total cholesterol >240 mg/dl; HDL-cholesterol <40 [men] or <50 [women] mg/dl; systolic blood pressure >160 mmHg; smoking; diabetes  
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Supplementary material

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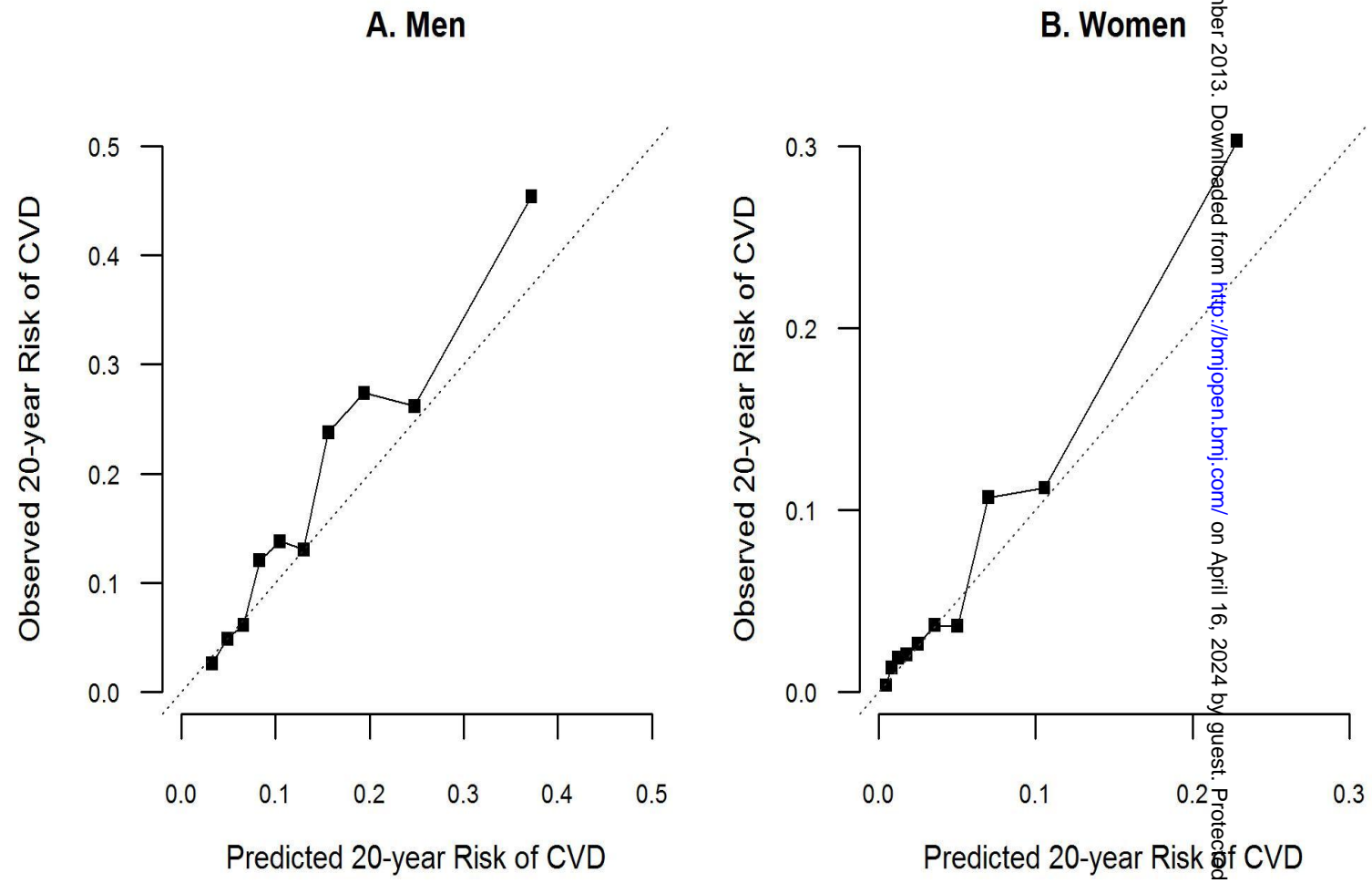
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**Table S1:** Beta-coefficients, standard errors and baseline survival for the 20-year risk prediction model in Northern Italy. Men and women, 35 to 69 years old, free of CVD at baseline.

	Men			Women		
	Beta	SE	p-value	Beta	SE	p-value
<b>Age (years)</b>	0.058	0.008	<.0001	0.084	0.017	<.0001
<b>Total Cholesterol<sup>^</sup></b>						
200-240 mg/dl	0.388	0.161		0.553	0.287	
240-280 mg/dl	0.690	0.167	<.0001	0.607	0.314	0.027
> 280 mg/dl	0.923	0.198		0.996	0.322	
<b>HDL-Cholesterol<sup>°</sup></b>						
<45 mg/dl	0.403	0.160		0.804	0.257	
45-50 mg/dl	0.367	0.186	0.013	0.364	0.309	0.015
50-60 mg/dl	0.024	0.177		0.261	0.221	
<b>Systolic Blood Pressure (mmHg)</b>	0.011	0.003	0.0003	0.015	0.005	0.001
<b>Anti-hypertensive treatment (yes/no)</b>	0.247	0.154	0.11	0.267	0.209	0.20
<b>Smoking (yes/no)</b>	0.521	0.117	<.0001	0.994	0.216	<.0001
<b>Diabetes (yes/no)</b>	0.744	0.163	<.0001	1.020	0.249	<.0001
<b>Baseline 20-year survival (S<sub>0</sub>(20))*</b>		0.94168			0.98532	
<b>G(μ)</b>		4.35638			6.20075	
<b>Calibration Slope</b>		0.948			0.937	

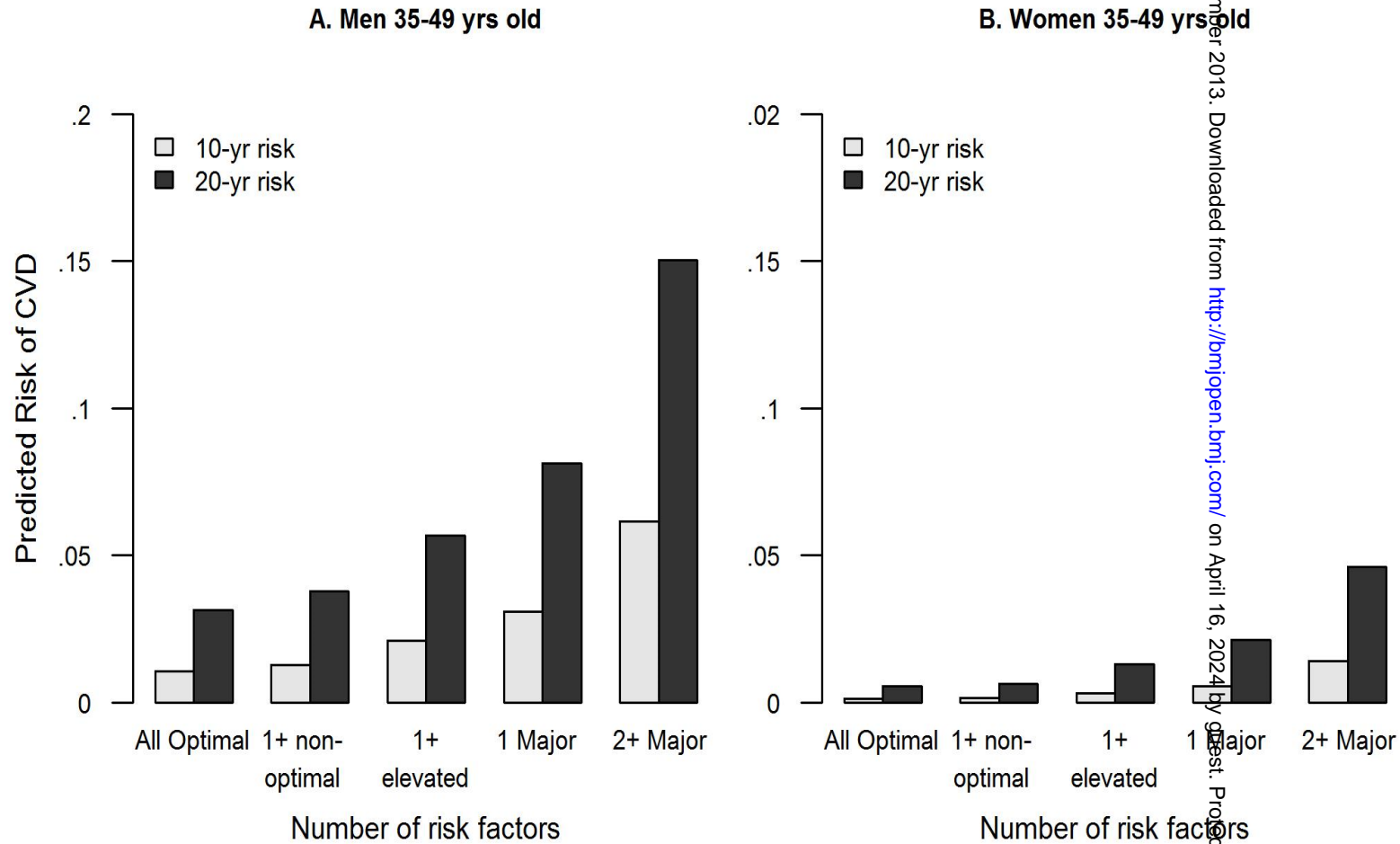
SE = Standard Error. <sup>^</sup>: reference group: total cholesterol ≤ 200 mg/dl. <sup>°</sup>: reference group: HDL-cholesterol > 60 mg/dl. \*: at the mean value for continuous RFs, and at the reference class for categorical variables. 20-year risk:  $1 - S_0(20)^{\exp(\sum \beta X - G(\mu))}$ . Calibration slope: correction term to be used in different population to shrink the beta-coefficients. See reference [25] for more details. The risk model should be used within the following range for continuous risk factors: total cholesterol 135-330 mg/dl; HDL-cholesterol 30-100 mg/dl; systolic blood pressure 100-190 mmHg.

**Figure S1:** Calibration plot for the final 20-year risk model. Men (left) and women (right), 35 to 69 years old, free of CVD at baseline.



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**Figure S2:** Distribution of predicted 10-year and 20-year risk of first major CVD event, according to the number of risk factors. Men (left) and women (right), 35 to 49 years old, free of CVD at baseline.



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3 Risk factors stratification derived from Lloyd-Jones [7].

4 All optimal: total cholesterol <180 mg/dl, HDL-Cholesterol  $\geq$  40 mg/dl [men] or  $\geq$  50 mg/dl [women], blood pressure <120/80 mmHg, non smoker, non diabetic;

5 1+ non-optimal: total cholesterol 180 to 199 mg/dl, systolic blood pressure 120 to 139 mmHg, diastolic blood pressure 80 to 89 mmHg, non smoker, non diabetic

6 1+ elevated: total cholesterol 200 to 239 mg/dl, systolic blood pressure 140 to 159 mmHg, diastolic blood pressure 90 to 99 mmHg, non smoker, non diabetic

7 Major risk factor: total cholesterol  $\geq$ 240 mg/dl, HDL-Cholesterol <40 mg/dl [men] or <50 mg/dl [women], systolic blood pressure  $\geq$ 160 mmHg or treatment,  
8 diastolic blood pressure  $\geq$ 100 mmHg, smoker, or diabetic  
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**Table S2:** Baseline characteristics of the study population, by study cohort, for risk factors included in the risk prediction model. Men and women, 35 to 69 years old, free of CVD at baseline.

	Cohort study name			
	MONICA 1	MONICA 2	PAMELA	MONICA 3
Recruitment period	1986-87	1989-90	1990-93	1993-94
Number of subjects	1259	1255	1442	1291
Age, years	49.4 (8.6)	49.6 (8.8)	52.5 (9.8)	50.3 (8.7)
Men, %	48.0	49.2	49.9	49.0
Total cholesterol, mg/dl	216.5 (43.3)	215.7 (42.7)	228.6 (42.3)	229.9 (41.7)
HDL-cholesterol, mg/dl	55.5 (14.4)	56.2 (14.6)	55.9 (15.9)	57.1 (15.1)
Systolic Blood Pressure, mmHg	136 (20)	132.3 (19.3)	133.6 (20)	130.6 (19.7)
Anti-hypertensive treatment, %	11.0	13.7	17.6	12.8
Current smokers, %	30.7	27.5	28.3	26.3
Diabetes, %	6.4	6.5	4.4	4.3

Data are mean values (SD) for continuous variables, and % for dichotomous risk factors.



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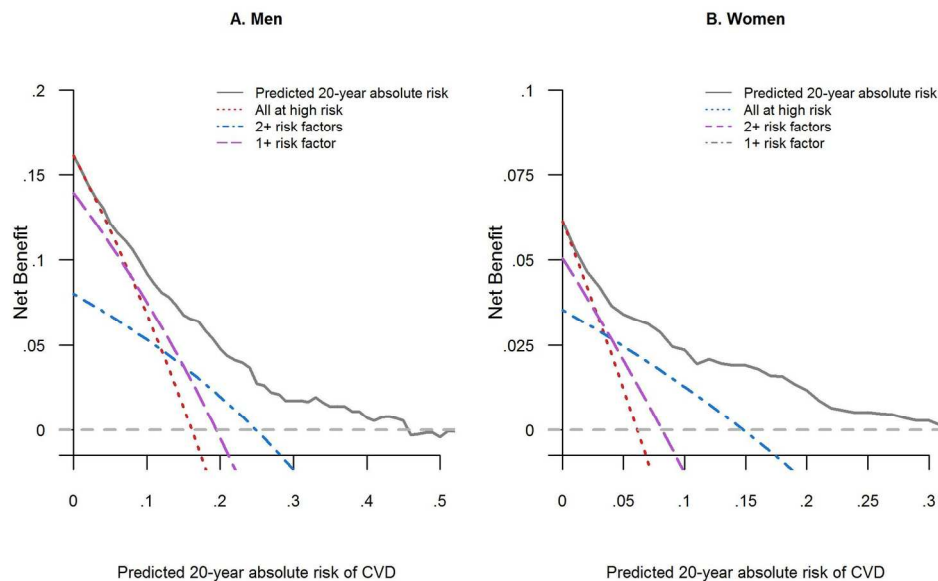


Figure 1: Decision curve for the 20-year risk prediction model in the CAMUNI population, Northern Italy. Men (left) and women (right), 35 to 69 years old, free of CVD at baseline.

Net Benefit:  $(TP - w \cdot FP) / n$ , where TP = True Positive; FP = False Positive;  $w = (\text{Absolute risk threshold}) / (1 - \text{Absolute risk threshold})$ ;  $n = \text{sample size}$

Number of risk factors: total cholesterol >240 mg/dl; HDL-cholesterol <40 [men] or <50 [women] mg/dl; systolic blood pressure >160 mmHg; smoking; diabetes

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**Supplementary material for the paper:**

**Long-term prediction of major coronary or ischemic stroke event in a low-incidence European population: model development and evaluation of clinical utility.**

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Actions
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	The study setting is clearly stated in the abstract.
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Done
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	See the introduction section at pages 3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	See page 4, end of introduction section
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	See the Methods section (pages 4-7)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Relevant information on cohorts setting, location and periods of recruitment are provided in the paragraphs "Study population" (page 4), "Baseline assessment of risk factors" (page 4) and "Study endpoint and follow-up procedures" (page 5).
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	See the paragraphs "Study population" (page 4) and "Study endpoint and follow-up procedures" (page 5).
		(b) For matched studies, give matching criteria and number of exposed and unexposed	Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	See the paragraph "Statistical analysis", page 6-7
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	See paragraphs "Baseline assessment of risk factors" (page 4), and "Statistical analysis" (page 6-7). Exposure group: not applicable for this analysis.
Bias	9	Describe any efforts to address potential sources of bias	See the Methods section.
Study size	10	Explain how the study size was arrived at	See the first period in the "Results" section (page 7)
Quantitative	11	Explain how quantitative variables were	See the "Statistical Analysis" paragraph

1	variables		handled in the analyses. If applicable, (page 6)
2			describe which groupings were chosen and
3			why
4	Statistical methods	12	
5			(a) Describe all statistical methods, including See the “Statistical Analysis” paragraph
6			those used to control for confounding (page 6)
7			(b) Describe any methods used to examine See the “Statistical Analysis” paragraph
8			subgroups and interactions (page 6)
9			(c) Explain how missing data were addressed See the first line in the “Results” section
10			(page 7)
11			(d) If applicable, explain how loss to follow- See the “Statistical Analysis” paragraph
12			up was addressed (page 6) for details on the survival analysis
13			techniques
14			(e) Describe any sensitivity analyses Not applicable
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16			
17	<b>Results</b>		
18	Participants	13*	
19			(a) Report numbers of individuals at each Participation rates are reported in the
20			stage of study—eg numbers potentially paragraph “Study population” (page 4).
21			eligible, examined for eligibility, confirmed Exposure group: not applicable for this
22			eligible, included in the study, completing analysis.
23			follow-up, and analysed
24			(b) Give reasons for non-participation at each Not applicable
25			stage
26			(c) Consider use of a flow diagram Not applicable
27			
28	Descriptive data	14*	
29			(a) Give characteristics of study participants See Table 1. Exposure group: not
30			(eg demographic, clinical, social) and applicable for this analysis.
31			information on exposures and potential
32			confounders
33			(b) Indicate number of participants with See the “Results” section, first period
34			missing data for each variable of interest (page 7). Exposure group: not applicable
35			for this analysis.
36			(c) Summarise follow-up time (eg, average “Results” section, second period (page 7).
37			and total amount) Exposure group: not applicable for this
38			analysis..
39			
40	Outcome data	15*	
41			Report numbers of outcome events or Number of events, by type, are reported in
42			summary measures over time Table 1. Exposure group: not applicable
43			for this analysis.
44	Main results	16	
45			(a) Give unadjusted estimates and, if The study model is reported in Table S1,
46			applicable, confounder-adjusted estimates and supplementary material; the analysis is
47			their precision (eg, 95% confidence interval). multivariable by nature.
48			Make clear which confounders were adjusted
49			for and why they were included
50			(b) Report category boundaries when Not applicable
51			continuous variables were categorized
52			(c) If relevant, consider translating estimates Not applicable
53			of relative risk into absolute risk for a
54			meaningful time period
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56	Other analyses	17	
57			Report other analyses done—eg analyses of Not applicable
58			subgroups and interactions, and sensitivity
59			analyses
60			

<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	See the first part of the Discussion section, page 9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Study limitations are reported and discussed at pages 11-12.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Done
Generalisability	21	Discuss the generalisability (external validity) of the study results	See pages 11-12
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Source of funding is reported at page 12.

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.