Cardiorespiratory fitness is a strong and consistent predictor of morbidity and mortality among adults: an overview of meta-analyses representing over 20.9 million observations from 199 unique cohort studies

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ABSTRACT

Objective To examine and summarise evidence from meta-analyses of cohort studies that evaluated the predictive associations between baseline cardiorespiratory fitness (CRF) and health outcomes among adults.

Design Overview of systematic reviews.

Data source Five bibliographic databases were searched from January 2002 to March 2024.

Results From the 9062 papers identified, we included 26 systematic reviews. We found eight meta-analyses that described five unique mortality outcomes among general populations. CRF had the largest risk reduction for all-cause mortality when comparing high versus low CRF (HR=0.47; 95% CI 0.39 to 0.56). A dose–response relationship for every 1-metabolic equivalent of task (MET) higher level of CRF was associated with a 11%–17% reduction in all-cause mortality (HR=0.89; 95% CI 0.86 to 0.92, and HR=0.83; 95% CI 0.78 to 0.88). For incident outcomes, nine meta-analyses described 12 unique outcomes. CRF was associated with the largest risk reduction in incident heart failure when comparing high versus low CRF (HR=0.31; 95% CI 0.19 to 0.49). A dose–response relationship for every 1-MET higher level of CRF was associated with a 18% reduction in heart failure (HR=0.82; 95% CI 0.79 to 0.84). Among those living with chronic conditions, nine meta-analyses described four unique outcomes in nine patient groups. CRF was associated with the largest risk reduction for cardiovascular mortality among those living with cardiovascular disease when comparing high versus low CRF (HR=0.27; 95% CI 0.16 to 0.48). The certainty of the evidence across all studies ranged from very low-to-moderate according to Grading of Recommendations, Assessment, Development and Evaluations.

Conclusion We found consistent evidence that high CRF is strongly associated with lower risk for a variety of mortality and incident chronic conditions in general and clinical populations.

INTRODUCTION

Cardiorespiratory fitness (CRF) is a physical trait that reflects the integrated function of numerous bodily systems to deliver and use oxygen to support muscle activity during sustained, rhythmic, whole-body, large muscle physical activity.1 CRF can

be objectively measured using direct (usually by maximal exercise testing with concomitant gas exchange analysis) or indirect (exercise predicted equations)2 4 methods with a variety of maximal or submaximal protocols using different modalities (eg, stationary cycling, treadmill running/walking, bench stepping, field-based running/walking).

Non-exercise prediction equations with reasonable validity are also available when direct CRF measurement is not feasible.5 6 CRF is commonly expressed as the maximum or peak rate of oxygen consumption (in kilograms of body mass (common units: mL/kg/min) or metabolic equivalents of task (METs). Nearly half of the variance in CRF is attributable to genetics, with the remainder modified primarily...
through habitual physical activity.7 For example, brisk walking for approximately 150 min per week can result in large relative improvements in CRF among sedentary and unfit individuals.8 9 Even those with severe chronic disease can improve CRF through well-planned aerobic physical activity programs.10

Low CRF is considered a strong chronic disease risk factor that is not routinely assessed in clinical practice.11 Evidence suggests that the inclusion of CRF as a clinical vital sign would enhance patient management by improving the classification of those at high risk of adverse outcomes.11 The evidence supporting CRF as an important risk factor has accumulated since the 1980s through large cohort studies that investigated the prospective risk of all-cause mortality and cardiovascular events associated with CRF.12–14 Research has linked CRF to the incidence of some cancers (eg, colon/rectum, lung),15 type 2 diabetes,16 metabolic syndrome,17 stroke18 and depression.19 Higher CRF may even improve the prognosis in those with chronic conditions such as cancer,20 peripheral artery disease,21 heart failure22 and chronic kidney disease.23

Given the mounting evidence supporting CRF as an important risk factor, numerous systematic reviews with meta-analyses summarising results of primary studies for various health outcomes have been published. Kodama et al24 published the first meta-analysis on the health-related predictive validity of CRF and found that a 1-MET (3.5 mL/kg/min) higher level of CRF was associated with a 13% and 15% reduction in the risk of all-cause mortality and cardiovascular disease (CVD) events, respectively. This study helped to establish the meaningful clinically important difference (MCID) of 1-MET for exercise trials. Since Kodama’s study, there have been several systematic reviews with meta-analyses, with several published in recent years (ie, 2020+). Most systematic reviews have focused on a single health outcome. To date, there has not been a systematic synthesis of the relationships between CRF and a broad range of health outcomes. To help summarise the breadth of evidence, an overview of reviews provides a systematic method to examine evidence across a range of outcomes for a specific exposure.25 Thus, the objective of this study was to conduct an overview of systematic reviews with meta-analyses from cohort studies that investigated relationships between CRF and prospective health-related outcomes among adults. We also aimed to assess the certainty of the evidence for each identified health outcome.

METHODS
This overview followed the methods outlined in the Cochrane handbook,25 and additional methods that were published elsewhere.26 We adhered to both the Preferred Reporting Items for Overviews of Reviews statement27 and the Meta-analyses of Observational Studies in Epidemiology reporting standards.28 The overview was prospectively registered with the PROSPERO international prospective register of systematic reviews (#CRD42022370149). Here, we present a condensed methods section with the full methods available in online supplemental methods.

Eligibility criteria
Population
Adult populations (≥18 years) including apparently healthy and clinical populations with diagnosed chronic conditions. Studies
that focused on certain special populations were excluded (ie, those recovering from surgery, athletes, disease at birth, pregnant individuals).

**Exposure**
The primary exposure was CRF measured using the following approaches: (1) maximal exercise testing with gas analysis (ie, directly measured VO$_{2max}$/kg), (2) maximal or submaximal exercise testing without gas analysis, which used either exercise prediction equations to estimate CRF or the measured exercise performance (ie, indirect measures) or (3) non-exercise prediction equations for estimating CRF.

**Outcome**
Any health-related outcome such as all-cause or cause-specific mortality, incident conditions related to physical risk factors, chronic conditions or mental health issues were included. Among populations with diagnosed chronic conditions, we included evidence on outcomes such as mortality or disease severity.

**Study design**
Only systematic reviews with meta-analyses that searched a minimum of two bibliographic databases and provided a sample search strategy were included. We also included meta-analyses that pooled data from primary prospective/retrospective cohort or case-control studies. These studies were the focus because of their ability to assess causality for observational research.

**Publication status and language restriction**
Only systematic reviews published in peer-reviewed journals in English, French or Spanish (based on authors’ language capacity) were eligible. Conference abstracts or papers, commentaries, editorials, dissertations or grey literature were ineligible.

**Time frame**
Systematic reviews published during the past 20 years for the initial search.

**Information sources**
Five bibliographic databases, including OVID Medline, OVID Embase, Scopus, CINAHL and EBSCOhost SPORTDiscus, were searched from 1 January 2002 to 21 November 2022. The search was later updated from 1 November 2022 to 8 March 2024.

**Search strategy**
A research librarian (KM) created the search strategy in collaboration with the authorship team, and the final search was peer-reviewed by an independent research librarian using the Peer Review of Electronic Search Strategies guidelines. The search strategies for each database are available in online supplemental appendix 1. The reference lists of included papers were also searched for additional relevant systematic reviews.

**Selection process**
All records were imported into RefWorks where duplicates were removed using automated and manual methods. Records were included. We also included meta-analyses that pooled data from primary prospective/retrospective cohort or case-control studies. These studies were the focus because of their ability to assess causality for observational research.

<table>
<thead>
<tr>
<th>First author, year</th>
<th>Population description</th>
<th>Exposure description(s)</th>
<th>Range of follow-up*</th>
<th>Outcome(s)</th>
<th>Number of studies included in meta-analysis</th>
<th>Sample size included in meta-analysis</th>
<th>AMSTAR2 rating†</th>
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<td>Aune, 2020††</td>
<td>General populations of adults</td>
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<td>Sudden cardiac mortality</td>
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<td>Barry, 2014‡‡</td>
<td>Data only presented in supplement</td>
<td>Normal weight fit&lt;br&gt;versus normal weight unfit, overweight unfit, overweight fit, obese unfit and obese fit</td>
<td>7.7–16 years</td>
<td>All-cause mortality</td>
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<td>Data only presented in supplement</td>
<td>Normal weight fit&lt;br&gt;versus normal weight unfit, overweight unfit, overweight fit, obese unfit and obese fit</td>
<td>8.1–19.8 years</td>
<td>CVD mortality</td>
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<td>High versus low&lt;br&gt;Per 1-MET increase</td>
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<td>High versus low&lt;br&gt;Per 1-MET increase</td>
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<td>All-cause mortality</td>
<td>15</td>
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<td>Laukkanen, 2022††</td>
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<td>High versus low&lt;br&gt;Per 1-MET increase</td>
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<td>8.8–24 years</td>
<td>All-cause mortality</td>
<td>7</td>
<td>154015</td>
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</tbody>
</table>

*Data presented are for all the papers included in the systematic reviews and may include exposures other than CRF.
†Details on the AMSTAR2 quality assessment are available from Shea et al.31
‡AMSTAR2, A MeaSurement Tool to Assess systematic Reviews 2; CRF, cardiorespiratory fitness; CVD, cardiovascular disease; MET, metabolic equivalent of task.
imported into Covidence for further deduplication and record screening. Reviewers were not blinded to the study metadata when screening. The title and abstract from each record were screened by two of the following independent reviewers (JJL, SAP, CC-, J-JP, TM, BS and GRT) against the inclusion criteria. Conflicts at the full-text stage were resolved through discussion by two reviewers (JJL and SAP), with a third reviewer resolving disagreements (GRT).

Data collection process
Data extraction was completed in Covidence using a form that was piloted by the authorship group for accuracy. Full-text papers were imported into Covidence for further deduplication and record screening. Reviewers were not blinded to the study metadata when screening. The title and abstract from each record were screened by two of the following independent reviewers (JJL, SAP, CC-, J-JP, TM, BS and GRT) against the inclusion criteria. Conflicts at the full-text stage were resolved through discussion by two reviewers (JJL and SAP), with a third reviewer resolving disagreements (GRT).

Data items
The data extraction form included several items related to the demographic characteristics of the primary studies, the meta-analyses effect estimates and related statistics, and details for risk of bias and subgroup analyses.

Review quality
We extracted the original risk of bias assessment for each primary study, as reported by the study authors. Most of the included studies used the Newcastle-Ottawa Scale (NOS) to assess risk of bias for cohort studies. In the event that risk of bias was not assessed, a new assessment was conducted and verified by two reviewers using the NOS. We also assessed quality of the systematic reviews using the second edition of A MeaSurement Tool to Assess systematic Reviews 2 (AMSTAR2) checklist. Two of the following independent reviewers (JJL, SAP, CC-, J-JP, TM, FBO, BS and GRT) assessed review quality. Conflicts were resolved by one reviewer (JJL), with the reviewers who extracted the data contacted to resolve outstanding conflicts.

Effect measures
We presented pooled hazard ratios (HRs) or relative risks (RRs) for an incident event (ie, mortality or morbidity) across the included systematic reviews. We extracted data from models that compared high versus low CRF and those that examined the impact of a 1-MET higher level of CRF.

Synthesis of data
We followed an outcome-centric approach, as outlined by Kho et al. Our goal was to identify systematic reviews with...
non-overlapping primary studies for each outcome to avoid double counting evidence. When more than one eligible systematic review was identified for a single outcome, we calculated the corrected covered area (CCA) to assess the degree of overlap in the primary studies.\(^{12}\)

\[
CCA = \frac{N - r}{(r + c) - r}
\]

Where, \(N\) is the total number of times a primary study appeared across reviews (inclusive of double counting), \(r\) is the number of unique primary studies and \(c\) is the number of systematic reviews included for the outcome.

The CCA was interpreted as slight (0%–5%), moderate (6%–10%), high (11%–15%) or very high (>15%). If the CCA was slight or moderate, we included multiple systematic reviews per outcome. If the CCA was high or very high, we selected the highest quality systematic review according to the AMSTAR2 assessment. We included the most recent systematic review when reviews of the same outcome were rated as equal in quality.

**Synthesis of results**

For each health outcome, we reported evidence for apparently healthy and clinical populations separately. We summarised results using a narrative synthesis approach using summary of results, including the effect, confidence limits, number of studies and number of participants, were presented by outcome using a forest plot to allow easy comparison between studies. RR values were taken to approximate the HR. When comparing high versus low CRF, we inverted the scale when studies compared low versus high by taking the reciprocal (ie, HR=2.00 was changed to HR=0.50). Dose–response values were rescaled to a 1-MET higher level of CRF when more than 1-MET was used or if the unit increase was in VO\(_2\). We rescaled by taking the natural log of the HR, dividing or multiplying it to correspond with 1-MET, and exponentiating the result. Subgroup analyses for sex were described when available.

**Certainty of the evidence assessment**

For each outcome, the certainty of the evidence was assessed using a modified Grading of Recommendations, Assessment, Development and Evaluations (GRADE) approach.\(^{33}\) Observational cohort evidence began at ‘high’ certainty because randomised controlled trials were deemed not feasible for our research question.\(^{34}\) The certainty of the evidence could be rated down based on five domains (ie, risk of bias, imprecision, inconsistency, indirectness and publication bias). See online supplemental table 1 for a GRADE decision rules table.

**Equity, diversity and inclusion statement**

Our research team included diversity across genders with representation from researchers at all career stages. We stratified our results by sex which allowed use to identify the potential need for more diversity in this area of the literature. This stratification allowed us to discuss the overall generalisability of our results. The GRADE evaluation carried out in this study assessed the indirectness of the results. We downgraded evidence that did not demonstrate good global representation or did not provide a gender-balanced sample. Reducing indirectness is important for ensuring the results are representative of the target population.
**RESULTS**

We identified 9062 records after removing duplicates, assessed 199 full-text papers, and excluded 165 papers during full-text screening, and 8 papers because of high or very high overlap based on the CCA calculation (see figure 1 and online supplemental appendix 2 for full texts with reasons for exclusion). The proportion of agreement between reviewers for title and abstract screening ranged from 95% to 100% while the agreement for full-text screening ranged from 75% to 100%. We included 26 systematic reviews with meta-analyses representing over 20.9 million observations from 199 unique cohort studies, including 21 mortality or incident chronic disease outcomes. We identified CCA values in the high or very high range for sudden cardiac mortality (CCA=33%; n=2), incident heart failure (33%; n=2), incident depression (50%; n=2), incident type 2 diabetes (25%; n=4) and all-cause mortality among those living with heart failure (14%; n=3; see online supplemental appendix 2 for more details). We included multiple systematic reviews for all-cause mortality because the CCA was moderate (10%; n=3).

Tables 1–3 describe the study characteristics. We identified 8 systematic reviews that investigated mortality outcomes, with pooled data from 95 unique primary cohort studies. Nine systematic reviews investigated incident outcomes, pooling data from 63 unique primary cohort studies. The remaining 9 systematic reviews investigated health-related outcomes among populations living with chronic conditions, which represented data from 51 unique primary cohort studies. 11 reviews were of critically low quality, 4 were low, 8 were moderate and 3 were of high quality as assessed using the AMSTAR2 (see online supplemental table 2). We included multiple systematic reviews for all-cause mortality because the CCA was moderate (10%; n=3).

**Figure 2** illustrates results for CRF as a predictor of mortality outcomes, which included all-cause, CVD, sudden cardiac, all cancer and lung cancer mortality. When comparing high versus low CRF across all outcomes, there was a 41% (HR for all-cause mortality 24=0.59; 95% CI 0.52 to 0.66) to 53% (HR for all-cause mortality 35=0.47; 95% CI 0.39 to 0.56) reduction in the risk of premature mortality. The certainty of the evidence was assessed as very low-to-moderate, mainly due to serious indirectness (ie, most studies only included male participants). In assessing the dose–response relationship, a 1-MET higher level of CRF was associated with a 7% (HR for all cancer mortality 35=0.93; 95% CI 0.91 to 0.96) to 51% (HR for sudden cardiac mortality 36=0.49; 95% CI 0.33 to 0.73) reduction in the risk of premature mortality. The certainty of the evidence ranged from very low-to-moderate, largely due to serious indirectness from a large proportion of male-only studies. Sex differences were similar between outcomes with larger CIs for females because of smaller samples (see online supplemental figure 1).

**Figure 3** describes results for CRF as a predictor of newly diagnosed chronic conditions, including: hypertension, heart failure, stroke, atrial fibrillation, dementia, chronic kidney disease, depression and type 2 diabetes. Online supplemental figure 2 describes results for all cancer (male only), lung cancer (male only), colon/rectum cancer (male only) and prostate cancer. When comparing high versus low CRF, there was a 37% (HR for incident hypertension 27=0.63; 95% CI 0.56 to 0.70) to 69% (HR for incident heart failure 38=0.31; 95% CI 0.19 to 0.49) reduction in the risk of incident conditions. The certainty of this evidence was rated as very low-to-low.
largely due to inconsistency and indirectness (ie, high heterogeneity that could not be described by subgroup analysis and largely male populations). The dose–response relationship per 1-MET higher level of CRF was associated with a 3% (HR for incident stroke \(=0.97; 95\% \text{ CI} 0.96 \text{ to } 0.98\)) to 18% (HR for incident heart failure \(=0.82; 95\% \text{ CI} 0.79 \text{ to } 0.84\)) reduction in the risk of incident conditions. The certainty of the evidence ranged from very low- to low due to inconsistency and indirectness. Only two studies reported results for females separately. High versus low CRF was more protective for incident stroke and type 2 diabetes among females compared with males (online supplemental figure 2). Among men, there was a null association between high versus low CRF for prostate cancer (HR=1.15; 95% CI 1.00 to 1.30).40

**Figure 3** HRs for each incident outcome in apparently healthy populations at baseline for high versus low CRF and per 1-MET increase in CRF. Note: Estimates from Cheng (2022), Aune (2021), Wang (2020), Xue (2020), Tarp (2019) and Kunutsor (2023) were reported as RR, the remaining studies were reported as HR. Kandola (2019) reported estimates for low versus high which were inverted for this study. The estimates from Tarp (2019) are fully adjusted for adiposity. Aune (2021) was reported per 5-MET increase which we converted to 1-MET increase for this study, CRF, cardiorespiratory fitness; CVD, cardiovascular disease; GRADE, Grading of Recommendations, Assessment, Development and Evaluations; MET, metabolic equivalent of task; NA, not applicable; NR, not reported; RR, relative risk.

**DISCUSSION**

This overview of systematic reviews demonstrated that CRF is a strong and consistent predictor of risk across many mortality outcomes in the adult general population. Among populations living with chronic conditions such as cancer, heart failure and CVD, this study showed better prognosis for those with higher CRF. We also demonstrated that low CRF is an important risk factor for developing future chronic conditions such as hypertension, heart failure, stroke, atrial fibrillation, dementia and depression. Given that we summarised evidence from cohort studies, and randomised controlled trials cannot be used in our investigation, the results of this study may signal a causal relationship between CRF and future health outcomes. We also found a significant dose–response effect showing protection for every 1-MET higher level of CRF. This evidence further supports 1-MET as an MCID for CRF and could be considered as a target for interventions. The strength and consistency of the evidence across a wide range of outcomes supports the importance of CRF for clinical assessment and public health surveillance.

Several studies have identified the need for the routine measurement of CRF in clinical and public health practice.11 43 For instance, a scientific statement from the American Heart Association concluded that healthcare providers should assess CRF during annual routine clinical visits using submaximal tests (eg, treadmill, cycling or bench stepping tests) or self-report estimates and that patients living with chronic conditions should have CRF measured regularly using a symptom-limited direct measure.11 There are several benefits to regular measurement of CRF in clinical practice. First, CRF is an important risk factor...
that provides additional information beyond traditional risk factors such as blood pressure, total cholesterol and smoking status. Second, given the strong link with habitual physical activity, CRF could be a valuable tool to help guide exercise prescription. In those with low CRF (defined based on age, sex and health status), large relative improvements can be attained through additional moderate physical activity (ie, brisk walking at a heart rate of 50% of peak VO2). The largest health benefits have been observed when individuals move from being unfit to fit. Lastly, CRF measured using field-based tests are easy to implement with a variety of tests that could be adapted to suit space and time limitations.

**Areas of future work**

Applying the GRADE approach to evaluate the certainty of the evidence helped identify several important gaps in the literature. Nearly all the outcomes identified in this study were downgraded due to the evidence being generated largely from samples comprising males. Although an increase in female samples would help improve the certainty of the evidence, it likely would not impact the magnitude of the observed effects because the benefits of CRF were similar for males and females in our study (see online supplemental figures 1,2) and other large cohort studies. There is also a need for higher-quality studies with larger samples sizes in clinical populations, as many of the outcomes were downgraded due to primary studies with high risk of bias, low sample sizes (<4000 participants), and inconsistencies in the measurement of CRF across studies. Improving the evidence for CRF in clinical populations remains an important research gap. For example, outcomes in clinical populations with a serious or very serious risk of bias were often rated this way due to a lack of adequate control for confounding, including a lack of adjustment for age, sex, and body mass.

In addition to the need for higher-quality studies with greater samples in more diverse populations including females, we did not identify any systematic reviews that explored the association between CRF and breast cancer or mental health outcomes beyond incident depression and dementia, as an example. These outcomes present important areas for future work. Finally, future studies would benefit from repeated longitudinal measures of CRF to further establish causality.

**Implications for clinical practice**

This study further demonstrates the importance of including CRF measurement in regular clinical practice. For every 1-MET (3.5 mL/kg/min) higher level of CRF, we identified substantial reductions in the risk of all-cause, CVD and cancer mortality. We also identified significant reductions in the risk of incident hypertension, heart failure, stroke, atrial fibrillation and type 2 diabetes per higher MET. For most, a 1-MET higher level of CRF is attainable through a regular aerobic exercise programme. For example, in a large population-based observational study of over 90 000 participants, nearly 30% were able to increase their CRF by 1-MET (median follow-up was 6.3 years) without intervention. However, for some, improvements as small as 0.5-METs may substantially benefit health.

Given the strength of the predictive utility of CRF across many health outcomes, CRF would be a valuable risk stratification tool in clinical practice. Furthermore, the predictive strength of CRF is maintained regardless of age, sex and race. Through regular CRF measurement, clinicians could better identify patients at greater risk of premature mortality, initiating the need for targeted exercise prescription. Improvements in CRF through regular physical activity results in a proportional reduction in mortality risk, regardless of the presence of other major risk factors such as higher body mass index, hypertension, type
2 diabetes, dyslipidaemia, or smoking. There is an important need for clinical and public health guidelines around the assessment, interpretation of results and MCID of CRF across age, sex and clinical populations.

**Strengths and limitations**

Our paper has several strengths, including a focus on pooled meta-analyses from cohort studies, assessment of the certainty of the evidence using a modified GRADE, and an evaluation of the systematic review quality using AMSTAR2. Our study identifies gaps where new evidence is needed across a broad range of health outcomes. However, this study is not without limitations. As in any overview, the quality of the data is restricted to the included papers. In our case, heterogeneity was high for many of the included meta-analyses and was often not explained by subgroup analyses. We also identified low-to-very low certainty of the evidence for most outcomes, suggesting the need for higher-quality studies in this research area including adequate adjustment for confounding and greater representation of females. The evidence was also limited to studies examining associations between a single measure of CRF and prospective health outcomes.

**CONCLUSION**

Our findings showed that high CRF is strongly associated with lower risk of premature mortality, incident chronic conditions (ie, hypertension, heart failure, stroke, atrial fibrillation, dementia and depression), and poor prognosis in those with existing chronic conditions. The consistency of the evidence across a variety of health outcomes demonstrates the importance of CRF and the need to incorporate this measure in routine clinical and public health practice. Future studies should focus on outcomes with limited evidence and where the certainty of the evidence was rated as very low by improving study quality.

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**Contributors**

JJL, GRT and SAP conceptualised and planned the study design. JJL and SAP led the study. JJL accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish. All coauthors contributed to article screening. JJL and SAP wrote the first draft of the article. All coauthors reviewed, revised and approved the final manuscript.

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**Competing interests**

None declared.

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Data are available on reasonable request.

**Supplemental material**

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