

SCREENING FOR CARDIAC CONDITIONS ASSOCIATED WITH SUDDEN CARDIAC DEATH IN THE YOUNG

An evidence map to outline the volume and type of evidence related to screening for cardiac conditions associated with sudden cardiac death in the young for the UK National Screening Committee

Version: 3.0

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Date: March 2026

This report was commissioned by the National Institute for Health and Care Research (NIHR) Evidence Synthesis Programme. The views expressed are those of the author(s) and not necessarily those of the NIHR or the Department of Health and Social Care.

**The UK National Screening Committee secretariat is hosted by the
Department of Health and Social Care**

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About the UK National Screening Committee (UK NSC)

The UK National Screening Committee (UK NSC) advises ministers and the NHS in the 4 UK countries about all aspects of [population](#) and targeted screening and supports implementation of screening programmes.

Conditions are reviewed against [evidence review criteria](#) according to the UK NSC's [evidence review process](#).

Read a [complete list of UK NSC recommendations](#).

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Summary

This document discusses the findings of the evidence map on screening for cardiac conditions associated with sudden cardiac death (SCD) in the young.

Evidence maps are a way of scanning published literature to look at the volume and type of evidence in relation to a specific topic. They inform whether the evidence is sufficient to commission a more sustained analysis on the topic under consideration.

The findings of this evidence map are unlikely to alter the current recommendation on screening for cardiac conditions associated with SCD in the young, as no new evidence was identified that would change this conclusion.

A significant volume of evidence has been published on the incidence of SCD and on test performance of screening tests to identify conditions associated with SCD. However, the type of evidence and outcomes appear consistent with those reported in previous UK NSC reviews. Across studies of young people participating in sport, there was no clearly defined high-risk group, with substantial variation in age group, type of sport, and level (elite or non-elite).

In addition, there is an extremely low volume of evidence on the effectiveness of screening versus no screening for preventing SCD in young individuals, and the available evidence has been assessed as inconclusive and of very low quality. The lack of information on control groups in such studies meant that it was difficult to judge the relevance of the studies to a UK setting.

It may be of interest to the UK NSC to consider a review of test accuracy, as some additional approaches to screening have been reported in papers published since the previous review. It should be noted that positive predictive value is the only test accuracy outcome which is likely to be derived from the studies included in this evidence map. However, in keeping with the UK NSC's multi-criteria approach to the evaluation of candidate screening programmes, a review of test accuracy on its own would be unlikely to alter the current recommendation.

Therefore, a full update review is not recommended at this stage, and so this topic should be re-considered in 3 years' time.

Introduction and approach

Background and objectives

The UK NSC external reviews (also known as evidence summaries or evidence reviews) are developed in keeping with the UK NSC evidence review process to ensure that each topic is addressed in the most appropriate and proportionate manner. Further information on the evidence review process can be accessed [online](#).

Screening for cardiac conditions associated with sudden cardiac death (SCD) in the young is a topic currently due for an update external review.

Furthermore, as part of the 2024 annual call for topics, a submission was made to screen for cardiac conditions in individuals aged 14 to 35 years old, with or without a family history of SCD, who engage in organised sport. An expert evaluation group, which included the UK NSC Chair, the Chairs of the Fetal, Maternal and Child Health Reference Group and Adult Reference Group, and the UK NSC Evidence Team, agreed that the population of athletes (competitive, non-competitive, elite) should also be considered in the evidence review.

SCD is sudden and unexpected death due to a problem with the heart. It is defined by the European Society of Cardiology (ESC) as “sudden natural death presumed to be of cardiac cause that occurs within 1 hour of onset of symptoms in witnessed cases, and within 24 hours of last being seen alive when it is unwitnessed; SCD in autopsied cases is defined as the natural unexpected death of unknown or cardiac cause (1).”

SCD can occur in the general population and young athletes, typically 34 years of age or younger. Sports and exercise-related SCD is SCD occurring during or within 1 hour of moderate- to high-intensity exercise. In young individuals and young athletes, SCD is often due to genetic disorders causing structural heart issues or abnormalities in the electrical activity of the heart, but can also be due to non-genetic disorders.

Previous review on screening for cardiac conditions associated with sudden cardiac death in the young

The UK NSC currently recommends against screening for cardiac conditions associated with SCD in people under the age of 39 years (<https://view-health-screening-recommendations.service.gov.uk/sudden-cardiac-death/>). The Committee based this recommendation on the evidence provided by the 2019 review carried out by the University of Warwick (2).

Within the 2019 review for the UK NSC (2), searches were conducted in December 2018. This review identified evidence on incidence of SCD and sudden cardiac arrest (SCA), but noted that there was uncertainty in estimates of incidence. This review also identified studies assessing test accuracy of screening for conditions that may cause SCD; however, only data from athletic populations (rather than young general populations) were identified, and the majority of studies lacked follow-up for individuals who screened negative, thereby preventing the calculation of key test accuracy outcomes. No studies were identified which compared clinical outcomes for individuals with a screen-detected cardiac abnormality versus non-screened individuals.

Aims of the evidence map

Evidence maps are rapid evidence products which aim to gauge the volume and type of evidence relating to a specific topic.

This evidence map has been developed to assess whether a more sustained review on screening for cardiac conditions associated with SCD should be commissioned in 2025 and to evaluate the volume and type of evidence on key issues related to screening for cardiac conditions associated with SCD.

The aim was to address the following questions:

1. **Question 1:** What is the volume and type of evidence on the reported incidence of SCD in young individuals aged 12 to 39 years old?
2. **Question 2:** What is the volume and type of evidence on the accuracy of available screening tests to identify cardiac conditions associated with SCD in young individuals aged 12 to 39 years old?
3. **Question 3:** What is the volume and type of evidence on the effectiveness of screening and intervention to prevent SCD in young individuals aged 12 to 39 years old with a screen-detected cardiac abnormality compared to non-screened individuals?

The findings of this evidence map will provide the basis for discussion to support decision making on whether there is sufficient evidence to justify commissioning a more sustained review of the evidence on screening for cardiac conditions associated with SCD in 2025.

The aim of this document is to present the information necessary to inform UK NSC decision-making processes.

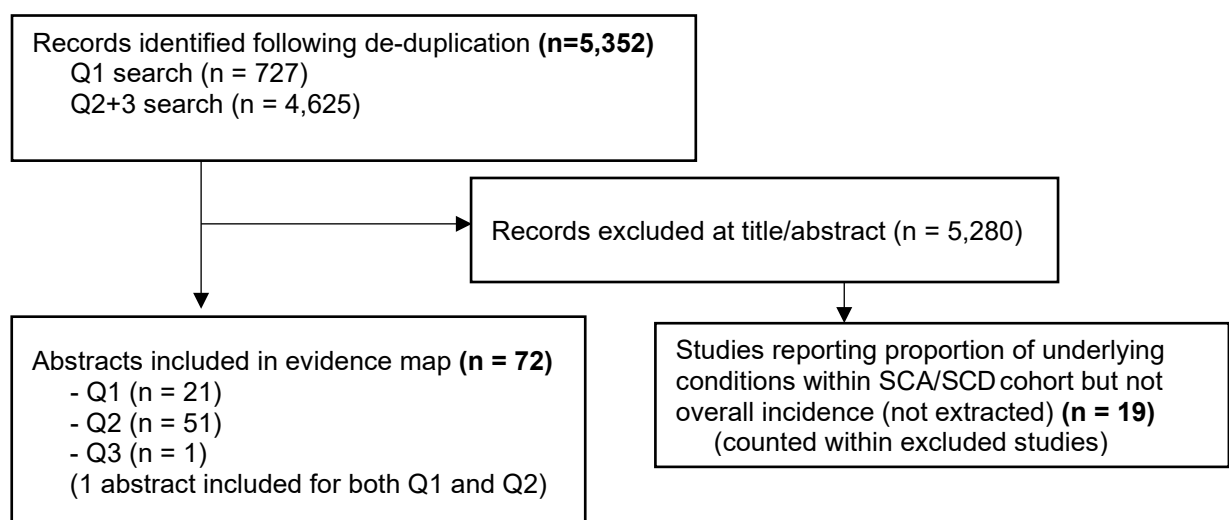
Search methods and results

The searches were conducted on 10th April 2025 on three databases: MEDLINE, EMBASE and the Cochrane Library. The search strategy for Question 1 combined the following search concepts: (sudden cardiac death or sudden cardiac arrest) AND (young people or athletes) AND incidence. The search strategy for Questions 2 and 3 combined the following search concepts: (sudden cardiac death or sudden cardiac arrest or cardiac conditions) AND (young people or athletes) AND screening, with a final “safety net” search string to identify any studies of cardiovascular screening in this population not already retrieved. Results of both searches were limited to English language and the year 2018 onwards. The detailed search strategies and inclusion/exclusion criteria are available in Appendix 1.

The first 100 titles and abstracts for each search (Q1 search and Q2+3 search) were screened by all three reviewers, then checked for consistency of inclusion decisions. The remaining titles and abstracts were each screened by a single reviewer. All included references were checked for inclusion by a second reviewer. For systematic reviews, full texts were obtained and extracted. For primary studies, full texts were only obtained and consulted where insufficient information was available from the abstract to assess eligibility. Due to volume of studies, full texts of included primary studies were not routinely checked for additional data. A formal quality appraisal of the evidence was not required, given the remit of the evidence map. Data were extracted by one reviewer and numerical data checked by a second reviewer. Summary tables of study characteristics and results are available in Appendix 2.

Following de-duplication, the search for Q1 returned 727 results and the search for Q2 returned 4,625 results (total 5,352 results). After automatic and manual de-duplication, 21 references were included for Q1 (3-23); 51 references were included for Q2 (12, 24-73); and 1 reference was included for Q3 (74). A flow diagram summarising the number of studies included and excluded is presented in Figure 1.

Figure 1: PRISMA flow diagram of study selection



Summary of findings

Question 1: What is the volume and type of evidence on the reported incidence of SCD in young individuals aged 12 to 39 years old?

Incidence of SCD

For Q1, 21 references were included: 4 systematic reviews (3-6) and 17 cohort studies (7-23). Summary tables are provided in Appendix 2; Table 2 summarises systematic reviews of SCA/SCD incidence, Table 3 presents study characteristics of cohort studies of SCA/SCD incidence, and Table 4 summarises results from cohort studies of SCA/SCD incidence.

Across four systematic reviews, three in athletes or military (4-6) and one in general populations, athletes or military (3), most estimates of SCD incidence were between 1 and 2 per 100,000 person-years (Table 2). One systematic review (Couper et al., 2020) (3) in people aged 12 to 39 years, including general populations, athletes and military, reported an SCD incidence of between 1 and 2 per 100,000 person-years in most studies, with a median of 1.7 across 26 studies, an interquartile range of 1.3 to 2.6 and a range of 0.8 to 11.9. A systematic review and meta-analysis in young athletes and military (Lear et al., 2022) (4) reported SCD incidence of 1.0 in all athletes and 1.9 in competitive athletes (meta-analyses of 5 and 3 low risk-of-bias studies, respectively). A systematic review and meta-analysis of 16 studies in competitive athletes (Li et al., 2025) (5) reported an SCA/SCD incidence of 1.5 per 100,000 person-years in males and 0.3 in females. Finally a further systematic review and meta-analysis of 15 studies in athletes (Quinn et al., 2022) (6) reported an SCD incidence of 0.9 per 100,000 person-years.

The included systematic reviews had search dates of 2019, 2019, 2021 and 2023. Their findings are broadly consistent with the findings of the UK NSC 2019 review, which reported an SCD incidence in most studies of between 1 and 2 per 100,000 person-years (2).

Primary studies in young general populations (Table 3 and Table 4) reported SCD incidence between 1 and 2 per 100,000 person-years in some studies (9, 13), and between 2 and 3 in others (14, 15, 19, 21, 22), with one being higher (6.2 per 100,000 person-years) (20). In primary studies in athletes or military, four studies reported on SCD or SCA/SCD incidence (per 100,000 person-years) with estimates ranging from 0.4 to 1.6 (12, 16-18).

Incidence of SCA

One systematic review and meta-analysis (4) reported SCA incidence within two low risk-of-bias studies as 0.9 and 1.6 per 100,000 person-years. Within two primary studies, SCA incidence was reported as 6.9 per 100,000 person-years in children and young adults (20) and 10.8 per 100,000 person-years in military personnel (11). The UK NSC 2019 review (2) only cited two studies reporting SCA, with an incidence of 2.97 (general population) and 1.49 (athletes).

Incidence of SCD by age

One systematic review (3) reported that SCD incidence was higher in older people, based on an analysis of 11 studies. Only two primary studies reported SCD or SCA/SCD incidence by age, both also suggesting an increase with age (11, 12). This is consistent with the UK NSC 2019 review (2) which also reported an increase in SCD incidence with age within the 12 to 39 age range.

Incidence of SCD by sex

Two systematic reviews reported that SCD incidence (per 100,000 person-years) was higher in males, one reporting median SCD incidence of 2.7 in males vs. 0.9 in females (3), and the other reporting pooled SCA/SCD incidence of 1.5 in males vs. 0.3 in females (5). Several primary studies also reported higher incidence in males (10, 12, 14, 17-19, 21-23). This is consistent with the UK NSC 2019 review (2) which also reported higher SCD incidence in males.

Incidence of SCD by general population or athletic status

One systematic review reported no clear difference in SCD incidence between athletic and non-athletic populations (3). Only one primary study reported data on this, indicating no clear difference in SCA/SCD incidence between athletes and non-athletes (12). The UK NSC 2019 review (2) also reported that the relationship to athletic status was unclear.

Incidence of SCD by ethnicity

There were limited data by ethnicity; one systematic review (3) reported higher SCD incidence in African-Americans based on 1 US study, while another primary US study reported higher SCD incidence in Black vs. White college athletes (17). The UK NSC 2019 review (2) also reported limited data on the effect of race.

Incidence of SCD by underlying condition

One systematic review (5) reported the most common SCA/SCD-associated conditions in competitive athletes as follows (note that these data were for all age groups, not only those ≤ 39 years). In males the most common causes were: hypertrophic cardiomyopathy (HCM, 45%), congenital coronary anomaly (CCA, 16%), and coronary artery disease (CAD, 10%). In females the most common causes were: CCA (33%), HCM (14%), and arrhythmogenic right ventricular cardiomyopathy (ARVC, 12%).

Additional studies of underlying conditions within SCA/SCD cohort

A number of additional studies were identified which report proportions of underlying conditions within an SCA/SCD cohort, but do not report overall incidence of SCA/SCD due to each condition in general population (that is, no data in the format of cases per 100,000 person-years). These studies are not formally included in this evidence map but are referenced here.(75-93)

Conclusion for Q1

A significant volume of evidence has been published on the incidence of SCD. However, the type of evidence and estimates of SCD incidence appear consistent with those reported in the UK NSC 2019 review (2). The new evidence is unlikely to lead to a change in the UK NSC's current understanding.

Question 2: What is the volume and type of evidence on the accuracy of available screening tests to identify cardiac conditions associated with SCD in young individuals aged 12 to 39 years old?

Accuracy of screening tests: Characteristics of reviews and studies

For Q2, 51 references were included: 4 systematic reviews (24-27) and 47 cohort studies (12, 28-73). Summary tables are provided in Appendix 2; Table 5 summarises systematic reviews of screening for conditions associated with SCD, Table 6 presents study characteristics for cohort studies of screening accuracy, and Table 7 summarises test accuracy results from cohort studies of screening.

Three systematic reviews were in athletes (25-27) and one in athletes and general population (24) (Table 5). One systematic review (Panhuyzen-Goedkoop et al., 2023 (27), with a search date of 2021, assessed the quality of evidence on athlete screening for SCD-associated conditions, and included 33 studies using a range of screening methods: history and physical exam (H+PE) in 8 studies, H-PE plus electrocardiogram (ECG) in 18 studies, and H+PE plus ECG and transthoracic echocardiography (TTE) in 7 studies. Another systematic review and meta-analysis (Goff et al., 2023) (26), with a search date of 2020, reported on 9 studies of screening with and without ECG in young athletes. A systematic review (Cantinotti et al., 2021 (24), search date 2020) analysed 9 studies of echocardiography screening for anomalous aortic origin of coronary arteries (AAOCA) in athletes, while another systematic review (Cassels et al., 2019 (25), search date 2017) analysed 5 studies of point-of-care ultrasound screening in athletes.

The systematic review by Panhuyzen-Goedkoop et al. focussed on quality of evidence for screening (27), and concluded that the quality of evidence was very low due to lack of randomised controlled trials (RCTs) of screening; lack of long-term follow-up on cardiac diagnoses or SCD occurrence in screened people; lack of follow-up of screen-negatives meaning sensitivity, specificity and negative predictive value (NPV) cannot be reliably calculated; absence of data blinding; and heterogeneity in populations and screening methods.

Among the 47 primary cohort studies of screening (Table 6 and Table 7), there were 5 studies in general populations and 42 studies in athletes. The 5 studies in general populations were in children, adolescents or young adults and were conducted in the UK (41), Spain (47, 70), Malta (28) and the USA (31). Most used H+PE plus ECG, while one also used echocardiography and ultrasound (31). The 42 studies in athletes were conducted in: the UK (59, 66), England + Wales (58), Italy (12, 35, 43, 57, 61, 63, 64, 67-69, 73), Switzerland (29, 32, 49, 50), Spain (44, 53, 54), Germany (42, 46), France (36), Norway (33), Greece (55), New Zealand (62) and USA (30, 34, 37-40, 45, 48, 51, 52, 56, 60, 65, 71, 72). Most used H+PE or H+PE plus ECG, while some used echocardiography, and a small number used other methods such as ultrasound.

There was substantial variation in the included populations across the 42 studies in athletes. The 3 UK studies included: adolescent soccer (n=1), adolescent and young adult soccer (n=1) and elite cricket (n=1). The 23 European studies included: high school athletes (n=12), high school elite athletes (n=3), young adult elite athletes (n=4), or elite athletes of mixed or unclear age (n=4). The 15 US studies included: high school or “youth” athletes (n=8), college athletes (n=5) and elite athletes (n=2), while 1 study in New Zealand included young adult elite athletes.

Outcomes reported

Most studies and reviews reported the proportion with abnormal screening results (and/or proportion referred for further testing) and the proportion of these diagnosed with SCD-associated cardiac conditions.

Proportion with abnormal primary screening test results

One systematic review (27) reported that primary screening abnormalities were identified in 14% of subjects overall (22% with H+PE, 20% with addition of ECG, and 7% with addition of ECG and TTE), while another systematic review (26) reported screening abnormalities in 10% with H+PE and 4% with ECG. A third systematic review (25) reported screening abnormalities in 20% with standard pre-participation screening, 18% with H+PE, 5% with addition of ECG, 1.4% with addition of ultrasound, and 5% with addition of ECG and ultrasound.

Within primary studies, the proportion with abnormal screening results varied widely between studies, within studies depending on the screening method, and also within screening methods depending on, for example, criteria for ECG interpretation.

Proportion diagnosed with SCD-associated cardiac conditions

Among systematic reviews, the proportion diagnosed with high-risk or SCD-associated cardiac conditions was reported as 0.4% in two systematic reviews (26, 27) and as 0.5% in another systematic review (25).

Among primary studies, two studies in general populations reported the proportion diagnosed with SCD-associated cardiac conditions, both reporting this as 0.3% (28, 41). In studies of athletes reporting this information, the proportion diagnosed with SCD-linked cardiac conditions varied from 0% to 1.5% with the majority of studies reporting estimates between 0.1% and 0.4% (12, 29, 30, 32-34, 37, 39, 40, 44, 48-51, 53-60, 63, 64, 67-69, 72, 73).

PPV and other diagnostic measures

All studies implied that only those with abnormal screen results had follow-up testing; that is, screen-negatives were not generally followed up. Therefore, in general, the only diagnostic outcome that could be calculated was positive predictive value (PPV: positive diagnoses / all screen-positives). This was not always reported directly in abstracts so often had to be calculated. Since PPV depends on the number of screen-positives, PPV varied by screening method and by method of interpretation of screening result.

One systematic review (27) reported a PPV of 3% overall (1% for H+PE, 4% with addition of ECG, and 4% with addition of ECG+TTE). Another systematic review (26) reported a PPV of 4% for H+PE and 9% for ECG, while a third systematic review (25) reported PPV of 1% for H+PE, 9% with addition of ECG, and 13% with addition of ECG + ultrasound. A fourth review (24) specifically assessed echocardiography screening for AAOCA and reported a PPV of 88% to 100% (though it was unclear how this was calculated).

Among primary studies, PPV varied widely, with most studies reporting a PPV (or data to calculate a PPV) of between 2% and 14% (28, 29, 32, 40, 41, 44, 47, 52, 54, 56-60, 67, 72, 73).

Few reviews and studies reported sensitivity and specificity due to the absence of follow-up of screen-negative cases. The systematic review of point-of-care ultrasound (25) reported sensitivity and specificity, though it was unclear how these were calculated since the review noted that follow-up testing was not performed on all screened athletes. A small number of primary studies reported sensitivity and/or specificity but again it was unclear how these were calculated (47, 50, 59, 72).

Comparison to evidence in the UK NSC 2019 review

The UK NSC 2019 review (2) reported screening data from 1 systematic review of 15 studies in athletes (Harmon et al., 2015 (94)) and 17 cohort studies (16 of which were in athletes). The screening strategies within studies in the UK NSC 2019 review included combinations of history, physical examination and ECG (with various interpretation criteria).

Screening strategies and reported outcomes identified in the current evidence map were broadly similar to those within the UK NSC 2019 review. The present evidence map identified a little more evidence in general populations as outlined above, as well as studies of additional screening methods such as echocardiography and ultrasound. In terms of study design, the studies in this evidence map appeared similar to those in the UK NSC 2019 review in terms of lack of follow-up of screen-test negative individuals. Therefore, only PPV could be reliably reported. Across the 44 PPVs calculated in the UK NSC 2019 review, most were under 10% (while three were over 10%), which is broadly consistent with PPV results in the present evidence map. The UK NSC 2019 review does acknowledge that detailed follow-up of screen-negative individuals would be challenging due to the range of tests required to exclude all conditions that may cause SCD.

Conclusion for Q2

A significant volume of evidence has been published on test performance of screening tests to identify conditions associated with SCD. The type of evidence appears broadly consistent with that in the UK NSC 2019 review, with some additional evidence on general populations and on additional screening methods such as echocardiography and ultrasound. Studies in athletes covered a range of different populations, including high school athletes, college athletes, young adult athletes, mixed ages, specific sports, or elite athletes. As in the UK NSC 2019 review, PPV was generally the only test accuracy outcome that could be derived from the studies, and PPV estimates were broadly similar to those reported in the UK NSC 2019 review. An up-to-date review of test accuracy may inform further discussions of cardiac screening with stakeholders. However, a review of test accuracy on its own would be unlikely to lead to a change in the UK NSC's current position.

Question 3: What is the volume and type of evidence on the effectiveness of screening and intervention to prevent SCD in young individuals aged 12 to 39 years old with a screen-detected cardiac abnormality compared to non-screened individuals?

Effectiveness of screening and intervention

For Q3, one reference was included: a systematic review and meta-analysis (74). A summary table is provided in Appendix 2 (Table 8).

The systematic review and meta-analysis (Lear et al., 2022 (74), search date 2019) included studies of screening with ECG versus no screening that included ECG. The review included four non-randomised studies assessed as high risk of bias: 3 in athletes and 1 in military. The review notes that it was unclear in the primary studies whether the control groups in the studies had no screening, or screening without ECG; this made it difficult to judge the relevance of the studies to a UK setting. The review pooled two studies of athletes (the other two studies either did not have extractable data or had overlapping population with a pooled study), giving a relative risk of SCD following ECG screening vs. no ECG screening of 0.58 (95% confidence interval [CI] 0.23 to 1.45), and an absolute risk reduction of 0.0016%. The review concluded that existing evidence for the effect of ECG screening is inconclusive and of very low quality.

The UK NSC 2019 review (2) did not identify any studies relevant to Q3.

Conclusion for Q3

There is an extremely low volume of evidence on the effectiveness of screening versus no screening for preventing SCD in young individuals, and this evidence has been reviewed and assessed as inconclusive and of very low quality. The lack of information on control groups in such studies meant that it was difficult to judge the relevance of the studies to a UK setting. Further evidence synthesis work on this question is unlikely to further the Committee's understanding of the effectiveness of screening for preventing SCD in young individuals.

Conclusions

Question 1: Incidence of SCD in young individuals

For incidence of SCD, 4 systematic reviews and 17 cohort studies were included. The systematic reviews reported incidence of SCD between 1 and 2 per 100,000 person-years in most included studies, while the cohort studies mainly reported incidence between 1 and 3 per 100,000 person-years. SCD incidence was higher in older people and in males, while there was no clear evidence regarding difference in SCD incidence by ethnicity or between athletic and non-athletic populations.

Question 2: Accuracy of screening tests for conditions associated with SCD

For accuracy of screening tests, 4 systematic reviews and 47 cohort studies were included. Three systematic reviews focussed on athletes and one included both athletes and general populations, while 42 cohort studies were in athletes and 5 in general populations. Studies in athletes covered a range of different populations, including high school athletes, college athletes, young adult athletes, mixed ages, specific sports, or elite athletes. Screening methods included history and physical examination, often with addition of ECG, while several studies added echocardiography to screening, and some assessed additional methods such as ultrasound. Most studies reported the proportion with abnormal screening results (which varied between studies and by screening method) and the proportion diagnosed with SCD-associated conditions, allowing calculation of PPV which mainly ranged from 2% to 14%. However, lack of follow-up of screen-negative cases meant that sensitivity, specificity and NPV could not be reliably calculated. One systematic review concluded that the quality of evidence for screening was very low due to lack of RCTs; lack of long-term follow-up; lack of follow-up of screen-negatives, and heterogeneity in populations and screening methods.

Question 3: Effectiveness of screening and intervention

For effectiveness of screening and intervention in screened vs. non-screened individuals, 1 systematic review and meta-analysis was included. The systematic review included four non-randomised studies of ECG screening (it was unclear whether control groups received no screening, or screening without ECG). Pooled data from two included studies gave a relative risk of SCD following ECG screening vs. no ECG screening of 0.58 (95% CI 0.23 to 1.45), and an absolute risk reduction of 0.0016%. The review concluded that evidence for the effect of ECG screening is inconclusive and of very low quality.

Overall conclusions

A significant volume of evidence has been published on the incidence of SCD and on test performance of screening tests to identify conditions associated with SCD. However, the type of evidence and outcomes appear consistent with those reported in previous UK NSC reviews.

In addition, there is an extremely low volume of evidence on the effectiveness of screening vs. no screening for preventing SCD in young individuals, and the available evidence has been assessed as inconclusive and of very low quality. The lack of information on control groups in such studies meant that it was difficult to judge the relevance of the studies to a UK setting.

Overall, further evidence synthesis work is unlikely to lead to a change in the UK NSC's current understanding of this topic.

Recommendations

Recommendations are developed in collaboration between SENSS, the Evidence Team (UK NSC Secretariat) and the UK NSC Adult Reference Group (ARG).

The findings of this evidence map are unlikely to alter the current recommendation on screening for cardiac conditions associated with SCD in the young, as no new evidence was identified that would change this conclusion.

A significant volume of evidence has been published on the incidence of SCD and on test performance of screening tests to identify conditions associated with SCD. However, the type of evidence and outcomes appear consistent with those reported in previous UK NSC reviews. Across studies of young people participating in sport, there was no clearly defined high-risk group, with substantial variation in age group, type of sport, and level (elite or non-elite).

In addition, there is an extremely low volume of evidence on the effectiveness of screening vs. no screening for preventing SCD in young individuals, and the available evidence has been assessed as inconclusive and of very low quality. The lack of information on control groups in such studies meant that it was difficult to judge the relevance of the studies to a UK setting.

It may be of interest to the UK NSC to consider a review of test accuracy, as some additional approaches to screening have been reported in papers published since the previous review. In an evidence map, it is difficult to know whether these are associated with a significant improvement in PPV. It should be noted that PPV is the only test accuracy outcome which is likely to be derived from the studies included in this evidence map. An up-to-date review of test accuracy may inform further discussions of cardiac screening with stakeholders.

However, in keeping with the UK NSC's multi-criteria approach to the evaluation of candidate screening programmes, a review of test accuracy on its own would be unlikely to alter the current recommendation. Therefore, a full update review is not recommended at this stage, and so this topic should be re-considered in 3 years' time.

Appendix 1 – Search strategy for the evidence map

Databases and platforms searched

Three databases were searched: MEDLINE, EMBASE and the Cochrane Library.

Search dates

The searches were conducted on 10th April 2025.

Search strategies

Question 1 search strategy

The search strategy for Question 1 combined the following search concepts: (sudden cardiac death or sudden cardiac arrest) AND (young people or athletes) AND incidence. Results were limited to English language and the year 2018 onwards. The search strategies are presented below.

OID MEDLINE

- 1 Death, Sudden, Cardiac/ - 18969
- 2 (sudden cardiac death* or sudden cardiac arrest*).mp. - 24594
- 3 1 or 2 - 33658
- 4 (young* or youth* or child* or adolescen* or teen* or student* or school or college).mp. or universit*.ti,ab. - 5888687
- 5 (athlet* or sport* or runn* or marathon* or rugby or football* or soccer or cyclist* or gymnast* or tennis or basketball or swimmer* or rowing or rower* or baseball or hockey or dancer*).mp. - 311950
- 6 4 or 5 - 6084223
- 7 incidence.mp. - 1129369
- 8 incidence/ - 319234
- 9 7 or 8 1129369
- 10 3 and 6 and 9 - 1405
- 11 limit 10 to (english language and yr="2018 -Current") - **446**

Embase

1. sudden cardiac death/ or sudden arrhythmic death syndrome/ - 28577
2. (sudden cardiac death* or sudden cardiac arrest*).mp. - 50240
3. 1 or 2 - 50335
4. (young* or youth* or child* or adolescen* or teen* or student* or school or college).mp. or universit*.ti,ab. - 6841825

5. (athlet* or sport* or runn* or marathon* or rugby or football* or soccer or cyclist* or gymnast* or tennis or basketball or swimmer* or rowing or rower* or baseball or hockey or dancer*).mp. - 390371
6. 4 or 5 - 7091526
7. incidence.mp. - 1674334
8. exp incidence/ - 775522
9. 7 or 8 - 1682805
10. 3 and 6 and 9 - 2113
11. limit 10 to (english language and yr="2018 -Current") - 913
12. limit 11 to conference abstract status - 347
13. 11 not 12 - **566**

Cochrane Library

1. MeSH descriptor: [Death, Sudden, Cardiac] explode all trees - 933
2. (sudden cardiac death* or sudden cardiac arrest*):ti,ab,kw - 2665
3. #1 or #2 - 2665
4. (young* or youth* or child* or adolescen* or teen* or student* or school or college):ti,ab,kw - 474065
5. (universit*):ab OR (universit*):ti - 73252
6. (athlet* or sport* or runn* or marathon* or rugby or football* or soccer or cyclist* or gymnast* or tennis or basketball or swimmer* or rowing or rower* or baseball or hockey or dancer*):ti,ab,kw - 37299
7. #4 or #5 or #6 - 541559
8. MeSH descriptor: [Incidence] explode all trees - 14064
9. (incidence):ti,ab,kw - 161475
10. #8 or #9 - 161475
11. #3 and #7 and #10 with Cochrane Library publication date Between Jan 2018 and May 2025 - **32**

Questions 2 and 3 search strategy

The search strategy for Questions 2 and 3 combined the following search concepts: (sudden cardiac death or sudden cardiac arrest or cardiac conditions) AND (young people or athletes) AND screening, with a final “safety net” search string to identify any studies of cardiovascular screening in this population not already retrieved. Results were limited to English language and the year 2018 onwards. The search strategies are presented below.

OVID MEDLINE

1. Death, Sudden, Cardiac/ - 18969
2. (sudden cardiac death* or sudden cardiac arrest*).mp. - 24594

3. 1 or 2 - 33658
4. (hypertroph* or HCM or arrhythmogenic right ventricular* or ARVC or cardiomyopath* or channelopath* or QT syndrome or LQTS or SQTS or Brugada syndrome or catecholaminergic polymorphic ventricular tachycardia or CPVT or progressive cardiac conduction defect* or early repolarisation syndrome or sodium channel disease or Wolff-Parkinson-White or WPW syndrome or Marfan syndrome or myocarditis).mp. - 319534
5. arrhythmogenic right ventricular dysplasia/ or exp cardiomyopathy, hypertrophic/ or myocarditis/ or exp Cardiomyopathies/ or Channelopathies/ or *Heart Diseases/di - 127379
6. brugada syndrome/ or exp long qt syndrome/ - 13410
7. Wolff-Parkinson-White Syndrome/ - 5710
8. 4 or 5 or 6 or 7 - 346351
9. 3 or 8 - 367384
10. (young* or youth* or child* or adolescen* or teen* or student* or school or college).mp. or universit*.ti,ab. - 5888687
11. (athlet* or sport* or runn* or marathon* or rugby or football* or soccer or cyclist* or gymnast* or tennis or basketball or swimmer* or rowing or rower* or baseball or hockey or dancer*).mp. - 311950
12. 10 or 11 - 6084223
13. exp Mass Screening/ or screen*.mp. - 1203558
14. 9 and 12 and 13 - 4737
15. (screen* adj2 (cardiac or heart or cardiovascular)).mp. - 3864
16. 12 and 15 - 1401
17. 14 or 16 - 5567
18. limit 17 to (english language and yr="2018 -Current") - **1990**

Embase <1974 to 2025 Week 14>

1. sudden cardiac death/ or sudden arrhythmic death syndrome/ - 28577
2. (sudden cardiac death* or sudden cardiac arrest*).mp. - 50240
3. 1 or 2 - 50335
4. (hypertroph* or HCM or arrhythmogenic right ventricular* or ARVC or cardiomyopath* or channelopath* or QT syndrome or LQTS or SQTS or Brugada syndrome or catecholaminergic polymorphic ventricular tachycardia or CPVT or progressive cardiac conduction defect* or early repolarisation syndrome or sodium channel disease or Wolff-Parkinson-White or WPW syndrome or Marfan syndrome or myocarditis).mp. - 550658
5. arrhythmogenic right ventricular dysplasia/ or exp hypertrophic cardiomyopathy/ or apical hypertrophic cardiomyopathy/ or hypertrophic nonobstructive cardiomyopathy/ or hypertrophic obstructive cardiomyopathy/ or exp familial hypertrophic cardiomyopathy/ - 77868
6. brugada syndrome/ or exp long qt syndrome/ or exp congenital long qt syndrome/ or exp myocarditis/ - 67319

7. exp Wolff-Parkinson-White Syndrome/ - 7617
8. 4 or 5 or 6 or 7 - 578355
9. 3 or 8 - 606625
10. (young* or youth* or child* or adolescen* or teen* or student* or school or college).mp. or universit*.ti,ab. - 6841825
11. (athlet* or sport* or runn* or marathon* or rugby or football* or soccer or cyclist* or gymnast* or tennis or basketball or swimmer* or rowing or rower* or baseball or hockey or dancer*).mp. - 390371
12. 10 or 11 - 7091526
13. exp screening/ or screen*.ti,hw,kw. - 1020315
14. 9 and 12 and 13 - 9288
15. (screen* adj2 (cardiac or heart or cardiovascular)).ti,hw,kw. - 1947
16. 12 and 15 - 812
17. 14 or 16 - 9763
18. limit 17 to (english language and yr="2018 -Current") - 4705
19. limit 18 to conference abstracts - 1518
20. 18 not 19 - **3187**

Cochrane Library

1. MeSH descriptor: [Death, Sudden, Cardiac] explode all trees - 933
2. (sudden cardiac death* or sudden cardiac arrest*):ti,ab,kw - 2665
3. (hypertroph* or HCM or arrhythmogenic right ventricular* or ARVC or cardiomyopath* or channelopath* or QT syndrome or LQTS or SQTS or Brugada syndrome or catecholaminergic polymorphic ventricular tachycardia or CPVT or progressive cardiac conduction defect* or early repolarisation syndrome or sodium channel disease or Wolff-Parkinson-White or WPW syndrome or Marfan syndrome or myocarditis):ti,ab,kw - 17362
4. MeSH descriptor: [Arrhythmogenic Right Ventricular Dysplasia] explode all trees - 15
5. MeSH descriptor: [Cardiomyopathy, Hypertrophic] explode all trees - 338
6. MeSH descriptor: [Myocarditis] explode all trees - 142
7. MeSH descriptor: [Brugada Syndrome] explode all trees - 33
8. MeSH descriptor: [Long QT Syndrome] explode all trees - 440
9. MeSH descriptor: [Wolff-Parkinson-White Syndrome] explode all trees - 44
10. #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 - 19560
11. (young* or youth* or child* or adolescen* or teen* or student* or school or college):ti,ab,kw - 474065
12. (universit*):ab OR (universit*):ti - 73252
13. ((athlet* or sport* or runn* or marathon* or rugby or football* or soccer or cyclist* or gymnast* or tennis or basketball or swimmer* or rowing or rower* or baseball or hockey or dancer*)):ti,ab,kw - 37299
14. #11 or #12 or #13 - 541559
- 19

15. #10 and #14 - 4138
16. MeSH descriptor: [Mass Screening] explode all trees - 6020
17. (screen*):ti,ab,kw - 110519
18. #16 or #17 - 110936
19. #15 and #18 - 290
20. ((cardiac or heart or cardiovascular) near/2 screen*):ti,ab,kw - 461
21. #14 and #20 - 117
22. #19 or #21 with Cochrane Library publication date Dec 2018 to Apr 2025 - **251**

Numbers of results for each database and question if applicable

The number of results for each database and question were as follows:

- Q1 MEDLINE: 446
- Q1 EMBASE: 566
- Q1 Cochrane library: 32
- Q2+3 MEDLINE: 1990
- Q2+3 EMBASE: 3187
- Q2+3 Cochrane library: 251

Totals:

- Q1: 1044
- Q2+3: 5428

After exclusion of duplicates:

- Q1: 727
- Q2+3: 4,625

Inclusions and exclusions

Inclusion criteria for all three questions are provided in Table 1.

Table 1: Inclusion criteria for evidence map

Question	1. Incidence of SCD in young individuals	2. Accuracy of screening tests to identify cardiac conditions associated with SCD	3. Effectiveness of screening and intervention to prevent SCD
Population	<ul style="list-style-type: none"> Age 12-39 prioritised (include studies for age 1-39; exclude studies that include people aged <1 or >40 years)^a Asymptomatic prioritised UK prioritised; if little data then include data from comparable countries (Europe, US, Canada, Australia, New Zealand)^b <p>Exclude:</p> <ul style="list-style-type: none"> Study cohorts with a known cardiac or cardiac-related condition Cascade screening in family members of person with a target condition 	<ul style="list-style-type: none"> Age 12-39 prioritised (include studies for age 1-39; exclude studies that include people aged <1 or >40 years)^a Asymptomatic prioritised UK prioritised; if little data then include data from comparable countries (see left) <p>Exclude:</p> <ul style="list-style-type: none"> Study cohorts with a known cardiac or cardiac-related condition Cascade screening in family members of person with a target condition 	<ul style="list-style-type: none"> Age 12-39 prioritised (include studies for age 1-39; exclude studies that include people aged <1 or >40 years)^a Screen-detected cardiac abnormality UK prioritised; if little data then include data from comparable countries (see left) <p>Exclude:</p> <ul style="list-style-type: none"> Study cohorts with a known cardiac or cardiac-related condition Cascade screening in family members of person with a target condition
Stratification ^c	Where possible, stratify by: <ul style="list-style-type: none"> Age, Ethnicity, Sex General population i.e. non-athletes Athletes (competitive, non-competitive, elite) Underlying cause, if known (see target conditions under Q2) 	Where possible, stratify by: <ul style="list-style-type: none"> General population i.e. non-athletes Athletes (competitive, non-competitive, elite) 	Where possible, studies by: <ul style="list-style-type: none"> General population i.e. non-athletes Athletes (competitive, non-competitive, elite)
Intervention	-	-	<ul style="list-style-type: none"> Screening and subsequent management strategies (as in identified studies)
Comparator	-	<ul style="list-style-type: none"> None or different combinations of index tests 	<ul style="list-style-type: none"> Current standard of care (as in identified studies) i.e. no offer or receipt of screening Note: studies must compare screened and non-screened groups
Index tests	-	<ul style="list-style-type: none"> History-taking Physical exam 12-lead electrocardiogram (ECG) Mobile health devices (e.g. mobile phones, tablets, smart watches and other wearables) Genetic testing Combinations of the above Other available screening tests 	-

Question	1. Incidence of SCD in young individuals	2. Accuracy of screening tests to identify cardiac conditions associated with SCD	3. Effectiveness of screening and intervention to prevent SCD
Reference standard	-	Any recognised ref standard e.g: <ul style="list-style-type: none"> • Autopsy reports • Genotyping • Testing for pathogenic variations 	-
Outcomes	<p>Incidence of:</p> <ul style="list-style-type: none"> • Sudden cardiac death (SCD) • Sudden cardiac arrest (SCA) • Sudden cardiac arrest and/or death [for SCA, only include studies which sought to exclude cases unlikely to relate to SCD e.g. trauma and asphyxia] <p>Note: Studies of cases occurring in specific locations or at specific times of day, such as at school, during working hours, or whilst playing sport, will be highlighted as such.</p> <p>Exclude:</p> <ul style="list-style-type: none"> • Studies only reporting incidence of target conditions within an SCD/SCA cohort, rather than incidence in general population (these studies will be listed separately) 	<p>Test accuracy outcomes:</p> <ul style="list-style-type: none"> • Sensitivity • Specificity • Positive predictive value (PPV) • Negative predictive value (NPV) • Likelihood ratios • Area under the curve (AUC) 	<p>Clinical outcomes:</p> <ul style="list-style-type: none"> • Incidence of sudden cardiac arrest and/or death • Change in any relevant cardiac outcome e.g. arrhythmia symptoms • Effect on quality of life <p>Harms:</p> <ul style="list-style-type: none"> • Overtreatment • Anxiety • Disqualification from sports • Exercise avoidance
Target conditions	-	<p>Potentially lethal CVD conditions, such as:</p> <p>Cardiomyopathies:</p> <ul style="list-style-type: none"> • Hypertrophic cardiomyopathy (HCM) • Arrhythmogenic right ventricular cardiomyopathy (ARVC) / arrhythmogenic right ventricular dysplasia (ARVD) / arrhythmogenic cardiomyopathy (ACM) • Dilated cardiomyopathy (DCM) <p>Channelopathies:</p> <ul style="list-style-type: none"> • Long QT syndrome (LQTS) • Brugada syndrome • Catecholaminergic polymorphic ventricular tachycardia (CPVT) • Progressive cardiac conduction defect (PCCD) 	-

Question	1. Incidence of SCD in young individuals	2. Accuracy of screening tests to identify cardiac conditions associated with SCD	3. Effectiveness of screening and intervention to prevent SCD
		<ul style="list-style-type: none"> • Short QT syndrome (SQTS) • Early repolarisation syndrome (ERS) • Sodium channel disease • Familial atrial fibrillation <p>Other cardiac conditions:</p> <ul style="list-style-type: none"> • Wolff-Parkinson-White (WPW) syndrome • Marfan syndrome • Myocarditis • Coronary artery anomalies • Premature coronary artery disease and familial hypercholesterolemia <p>Exclude:</p> <ul style="list-style-type: none"> • SCD due to non-cardiac conditions such as COVID-19 • SCD following surgical procedures • Studies which only report the frequency of specific ECG abnormalities rather than target conditions (consistent with 2019 review) 	
Study designs	<ul style="list-style-type: none"> • Cohort studies • Systematic reviews of the above • (Other designs if none/few of the above) 	<ul style="list-style-type: none"> • RCTs • Cohort studies • Cross-sectional studies • Systematic reviews of the above • (Other designs if none/few of the above, e.g. case-control / two-gate studies) 	<ul style="list-style-type: none"> • RCTs • Quasi-experimental studies • Cohort studies • Systematic reviews of the above • (Other designs if none/few of the above)
Publication types ^d	<ul style="list-style-type: none"> • Full publications only (exclude conference abstracts) • Publications with results only (exclude protocols and trial registries) 	<ul style="list-style-type: none"> • Full publications only (exclude conference abstracts) • Publications with results only (exclude protocols and trial registries) 	<ul style="list-style-type: none"> • Full publications only (exclude conference abstracts) • Publications with results only (exclude protocols and trial registries)
Date limit	Since Dec 2018	Since Dec 2018	Since Dec 2018
Language	English language	English language	English language
^a The main age range of interest is age 12-39; however, in the 2019 UK NSC review, due to variability in age ranges across studies and because SCD incidence is broadly similar from age 1 to 19, studies including ages 1-39 were included while studies that include people aged <1 or >40 were excluded. The same criteria are used here.			

Question	1. Incidence of SCD in young individuals	2. Accuracy of screening tests to identify cardiac conditions associated with SCD	3. Effectiveness of screening and intervention to prevent SCD
<p>^bIncludes: European Economic Area (EEA, i.e. 27 EU countries plus Iceland, Liechtenstein, Norway and Switzerland); United States, Canada, Australia, New Zealand.</p> <p>^cStratification is not technically an inclusion criterion, but is included here for completeness.</p> <p>^dIn line with NIHR-NSC Evidence Map Process Document.</p> <p>RCT, randomised controlled trial; SCA, sudden cardiac arrest; SCD, sudden cardiac death.</p>			

Appendix 2 – Summary tables of studies

Question 1: Incidence of SCD in young individuals

The following tables summarise the abstracts of studies for Q1 (incidence of SCD in young individuals). Table 2 summarises systematic reviews of SCA/SCD incidence, Table 3 presents study characteristics of cohort studies of SCA/SCD incidence, and Table 4 summarises results from cohort studies of SCA/SCD incidence.

Table 2: Question 1: Systematic reviews of SCA/SCD incidence

Study Details	FT	Country	Population Outcome N studies	Age	SCA/SCD incidence (per 100,000 person-yrs)	Incidence of SCA/SCD by age	Incidence of SCA/SCD by sex	Incidence by Athletic status, Ethnicity, Condition	Conclusions
Couper, 2020 (3) SR of SCD incidence in the young Search 2019	Y	Mostly Europe + N America	Young gen pop + athletes (incl military) 38 studies (26 in analysis)	12-39y	SCD: 1.7 (median of 26 studies) IQR 1.3-2.6, range 0.8-11.9 Most studies: 1-2	SCD by age: Higher in older people (11 studies)	SCD by sex: Higher in males (13 studies) 2.7 (median in males, range 1.3-36) 0.9 (median in females, range 0-7.0)	SCD by athletic status: No clear difference between athletic and non-athletic SCD by ethnicity: Higher in African-Americans (1 US study)	This systematic review identified variability in the reported incidence of SCD in the young across studies. Most studies reported an incidence between one and two cases per 100 000 person-years.
Lear, 2022 (4) SR+MA of SCA/SCD incidence in young athletes + military + quality of evidence Search 2019	Y	Mostly Europe + USA	Young athletes + military 40 studies (5 and 3 studies in MA)	Age <40y	SCD: 1.0 (MA of 5 low RoB studies in all athletes) 1.9 (MA of 3 low RoB studies in competitive athletes) SCA: 0.9 and 1.6 (in two low RoB studies)	-	-	-	The worldwide incidence of SCD is rare. Low-RoB studies indicated the incidence was <2 per 100 000 athlete-years. Overall, the quality of the available evidence was low, but high-quality individual studies inform the question of incidence levels.
Li, 2025 (5) SR+MA of sex differences in SCA/SCD incidence in competitive athletes Search 2023	Y	Mostly Europe + USA	Competitive athletes 16 studies (11 in age ≤35 y)	Age ≤35y [extracted]	SCA/SCD: Reported by sex	-	SCA/SCD by sex: 1.5 (males) 0.3 (females)	SCA/SCD by condition: Males: HCM (45%), CCA (16%), CAD (10%). Females: CCA (33%), HCM (14%), ARVC (12%) [all ages]	The incidence of SCA/SCD in females was approximately 6 times lower than in males, with sex differences also in the leading causes of SCA/SCD.
Quinn, 2022 (6) SR+MA of sports-related SCD incidence due to myocarditis Search 2021	Y	Europe, USA, Canada	Athletes, sports-related SCD due to myocarditis 15 studies	-	SCD: 0.9 (MA of 15 studies) 1.0 (N America), 0.8 (Europe)	SCD by age: 0.5 (high school / college)	-	SCD by condition: 0.05 per 100,000 person-years (due to myocarditis)	No specific conclusion.

Abbreviations: ARVC, arrhythmogenic right ventricular cardiomyopathy; CAD, coronary artery disease; CCA, congenital coronary anomaly; FT, full-text checked; Gen pop, general population; HCM, hypertrophic cardiomyopathy; IQR, interquartile range; MA, meta-analysis; NR or -, not reported; RoB, risk of bias; SCA, sudden cardiac arrest; SCD, sudden cardiac death; SR, systematic review; y, year.

Table 3: Question 1: Study characteristics for cohort studies of SCA/SCD incidence

Study	FT	Title	Country Study type	Objectives	Population (N) Age Outcome	Conclusions
General population						
Carrington, 2023 (9)	N	Sudden death in young South European population: a cross-sectional study of postmortem cases	Portugal Retrospective study (autopsy database)	To describe the annual incidence and the leading causes of non-cardiac and cardiac SCD in children and young adult Portuguese population.	Children + young adults (N=NR) 1-40y, mean 32 SCD incidence	The annual incidence of SD was low. Atherosclerotic CAD was diagnosed in 33% victims, suggesting the need to intensify primary prevention measures in the young.
Ha, 2020 (13)	N	Sudden Cardiac Death in the Young: Incidence, Trends, and Risk Factors in a Nationwide Study	Australia Retrospective registry study	To determine incidence, trends, causes, and risk factors for SCD in the young.	Gen pop 1-35y, mean 28 SCD incidence	Incidence of SCD in the young and specifically CAD-related SCD has declined in recent years. Proportion of SCD related to SADS increased over the study period. Geographic remoteness and obesity are risk factors for specific causes of SCD in the young.
Hansen, 2025 (14)	N	Declining Trend of Sudden Cardiac Death in Younger Individuals: A 20-Year Nationwide Study	Denmark Retrospective registry study	To provide contemporary nationwide estimates of the temporal trends of SCD in young individuals (1–35 years of age) from 2000 through 2019 and correlate these trends to changes in OHCA patterns, rates of inherited cardiac diseases, and implantations of ICD.	Gen pop (N=NR) 1-35y SCD incidence	SCD incidence rates in young individuals declined by 49% over the past 2 decades. The decline was paralleled by improved survival of OHCA, higher diagnostic rates of inherited cardiac diseases, and higher ICD implantation rates. However, rates of unwitnessed SCD were unchanged, which calls for new perspectives in preventive strategies.
Lyngø, 2019 (15)	N	Decline in incidence of sudden cardiac death in the young: a 10-year nationwide study of 8756 deaths in Denmark	Denmark Registry/autopsy study	Nationwide study to examine temporal changes in incidence and causes of SCD in the young in Denmark in 2000-2009.	Gen pop 1-35y SCD incidence	Incidence of SCD in the young decreased significantly from 2000 through 2009 in Denmark with an average annual percent change of -3%.
Rucklova, 2022 (19)	N	Burden of sudden cardiac death in persons aged 1-40 years in the Czech Republic	Czech Republic Retrospective study	To ascertain the incidence, circumstances and causes of SCD in persons aged 1-40 years in the Czech Republic.	Gen pop (N=NR) 1-40y SCD incidence	CAD is the predominant cause of SCD in the young population of the Czech Republic ... The second most prevalent cause in our population are potentially heritable heart conditions such as CMs and SADS.
Sakai-Bizmark, 2018 (20)	N	Patient Characteristics and Emergency Department Factors Associated with Survival After Sudden Cardiac Arrest in Children and Young Adults: A Cross-Sectional Analysis of a Nationally Representative Sample, 2006-2013	USA Retrospective registry study	To examine (1) nationally representative incidence rates of ED visits due to SCA in paediatric and young adult populations, (2) basic characteristics of the ED visits with SCA, and (3) patient and hospital factors associated with survival after SCA.	Children + young adult (N=NR) ≤30y SCD incidence	Data showed no benefit of regionalized care for post-SCA in ≤30-year-old populations. With further examination of the differences between sexes, new management strategies for SCA cases can be developed.

Study	FT	Title	Country Study type	Objectives	Population (N) Age Outcome	Conclusions
Skjelbred, 2022 (21)	Y	Sex differences in sudden cardiac death in a nationwide study of 54 028 deaths	Denmark Prospective registry	To examine differences in incidence rates, clinical characteristics, comorbidities and autopsy findings between male and female SCD cases.	Gen pop (N=54,028 deaths) <35y SCD incidence	Differences in incidence rates between males and females were greatest among young adults and the middle-aged. Incidence rates of SCD among older female population approached that of the male population, despite having significantly more CVD and diabetes in male SCD cases.
Vahatalo, 2022 (22)	N	Temporal Trends in the Incidence and Characteristics of Sudden Cardiac Death among Subjects under 40 Years of Age in Northern Finland during 1998-2017	Finland Prospective study (autopsy database)	To assess temporal trends in the incidence and characteristics of SCD in subjects under 40 years of age.	Gen pop <40y SCD incidence	The incidence of SCD in subjects under 40 years of age has decreased in Northern Finland during 1998-2017. According to autopsy data, most of the deaths are due to non-ischemic myocardial diseases and relative proportion of CAD has decreased.
Athletes and military						
Bohm, 2023 (7)	N	Sports-related sudden cardiac arrest in young adults	Germany + France Prospective cohort study	To determine the overall SrSCA incidence, characteristics, and outcomes in young adults.	Young adults, sports related (N=NR) 18-35y SrSCA incidence	SrSCA in the young occurs mainly in recreational male sports participants ... CAD is the most prevalent cause of SrSCA in young adults.
Bohm, 2021 (8)	N	Sports-Related Sudden Cardiac Arrest in Germany	Germany Prospective registry study	Not explicitly stated	Athletes, sports-related (N NR) ≤35y Sports-related SCA incidence	In Germany, premature CAD, SADS, and myocarditis are the leading causes of SrSCA in young athletes.
Endres, 2019 (10)	Y	Epidemiology of Sudden Death in Organized Youth Sports in the United States, 2007-2015	USA Retrospective descriptive epidemiology study	To describe the epidemiology of SD in organized youth sports in the United States from 2007 through 2015.	Athletes, organised sports ≤17y, mean 13 SrSCD incidence	SDs in organized youth sports in the United States from 2007 through 2015 were most often experienced during practices by males, were cardiac related, and occurred while playing basketball. These findings are similar to those in high school and collegiate sports.
Franzos, 2025 (11)	Y	No One Left Behind: Incidence of Sudden Cardiac Arrest and 30-Day Survival in Military Members	USA Retrospective registry study	To leverage claims made on behalf of SCA victims transported to the hospital or receiving medical treatment, estimating the rates of SCA and post-arrest survival in the military.	Military (N=2,220,701) 17-24y, 25-34y, 35-49y SCA incidence	Despite a high incidence of SCA in the military, survival beyond 30 days for those transported to the hospital was excellent.

Study	FT	Title	Country Study type	Objectives	Population (N) Age Outcome	Conclusions
Graziano, 2024 (12)	Y	Causes of sudden cardiac arrest and death and the diagnostic yield of sport preparticipation screening in children	Italy Retrospective study	To (1) compare the burden of SCA/SCD, either resuscitated SCA with survival or SCD, between children engaged in competitive sports (defined as 'athletes') and non-athletes, and (2) evaluate the diagnostic yield of PPS for CVD at risk of SCA/SCD in children aged 8–15 years from the Veneto region of Italy.	Athletes (N=25,251) 8-15y SCA/SCD incidence	In children aged 8–15 years, the incidence of SCA/SCD and the yield of PPS for identifying at-risk CVD were both substantially higher in those ≥12 years, suggesting that systematic PPS may be more useful beyond this age.
Miguel 2025 (16)	N	Sudden cardiac death in athletes: A 20-year analysis in Portugal	Portugal NR (cases identified via media and sports organisations)	To evaluate cases of SCD in athletes in Portugal within the last 20 years.	Competitive athletes (N=NR) Median 27y SCD incidence	The incidence of SCD in athletes in Portugal is very low, mainly occurring in male, outdoor sports and during competitions or training sessions.
Petek, 2024 (17)	N	Sudden Cardiac Death in National Collegiate Athletic Association Athletes: A 20-Year Study	USA Retrospectively for 2002 – 2004 and prospectively from 2005 – 2022	Understanding the incidence, causes, and trends of SCD among young competitive athletes is critical to inform preventive policies	College athletes (N=NR) NR SCD incidence	The incidence of SCD in college athletes has decreased. Male sex, Black race, and basketball are associated with a higher incidence of SCD.
Peterson, 2021 (18)	N	Aetiology and incidence of sudden cardiac arrest and death in young competitive athletes in the USA: a 4-year prospective study	USA Prospective surveillance and autopsy reports	To investigate the aetiology and incidence of SCA/SCD in US competitive athletes.	Young competitive athletes 11-29y, average 17 SCA/SCD incidence	CMs account for nearly half of SCA/SCD cases in college and professional athletes, while CAA play a more prominent role than expected in middle school athletes. Over half of SCA cases in athletes result in SD, calling for improved prevention strategies.
Weizman, 2023 (23)	Y	Incidence of Cardiac Arrest During Sports Among Women in the European Union	France, Denmark, Sweden Retrospective registry study	To assess the incidence, characteristics, and outcomes of women presenting with SrSCA.	Women, SCA during sports 18-39y SCA incidence	These findings emphasize the dramatically lower risk of SrSCA in women compared with men, despite similar subject characteristics.

Abbreviations: CAA, coronary artery anomaly; CAD, coronary artery disease; CM, cardiomyopathy; CVD, cardiovascular disease; ED, emergency department ; FT, full-text checked; Gen pop, general population; ICD, implantable cardioverter defibrillators; NR or -, not reported; OHCA, out-of-hospital cardiac arrest; PPS, preparticipation screening; SADS, sudden arrhythmic death syndrome; SCA, sudden cardiac arrest; SCD, sudden cardiac death; SD, sudden death; SrSCA, sports-related sudden cardiac arrest; SrSCD, sports-related sudden cardiac death; y, year.

Table 4: Question 1: Results summary for cohort studies of SCA/SCD incidence

Study	FT	Country	Population (N)	Age	SCD incidence (per 100,000 person-yrs)	Incidence of SCA	Incidence of SCA/SCD	Incidence of SCA/SCD by age	Incidence of SCA/SCD by sex	Incidence of SCA/SCD by ethnicity	Incidence of SCA/SCD by athletic status	Incidence of SCA/SCD by condition
General population												
Carrington, 2023 (9)	N	Portugal	Children + young adults (N NR)	1-40y, mean 32	1.7	-	-	-	-	-	-	Atherosclerotic CAD (33%), LVH (15.2%), HCM (2.7%)
Ha, 2020 (13)	N	Australia	Gen pop	1-35y, mean 28	0.9 to 1.5 (by year)	-	-	-	-	-	-	Most common CAD (40%), SADS (14%)
Hansen, 2025 (14)	N	Denmark	Gen pop (N= NR)	1-35y	2.2 Declined by 3.3% annually	-	-	-	69% of 1057 SCD cases were male	-	-	-
Lynge, 2019 (15)	N	Denmark	Gen pop	1-35y	2.5 (year 2009) 3.1 (year 2000)	-	-	-	-	-	-	-
Rucklova, 2022 (19)	N	Czech Republic	Gen pop (N=NR)	1-40y	2.4	-	-	-	81% SCD cases were in males	-	>80% SCD non-sport / sleep 7% SrSCD	CAD (38%), CM (15%), SADS (12%), LVH (10%), and CHD (7%)
Sakai-Bizmark, 2018 (20)	N	USA	Children + young adult (N=NR)	≤30y	6.2	6.9	-	-	-	-	-	-
Skjelbred, 2022 (21)	Y	Denmark	Gen pop (N=54,028 deaths)	<35y	2.9	-	-	-	2.0 (female) 3.8 (male)	-	-	-
Vahatalo, 2022 (22)	N	Finland	Gen pop	<40y	2.9 overall 1.5 (2013-2017) 2.5 (2008-2012) 3.7 (2003-2007) 4.0 (1998-2002)	-	-	-	81% SCD cases were in males	-	-	CAD (29%)
Athletes and military												
Bohm, 2023 (7)	N	Germany + France	Young adults, sports related (N NR)	18-35y	-	4.8 per million-year	-	-	-	-	-	CAD most common (26%), mainly ACS (87%)

Study	FT	Country	Population (N)	Age	SCD incidence (per 100,000 person-yrs)	Incidence of SCA	Incidence of SCA/SCD	Incidence of SCA/SCD by age	Incidence of SCA/SCD by sex	Incidence of SCA/SCD by ethnicity	Incidence of SCA/SCD by athletic status	Incidence of SCA/SCD by condition
Bohm, 2021 (8)	N	Germany	Athletes, sports- related (N NR)	≤35y	-	-	-	-	-	-	-	Most common: premature CAD, SADS, then myocarditis (for ≤35y)
Endres, 2019 (10)	Y	USA	Athletes, organised sports	≤17y, mean 13	1.8 SD per 10 million athlete- years; 69% cardiac	-	-	-	More SCDs in males (n=36/45, 80%)	-	-	-
Franzos, 2025 (11)	Y	USA	Military (N=2,220,701)	17-24y 25-34y 35-49y	-	10.8	-	5.9 (17-24y) 10.6 (25-34y) 22.2 (35-49y)	-	-	-	-
Graziano, 2024 (12)	Y	Italy	Athletes (N=25,251)	8-15y	-	-	0.7	SCA/SCD: 0.2 (8-11y) 1.3 (12-15y)	7/23 (30%) cases in females (12- 15y)	-	8-15y: 0.7 (athletes); 0.7 (non-athletes) 12-15y: 1.2 (athletes); 1.3 (non-athletes)	-
Miguel 2025 (16)	N	Portugal	Competitive athletes (N=NR)	Median 27y	0.4	-	-	-	-	-	-	-
Petek, 2024 (17)	N	USA	College athletes (N=NR)	-	1.6	-	-	-	2.3 (males) 0.6 (females)	3.7 (Black) 1.3 (White)	-	Most common: LVH or CM (17%); HCM (13%). myocarditis (6%)
Peterson, 2021 (18)	N	USA	Young competitive athletes	11-29y, average 17	-	-	0.7 (high school) 0.5 (college)	-	SCA/SCD: 2.3, 2.9 (males, HS+ college) 0.5, 0.8 (females, HS + college)	SCA/SCD: 47.9 (African American male college basketball)	-	HCM (21%), idiopathic LVH (13%), CAA (12%), unexplained (10%)
Weizman, 2023 (23)	Y	France, Denmark, Sweden	Women, SCA during sports	18-39y	-	Reported by sex	-	-	0.01 (women 18-39y) 0.06 (men 18- 39y)	-	-	-

Abbreviations: ACS, acute coronary syndrome; CAA, coronary artery anomaly; CAD, coronary artery disease; CHD, congenital heart defect; CM, cardiomyopathy; FT, full-text checked; Gen pop, general population; HCM, hypertrophic cardiomyopathy; HS, high school; LVH, left ventricular hypertrophy; NR or -, not reported; SADS, sudden arrhythmic death syndrome; SCA, sudden cardiac arrest; SCD, sudden cardiac death; SD, sudden death; SrSCD, sports-related sudden cardiac death; y, year.

Question 2: Accuracy of screening tests to identify cardiac conditions associated with SCD

The following tables summarise the abstracts of studies for Q2 (accuracy of screening tests to identify cardiac conditions associated with SCD in young individuals). Table 5 summarises systematic reviews of screening for conditions associated with SCD, Table 6 presents study characteristics for cohort studies of screening accuracy, and Table 7 summarises test accuracy results from cohort studies of screening.

Table 5: Question 2: Systematic reviews of screening for conditions associated with SCD

Study Details	FT	Country Population N studies, Age	Screening tests	Ref standard Target conditions	N (%) with Abnormal Findings	N (%)with Cardiac Condition	Positive predictive value (PPV)	Sensitivity, Specificity, diagnostics	Conclusions
Panhuyzen-Goedkoop, 2023 (27) SR of athlete screening for SCD-associated conditions + quality of evidence Search 2021	Y	Mainly Europe + USA Athletes (N=82,417) 33 studies Mean per study 12-55y, ≤35y in 28 of 33 studies	H+PE(8 studies) H+PE+ECG (18 studies) H+PE+ECG+TTE (7 studies)	Additional testing e.g. ECG, TTE, CMR or genotyping Conditions associated with SCD	Screening abnormalities in 11,167/82,417 (14%) Per test: H+PE: 22% H+PE+ECG: 20% H+PE+ECG+TTE: 7%	High-risk CV conditions: 354/82,417 (0.4%) In athletes ≤35 years: - WPW syndrome (48%) - HCM (17%)	PPV: 354/11,167 (3%) PPV per test: H+PE: 1% H+PE+ECG: 4% H+PE+ECG+TTE: 4%	False positive rate: 10,742/82,417 (13%) Quality of evidence very low due to: absence of data blinding; inappropriate statistical analysis; observational designs; and population heterogeneity	Methodological quality and quality of evidence on athlete screening are suboptimal. Efficacy could not be reliably established. The prevalence of screen-detected high-risk CV conditions was very low and false positive rate high. Given the limitations of the evidence, individual recommendations need to be prudent.
Goff, 2023 (26) SR+MA of screening with + without ECG in young athletes Search 2020	Y	Mainly Europe, USA, Canada Young Athletes (N=28,011) 9 studies 11-35y	H+PE or ECG	NR Conditions associated with SCD	Abnormal findings: H+PE: 2857/28,011 (10%) ECG: 1125/28,011 (4%)	Incidence of SCD-associated conditions: 103/28011 (0.4%)	PPV: H+PE: 103/2857 (4%) ECG: 103/1125 (9%) [calculated]	OR for association between H-PE and detecting SCD-associated conditions: (OR=2.9, P=0.082) OR for association between ECG and detecting SCD-associated conditions: (OR=148, P<0.0001).	Using a 12-lead ECG as a screening tool improves the odds of identifying cardiac disease and SCD in young athletes, compared with H-PE.
Cantinotti, 2021 (24) SR of ECHO screening for AAOCA in athletes Search 2020	Y	Europe + USA Athletes and gen pop 9 studies Range 12-49y	ECHO	Coronary angiography or CT angiography AAOCA	NR	Incidence of CAA: 0% to 0.8%	PPV: 88% to 100%	NR	The screening of AAOCA by ECHO is feasible and accurate when appropriate examinations are performed; however, specific acoustic windows and definitions of defects other than AAOCA need to be standardized to improve sensitivity and specificity.
Cassels, 2019 (25) SR of addition of POCUS to ECG screening in athletes Search 2017	Y	USA Athletes (N=2,646) 5 studies NR	Tests: - H+PE - ECG - POCUS (+/- ECG)	NR Conditions associated with SCD	Abnormal findings: - Standard PPS: 20% - H+PE: 18% - ECG: 5% - POCUS: 1.4% - POCUS + ECG: 5%	Incidence of SCD-associated conditions: 0.5%	PPV: - H+PE: 1% - ECG: 9% - PoC ultrasound (+ECG): 13%	Sensitivity: - H+PE: 36% - ECG: 86% - POCUS (+ECG): 38% Specificity: - H+PE: 83% - ECG: 95% - POCUS (+ECG): 99%	There are insufficient data to recommend the inclusion of PoC ultrasound as an adjunct screening modality at this time.

Abbreviations: AAOCA, anomalous aortic origin of coronary arteries; CAA, coronary artery abnormality; CV, cardiovascular; CT, computed Tomography; CMR, cardiac magnetic resonance imaging; ECG, electrocardiogram; ECHO, echocardiography; FT, full-text checked; H, history; HCM, hypertrophic cardiomyopathy; NR, not reported; OR, odds ratio; PE, physical examination; PoC, point-of-care; POCUS, point-of-care ultrasound; PPS, pre-participation screening; ref standard, reference standard; SCD, sudden cardiac death; SR, systematic review; TTE, trans-thoracic echocardiography; WPW, Wolff-Parkinson-White; y, year.

Table 6: Question 2: Study characteristics for cohort studies of screening accuracy

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
General population							
Abela, 2024 (28)	N	BEAT-IT: A de-novo cardiac screening programme in Maltese adolescents	Malta Screening programme evaluation	To assess the feasibility and diagnostic yield of a nationwide cardiac screening programme in adolescents.	Students (N=2,708) Mean 15y	% abnormal findings % diagnosed	A nationwide systematic cardiac screening programme for adolescent athletes and non-athletes is feasible and cost-efficient, provided that responsible centres have the appropriate infrastructure.
Bates, 2025 (31)	N	Rewarding twenty-year experience with initial and repeat EKG and echocardiographic screening for prevention of sudden death in detecting abnormal findings	USA Screening programme evaluation	To further analyse the impacts, findings, and modalities of multiple cardiac screenings.	Youth NR	% abnormal findings % diagnosed	Cardiac screening involving multiple repeated screenings appears to be effective in detecting increasing numbers of abnormal findings that can be lifesaving.
Dhutia, 2021 (41)	N	Diagnostic yield and financial implications of a nationwide electrocardiographic screening programme to detect cardiac disease in the young	UK Prospective study	To assess the role of screening with ECG for identifying CVD associated with SCD in a non-select group of adolescents and young adults in the general population.	Adolescents and young adults, gen pop (N=26,900) 14-35y	% abnormal findings % diagnosed	The inclusion of an ECG to a health questionnaire is associated with a five-fold increase in the ability to detect disease associated with SCD in young individuals and is more cost effective for detecting serious disease compared with screening with a health questionnaire alone.
Greciano 2024 (47)	Y	Can we screen for heart disease in children at public health centres? A multicentre observational study of screening for heart disease with a risk of sudden death in children	Spain Observational, descriptive, and cross-sectional	To assess how to put into practice and conduct CV assessment within the routine healthy-child check-ups; by reflecting CV symptoms and signs, as well as the ECG alterations present in children with a risk of SCD in the selected population; and assessing the primary care paediatricians' skill at interpreting an ECG and detecting the ECG signs of SCD risk.	Children with routine check-ups at 6y and 12y (N=408) 5-13 years	% abnormal findings % diagnosed	This study lays the foundations for future SCD risk screening in children, performed by PCPs. However, previously, it would be important to optimise their training in reading and interpreting paediatric ECGs.
Vilardell, 2020 (70)	N	Characterization of electrocardiographic findings in young students	Spain Observational cross-sectional study	We aimed to determine the prevalence and spectrum of ECG findings in a population of secondary school students.	Secondary school students (N=1911) 13-14y	% abnormal findings % diagnosed	One third of the students had ECG findings that were mostly suggestive of physiological adaptation. One seventh of the students with pathologic ECG findings had pre-existing heart disease, although the overall prevalence of pre-existing heart disease was low.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Athletes							
Albinski, 2022 (29)	N	Diagnostic yield and cost analysis of electrocardiographic screening in Swiss paediatric athletes	Switzerland Retrospective observational study	To assess ECG interpretation criteria in paediatric athletes and to evaluate the cost of screening.	Paediatric athletes (N=891) <18y	% abnormal findings % diagnosed	Our study using the International Recommendations for Electrographic Interpretation in Athletes identified a low count of abnormal findings in paediatric athletes, yet raising substantially the cost of screening.
Angelini, 2018 (30)	N	High-Risk Cardiovascular Conditions in Sports-Related Sudden Death: Prevalence in 5,169 Schoolchildren Screened via Cardiac Magnetic Resonance	USA Screening programme evaluation	To assess the use of CMR to estimate the prevalence of high-risk CV conditions.	School children (N=5,169) 11-14y, mean 13y	% diagnosed	If our estimate is accurate, only 1.47% of school-age sports participants will need focused secondary evaluations; the rest can probably be reassured about their cardiac health after one 30-minute screening study.
Beale, 2019 (32)	N	Electrocardiographic findings in elite professional cyclists: The 2017 international recommendations in practice	Switzerland Cross-sectional study	To categorize ECG findings into normal, borderline or abnormal in a team of professional elite cyclists according to the 2017 international recommendations.	Professional elite male cyclists (N=43) 21-38y	% abnormal findings	In this team of professional cyclists, the prevalence of abnormal ECG findings requiring further investigation, and the false positive rate were low, despite a very high prevalence of normal variations expected in athletes.
Berge, 2019 (33)	N	Cardiovascular incidents in male professional football players with negative preparticipation cardiac screening results: an 8-year follow-up	Norway Retrospective follow-up study	To identify CV incidents in a cohort of male professional football players who were cleared to play after a negative screening result.	Male professional football players (N=595) NR	% abnormal findings % CV incidents during follow-up	A comprehensive preparticipation cardiac screening did not identify a subset of 6 of 595 players who experienced subsequent CV incidents as being at risk. It is important to remind athletes that a normal cardiac screening exam does not protect against all cardiac diseases.
Brandt, 2019 (34)	N	Integration of 12-Lead Electrocardiograms Into Preparticipation Screenings to Prevent Sudden Cardiac Death in High School Athletes	USA Retrospective chart review	To evaluate a community youth heart screening programme in Minnesota.	Youth athletes (N=840) 14-18y	% abnormal findings % diagnoses	It was clinically significant that six participants were found to have potentially lethal electrical or structural heart abnormalities who would have otherwise have remained unidentified with the standard PPS guidelines.
Calo, 2019 (35)	N	Electrocardiographic and echocardiographic evaluation of a large cohort of peri-pubertal soccer players during pre-participation screening	Italy Prospective study	To investigate the prevalence of cardiac abnormalities in a population of young male soccer players undergoing PPS through ECG and TTE.	Peri-pubertal male soccer players (N=2261) Mean 12y	% abnormal findings % diagnoses	In a wide population of peri-pubertal male athletes, evaluation of the ECG identified all cardiac diseases requiring sport disqualification. TTE alone allowed the identification of cardiac abnormalities potentially leading to CM or major CV events over time.
Chevalier, 2021 (36)	Y	Aortic dilatation: Value of echocardiography in the systematic assessment of elite rugby players in the French National Rugby League (LNR)	France Prospective study	To quantify the proportion of aortic abnormalities in a population of young rugby players and to evaluate the potential diagnostic contribution of systematic ECHO in addition to the routine CV screening recommended by the ESC with respect to the risk of SD in elite professional rugby players.	Male professional rugby players (N=336) Mean 24y	% abnormal findings % diagnosed	In a population of professional rugby players, ECHO was contributive. The main anomaly was aortic dilatation (14/336, 4.2%). While this is proportionally much higher than in other sports, the cutoffs need to be defined more precisely by including the criterion of ethnicity, as is already the case for ECG.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Conway, 2022 (37)	N	Evaluation of a Preparticipation Cardiovascular Screening Program Among 1,686 National Collegiate Athletic Association Division I Athletes: Comparison of the Seattle, Refined, and International Electrocardiogram Screening Criteria	USA Retrospective chart review	To: (1) analyze the results of 5 years of PPS including 12-lead ECG of NCAA Division I athletes; and (2) assess the rates of ECG screening abnormalities and false-positive rates among 3 ECG screening criteria.	First-year college athletes (N=1686) NR	% abnormal findings % diagnosed	There was a low rate of significant cardiac pathology in this population, and no athletes were permanently restricted from play as a result of screening. Our results suggest that the International criteria have the lowest false-positive rate of athlete-specific ECG criteria, and thus, it is the preferred method for pre-participation ECG screening in NCAA athletes.
Corsi, 2025 (38)	N	Cardiac screening findings and referral patterns in male African-American basketball players: Analysis of the HeartBytes Registry	USA Retrospective analysis of registry	To characterize cardiac screening findings, including symptoms, family history, PE, and ECG abnormalities in male African American basketball players compared to other youth athletes undergoing cardiac screening.	Youth athletes (N=8,303) NR	% abnormal findings	Male African American basketball players exhibited higher rates of concerning cardiac screening findings compared to non-male African American basketball players, including symptoms, PE findings, and ECG abnormalities.
Darche, 2019 (39)	N	Assessing the utility of yearly pre-season laboratory screening for athletes on a major professional sports team	USA Retrospective chart review	To assess the clinical value of annual pre-season laboratory screening tests for a major professional sports team over multiple years.	Professional athletes NR	% abnormal findings	In this study population, yearly pre-season laboratory screening of professional athletes did not yield substantial clinically significant outcomes and would not be warranted under normal clinical standards.
Dennison, 2021 (40)	N	Feasibility of a Novel Strategy for Cardiovascular Screening During the Preparticipation Physical Examination	USA Cross-sectional study	To determine the feasibility of simultaneously conducting H&PE, limb-lead ECG, and preparticipation ECHO by frontline providers at one screening station.	College athletes (N=36 and N=53) NR	% abnormal findings % diagnosed	A comprehensive PPE can be completed in a timely fashion using a single screening station and limb-lead ECG to improve efficiency, while still allowing providers to gather information on H, PE, heart rhythm, and heart structure.
Dobel, 2020 (42)	N	Possible new options and benefits to detect myocarditis, right ventricular remodeling and coronary anomalies by echocardiography in systematic preparticipation screening of athletes	Germany Retrospective study,	To assess the extended TTE protocol for athletes to improve the detection of CV disorders (myocarditis, RV remodeling and coronary anomalies)—especially for acquired cardiac diseases—and to test its feasibility in athletes.	Male elite athletes (N=54) NR	% abnormal findings % diagnosed	Due to the excessive cardiac stress in highly competitive sports, high-quality and precise screening modalities are necessary ... The documented feasibility of the proposed extended protocol underlines the suitability to detect distinct morphological and functional cardiac alterations and documents the potential added value of a comprehensive ECHO.
Donati, 2023 (43)	N	Echocardiography in the preparticipation screening: an old topic revisited	Italy Retrospective chart review	To evaluate the additional role of ECHO in identifying CV abnormalities that might be undetected by commonly used PPS.	Young athletes (N=500) Mean 34y	% abnormal findings	Screening ECHO showed an additional value (about 10% more) in detecting patients with CV abnormalities, otherwise undiagnosed with the 'standard' PPS protocol.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Fabregat-Andres, 2020 (44)	Y	Feasibility and diagnostic performance of including point-of-care ultrasound (POCUS) in preparticipation screening of young competitive athletes	Spain Prospective study	To evaluate the strategy of including POCUS to ECG in PPS of young competitive athletes.	Young competitive athletes (N=1188) 7-27y, mean 16y	% abnormal findings % diagnosed	POCUS proved to be a useful strategy by improving diagnostic performance primarily with respect to detect structural abnormalities and also by minimising positive false cases of ECG alone.
Fischetti, 2019 (45)	N	Evaluation of a Standardized Cardiac Athletic Screening for National Collegiate Athletic Association (NCAA) Athletes	USA Prospective study	To evaluate the feasibility of adding ultrasound to PPS for collegiate athletes.	Collegiate athletes (N=42) NR	% abnormal findings	Adding POCUS to the preparticipation exam of college athletes is feasible. This workflow may provide a model for athletic departments' screening.
Gerling, 2019 (46)	N	Echocardiographic diagnosis of congenital coronary artery abnormalities in a continuous series of adolescent football players	Germany Prospective cohort study	To determine the prevalence of high-risk congenital coronary arteries in elite adolescent football players using two dimensional TTE.	Adolescent elite football players (N=1045) NR	% abnormal findings	Basic PPS tests including 12-lead or exercise ECG do not safely identify high-risk CAAs. In adolescent athletes an expert cardiologist is able to describe the origin and the proximal course of the coronary arteries and identify major abnormalities in most of the cases by 2D TTE.
Graziano, 2024 (12)	N	Causes of sudden cardiac arrest and death and the diagnostic yield of sport preparticipation screening in children	Italy Retrospective study	The objectives of this study were to: (1) compare the burden of SCA/SCD, either resuscitated SCA with survival or SCD, between children engaged in competitive sports (defined as 'athletes') and non-athletes, and (2) evaluate the diagnostic yield of PPS for CVD at risk of SCA/SCD in children aged 8–15 years from the Veneto region of Italy.	Young people undergoing annual PPS (N=25,251) 8-15y, mean 12y	% abnormal findings % diagnosed	In children aged 8–15 years, the incidence of SCA/SCD and the yield of PPS for identifying at-risk CVD were both substantially higher in those ≥12 years, suggesting that systematic PPS may be more useful beyond this age.
Grossfeld, 2021 (48)	Y	Combined Non-Invasive Cardiac Imaging and Genetic Testing of Elite Volleyball Players: A Ten-Year Experience	USA Prospective screening study	To summarize our experience of screening 150 US Olympic National team members and how cardiac imaging combined with genetic testing can help identify at-risk individuals, with the hopes of preventing such tragedies from occurring in the future.	Members of the USA Men's and Women's National Volleyball teams (N=150) NR	% abnormal findings % diagnosed	Through a combination of H, PE, ECHO and genetic testing, we have identified one previously undiagnosed athlete with Marfan syndrome, along with four others with a possible aortopathy. Taken together, this approach is a cost-effective strategy for the identification of at-risk tall athletes leading to potentially lifesaving interventions, and raises the issue of the feasibility of screening for all tall individuals.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Halasz, 2021 (49)	N	Early Repolarization in Pediatric Athletes: A Dynamic Electrocardiographic Pattern With Benign Prognosis	Switzerland Prospective screening study	We aimed to evaluate the ERP prevalence, characteristics, and prognosis in pediatric athletes aged ≤16 years.	Pediatric athletes (N=886) 7-16y, mean 12y	% abnormal findings % diagnosed	ERP is common in pediatric athletes. It was mostly located in the inferolateral leads and associated with concave ascending ST segment with other training-related ECG changes. The lack of either SCD or CM linked to SCD over follow-up suggests that in pediatric athletes, ERP may be considered a benign training-related ECG phenomenon with a potential dynamic pattern.
Halasz, 2021 (50)	N	Pediatric athletes' ECG and diagnostic performance of contemporary ECG interpretation criteria	Switzerland Prospective screening study	We aimed to assess the features of pediatric athletes' ECG and compared the diagnostic performance of 2017 International ECG recommendation, 2010 ESC recommendation and 2013-Seattle criteria in detecting clinical conditions at risk of SCD.	Pediatric athletes (N=886) 7-16y, mean 12y	% abnormal findings % diagnosed	Pediatric athletes like the adult counterpart exhibit a high prevalence of ECG abnormalities mostly representing training-related ECG adaptation. The International criteria showed a lower false-positive rate but at the cost of loss of sensitivity.
Harmon, 2020 (51)	N	Comparison of cardiovascular screening in college athletes by history and physical examination with and without an electrocardiogram: Efficacy and cost	USA Prospective screening study	The purpose of this study was to compare disease prevalence, positive findings, and costs of 2 different screening strategies: H&PE alone or H&PE+ECG.	8602 records (4955 H+PE, 3647 H+PE+ ECG) NR	% diagnosed	H&PE with the addition of ECG is 6 times more likely to detect a CV condition associated with SCD than without. The addition of ECG improves the cost efficiency per diagnosis by 5-fold and should be considered at college institutions with appropriate resources.
Ho, 2023 (52)	Y	Outcomes of Investigating T Wave Inversion With Echocardiography in an Unselected Young Male Preparticipation Cohort	USA Prospective screening study	This study aims to describe the prevalence of abnormal TWI in an unselected young male cohort and the outcomes of an ECHO-guided approach to investigating these individuals for structural heart diseases, focusing on yield for CM.	Young males undergoing pre-enlistment cardiac screening (N=69,714) Mean 18y	% abnormal findings % diagnosed	CM diagnoses were more strongly associated with certain patterns of abnormal TWI. Our findings may support decisions to prioritize ECHO in these individuals.
Idiazabal-Ayesa, 2024 (53)	N	Diagnostic cost-effectiveness of a two-stage cardiovascular evaluation programme in young-adolescent athletes. Role of echocardiography	Spain Prospective screening study	The aim was to describe the diagnostic performance of a 2-step ECG and ECHO screening model in a large sample of healthy young-adolescent athletes (aged 11-16 years), evaluating its cost-effectiveness for CVD detection.	Young-adolescent athletes (N=2,617) 11-16y, mean 15y	% abnormal findings % diagnosed	Our study shows the diagnostic cost-effectiveness of a two-step cardiac screening protocol, including ECG, and highlights the role of ECHO in young adolescent athletes, which could be implemented at a low and reasonable cost.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Idiazabal-Ayesa, 2023 (54)	N	Electrocardiographic findings in pediatric versus young-adolescent athletes: A comparative analysis using general international criteria	Spain Retrospective observational study	This study aims to describe the prevalence of ECG findings in a sample of children and young-adolescent athletes aged 11-16y, employing refined Seattle interpretation criteria. Additionally, we seek to compare these findings based on age group and sex.	Child and young adolescent athletes (N=3,747) 11-16y	% abnormal findings % diagnosed	The study confirms that ECG screening is a useful tool for identifying cardiac abnormalities in pediatric and young-adolescent athletes, even though the prevalence of significant findings in this population is relatively low.
Koufou, 2022 (55)	Y (no abstract)	Cardiovascular pre-participation evaluation of male competitive athletes: results of a clinical and electrocardiographic screening programme in southwestern Greece	Greece Prospective screening study	ECG findings in athletes are classified into 3 categories: normal, borderline, and abnormal. The aim of our study was to investigate the incidence of the above findings in professional soccer athletes in southwestern Greece.	Male competitive athletes (soccer) (N=582) 12-35y, mean 22y	% abnormal findings % diagnosed % not complying or lost to FU	Our study indicates that borderline or abnormal ECG findings, according to the international criteria, in professional young footballers are relatively rare.
Krivenko, 2022 (56)	N	Feasibility of electrocardiogram screening in the USA prior to high school sport participation	USA Prospective screening study	The study describes a large-scale ECG screening programme for middle and HS students. The aim is to depict important components, partners, and plans that can be adopted by other municipalities to help prevent sudden cardiac arrest in this population.	Middle/high school athletes (N=5,877) NR	% abnormal findings % diagnosed	This pilot project demonstrates that large volume ECG screening prior to school sport participation is feasible at a low cost when utilizing appropriate manpower and providing access to FU-care.
Limongelli, 2021 (57)	N	Yield and clinical significance of genetic screening in elite and amateur athletes	Italy Prospective screening study	The purpose of this study was to assess the value of genetic testing in addition to a comprehensive clinical evaluation, as part of the diagnostic work-up of elite and/or amateur Italian athletes referred for suspicion of inherited cardiac disease, following a PPS programme.	Athletes, elite and amateur (N=5,892) NR	% abnormal findings % diagnosed	A combined clinical and genetic evaluation, based on the subtle evidence of clinical markers for inherited disease, was able to identify an inherited cardiac disease in about one-quarter of the examined athletes.
MacLachlan, 2022 (58)	N	Results of a nationally implemented cardiac screening programme in elite cricket players in England and Wales	England + Wales Prospective screening study	We assessed the diagnostic yield and costs of an ECG-based national screening programme in elite cricket players and the incremental value of TTE and periodic evaluation.	Elite cricket players (N=1,208) NR	% abnormal findings % diagnosed	An ECG-based national screening programme identified a major cardiac condition in 0.3% of athletes. Routine TTE and periodic evaluation increased the diagnostic yield to 0.6%, at an incremental cost.
Malhotra, 2020 (59)	N	Accuracy of the 2017 international recommendations for clinicians who interpret adolescent athletes' ECGs: a cohort study of 11 168 British white and black soccer players	UK Retrospective analysis of screening study	To investigate the accuracy of the recently published international recommendations for ECG interpretation in young athletes in a large cohort of white and black adolescent soccer players.	Adolescent athletes, soccer (11,168) Mean 16y	% abnormal findings % diagnosed	The 2017 international recommendations for ECG interpretation in young athletes can be applied to adolescent athletes to detect serious cardiac disease. These recommendations perform more effectively than previous ECG criteria in both white and black adolescent soccer players.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Modaff, 2019 (60)	N	Usefulness of Focused Screening Echocardiography for Collegiate Athletes	USA Retrospective chart review	We hypothesized that a focused ECHO can identify structural abnormalities that may lead to SCD in athletes, which might otherwise go undetected by H&PE.	College athletes (N=2,898) NR	% abnormal findings (PPS vs ECHO) % diagnosed	In conclusion, although the overall number was low, the 5-minute screening ECHO detected athletes at risk for SCD not discovered on preparticipation H&PE.
Molinari, 2024 (61)	N	Different patterns of pre-excitation in a large Italian cohort of asymptomatic non-competitive athletes evaluated by telecardiology screening: Prevalence and ECG features	Italy Prospective screening study	To evaluate and detail the prevalence of the WPW syndrome in a large Italian cohort of young non-competitive athletes.	Non-competitive athletes (N=216,424) Mean 14y	% abnormal findings % diagnosed	In a large population of young non-competitive athletes, the prevalence of ECG pre-excitation at telemedicine remote screening was 4.1 per 10,000.
Orchard, 2023 (62)	N	Clinical outcomes of 10 years of cardiac screening in elite New Zealand athletes	New Zealand Retrospective cohort study	To report findings from the High Performance Sport New Zealand cardiac screening programme, including comparisons between sexes and ethnicities.	Elite Olympic athletes (N=1,189) Mean 21y	% abnormal findings % diagnosed	WPW syndrome was the most frequent diagnosis, with very little CM found. The proportion of abnormal ECGs was low overall, but higher in females.
Sarto, 2023 (63)	Y	Value of screening for the risk of sudden cardiac death in young competitive athletes	Italy Prospective screening study	This study aimed to report the long-term findings of the Italian programme of CV PPS in young, competitive athletes.	Young competitive athletes (N=22,324) 7-18y, mean 12y	% abnormal findings % diagnosed	The PPS programme led to the identification of CVD at risk of SCD over the whole study age range of children and more often on repeat evaluations. Among screened children, the incidence of SrSCA during long-term follow-up was low.
Sarto, 2021 (64)	Y no abst	Serial Versus Single Cardiovascular Screening of Adolescent Athletes	Italy Consecutive series of screened athletes	To evaluate the diagnostic yield and outcomes of serial (annual) versus single (initial) PPCE to screen adolescent athletes for CVDs at risk of SCD.	Competitive child athletes (N=15,127 athletes, 53,396 screens) 12-18y, median 13y	% abnormal findings % diagnosed	These results show that annual CV screening of adolescent athletes increased by 3 times the diagnostic yield of CVD at risk of SCD compared with a once-only (initial) evaluation.
Sattler, 2024 (65)	N	Identifying Sudden Cardiac Arrest Risk in Adolescent Male Athletes	USA Prospective screening study	The purpose of the study was to determine the prevalence of SCA risk factors in HS athletes.	Male HS athletes (N=33) 14-17y, mean 16y	% abnormal findings	The current AHA suggested screening method is limited. An ECG should be used in PPS and RTP decisions for athletes with a COVID-19 history. Family cardiac history, chest pain during exercise, and an abnormal QRS interval should be used to identify SCA risk.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Speers, 2019 (66)	Y	Defining the Process of a Cardiovascular Risk Assessment Program: Lessons Learned From Cardiac Assessment of Elite Soccer Players in the United Kingdom	UK Retrospective descriptive epidemiology study	Retrospectively analyse the cardiac assessment process for elite soccer players, and provide team physicians with a systematic guide to managing longitudinal cardiac risk.	Soccer players (N=265) 13-37y, mean 21y	% abnormal findings	CV assessment is a vital tool in identifying athletes at risk of SCD to mitigate their risk through surveillance, intervention, or participation restriction. The decision whether a player is fit to play or not requires a robust risk assessment followed by input from a multidisciplinary team that includes both the team physician and cardiologist.
Squeo, 2025 (67)	N	Pre-participation Cardiovascular Evaluation for Paris 2024 Olympic Games in Elite Athletes: The Italian Experience	Italy Prospective screening study	Our aim was to assess the prevalence and type of CV abnormalities in athletes candidate to Paris 2024 Olympic Games, after implementation of this Olympic medical programme.	Elite athletes (N=772) Mean 25y (female), 27y (male)	% abnormal findings % diagnosed	Olympic athletes, despite the highest level of physical performance, are not exempt from CV and metabolic diseases, including a small proportion of cardiac conditions at risk of SCD. More advanced diagnostic tools, including CPET, ECHO and full blood tests, implemented in our protocol, were required to identify hidden CV abnormalities that could have jeopardized athlete's health and performance.
Tranchita, 2024 (68)	N	The role of Italian pre-participation screening in early detection of cardiomyopathies: what is the meaning of T wave inversion in young athletes?	Italy Prospective cross-sectional study	The aim of this study is to evaluate the prevalence of TWI in a population of young competitive athletes and determine whether they can be associated with the occurrence of CM in the absence of other pathological features	Young athletes (N=581) Mean 15y	% abnormal findings % diagnosed	The probability that competitive athletes have a concealed CM is low, but not negligible. PPS for competitive sport activity represents an excellent opportunity to early identify CM and other pathologies that increase the risk of SD in apparently healthy young athletes.
Vessella, 2020 (69)	N	The Italian preparticipation evaluation programme: diagnostic yield, rate of disqualification and cost analysis	Italy Prospective screening study	To investigate the diagnostic yield, rate of disqualification and costs of our PPE	Athletes (N=5910) Mean 15y	% abnormal findings % diagnosed	PPE according to the Italian model identified a range of diseases in 2.0% of apparently healthy athletes at an average cost of €79.
Willard, 2021 (71)	N	Differences in American Athletes Undergoing Preparticipation Examination by Sex, Participation Level, and Age	USA Retrospective cohort study	To describe the preparticipation examination findings among American athletes by sex, participation level, and age.	Student athletes (N=2954) NR	% abnormal findings % diagnosed	Among this American cohort of athletes, male athletes reported fewer symptoms and had higher prevalence of abnormal ECG findings compared with female athletes. The prevalence of clinically important findings was comparable among groups.
Williams, 2019 (72)	Y	Performance of the American Heart Association (AHA) 14-Point Evaluation Versus Electrocardiography for the Cardiovascular Screening of High School Athletes: A Prospective Study	USA Prospective screening study	To compare the performance of the AHA 14-point screening evaluation and a resting ECG for CV screening of high school athletes.	High school athletes (N=5003) 13-19y, median 16y	% abnormal findings % diagnosed	The AHA 14-point evaluation performs poorly compared with ECG for CV screening of high school athletes. The use of consensus-derived history questionnaires as the primary tool for CV screening in athletes should be re-evaluated.

Study	FT	Title	Country Study type	Objectives	Population (N) Age	Outcomes (list)	Conclusions
Zorzi, 2020 (73)	Y	Screening young athletes for diseases at risk of sudden cardiac death: role of stress testing for ventricular arrhythmias	Italy Prospective screening study	The aim of this study was to assess the results of adding constant-load ECG stress testing to the protocol for the evaluation of VA inducibility.	Young competitive non-professional athletes (N=10,985) 13-18y, median 15y	% abnormal findings % diagnosed	The addition of exercise testing for the evaluation of VA inducibility to H, PE and ECG resulted in an increase of the diagnostic yield of PPE at the expense of an increase in false-positive findings.

Abbreviations: AAOCA , anomalous aortic origin of coronary arteries; abst, abstract; AHA, American Heart Association; CAA, coronary artery abnormality; CM, cardiomyopathy; CMR, cardiac magnetic resonance imaging; COVID-19, coronavirus disease 2019; CPET, cardiopulmonary exercise testing; CV, cardiovascular; ECG, electrocardiogram; ECHO, echocardiography; EPR, early repolarisation pattern; ESC, European Society of Cardiology; FT, full-text checked; FU, follow-up; Gen pop, general population; H, history; HS, high school; LV, left ventricular; NCAA, National Collegiate Athletic Association; NR, not reported; PCPs, primary care physicians; PE, physical examination; POCUS, point-of-care ultrasound; PPCE, preparticipation cardiovascular evaluation; PPE, preparticipation evaluation; PPS, pre-participation screening; RTP, return to participation; RV, right ventricular; SCA, sudden cardiac arrest; SCD, sudden cardiac death; SD, sudden death; SrSCA, sports-related sudden cardiac arrest; TTE, trans-thoracic echocardiography; TWI, T wave inversion; VA, ventricular arrhythmias; WPW, Wolff-Parkinson-White; y, year.

Table 7: Question 2: Results summary for cohort studies of screening accuracy

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
General population									
Abela, 2024 (28)	N	Malta	Students (N=2,708) Mean 15y	ECG H+PE	Further investigations Cardiac conditions linked to SCD	109 (4%) referred 4% abnormal ECG	15 (0.6%) diagnosed cardiac condition 9 (0.3%) cardiac condition linked to SCD Conditions: LQTS (1), HCM (1), WPW syndrome (5), coronary anomalies (2)	14% (15/109) [calculated]	NR
Bates, 2025 (31)	N	United States	Youth NR	Repeat screening with: ECG, ECHO, blood pressure, ultrasound	NR NR	10-13% abnormal findings 32% with multiple screening 17% abnormal ECHO	PLT findings: 2.5% Multiple screening PLT: 11%	NR	NR
Dhutia, 2021 (41)	N	UK	Adolescents + young adults, gen pop (N=26,900) 14-35y	H ECG	Further investigations Cardiac abnormalities associated with SCD	675/26,900 (2.5%) abnormal questionnaire 2175/26,900 (8%) abnormal ECG 114/26,900 (0.5%) both abnormal	88/26,900 (0.3%) conditions associated with young SCD - 15 (17%) via H - 72 (81%) via ECG - 2 (2%) via both	H: 15/675 (2.2%) ECG: 72/2175 (3.3%) Both: 2/114 (1.8%)	NR
Greciano 2024 (47)	Y	Spain	Children with routine check-ups at 6y and 12y (N=408) 5-13 years	H+PE ECG	NR CV abnormalities	30/408 (7%) ECG alterations possibly related to a heart disease with risk of SCD	13 borderline QT interval; 4 long QT interval; 4 left heart axis; 4 abnormal repolarisation; 3 LV enlargement; 1 short QT interval; 1 pre-excitation syndrome	PPV: 45%	Sensitivity: 29%
Vilardell, 2020 (70)	N	Spain	Secondary school students (N=1911) 13-14y	ECG	Further investigations Heart disease	36 (2%) pathologic ECG 554 (29%) adaptive ECG changes (non-pathologic) 47/554 (2.5%) EPR 2/36 (0.1%) QTc segment abnormalities	5/1911 (0.3%) CVD	NR	NR
Athletes									
Albinski, 2022 (29)	N	Switzerland	Paediatric athletes (N=891) <18y	ECG H+PE	Further investigations NR	19 (2%) abnormal ECG	0 (0%) diagnosed cardiac condition	0% (0/19) [calculated]	NR

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Angelini, 2018 (30)	N	United States	School children (N=5,169) 11-14y, mean 13y	CMR ECG H+PE	NR High-risk CV conditions	NR	76 (1.5%) high-risk CV conditions: Dilated CM (11), HCM (3), ACAOS-IM (23), WPW syndrome (4), prolonged QT (34), Brugada syndrome (1)	NR	NR
Beale, 2019 (32)	N	Switzerland	Professional elite male cyclists (N=43) 21-38y	ECG (2017 classification)	Further investigations NR	43 (100%) normal ECG variations 4 (9%) borderline ECG 2 (5%) abnormal ECG 4 (9%) referred	0 diagnoses	PPV: 0/4 (0%)	False positive rate: 4/43 (9%) [No pathology identified on further investigation of 4 cyclists with 2 concurrent borderline or any abnormal ECG]
Berge, 2019 (33)	N	Norway	Male professional football players (N=595) NR	Screening including: ECG ECHO	Incidents cross-checked with medical records Sudden CV incidents	0% (negative screening results)	1% (6/595) severe CV incidents: SCA (3), MI (1), TIA (1), atrial flutter (1)	NR	False negative: 6 (but 1 person had abnormal ECG but not picked up at screening) NPV: 99% (589/595) [calculated]
Brandt, 2019 (34)	N	United States	Youth athletes (N=840) 14-18y	PPS screening: ECG ECHO Blood pressure	NR NR	2 (0.2%) abnormal ECG 12 (1.4%) abnormal ECHO 59 (7%) high blood pressure	6 (0.7%) potentially lethal electrical or structural heart abnormalities	NR	1 with abnormal ECG and 6 with abnormal ECHO had no other abnormal findings at screening
Calo, 2019 (35)	N	Italy	Peri-pubertal male soccer players (N=2261) Mean 12y	H+PE ECG TTE	NR Cardiac abnormalities	Abnormal findings: - 65 (3%) ECG - 102 (5%) TTE	2 HCM, 8 mild LVH, 6 mild LVD, 17 bicuspid aortic valve [N SCD-linked conditions: unclear]	NR	NR
Chevalier, 2021 (36)	Y	France	Male professional rugby players (N=336) Mean 24y	ECG ECHO	NR Aortic abnormalities	Abnormal findings: 25/336 (7%) cardiac 6/336 (2%) ECG 21/336 (6%) ECHO	NR definite diagnoses 1 possible early HCM, 1 AAOCA, 2 LVD, 1 bicuspid aortic valve, 2 aortic regurgitations, 14 ascending aortic dilatations	NR	NR
Conway, 2022 (37)	N	United States	First-year college athletes (N=1686) NR	PPS including ECG	NR Cardiac abnormalities	3.0% ECG Seattle criteria 2.1% ECG refined criteria 1.8% ECG International criteria	3/1686 (0.2%) conditions associated with SCD	NR	International criteria had lower false-positive rate vs. Seattle criteria. No significant difference in false-positive rates between Seattle and refined or International and refined criteria.

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Corsi, 2025 (38)	N	United States	Youth athletes (N=8,303) NR	PPS including: H+PE ECG	NR Cardiac abnormalities	Male African American basketball players vs. other youth athletes: -ECG abnormalities + TWI (4% vs. 0.8%) -Referrals (3.5% vs. 3.2%)	NR	NR	NR
Darche, 2019 (39)	N	United States	Professional athletes NR	Laboratory tests ECG	NR NR	10% abnormal screen (40% of these had additional screening)	0.4% clinically significant outcome	NR	NR
Dennison, 2021 (40)	N	United States	College athletes (N=36 and N=53) NR	H+PE ECG ECHO	NR Cardiac abnormalities	Referred: Year 1: 5/36 (14%) Year 2: 3/53 (9%)	0 diagnosis	Year 1 : (0/5) 0% Year 2: (0/3) 0%	NR
Dobel, 2020 (42)	N	Germany	Male elite athletes (N=54) NR	TTE	Post-processing Structural cardiac abnormalities	NR	1 myocarditis, 1 HCM, 2 bicuspid aortic valves	NR	NR
Donati, 2023 (43)	N	Italy	Young athletes (N=500) Mean 34y	Standard PPS: H+PE, ECG, stress test Advanced PPS: H+PE, ECG, stress test, ECHO	NR CV abnormalities	Abnormal findings: Standard protocol 161/500 (32%) Advanced protocol: 192/500 (38%)	NR	NR	NR
Fabregat-Andres, 2020 (44)	Y	Spain	Young competitive athletes (N=1188) 7-27y, mean 16y	H+PE ECG POCUS	Further exam (CMR, Holter, genetic testing) CV structural abnormalities	Abnormal findings: 50/1188 (4%), mostly structural	5/1188 (0.4%) potential SCD-linked conditions (HCM, right CAA , suspected LQTS, WPW syndrome)	(5/50) 10% [calculated]	NR
Fischetti, 2019 (45)	N	United States	Collegiate athletes (N=42) NR	H+PE ECG Cardiac ultrasound	NR Cardiac abnormalities	Abnormal findings: 0% (H+PE and/or ECG) 1/42 (2.4%) (H+PE, ECG, cardiac ultrasound)	NR	NR	NR
Gerling, 2019 (46)	N	Germany	Adolescent elite football players (N=1045) NR	H+PE ECG TTE	NR Congenital CAA	2/1045 (0.2%) high-risk CAA 16/1045 (1.5%) low-risk CAA	NR	NR	NR

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Graziano, 2024 (12)	N	Italy	Young people undergoing annual PPS (N=25,251) 8-15y, mean 12y	H+PE, ECG, limited stress ECG Blood pressure, spirometry, urine, visual acuity	NR CV conditions associated with SCD	Abnormalities: 5/26 (19%) H 3/26 (12%) PE 11/26 (42%) ECG 13/16 (50%) exercise test	26/25,251 (0.1%) conditions at risk of SCD: 11 HCM, 3 LQTS, 3 bicuspid aortic valve with aortic dilation, 2 dilated CM, 2 at-risk ventricular pre-excitation, 2 AAOCA, 3 other	NR	NR
Grossfeld, 2021 (48)	Y	USA	Men's and Women's National Volleyball teams (N=150) NR	H+PE ECHO Genetic testing	NR SCD due to structural heart disease	5/150 (3%) mild to moderate dilation of sinuses of Valsalva	0/150 (0%) CM or AAOCA 1/150 (0.7%) Marfan syndrome (via genetic testing)	NR	NR
Halasz, 2021 (49)	N	Switzerland	Pediatric athletes (N=886) 7-16y, mean 12y	H+PE ECG TTE	NR EPR	117/886 (13%) EPR	7/886 (0.8%) conditions at risk for SCD in group without ERP 3 WPW syndrome, 1 LQTS, 2 Ebstein anomaly, 1 Botallo duct with LVD	NR	NR
Halasz, 2021 (50)	N	Switzerland	Paediatric athletes (N=886) 7-16y, mean 12y	H+PE ECG TTE	NR Conditions associated with SCD	27% LVH criteria 22% juvenile T-wave pattern 13% EPR 1.8% left axis deviation 0.9% right axis deviation 0.8% T-wave inversion	7/886 (0.8%) conditions related to SCD	NR	Sensitivity: International 4/7 (57%) ESC/ Seattle 6/7 (86%) Specificity: International 98% ESC 64%, Seattle 95% False-positives 36% ESC vs. 2% International; latter more false-negative (0.3%)
Harmon, 2020 (51)	N	United States	College athletes (N=8,602) NR	H+PE alone H+PE+ ECG	NR CV conditions associated with SCD	NR	11 conditions associated with SCD (2 via H+PE only, 9 H+PE+ ECG) CV conditions associated with SCD: - H+PE alone: 0.04% (1/2454) - H+PE+ ECG: 0.2% (1/410)	NR	NR
Ho, 2023 (52)	Y	United States	Young males undergoing pre-enlistment cardiac screening (N=69,714) Mean 18y	ECG	ECHO, cardiac MRI if needed Structural heart diseases, CM	562/69,714 (0.8%) TWI	12/69,714 (0.02%) CM: 6 HCM, 1 arrhythmogenic RV CM, 1 dilated CM, 1 LV noncompaction, 3 hypertensive heart disease 15 /69,714 (2.7%) non-CM structural heart diseases	NR [12/562] 2.1%	NR

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Idiazabal-Ayesa, 2024 (53)	N	Spain	Young-adolescent athletes (N=2,617) 11-16y, mean 15y	H+PE ECG TTE	NR SCD-related CV conditions	2.5% abnormal ECG NR abnormal ECHO 80% of conditions diagnosed by ECHO had normal ECG	Diagnosed: 16/2,617 (0.6%)	Unclear	NR
Idiazabal-Ayesa, 2023 (54)	N	Spain	Child and young adolescent athletes (N=3,747) 11-16y	H+PE ECG	Further examinations NR	2% abnormal ECG	Diagnosed: 0.3%	PPV: 13% [0.27/2.05]	NR
Koufou, 2022 (55)	Y (no abstr)	Greece	Male competitive athletes (soccer) (N=582) 12-35y, mean 22y	H+PE ECG	Further investigation (Holter, stress test, CMR) NR	Referred: - Abnormal ECG: 4% >1 borderline ECG: 0.5% - Symptomatic: 5%	Diagnosed: 0 Of those referred for further investigation, 40% did not comply or lost to FU. May be due to fear of being disqualified from sports	NR	NR
Krivenko, 2022 (56)	N	USA	Middle/high school athletes (N=5,877) NR	ECG	Further investigations Cardiac conditions with SCD risk	Abnormal ECG: 199/5,877 (3%)	Diagnosed: 8/5,877 (0.1%): 6 WPW syndrome, 1 LQTS, 1 possible HCM	8/199 (4%) (calculated)	NR
Limongelli, 2021 (57)	N	Italy	Athletes, elite and amateur (N=5,892) NR	PPS	Clinical evaluation, genetic testing Inherited cardiac disease	Referred: 61/5,862 (1%)	Diagnosed: 14/5,862 (0.2%)	14/61 (23%) (calculated)	NR
MacLachlan, 2022 (58)	N	England + Wales	Elite cricket players (N=1,208) NR	H+PE ECG TTE in subset (N=342)	TTE, further investigations Major cardiac conditions	Referred for ECHO: 47/1,208 (4%) Referred further: 35/1,208 (3%)	Diagnosed: 4/1,208 (0.3%): 1 HCM, 1 arrhythmogenic CM, 2 WPW syndrome Repeat evaluation: 1 more case HCM (initially normal screening) but no other diagnoses in 5.8 years FU Routine TTE: 2/342 more diagnoses	H+PE + ECG: 4/47 (9%) H+PE + ECG + TTE: 4/35 (11%) (calculated)	NR

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Malhotra, 2020 (59)	N	UK	Adolescent athletes, soccer (11,168) Mean 16y	H ECG (4 different criteria) ECHO	NR Serious cardiac conditions	Abnormal ECGs: - ESC criteria: 13% - Seattle criteria: 4.3% - Refined criteria: 2.9% - International criteria: 1.8% More abnormal ECGs in Black vs. White athletes	Diagnosed: 42/11,168 (0.4%)	PPV ranges from 3% to 21% (calculated as 0.38/13.2 to 0.38/1.8)	Sensitivity: - All criteria: 36/42 (86%) Specificity: - ESC criteria: 87% (White), 84% (Black) - Seattle criteria: 96% (White), 94% (Black) - International criteria: 99% (White), 97% (Black)
Modaff, 2019 (60)	N	USA (via author affiliations)	College athletes (N=2,898) NR	H+PE ECHO (focused 5-minute)	Further testing Structural abnormalities linked to SCD	Abnormal findings: 159/2,898 (5%) Further testing: 40/2,898 (1.4%) Of 661 with abnormal H+PE, 1 (0.15%) had abnormal ECHO	Diagnosed: 3/2,898 (0.1%): 1 HCM, 1 atrial septal defect with RV dysfunction, 1 dilated ascending aorta 2 of 3 diagnosed via ECHO had normal H+PE	3/40 (7.5%)	NR
Molinari, 2024 (61)	N	Italy	Non-competitive athletes (N=216,424) Mean 14y	ECG via telecardiology	NR WPW syndrome	Abnormal findings: 88/216,424 (0.04%)	Implies all abnormal ECG due to WPW syndrome	NR	NR
Orchard, 2023 (62)	N	New Zealand	Elite Olympic athletes (N=1,189) Mean 21y	H+PE ECG	NR NR	Abnormal ECGs: 3.5% (males 2.5%, females 4.4%)	NR total % diagnosed. 0.7% WPW syndrome 0.3% CM	NR	NR
Sarto, 2023 (63)	Y	Italy	Young competitive athletes (N=22,324) 7-18y, mean 12y	H+PE ECG Stress testing	Further investigations CV diseases at risk of SCD	41/69 (59%) abnormal ECG 36/69 (52%) abnormal exercise testing	69/22,324 (0.3%) CVD at risk of SCD (25 (0.1%) at initial screening, 44 (0.2%) on repeat screening) 63/69 (91%) in children aged ≥12y 14 channelopathies, 15 CM, 17 CHD, 18 non-ischaemic LV scar with VA	NR	NR
Sarto, 2021 (64)	Y no abst	Italy	Competitive child athletes (N=15,127; 53,396 screens) 12-18y, median 13y	H+PE ECG Limited stress testing	Further investigations (ECHO, Holter, stress test, CMR) CV diseases at risk of SCD	5,389/53,396 (10%) referred 2% positive family H 1% abnormal PE 3% abnormal ECG 6% exertional arrhythmias	63/15,127 (0.4%) CVD at risk of SCD (via multiple screens) CHD (17), ion channel disease (n=11), inherited CM (n=13), isolated nonischemic LV scar with VA (n=18)	NR	NR

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Sattler, 2024 (65)	N	United States	Male HS athletes (N=33) 14-17y, mean 16y	H ECG Blood pressure	NR Cardiac abnormalities	11/33 (33%) ECG abnormalities	NR	NR	NR
Speers, 2019 (66)	Y	United Kingdom	Soccer players (N=265) 13-37y, mean 21y	H+PE ECG ECHO	NR Cardiac abnormalities	30/265 (11%) cardiac abnormalities 25/30 (83%) referred for further investigation 5/30 (17%) ECG changes	NR	NR	NR
Squeo, 2025 (67)	N	Italy	Elite athletes (N=772) Mean 25y (female), 27y (male)	H+PE, ECG, TTE Exercise test Full blood and urine tests	NR Cardiac abnormalities	145/772 (19%) one or more abnormalities 3% abnormal ECG 6% abnormal TTE 2% abnormal ECG+TTE 6% exercise arrhythmias	4/772 (0.5%) cardiac conditions at risk of SCD 5/772 (0.6%) borderline QT interval prolongation, 2/772 (0.2%) arrhythmogenic CM	4/145 (3%) (calculated)	NR
Tranchita, 2024 (68)	N	Italy	Young athletes (N=581) Mean 15y	H+PE ECG, step test Spirometry	TTE, stress test, Holter, cardio-MRI, cardio-CT TWI, CMs	53/580 (9%) TWI	8/581 (1.4%) dilated CM or HCM 7/581 (1.2%) dubious cardiomyopathy diagnosis	NR	NR
Vessella, 2020 (69)	N	Italy	Athletes (N=5910) Mean 15y	H+PE ECG, exercise test Blood pressure, height, weight, visual acuity, spirometry, urine	Further investigations CV diseases with risk of sudden death	584/5910 (10%) abnormal findings	18/5910 (0.3%) CVD at-risk of SCD 88/5910 (1.5%) CVD	NR	NR
Willard, 2021 (71)	N	United States	Student athletes (N=2954) NR	H+PE ECG TTE	NR NR	NR	NR	NR	NR
Williams, 2019 (72)	Y	United States	HS athletes (N=3,620) 13-19y, median 16y	AHA 14-point screening (H+PE, cardiac auscultation, blood pressure, height, weight) ECG (Seattle Criteria)	ECHO CV disorders associated with SCD	356/3620 (10%) abnormal PE 103/3620 (3%) abnormal ECG	16/3620 (0.4%): 9 WPW syndrome, 3 LQTS, 2 HCM, 1 dilated aorta, 1 AAOCA AHA 14-point evaluation: flagged as abnormal 7/16 (44%) ECG: flagged as abnormal 15/16 (94%)	AHA 14-point: 0.3% ECG: 14%	AHA 14-point: Sensitivity: 19% Specificity: 68% ECG: Sensitivity: 88% Specificity: 98%

Study	FT	Country	Population Age	Screening tests	Ref standard Target conditions	N (%) Abnormal Findings/ Referred	N (%) Diagnosed with Cardiac Condition	PPV	Sensitivity, Specificity, diagnostics
Zorzi, 2020 (73)	Y	Italy	Young competitive non-professional athletes (N=10,985) 13-18y, median 15y	H+PE ECG Exercise stress test Blood pressure	CMR VA	451/10,985 (4%)	31/10,985 (0.3%) cardiac disease with risk of SCD 9 LQTS, 5 HCM, 4 arrhythmogenic CM, 4 dilated CM, 3 at-risk ventricular preexcitation, 2 Marfan syndrome with aortic dilatation, 2 myocarditis, 1 LV non-compaction, 1 Brugada syndrome	31/451 (7%) (calculated)	NR

Abbreviations: AAOCA, anomalous aortic origin of coronary arteries; abst, abstract; ACAOS-IM, anomalous coronary artery origin from the opposite sinus with intramural course; AHA, American Heart Association; CAA, coronary artery abnormality; CHD, congenital heart defect; CM, cardiomyopathy; CT, computed tomography; CMR, cardiac magnetic resonance imaging; CV, cardiovascular; CVD, cardiovascular disease; ECG, electrocardiogram; ECHO, echocardiography; EPR, early repolarisation pattern; ESC, European Society of Cardiology; FT, full-text checked; FU, follow-up; Gen pop, general population; H, history; HCM, hypertrophic cardiomyopathy; HS, high school; LQTS, long-QT syndrome; LV, left ventricular; LVD, left ventricular dilation; LVH, left ventricular hypertrophy; MI, myocardial infarction; MRI, magnetic resonance imaging; NPV, negative predictive value; NR, not reported; OR, odds ratio; PE, physical examination; PLT, Potential Life-Threatening; POCUS, point-of-care ultrasound; PPS, pre-participation screening; PPV, positive predictive value; QTc, corrected QT; ref standard, reference standard; RV, right ventricular; SCA, sudden cardiac arrest; SCD, sudden cardiac death; TIA, transient ischaemic attack; TTE, trans-thoracic echocardiography; TWI, T wave inversion; VA, ventricular arrhythmias; WPW, Wolff-Parkinson-White; y, year.

Question 3: Effectiveness of screening and intervention to prevent SCD

Table 8 summarises studies and reviews for Q3 (effectiveness of screening and intervention to prevent SCD in young individuals).

Table 8: Question 3: Effectiveness of screening and intervention to prevent SCD

Study Title	FT	Study design Objective	Population Age N studies (in SR) Country	Intervention	Comparator (N)	Outcomes (results)	Conclusions
Lear, 2022 (74) Screening Electrocardiogram in Young Athletes and Military Members: A Systematic Review and Meta-Analysis	Y	SR+MA (search 2019) To assess ECG screening to prevent SCA/SCD in young athletes + military	Young athletes + military ≤40y Included 4 non-randomised studies at high risk of bias: 3 in athletes (N=6,431,380), 1 in military (N=5,257,792) Switzerland, Italy, USA, Israel	Screening with ECG	No screening, usual care, or screening without ECG (3 studies historical control; 1 study ECG vs. non-ECG cohorts; unclear if control groups no screening or screening without ECG)	Risk of SCD following ECG screening vs. no ECG screening: RR 0.58 (95% CI: 0.23 to 1.45); absolute risk reduction 0.0016% (based on pooled data from 2 studies)	Existing evidence for the effect of ECG screening is inconclusive and of very low quality. Higher-quality studies are needed to reduce this uncertainty.

Abbreviations: CI, confidence interval; ECG, electrocardiogram; FT, full-text checked; FU, follow-up; HS, high school; LV, left ventricular; MA, meta-analysis; NR, not reported; RR, relative risk; SCA, sudden cardiac arrest; SCD, sudden cardiac death; SR, systematic review; WPW, Wolff-Parkinson-White; y, year.

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