



HAL
open science

Impact on All-Cause and Cardiovascular Mortality Rates of Coronary Artery Calcifications Detected during Organized, Low-Dose, Computed-Tomography Screening for Lung Cancer: Systematic Literature Review and Meta-Analysis

Sébastien Gendarme, Helene Goussault, Jean-Baptiste Assié, Cherifa Taleb, Christos Chouaïd, Thierry Landre

► To cite this version:

Sébastien Gendarme, Helene Goussault, Jean-Baptiste Assié, Cherifa Taleb, Christos Chouaïd, et al.. Impact on All-Cause and Cardiovascular Mortality Rates of Coronary Artery Calcifications Detected during Organized, Low-Dose, Computed-Tomography Screening for Lung Cancer: Systematic Literature Review and Meta-Analysis. *Cancers*, 2021, 13 (7), pp.1553. 10.3390/cancers13071553 . hal-03190285

HAL Id: hal-03190285

<https://hal.sorbonne-universite.fr/hal-03190285v1>



Submitted on 6 Apr 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Systematic Review

Impact on All-Cause and Cardiovascular Mortality Rates of Coronary Artery Calcifications Detected during Organized, Low-Dose, Computed-Tomography Screening for Lung Cancer: Systematic Literature Review and Meta-Analysis

Sébastien Gendarme^{1,2,*}, Helene Goussault¹, Jean-Baptiste Assié^{1,3}, Cherifa Taleb⁴, Christos Chouaid^{1,2}  and Thierry Landre⁵ 

¹ Service de Pneumologie, Centre Hospitalier Intercommunal de Créteil, 94010 Créteil, France; Helene.goussault@chicreteil.fr (H.G.); jean-baptiste.assie@inserm.fr (J.-B.A.); Christos.Chouaid@chicreteil.fr (C.C.)

² Inserm U955, UPEC, IMRB, équipe CEpiA, 94010 Créteil, France

³ Functional Genomics of Solid Tumours Laboratory, Centre de Recherche des Cordeliers, Inserm, Sorbonne Université, Université de Paris, 75013 Paris, France

⁴ Service de gériatrie, Hôpital René Muret, APHP, 93270 Sevran, France; cherifa.taleb@aphp.fr

⁵ UCOG, Hôpital René Muret, APHP, 93270 Sevran, France; thierry.landre@aphp.fr

* Correspondence: Sebastien.GENDARME@gustaveroussy.fr



Citation: Gendarme, S.; Goussault, H.; Assié, J.-B.; Taleb, C.; Chouaid, C.; Landre, T. Impact on All-Cause and Cardiovascular Mortality Rates of Coronary Artery Calcifications Detected during Organized, Low-Dose, Computed-Tomography Screening for Lung Cancer: Systematic Literature Review and Meta-Analysis. *Cancers* **2021**, *13*, 1553. <https://doi.org/10.3390/cancers13071553>

Academic Editor: Giorgio Treglia

Received: 15 February 2021

Accepted: 25 March 2021

Published: 28 March 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Simple Summary: The results of several randomized studies showed the efficacy of organized, low-dose, computed-tomography (CT) scan lung-cancer screening in lowering all-cause and lung-cancer-specific mortality rates. Low-dose CT scans can also detect and quantify coronary artery calcifications (CACs). By means of meta-analysis, we were able to show that the presence of CACs in CT performed in this setting was associated with an enhanced risk of cardiovascular and all-cause mortality for men and women. These findings plead for the implementation of preventive interventions against cardiovascular risk in lung-cancer screening-program participants found to have CACs.

Abstract: Although organized, low-dose, computed-tomography (CT) scan lung-cancer screening has been shown to lower all-cause and lung-cancer-specific mortality, the primary cause of death for subjects eligible for such screening remains cardiovascular (CV) mortality. This meta-analysis study was undertaken to evaluate the impact of screening-scan-detected coronary artery calcifications (CACs) on CV and all-cause mortality. We conducted a systematic review and meta-analysis of studies reporting CV mortality according to the Agatston CAC score for participants in a lung-cancer screening program of randomized clinical or cohort studies. PubMed, Embase, and Cochrane databases were screened in June 2020. Two authors independently selected articles and extracted data. Six studies, including 20,175 subjects, were retained. CV and all-cause mortality rates were higher for subjects with CAC scores >0, with respective relative risks of 2.02 [95% CI 1.23–3.32] and 2.29 [95% CI 1.00–5.21]. Both mortality rates were even higher for those with high CAC scores (>400 or >1000). CACs are more common in men than in women, with an odds ratio of 1.49 [95% CI 1.40–1.59]. The presence of CAC is associated with CV mortality with an RR of 2.05 [95% CI 1.20–3.57] in men and 2.37 [95% CI 1.29–5.09] in women, respectively. Analysis of lung-cancer-screening scans for CACs is a tool able to predict CV mortality. Prospective studies within those programs are needed to assess the benefit of primary CV prevention based on CAC detection.

Keywords: cardiovascular mortality; coronary artery calcification; lung cancer screening; meta-analysis

1. Introduction

Results of the American NLST and the European NELSON studies showed the efficacy of organized, low-dose, computed-tomography (CT) scan screening for lung cancer of

smokers or ex-smokers [1,2]. All-cause and specific lung-cancer mortality rates, respectively, were 6.8% and 20% lower in the NLST study [1], and specific mortality was 24% lower in the NELSON study [2]. According to the latter, the benefit could be even greater for women, with 39–61% lower lung-cancer-specific mortality. Those findings led the United States and numerous other countries to initiate organized lung-cancer-screening programs [3,4].

Those studies also showed the notable impact on all-cause mortality of other pathologies associated with tobacco, namely, cardiovascular (CV) events. Indeed, in the NLST study, more than 50% of deaths were attributed to CV events [1]. Smoking is also a major risk factor in CV mortality, thereby explaining the relationship between those pathologies and lung cancer [5,6]. All those findings highlighted the interest of combining organized, low-dose, CT scan lung-cancer screening with a more general search for tobacco-associated diseases [7], especially targeting chronic obstructive pulmonary disease (COPD) and CV events, aptly called “Big-3” screening [8].

The benefit of organized screening for CV prevention in this population of smokers and ex-smokers has rarely been studied and not yet demonstrated. In theory, CV prevention seems clearly amenable to organized screening. Identified risk factors are modifiable at the individual level, and a decrease in their exposure leads to decrease in risk [9]. Moreover, the existence of an asymptomatic or latent phase, during which interventions can effectively change the natural evolution of the disease [10]. Indeed, no test—with an acceptable cost—has demonstrated sufficient ability to justify CV diseases screening. The performance of thoracic low-dose CT scans to identify CACs, as a tool able to predict CV events, was validated in several studies [11,12], despite the diminished spatial resolution of low-dose scan slices [13–15]. Although low-dose CT scans require a low radiation dose (<1.5 mSv) and is not ECG-gated, they can detect CAC with good agreement ($r = 0.89$) in comparison with conventional ECG-gated CT protocol and depending on the attenuation and thickness of the slices [16]. The Agatston score enables quantification of lesions containing calcium deposits and risk stratification [17].

Therefore, we conducted a systematic literature review and a meta-analysis to determine the efficacy of measuring CACs, visualized on low-dose CT scans, as a tool to predict CV and all-cause mortality in subjects participating in an organized program screening for lung cancer.

2. Methods

2.1. Literature Search

The literature review consisted of searching PubMed, Embase, and Cochrane databases using the following terms: “(lung cancer OR lung carcinoma OR pulmonary carcinoma [MeSH Major Topic]) AND (calcification OR arterial calcification OR aortic calcification [MeSH Major Topic])”. Two authors (S.G. and T.L.) ran the search on 1 June 2020. We also considered the references cited in the main reviews published on the subject, the gray literature identified by searching congress abstracts and scientific communications, and by contacting experts in the field.

Articles, published in English or French, were selected according to 2015 PRISMA-P (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations. After exclusion of doubles, the same two authors independently examined the titles and abstracts. The inclusion criteria for selected papers were: Subjects eligible for lung-cancer screening, i.e., smokers or ex-smokers, not diagnosed with lung cancer and without signs suggestive of lung cancer at inclusion, who underwent thoracic, low-dose, CT scan in the framework of a randomized or non-randomized clinical trial, or cohort studies on organized screening for lung cancer. CV and/or all-cause mortality rates were given in each report as a function of the presence or absence of CACs in the population or expressed as relative risk (RR), hazard ratio (HR), or odds ratio (OR). Cross-sectional studies, case reports, or case series were excluded from the analysis (Table S1), as well as ECG-gated CT protocol and extra-coronary calcification detection studies. Then, the two authors independently read the full texts of each article and extracted the data of interest:

Sample size, participants characteristics (age, sex, body mass index), duration of smoking, number of current and former smokers (>2 or 4 weeks since smoking cessation, according to studies), hypertension status, diabetes status, Agatston CAC score, and CV events at inclusion and during follow-up (myocardial infarction, angina, CV death, congestive heart failure, revascularization of coronary arteries). Divergences were resolved by consensus or the decision of a third author (C.C.).

The methodological quality of the selected studies was evaluated (S.G. and T.L.) using the grid published by Downs and Black [18] that enabled assessment of randomized and non-randomized trials. This evaluation concerned the quality of the study, its internal and external validities, management of selection and measurement biases and confounding factors.

2.2. Statistical Analyses

The primary endpoint was CV and all-cause mortality rates as according presence or absence of CAC. Secondary endpoints were the mortality rates according to a high Agatston score (>400 or >1000, depending on the study) and sex.

CV mortality is defined by diseases of the circulatory system (according to International Classification of Diseases-10-CM Diagnostic Code I00-99), which mainly includes hypertensive diseases, ischemic heart diseases, pulmonary circulation diseases, and cerebrovascular and artery diseases.

For studies reporting CV or all-cause mortality risk stratified according to the different Agatston scores, a pooled risk was obtained for all CAC classes > 0. The results are expressed as RR [95% confidence interval (CI)] for a random-effect (for $I^2 > 50\%$) or fixed-effect model (for $I^2 < 50\%$) as a function of heterogeneity. The weight of each study was estimated by the inverse variance of the fixed-effect model and with the Paule–Mandel estimator for the random-effect model [19]. Heterogeneity of the studies was analyzed visually and with the I^2 heterogeneity test, with $I^2 > 50\%$ supporting significant heterogeneity of the studies included in the meta-analysis. Publication bias was evaluated with a funnel plot for each meta-analysis. All statistical analyses were computed with R software version 3.6.3. and its metagen library [20].

3. Results

Among the 1913 references identified in Medline and Cochrane databases and other sources (Figure 1), 1794 articles did not meet inclusion criteria on reading the title, and 91 articles on reading the abstract. Twenty-eight articles were selected for full-text reading. Twenty-two were excluded: Nine concerned populations that did not participate in an organized lung-cancer screening program; three each were doubles, did not report mortality data, or had not stratified the CAC quantification score; and two each examined extra coronary artery calcifications or had used ECG-guided CT scans.

Only six studies fulfilled the inclusion/exclusion criteria, reporting CV and/or global mortality rates for 20,175 subjects according to their CAC scores [21–26]; five were randomized clinical trials on organized screening for lung cancer, and the last was a cohort study (Table 1). These studies enrolled 57% men and 47% active smokers. The Agatston CAC score was determined in five of them [21–25] and the last applied a visual quantitative score [26] with excellent agreement with the Agatston score using non-parametric concordance test ($R = 0.84$, $p < 0.001$). The CAC frequency ranged from 46% to 76%, depending on the study, with a high score for 7–19% of the participants. No study was excluded after assessment of the methodological quality (Table S2).

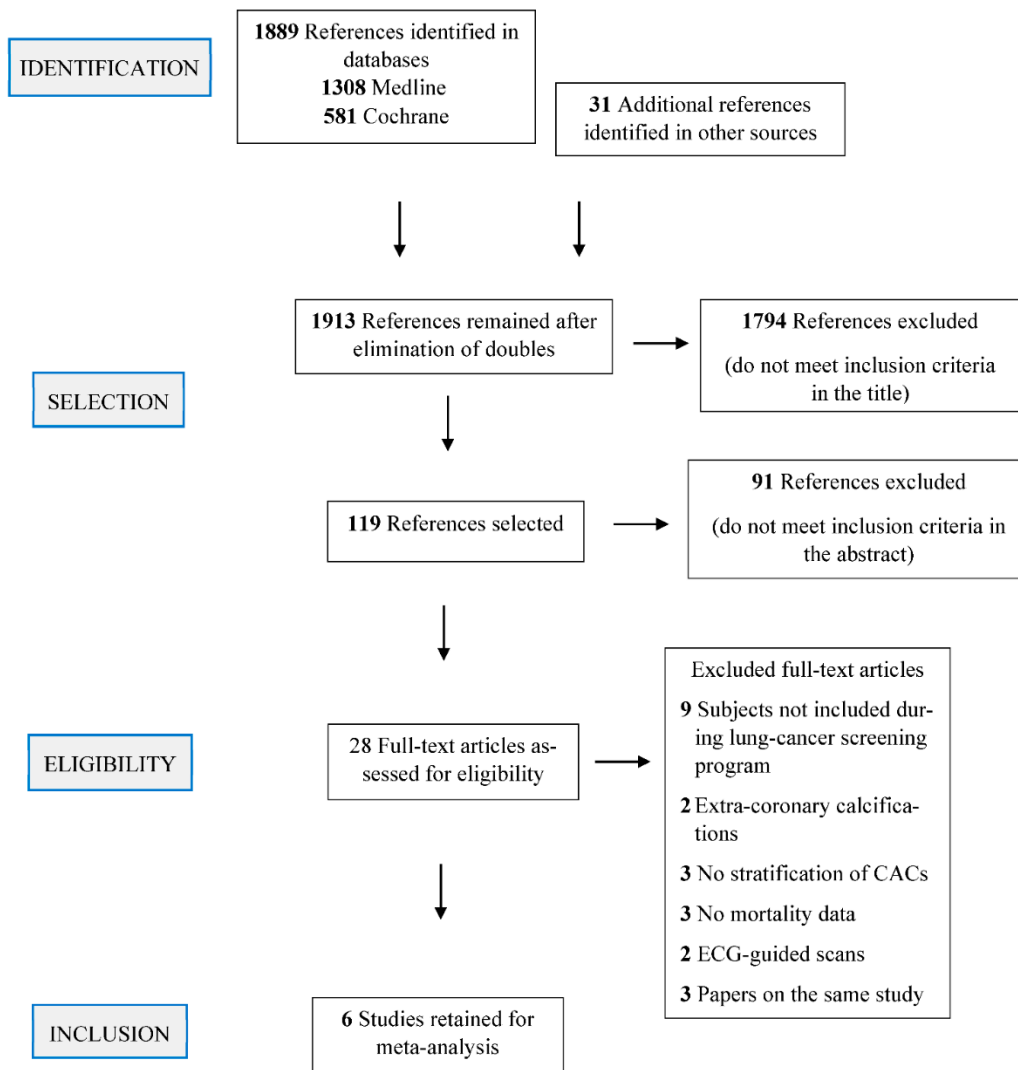


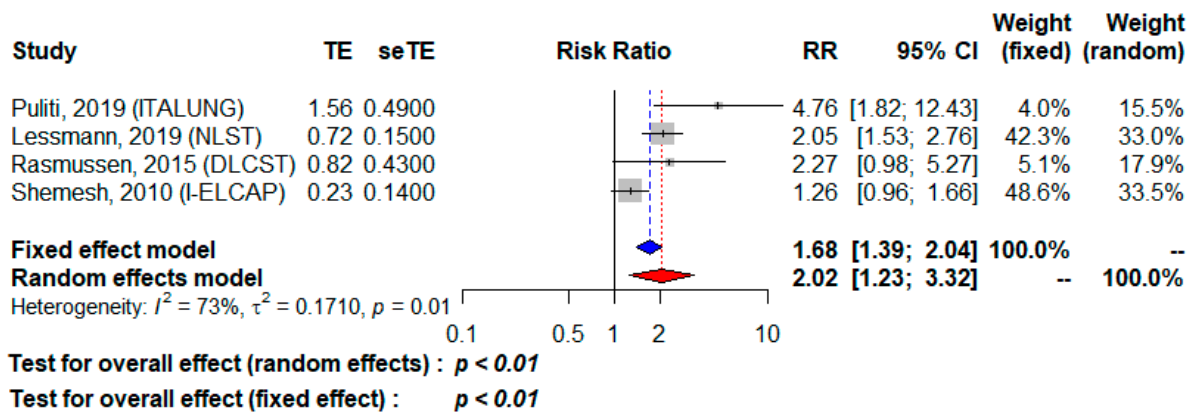
Figure 1. Flow chart for article selection.

Table 1. Sociodemographic and clinical characteristics of the populations in studies retained for the meta-analysis.

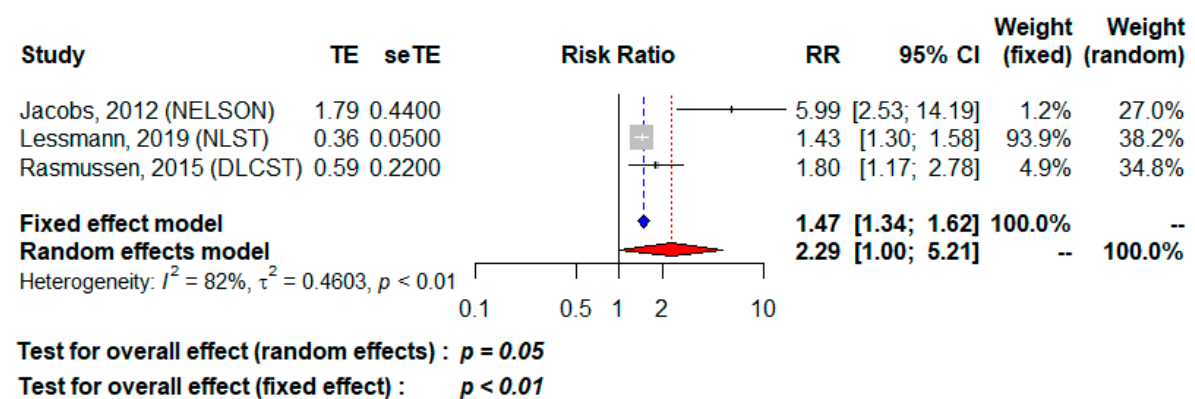
| Parameter | Jacobs [21] | Lessmann [22] | Sverzellati [23] | Shemesh [26] | Rasmussen [25] | Puliti [24] |
|--------------------------|--|--|--|--------------------|--|--|
| Study name | NELSON | NLST | MILD | ELCAP | DLCST | ITALUNG |
| Countries | Belgium, Holland | United States | Italy | United States | Denmark | Italy |
| Type of study | Case-control niched in a clinical randomized trial | Case-control niched in a clinical randomized trial | Cohort niched in a clinical randomized trial | Cohort | Case-control niched in a clinical randomized trial | Cohort niched in a clinical randomized trial |
| Number of subjects | 958 | 5718 | 1159 | 8782 | 1945 | 1613 |
| | | | Inclusion criteria | | | |
| Age range, years | 50–74 | 55–74 | 49–75 | 40–85 | 50–70 | 55–69 |
| Pack-years | >15 * | >30 | >20 | >10 | >20 | >20 |
| Median follow-up, months | 21.5 | 78 | 36 | 72.3 | 85.2 | 135.6 |
| | | | Clinical characteristics of the populations | | | |
| Men | 83% | 62.1% | 68.4% | 48.9% | 55% | CAC +/–:73%/58% |
| BMI (kg/m ²) | – | DS/C: 27.3/27.4 | 26.0 | – | 25 | – |
| CV risk factor | | | | | | |
| Active smoker, % | 56% | DS/C: 58%/45% | 65.1% | 34% | 76% | – |
| Mean pack/year | – | DS/C: 60/50 | 38.4 | M/F: 0.7/45.6 | 34 | CAC +/–: 42/39 |
| Hypertension | 64% | DS/C: 42%/34% | 24.9% | – | 14% | – |
| Diabetes | 7% | DS/C: 18%/11% | 6% | M/F: 9.2%/5.1% | 2% | – |
| Hypercholesterolemia | 75% | – | – | – | 7% | – |
| No CACs | 24% | 24.5% | 53.8% | 40.7% | 53% | 54.3% |
| High CAC > score | 17% ^a | – | 6.9% ^b | 18.7% ^b | 7% ^b | – |

* Or >15 cigarettes/day for >25 years or >10 cigarettes/day for >30 years, DS: Deceased subjects, C: Controls; Abbreviations BMI, body mass index; CV, cardiovascular; CAC +/–, coronary artery calcification positive or negative; ^a Agatson score >1000, ^b Agatson score >400.

The globally symmetrical distribution of the funnel plots for each of the studies showed the absence of major publication bias (Figure S1). Among the 17,851 subjects for whom a CV mortality analysis was possible (Table 2A), CAC detection was associated with excess CV mortality, with RR estimated at 1.68 [95% CI 1.39–2.04] for the fixed-effect model, and 2.02 [95% CI 1.23–3.32] for the random-effect model that was retained in light of the significant heterogeneity among studies ($I^2 = 73\%$, $p = 0.01$, Figure 2A). Among the 8621 participants for whom the all-cause mortality rate could be analyzed (Table 2B), CAC positivity was associated with a higher risk, with an RR of 1.47 [95% CI 1.34–1.62] for the fixed-effect model and 2.29 [95% CI 1.00–5.21] for the random-effect model (Figure 2B). Between-study heterogeneity was found with I^2 at 82% and $p < 0.01$. Among the 16,445 subjects for whom CV mortality could be analyzed according to a high CAC score (>400 or >1000 or score > category 4) (Table 3A), CV mortality was higher, with RR at 2.55 [95% CI 1.70–3.84] for both the fixed effect model and the random-effect model (Figure 3A); notably, heterogeneity was absent: $I^2 = 0\%$ et $p = 0.68$. Finally, for the 9780 subjects for whom all-cause mortality could be analyzed according to a high CAC score (Table 3B), all-cause mortality was also higher with RR at 2.47 [95% CI 1.75–3.47] for the fixed-effect model and 2.90 [95% CI 1.57–5.36] for the random-effect model (Figure 3B), with I^2 at 35% indicating moderate heterogeneity among studies.

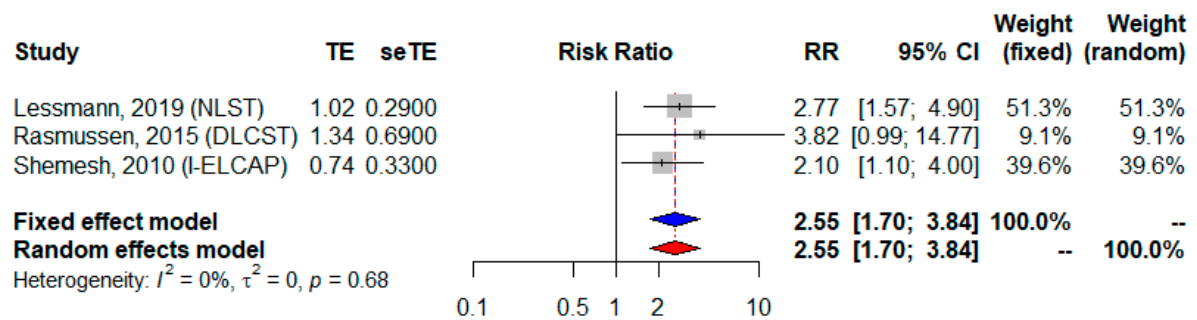


(A)



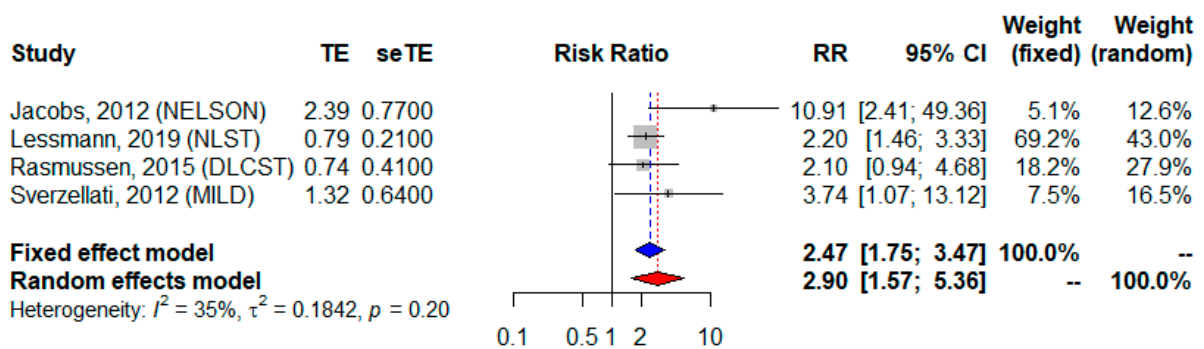
(B)

Figure 2. Cardiovascular (A) and all-cause (B) mortality according to the presence of coronary artery calcifications. TE, estimate of treatment effect, e.g., log hazard ratio or risk difference; seTE, Standard error of treatment estimate; RR, relative risk.



Test for overall effect (random effects) : $p < 0.01$
 Test for overall effect (fixed effect) : $p < 0.01$

(A)



Test for overall effect (random effects) : $p < 0.01$
 Test for overall effect (fixed effect) : $p < 0.01$

(B)

Figure 3. Cardiovascular (A) and all-cause (B) mortality according to a high coronary artery calcifications score. TE, estimate of treatment effect, e.g., log hazard ratio or risk difference; seTE, Standard error of treatment estimate; RR, relative risk.

Table 2. Cardiovascular (CV) or global mortality according to coronary artery calcification (CAC) status.

| Study | N | CV Mortality | CAC > 0 | | RR (CI 95%) | | Adjusted Log RR (SD Log RR Adjusted) | Adjusted TO |
|-----------------------------|------|--------------|---------|-------|-------------------|-------------------|--------------------------------------|---|
| | | | Events | Total | Non-adjusted | Adjusted | Adjusted (SD). | |
| CV MORTALITY PULITI [24] | 1406 | Undefined | 19 | 624 | 4.76 [1.79–12.68] | – | 1.56 (0.49) (not adjusted) | – |
| LESSMANN | 5718 | ICD I00–99 | 403 | 4318 | 3.27 [2.37–4.50] | 2.05 [1.51–2.79] | 0.72 (0.15) | Age, smoking, BMI, CV history, diabetes and hypertension |
| RASMUSSEN [25] | 1945 | ICD I00–99 | 19 | 910 | 3.19 [1.15–8.81] | 2.26 [0.97–5.29] | 0.82 (0.43) | Sex, age, smoker status, hypertension, hyper-cholesterolemia, diabetes |
| SHEMESH [26] | 8782 | ICD I00–78 | 150 | 5209 | 2.39 [1.70–3.35] | 1.26 [0.95–1.67] | 0.23 (0.14) | Sex, age, smoking history (no. of PY), diabetes |
| ALL-CAUSE MORTALITY | | | | | | | | |
| JACOBS [21] | 958 | – | 54 | 614 | 8.53 [2.10–34.67] | 5.98 [2.49–14.35] | 1.79 (0.44) | Sex, age, smoker status, hypertension diabetes, hyper-cholesterolemia |
| LESSMANN [22] | 5718 | – | 1480 | 4318 | 1.97 [1.74–2.22] | 1.43 [1.29–1.58] | 0.36 (0.05) | Age, smoking status, BMI, CV history, diabetes and hypertension |
| RASMUSSEN [25] | 1945 | – | 48 | 910 | 2.28 [1.41–3.68] | 1.81 [1.17–2.81] | 0.59 (0.22) | Sex, age, smoking status, hypertension, diabetes, hyper-cholesterolemia |

Abbreviations: RR, relative risk; ICD, International Classification of Diseases; BMI, body mass index; PY, pack-years.

Table 3. Cardiovascular (CV) or all-cause mortality according to a high coronary artery calcification (CAC) score.

| Study | N | Agaston Score | High CAC | | RR (95% CI) | | Log RR (σ log RR ajusté) | Adjusted to |
|---------------------|------|---------------|----------|-------|--------------------|--------------------|-------------------------------------|---|
| | | | Events | Total | Unadjusted | Adjusted | | |
| CV MORTALITY | | | | | | | | |
| LESSMANN [22] | 5718 | >1000 | – | – | – | 2.76 [1.56–4.88] | 1.02 (0.29) | Age, smoking status, BMI, CV history, diabetes and hypertension |
| RASMUSSEN [25] | 1945 | >400 | 5 | 132 | 7.84 [2.30–26.73] | 3.8 [1.0–15] | 1.34 (0.69) | Sex, age, smoking status, diabetes, hypertension, hypercholesterolemia |
| SHEMESH [26] | 8782 | Category 4–12 | 84 | 1640 | 4.26 [2.96–6.12] | 2.1 [1.4–4.1] | 0.74 (0.33) | Sex, age, smoking history (no. de PY), diabetes |
| ALL-CAUSE MORTALITY | | | | | | | | |
| JACOBS [21] | 958 | >1000 | 24 | 137 | 16.99 [4.08–70.71] | 10.93 [2.36–50.60] | 2.39 (0.77) | Sex, age, smoker status, hypertension diabetes, hyper-cholesterolemia |
| LESSMANN [22] | 5718 | >1000 | – | – | – | 2.20 [1.44–3.36] | 0.79 (0.21) | Age, smoking status, BMI, CV history, diabetes and hypertension |
| RASMUSSEN [25] | 1945 | >400 | 10 | 132 | 3.27 [1.60–6.68] | 2.1 [1.0–4.8] | 0.74 (0.41) | Sex, age, smoking status, diabetes, hypertension, hypercholesterolemia |
| SVERZELLATI [23] | 1159 | >400 | 5 | 80 | 7.49 [2.57–21.83] | 3.73 [1.05–13.32] | 1.32 (0.64) | Sex, age, smoking status, smoking duration, BMI, hypertension, diabetes |

In studies reporting CAC scores according to sex [22,23,25,26], CAC frequencies and rate of high CAC score were significantly higher for men than women, respectively: 60% vs. 50% ($p < 0.001$) and 20% vs. 11% ($p < 0.001$) (Table 4). One study based on 5718 subjects reported CV mortality in both men and women according to CAC score [22]. In this study, the presence of CAC was associated with CV mortality with an RR of 2.05 [95% CI 1.20–3.57] in men and 2.37 [CI 95% 1.29–5.09] in women, respectively. Five studies described the number of CV events and CV mortality according to sex for 18,562 subjects (Table 5). The respective number of CV events and CV mortality for men had RRs of 5.55 [95% CI 2.65–11.61] and 2.11 [95% CI 1.01–4.39], with moderate global heterogeneity ($I^2 = 37%$ and $p = 0.19$) (Figure 4).

Table 4. Frequency of coronary artery calcifications (CACs) according to sex, when available.

| | Men | | Women | | <i>p</i> -Value |
|---------------------------|-----------|-----|-----------|-------|-----------------|
| | <i>n</i> | % | <i>n</i> | % | |
| CAC > 0 | | | | | |
| Sverzellati [23] | 442/793 | 56% | 93/366 | 25% | 0.001 |
| Jacobs [21] | NA | NA | NA | NA | |
| Lessmann [22] | 2955/3553 | 83% | 1363/2165 | 63% | <0.001 |
| Rasmussen [25] | 644/1075 | 60% | 266/870 | 31% | <0.001 |
| Shemesh [26] | 2975/4294 | 69% | 2238/4488 | 49.9% | <0.001 |
| Puliti [24] | NA | NA | NA | NA | |
| Total | 4061/6764 | 60% | 3960/7889 | 50% | <0.001 |
| CAC > 400 or > category 4 | | | | | |
| Sverzellati [23] | 72/793 | 9% | 8/366 | 2% | <0.001 |
| Jacobs [21] | NA | NA | NA | NA | |
| Lessmann [22] | NA | NA | NA | NA | |
| Rasmussen [25] | 105/1075 | 10% | 27/870 | 3% | <0.001 |
| Shemesh [26] | 1062/4294 | 25% | 578/4488 | 12.9% | <0.001 |
| Puliti [24] | NA | NA | NA | NA | |
| Total | 1239/6166 | 20% | 613/5724 | 11% | <0.001 |

Table 5. Cardiovascular (CV) events and mortality according to sex.

| Study | <i>N</i> | Type | Men | | Women | | Unadjusted RR (95% CI) | LOG RR (σ log RR) |
|------------------|----------|---------------------------|--------|-------|--------|-------|---------------------------|------------------------------|
| | | | Events | Total | Events | Total | | |
| Sverzellati [23] | 1159 | CV event ^a | 30 | 793 | 3 | 366 | 4.62 [1.42–15.03] | 1.53 (0.59) |
| Jacobs [21] | 958 | CV event ^b | 123 | 671 | 4 | 137 | 6.28 [2.36–16.71] | 1.84 (0.49) |
| Lessmann [22] | 5718 | CV mortality ^c | 318 | 3553 | 125 | 2165 | 1.55 [1.27–1.89] | 0.44 (0.10) |
| Rasmussen, [25] | 1945 | CV mortality ^c | 17 | 1075 | 2 | 870 | 6.88 [1.59–29.69] | 1.93 (0.73) |
| Shemesh [26] | 8782 | CV mortality ^d | 122 | 4294 | 71 | 4488 | 1.80 [1.34–2.40] | 0.59 (0.14) |

Abbreviation: RR, relative risk. ^a Acute coronary syndrome, unstable angina, coronary revascularization. ^b International; Classification of Diseases, Ninth Revision Codes 424, 428, 430–438, 440, 441, 443–444. ^c ICD 100–199. ^d ICD 100–178.

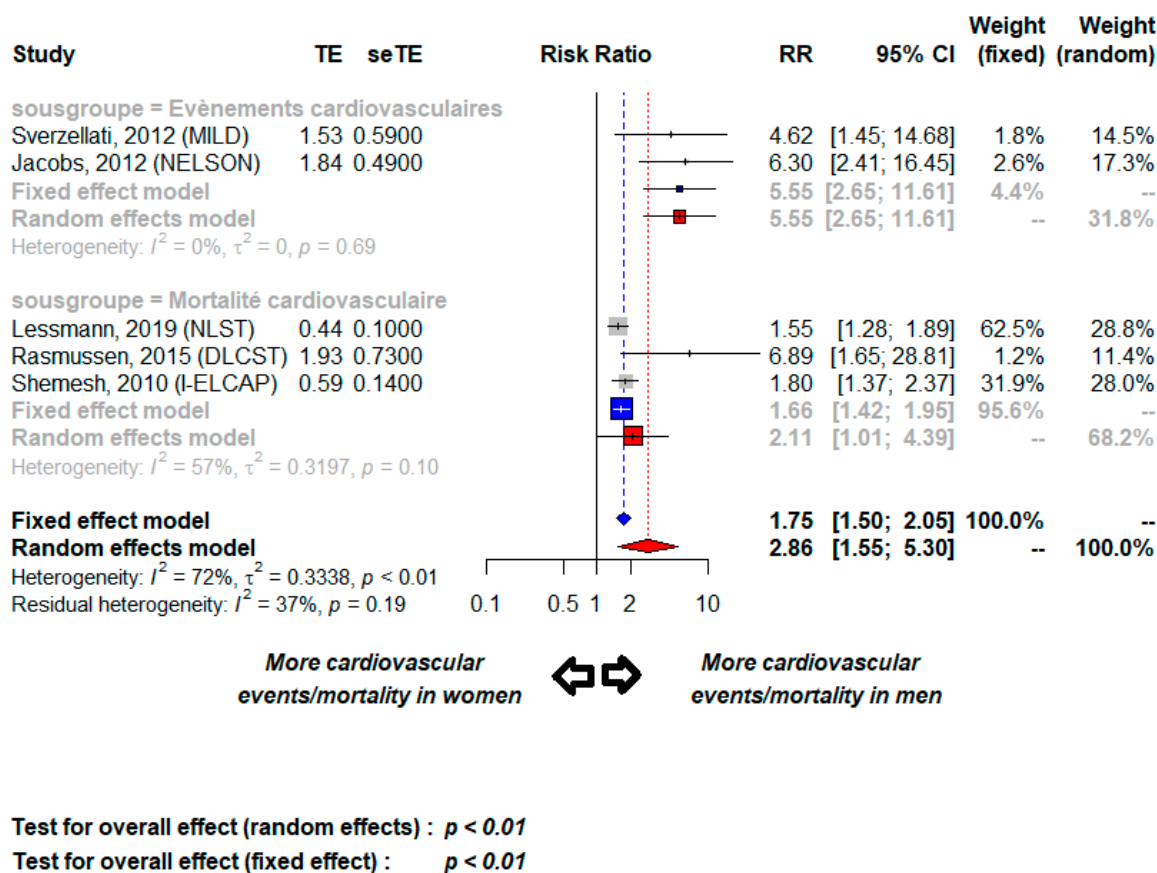


Figure 4. Cardiovascular events and mortality according to sex; TE, estimate of treatment effect, e.g., log hazard ratio or risk difference; seTE, Standard error of treatment estimate; RR, relative risk.

4. Discussion

This meta-analysis showed that CAC detection by thoracic low-dose CT scan during an organized lung-cancer screening program is able to predict CV and all-cause mortality rates in this population. This CV mortality risk was significantly higher for individuals with high CAC scores. CAC and elevated CAC score frequencies were significantly higher for men, but the predictive value of the CAC score on CV mortality did not seem to differ between men and women. These findings agree with reported observations—in other populations—of a significant link between CACs and CV and all-cause mortality rates [26–29].

Thus, in a prospective cohort of 9715 patients, including 8.3% with diabetes, the adjusted risk of death for the participants with most elevated CAC scores (>400) vs. those with no detected CACs (CAC = 0) increased by HRs of 4.64 (95% CI: 3.74–5.76) and 3.41 (95% CI: 2.22–5.22) for non-diabetics and diabetics, respectively [30]. Analysis of another cohort comprised of 4143 consecutive asymptomatic patients, at least 55 years old with no known coronary artery disease, followed for almost 15 years, showed that independently of smoking status, high CAC score was associated with a higher mortality. For any CAC, the non-smokers adjusted mortality risk was more than three-times higher (HR 3.07, 95% CI = 2.32–4.07, $p < 0.001$) and that for smokers it was almost five-time higher (HR 4.67, 95% CI = 3.52–6.20, $p < 0.001$) [27]. Patients without additional cardiac risk factors (such as hypertension, diabetes, dyslipidemia, family history of premature coronary artery disease) had similar findings: The adjusted risk of death increased incrementally according to CAC severity.

The prevalence of CACs reported in our meta-analysis (55%) is in agreement with previous reports; Ruparel et al. have reported a CAC prevalence of 62% in 680 subjects,

current or ex-smokers aged 60–75 invited to a “lung health check” and undergoing ungated, non-contrast low-dose computed tomography [31]. At present, other studies are needed, especially cost–efficacy analyses, to establish which CAC score should serve as an indication for diagnostic or therapeutic intervention [8,18,32]. For CV-specific and all-cause mortality rates, comparable findings were reported for the absence of interaction with other causes of death, e.g., linked to chronic respiratory or neoplastic diseases [33]. CAC enable better prediction of CV events than some clinical scores [34,35]. However, even in the absence of CACs, almost 15% of individuals meeting the eligibility criteria for organized lung-cancer screening can experience a CV event [36].

The CAC predictive value for CV risk could differ between men and women. Indeed, in contrast to some reported observations [37], our meta-analysis revealed that men had a greater risk for CV events and CV mortality (RR: 2.86, 95% CI: 1.55–5.30) and a higher CAC frequency and more elevated Agaston scores than women. Other studies found CAC appeared in women more than 10 years later [22]. According to the NLST study, CAC frequency was higher for men (83%) than women (63%) [22]. The predictive value of the Agaston scores of 0–100, 100–1000, and >1000, respectively, were similar according to sex, with respective RRs of 1.51 (95% CI 0.88–2.59), 2.13 (95% CI 1.26–3.62), 2.76 (95% CI 1.56–4.88) for men and 1.87 (95% CI 1.04–3.36), 2.43 (95% CI 1.29–4.56), 3.74 (95% CI 1.62–8.63) for women. In this setting, the concomitant screening for lung cancer and CV risk assessment might optimize recommendations and management of stopping smoking and develop primary prevention and therapeutic intervention programs to prevent or slow the progression of tobacco-associated diseases [38,39].

This meta-analysis has several limitations. First, marked heterogeneity existed among the studies, mainly because of the results of the NELSON study [21]. The risks of CV-specific and all-cause mortality in that study were heightened even more, with an adjusted RR at 5.98 [95% CI 2.49–14.35]. The characteristics of their population, notably the higher percentage of men (83%), might explain that difference, at least in part. Second, classification of the Agaston CAC score varied depending on the study, with heterogeneity for the definition of the high threshold. Other types of scores, notably qualitative score or algorithms based on artificial intelligence, are being evaluated to establish a standardized analysis of the CAC score [40–42]. Compared to the Agaston score, an assessment taking into consideration the volume, density, and morphology of the CACs might better predict the CV risk [43].

Another limitation of this meta-analysis is the heterogeneity of participants’ characteristics inherent in the inclusion criteria for lung-cancer screening, depending on the study. Age, duration of smoking, the number of pack-years, and CV comorbidities differed between the populations included and could explain the heterogeneity of CAC frequencies and the predictive value for CV mortality. Furthermore, this meta-analysis was based on aggregated data, which did not allow subgroup analyses on individual subject’s information, notably examination of different CAC thresholds or different risk levels according to age, smoker status, or CV comorbidities.

Finally, it is not clear from the current data whether knowledge of the presence of CAC on a low-dose CT scan in this population could be translated in a decrease of CV mortality. Nevertheless, the ITALUNG study suggests that information about CAC presence in the screening report may be a factor reducing CV-specific mortality through further investigation and earlier management of CV diseases [24].

5. Conclusions

In these specific population of active and former smokers, CT-scan evaluation of CACs detected during organized lung-cancer screening was able to predict CV-specific and all-cause mortality risks and should support taking CV risk into account in these programs.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/cancers13071553/s1>, Figure S1: Study of publication bias; Table S1: Grid to evaluate the quality study (“Checklist for the assessment of the methodological quality”, Downs and Black

1998 [17]) of the six studies included in the meta-analysis; Table S2: Table S1. Eligibility criteria for study inclusion in the meta-analysis.

Author Contributions: Conceptualization: S.G., C.C., T.L.; methodology: S.G., T.L., C.C.; software: S.G., T.L.; validation, H.G., J.-B.A., C.T.; formal analysis, all the authors; original draft preparation: S.G., T.L.; writing—review: S.G., H.G., J.-B.A., C.T.; supervision: C.C., T.L. All authors have read and agreed to the published version of the manuscript.

Funding: No specific funding for this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. The National Lung Screening Trial Research Team. Reduced Lung-Cancer Mortality with Low-Dose Computed Tomographic Screening. *N. Engl. J. Med.* **2011**, *365*, 395–409. [[CrossRef](#)]
2. De Koning, H.J.; Van Der Aalst, C.M.; De Jong, P.A.; Scholten, E.T.; Nackaerts, K.; Heuvelmans, M.A.; Lammers, J.-W.J.; Weenink, C.; Yousaf-Khan, U.; Horeweg, N.; et al. Reduced Lung-Cancer Mortality with Volume CT Screening in a Randomized Trial. *N. Engl. J. Med.* **2020**, *382*, 503–513. [[CrossRef](#)] [[PubMed](#)]
3. Moyer, V.A. Screening for Lung Cancer: U.S. Preventive Services Task Force Recommendation Statement. *Ann. Intern. Med.* **2014**, *160*, 330–338. [[CrossRef](#)]
4. Veronesi, G.; Baldwin, D.R.; Henschke, C.I.; Ghislandi, S.; Iavicoli, S.; Oudkerk, M.; De Koning, H.J.; Shemesh, J.; Field, J.K.; Zulueta, J.J.; et al. Recommendations for Implementing Lung Cancer Screening with Low-Dose Computed Tomography in Europe. *Cancers* **2020**, *12*, 1672. [[CrossRef](#)]
5. Yuan, M.; Li, Q.-G. Lung Cancer and Risk of Cardiovascular Disease: A Meta-analysis of Cohort Studies. *J. Cardiothorac. Vasc. Anesthesia* **2018**, *32*, e25–e27. [[CrossRef](#)]
6. Tabata, N.; Sueta, D.; Yamamoto, E.; Takashio, S.; Arima, Y.; Araki, S.; Yamanaga, K.; Ishii, M.; Sakamoto, K.; Kanazawa, H.; et al. Outcome of Current and History of Cancer on the Risk of Cardiovascular Events Following Percutaneous Coronary Intervention: A Kumamoto University Malignancy and Atherosclerosis (KUMA) Study. *Eur. Hear. J. Qual. Care Clin. Outcomes* **2018**, *4*, 290–300. [[CrossRef](#)] [[PubMed](#)]
7. Mets, O.M.; De Jong, P.A.; Prokop, M. Computed Tomographic Screening for Lung Cancer. *JAMA* **2012**, *308*, 1433–1434. [[CrossRef](#)] [[PubMed](#)]
8. Heuvelmans, M.A.; Vonder, M.; Rook, M.; Groen, H.J.; De Bock, G.H.; Xie, X.; Ijzerman, M.J.; Vliegthart, R.; Oudkerk, M. Screening for Early Lung Cancer, Chronic Obstructive Pulmonary Disease, and Cardiovascular Disease (the Big-3) Using Low-dose Chest Computed Tomography. *J. Thorac. Imaging* **2019**, *34*, 160–169. [[CrossRef](#)] [[PubMed](#)]
9. Jairam, P.M.; De Jong, P.A.; Mali, W.P.T.H.M.; Isgum, I.; De Koning, H.J.; Van Der Aalst, C.; Oudkerk, M.; Vliegthart, R.; Van Der Graaf, Y. Impact of Cardiovascular Calcifications on the Detrimental Effect of Continued Smoking on Cardiovascular Risk in Male Lung Cancer Screening Participants. *PLoS ONE* **2013**, *8*, e66484. [[CrossRef](#)]
10. Mols, R.E.; Jensen, J.M.; Sand, N.P.; Fuglesang, C.; Bagdat, D.; Vedsted, P.; Bøtker, H.E.; Nielsen, L.H.; Nørgaard, B.L. Visualization of Coronary Artery Calcification: Influence on Risk Modification. *Am. J. Med.* **2015**, *128*, 1023.e23–1023.e31. [[CrossRef](#)]
11. Waugh, N.; Black, C.; Walker, S.; McIntyre, L.; Cummins, E.; Hillis, G. The Effectiveness and Cost-Effectiveness of Computed Tomography Screening for Coronary Artery Disease: Systematic Review. *Heal. Technol. Assess.* **2006**, *10*. [[CrossRef](#)] [[PubMed](#)]
12. Detrano, R.; Guerci, A.D.; Carr, J.J.; Bild, D.E.; Burke, G.L.; Folsom, A.R.; Liu, K.; Shea, S.; Szklo, M.; Bluemke, D.A.; et al. Coronary Calcium as a Predictor of Coronary Events in Four Racial or Ethnic Groups. *N. Engl. J. Med.* **2008**, *358*, 1336–1345. [[CrossRef](#)] [[PubMed](#)]
13. Arcadi, T.; Maffei, E.; Sverzellati, N.; Mantini, C.I.; Guaricci, A.; Tedeschi, C.; Martini, C.; La Grutta, L.; Cademartiri, F. Coronary Artery Calcium Score on Low-Dose Computed Tomography for Lung Cancer Screening. *World J. Radiol.* **2014**, *6*, 381–387. [[CrossRef](#)] [[PubMed](#)]
14. Budoff, M.J.; Nasir, K.; Kinney, G.L.; Hokanson, J.E.; Barr, R.G.; Steiner, R.; Nath, H.; Lopez-Garcia, C.; Black-Shinn, J.; Casaburi, R. Coronary Artery and Thoracic Calcium on Noncontrast Thoracic CT Scans: Comparison of Ungated and Gated Examinations in Patients from the COPD Gene Cohort. *J. Cardiovasc. Comput. Tomogr.* **2011**, *5*, 113–118. [[CrossRef](#)]
15. Htwe, Y.; Cham, M.D.; Henschke, C.I.; Hecht, H.; Shemesh, J.; Liang, M.; Tang, W.; Jirapatnakul, A.; Yip, R.; Yankelevitz, D.F. Coronary Artery Calcification on Low-Dose Computed Tomography: Comparison of Agatston and Ordinal Scores. *Clin. Imaging* **2015**, *39*, 799–802. [[CrossRef](#)]
16. Kim, S.M.; Chung, M.J.; Lee, K.S.; Choe, Y.H.; Yi, C.A.; Choe, B.-K. Coronary Calcium Screening Using Low-Dose Lung Cancer Screening: Effectiveness of MDCT with Retrospective Reconstruction. *Am. J. Roentgenol.* **2008**, *190*, 917–922. [[CrossRef](#)]
17. Hecht, H.S.; Blaha, M.J.; Kazerooni, E.A.; Cury, R.C.; Budoff, M.; Leipsic, J.; Shaw, L. CAC-DRS: Coronary Artery Calcium Data and Reporting System. An expert consensus document of the Society of Cardiovascular Computed Tomography (SCCT). *J. Cardiovasc. Comput. Tomogr.* **2018**, *12*, 185–191. [[CrossRef](#)]

18. Downs, S.H.; Black, N. The Feasibility of Creating a Checklist for the Assessment of the Methodological Quality Both of Randomised and Non-randomised Studies of Health Care Interventions. *J. Epidemiol. Community Health* **1998**, *52*, 377–384. [[CrossRef](#)] [[PubMed](#)]
19. Veroniki, A.A.; Jackson, D.J.; Viechtbauer, W.; Bender, R.; Bowden, J.; Knapp, G.; Kuss, O.; Higgins, J.P.T.; Langan, D.; Salanti, G. Methods to Estimate the between-Study Variance and Its Uncertainty in Meta-Analysis. *Res. Synth. Methods* **2016**, *7*, 55–79. [[CrossRef](#)]
20. Shim, S.R.; Kim, S.-J. Intervention Meta-Analysis: Application and Practice Using R Software. *Epidemiol. Heal.* **2019**, *41*, e2019008. [[CrossRef](#)]
21. Jacobs, P.; Gondrie, M.; Van Der Graaf, Y.; De Koning, H.; Işgum, I.; Van Ginneken, B.; Mali, W.P.T.M. Coronary Artery Calcium Can Predict All-Cause Mortality and Cardiovascular Events on Low-Dose CT Screening for Lung Cancer. *Am. J. Roentgenol.* **2012**, *198*, 505–511. [[CrossRef](#)] [[PubMed](#)]
22. Lessmann, N.; De Jong, P.A.; Celeng, C.; Takx, R.A.; Viergever, M.A.; Van Ginneken, B.; Işgum, I. Sex Differences in Coronary Artery and Thoracic Aorta Calcification and Their Association with Cardiovascular Mortality in Heavy Smokers. *JACC: Cardiovasc. Imaging* **2019**, *12*, 1808–1817. [[CrossRef](#)] [[PubMed](#)]
23. Sverzellati, N.; Cademartiri, F.; Bravi, F.; Martini, C.; Gira, F.A.; Maffei, E.; Marchianò, A.; La Vecchia, C.; De Filippo, M.; Kuhnigk, J.-M.; et al. Relationship and Prognostic Value of Modified Coronary Artery Calcium Score, FEV1, and Emphysema in Lung Cancer Screening Population: The MILD Trial. *Radiology* **2012**, *262*, 460–467. [[CrossRef](#)]
24. Puliti, D.; Mascalchi, M.; Carozzi, F.M.; Carrozzi, L.; Falaschi, F.; Paci, E.; Pegna, A.L.; Aquilini, F.; Barchielli, A.; Bartolucci, M.; et al. Decreased Cardiovascular Mortality in the ITALUNG Lung Cancer Screening Trial: Analysis of Underlying Factors. *Lung Cancer* **2019**, *138*, 72–78. [[CrossRef](#)] [[PubMed](#)]
25. Rasmussen, T.; Køber, L.; Abdulla, J.; Pedersen, J.H.; Wille, M.M.W.; Dirksen, A.; Kofoed, K.F. Coronary Artery Calcification Detected in Lung Cancer Screening Predicts Cardiovascular Death. *Scand. Cardiovasc. J.* **2015**, *49*, 159–167. [[CrossRef](#)] [[PubMed](#)]
26. Shemesh, J.; Henschke, C.I.; Shaham, D.; Yip, R.; Farooqi, A.O.; Cham, M.D.; McCauley, D.I.; Chen, M.; Smith, J.P.; Libby, D.M.; et al. Ordinal Scoring of Coronary Artery Calcifications on Low-Dose CT Scans of the Chest is Predictive of Death from Cardiovascular Disease. *Radiology* **2010**, *257*, 541–548. [[CrossRef](#)]
27. Schulman-Marcus, J.; Valenti, V.; Hartaigh, B.Ó.; Gransar, H.; Truong, Q.; Giambone, A.; Callister, T.Q.; Shaw, L.J.; Lin, F.Y.; Min, J.K. Prognostic Utility of Coronary Artery Calcium Scoring in Active Smokers: A 15-Year Follow-up Study. *Int. J. Cardiol.* **2014**, *177*, 581–583. [[CrossRef](#)]
28. Shaw, A.T.; Yeap, B.Y.; Mino-Kenudson, M.; Digumarthy, S.R.; Costa, D.B.; Heist, R.S.; Solomon, B.; Stubbs, H.; Admane, S.; McDermott, U.; et al. Clinical Features and Outcome of Patients with Non-Small-Cell Lung Cancer Who Harbor EML4-ALK. *J. Clin. Oncol.* **2009**, *27*, 4247–4253. [[CrossRef](#)]
29. Möhlenkamp, S.; Lehmann, N.; Moebus, S.; Schmermund, A.; Dragano, N.; Stang, A.; Siegrist, J.; Mann, K.; Jöckel, K.-H.; Erbel, R. Quantification of Coronary Atherosclerosis and Inflammation to Predict Coronary Events and All-Cause Mortality. *J. Am. Coll. Cardiol.* **2011**, *57*, 1455–1464. [[CrossRef](#)]
30. Shaw, L.J.; Raggi, P.; Callister, T.Q.; Berman, D.S. Prognostic Value of Coronary Artery Calcium Screening in Asymptomatic Smokers and Non-smokers. *Eur. Hear. J.* **2006**, *27*, 968–975. [[CrossRef](#)]
31. Ruparel, M.; Quaipe, S.L.; Dickson, J.L.; Horst, C.; Burke, S.; Taylor, M.; Ahmed, A.; Shaw, P.; Soo, M.-J.; Nair, A.; et al. Evaluation of Cardiovascular Risk in a Lung Cancer Screening Cohort. *Thorax* **2019**, *74*, 1140–1146. [[CrossRef](#)]
32. Shaw, L.J.; Raggi, P.; Berman, D.S.; Callister, T.Q. Cost Effectiveness of Screening for Cardiovascular Disease with Measures of Coronary Calcium. *Prog. Cardiovasc. Dis.* **2003**, *46*, 171–184. [[CrossRef](#)]
33. Budoff, M.J.; Shaw, L.J.; Liu, S.T.; Weinstein, S.R.; Tseng, P.H.; Flores, F.R.; Callister, T.Q.; Raggi, P.; Berman, D.S.; Mosler, T.P. Long-Term Prognosis Associated with Coronary Calcification. *J. Am. Coll. Cardiol.* **2007**, *49*, 1860–1870. [[CrossRef](#)]
34. Garg, P.K.; Jorgensen, N.W.; McClelland, R.L.; Leigh, J.A.; Greenland, P.; Blaha, M.J.; Yoon, A.J.; Wong, N.D.; Yeboah, J.; Budoff, M.J. Use of Coronary Artery Calcium Testing to Improve Coronary Heart Disease Risk Assessment in a Lung Cancer Screening Population: The Multi-Ethnic Study of Atherosclerosis (MESA). *J. Cardiovasc. Comput. Tomogr.* **2018**, *12*, 493–499. [[CrossRef](#)] [[PubMed](#)]
35. Johnson, K.M.; Dowe, D.A. The Detection of Any Coronary Calcium Outperforms Framingham Risk Score as a First Step in Screening for Coronary Atherosclerosis. *Am. J. Roentgenol.* **2010**, *194*, 1235–1243. [[CrossRef](#)] [[PubMed](#)]
36. Leigh, A.; McEvoy, J.W.; Garg, P.; Carr, J.J.; Sandfort, V.; Oelsner, E.C.; Budoff, M.; Herrington, D.; Yeboah, J. Coronary Artery Calcium Scores and Atherosclerotic Cardiovascular Disease Risk Stratification in Smokers. *JACC Cardiovasc. Imaging* **2019**, *12*, 852–861. [[CrossRef](#)] [[PubMed](#)]
37. Fan, L.; Fan, K. Lung Cancer Screening CT-Based Coronary Artery Calcification in Predicting Cardiovascular Events. *Medicine* **2018**, *97*, e10461. [[CrossRef](#)]
38. Rasmussen, T.; Frestad, D.; Køber, L.; Pedersen, J.H.; Thomsen, L.H.; Dirksen, A.; Kofoed, K.F. Development and Progression of Coronary Artery Calcification in Long-Term Smokers: Adverse Effects of Continued Smoking. *J. Am. Coll. Cardiol.* **2013**, *62*, 255–257. [[CrossRef](#)] [[PubMed](#)]
39. Osawa, K.; Trejo, M.E.P.; Nakanishi, R.; McClelland, R.L.; Blaha, M.J.; Blankstein, R.; McEvoy, J.W.; Ceponiene, I.; Stein, J.H.; Sacco, R.L.; et al. Coronary Artery Calcium and Carotid Artery Intima-Media Thickness for the Prediction of Stroke and Benefit from Statins. *Eur. J. Prev. Cardiol.* **2018**, *25*, 1980–1987. [[CrossRef](#)] [[PubMed](#)]

40. Lessmann, N.; Van Ginneken, B.; Zreik, M.; De Jong, P.A.; De Vos, B.D.; Viergever, M.A.; Isgum, I. Automatic Calcium Scoring in Low-Dose Chest CT Using Deep Neural Networks with Dilated Convolutions. *IEEE Trans. Med. Imaging* **2017**, *37*, 615–625. [[CrossRef](#)]
41. Takx, R.A.; De Jong, P.; Leiner, T.; Oudkerk, M.; De Koning, H.; Mol, C.; Viergever, M.; Isgum, I. Automated Coronary Artery Calcification Scoring in Non-Gated Chest CT: Agreement and Reliability. *PLoS ONE* **2014**, *9*, e91239. [[CrossRef](#)] [[PubMed](#)]
42. Azour, L.; Kadoch, M.A.; Ward, T.J.; Eber, C.D.; Jacobi, A.H. Estimation of Cardiovascular Risk on Routine Chest CT: Ordinal Coronary Artery Calcium Scoring as an Accurate Predictor of Agatston Score Ranges. *J. Cardiovasc. Comput. Tomogr.* **2017**, *11*, 8–15. [[CrossRef](#)] [[PubMed](#)]
43. Foldyna, B.; Eslami, P.; Scholtz, J.-E.; Baltrusaitis, K.; Lu, M.T.; Massaro, J.M.; D'Agostino, R.B.; Ferencik, M.; Aerts, H.J.W.L.; O'Donnell, C.J.; et al. Density and Morphology of Coronary Artery Calcium for the Prediction of Cardiovascular Events: Insights from the Framing-Ham Heart Study. *Eur. Radiol.* **2019**, *29*, 6140–6148. [[CrossRef](#)] [[PubMed](#)]