# Preoperative risk assessment tools for morbidity after cardiac surgery: a systematic review

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| **Background** | Postoperative morbidity places considerable burden on health and resources. Thus, strategies to identify, predict, and reduce postoperative morbidity are needed. |
| **Aims** | To identify and explore existing preoperative risk assessment tools for morbidity after cardiac surgery. |
| **Methods** | Electronic databases (including MEDLINE, CINAHL, and Embase) were searched to December 2020 for preoperative risk assessment models for morbidity after adult cardiac surgery. Models exploring one isolated postoperative morbidity and those in patients having heart transplantation or congenital surgery were excluded. Data extraction and quality assessments were undertaken by two authors. |
| **Results** | From 2251 identified papers, 22 models were found. The majority (54.5%) were developed in the USA or Canada, defined morbidity outcome within the in-hospital period (90.9%), and focused on major morbidity. Considerable variation in morbidity definition was identified, with morbidity incidence between 4.3% and 52%. The majority (45.5%) defined morbidity and mortality separately but combined them to develop one model, while seven studies (33.3%) constructed a morbidity-specific model. Models contained between 5 and 50 variables. Commonly included variables were age, emergency surgery, left ventricular dysfunction, and reoperation/previous cardiac surgery, although definition differences across studies were observed. All models demonstrated at least reasonable discriminatory power [area under the receiver operating curve (0.61–0.82)]. |
| **Conclusion** | Despite the methodological heterogeneity across models, all demonstrated at least reasonable discriminatory power and could be implemented depending on local preferences. Future strategies to identify, predict, and reduce morbidity after cardiac surgery should consider the ageing population and those with minor and/or multiple complex morbidities. |
| **Keywords** | Postoperative morbidity • Cardiac surgery • Preoperative risk • Risk prediction models • Morbidity outcome |

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> **Implications for practice**
> - Clinical risk prediction models are important for person-centred care and can provide a basis for shared decision-making.
> - Three models exhibit good discrimination and could be used in preoperative clinics to optimize patient outcome and experience.
> - Age, frailty, and multiple complex morbidities are important factors to consider.
> - New models that include minor morbidities and consider longer-term recovery are needed.

# Introduction

It is widely recognized that mortality alone provides only a crude representation of surgical quality and that high-quality surgical care should include mortality, morbidity, and patient-reported outcomes.[1] In particular, postoperative complications are a serious global concern affecting up to 16.8% of patients.[2] In cardiac surgery, where over 1 million cardiac surgeries are performed worldwide each year,[3] up to 48% of patients experience at least one complication.[4] Those experiencing postoperative complications experience increased intensive care length of stay (LOS),[4] hospital LOS,[4–6] substantial morbidity at 6 weeks after surgery (between 28%[7] and 38.9%[8]), and readmission requirement (between 6%[7] and 15.3%[8]). Moreover, almost a quarter of cardiac surgery patients require community health service support in the initial period after discharge[7] and those who suffer postoperative complications also experience worse quality of life[9] lasting up to 3 years after surgery[10] and report increased anxiety and fear of dying.[11]

In addition to the patient and societal health burden, this poses a huge financial and organizational load on healthcare systems. Data from the Society of Thoracic Surgeons (STS) suggest the total cost of complications after isolated coronary artery bypass graft surgery (CABG) over the last 10 years was $78.6 million in the USA alone.[12] More specifically, the average in-hospital incremental cost of experiencing any complication after CABG is approximately $15 000 per patient,[13] higher in those undergoing combined CABG and valve surgery,[5] with additional morbidities exponentially increasing costs.[12] Such costs, and the associated challenges imposed on healthcare delivery services, will only continue to increase as surgical complexity, increasing patient age and associated comorbid conditions also increase.[12]

Despite this increasing burden, few countries reliably record postoperative morbidity outcomes after cardiac surgery[14] due to its considered subjective and imprecise nature.[15] That said, greater emphasis has been placed on morbidity outcome in recent years with both the STS National Database (USA) and the National Institute of Cardiovascular Outcomes Research Adult Cardiac Surgery (UK) reporting some morbidity outcomes at national level (e.g. reoperation for bleeding or wound infection, postoperative stroke or postoperative renal failure). However, there lacks an international consensus or standardized definition for postoperative morbidity and clinical endpoints in cardiac surgery trials are measured and reported inconsistently.[16,17] This poses considerable challenges as there is a specific need to be able to identify, measure, and then accurately predict complications after cardiac surgery.[12] If strategies to identify, predict, and then subsequently reduce postoperative morbidity after cardiac surgery can be found this will improve patient well-being, reduce healthcare costs and increase healthcare service efficiency.

Thus, we sought to undertake a systematic review of preoperative risk assessment tools of postoperative morbidity after cardiac surgery to identify and examine the existing tools used to define, measure, and assess preoperative risk of postoperative morbidity after cardiac surgery.

# Methods

## Protocol and registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines.[18] This review was registered on PROSPERO, an international prospective register of systematic review (February 2019, reference CRD42019120080).

## Eligibility criteria

All studies that develop (with or without validation) a preoperative risk assessment tool of postoperative morbidity after cardiac surgery were eligible for inclusion. Studies were included if they met the following inclusion and exclusion criteria: *Population*: adults (≥18 years of age) undergoing any form of cardiac surgery (including coronary artery bypass grafts and/or valve surgery in isolation or combination) but excluding those undergoing heart transplant and cardiology procedures (e.g. percutaneous coronary intervention or Transcatheter Aortic Valve Implantation); *Outcome*: morbidity after cardiac surgery, excluding those that assess one isolated postoperative morbidity outcome (e.g. stroke or bleeding only). Studies were not excluded on the basis of publication date or quality assessment outcome but were required to be available in English language.

## Information sources

A search of MEDLINE, Cumulated Index of Nursing and Allied Health Literature, Embase, British Nursing Index, the Cochrane Library, and ClinicalTrials.gov (www.clinicaltrials.gov) was undertaken for relevant papers published up to and including December 2020 (last search date 14 sDecember 2020). Identified systematic reviews were reviewed to identify any additional tools.

## Search strategy

The above data sources were searched using a strategy comprised of title/abstract text terms paired with (majored) exploded Medical Subject Heading (MeSH) terms, or equivalent, in the following combinations, as per the Cochrane Library search: (*MeSH descriptor:* [Thoracic Surgery] *explode all trees* OR *MeSH descriptor:* [Cardiovascular Surgical Procedures] *explode all trees* OR (((cardiac OR heart*) NEXT (surge* OR surgical*)) OR CABG OR "coronary artery bypass"):ti, ab, kw) AND (*MeSH descriptor:* [Morbidity] *explode all trees* OR (Morbidit*):ti, ab, kw) AND (*MeSH descriptor:* [Risk Assessment] *explode all trees* OR (risk* NEXT (assess* OR scor* OR tool*)):ti, ab, kw). Clinicaltrials.gov (www.clinicaltrials.gov)

was also searched for trials-in-progress, and citation searches were performed on relevant papers.

## Study selection

Two rounds of screening occurred. First, a title and abstract review was undertaken followed by a full paper review of those included from the first screening. All screening was undertaken independently by two authors, in accordance with the inclusion and exclusion criteria, with a third author reviewing any discrepancies between authors. The full-text paper of potential studies identified through systematic reviews were obtained and were also screened as per the above process.

## Data collection and syntheses (data items and data collection process)

Data extraction included primary author, date of publication, country of study, study design, type of surgery, sample size (in development and validation datasets, where appropriate, definition of morbidity use, morbidity rate, variables (and attributed scores) included in the final tool, and reliability and validity assessment outcome. All data were extracted and collated into a standardized proforma by two authors, with differences resolved through discussion until consensus achieved.

## Risk of bias and quality assessment

All included papers were reviewed for quality by two authors using the Critical Appraisal Skills Programme template for clinical prediction rule.[19] A risk of bias graph was generated[20] and studies were not excluded on the basis of the quality assessment.

## Analysis

Results were summarized using descriptive statistics, tables, and narrative synthesis, as appropriate. Interpretation of the discriminatory power of the models followed that described by Hosmer and Lemeshow.[21] MedCalc® version 19.7.4 was used to generate a forest plot to compare the discriminatory power of each the models. Interpretation of the analysis was discussed and agreed by all members of the authorship team.

# Results

## Study selection

A total of 2251 non-duplicate papers were identified for possible inclusion (*Figure 1*) with 105 papers undergoing independent full-text assessment. This resulted in 22 papers being included for data analysis
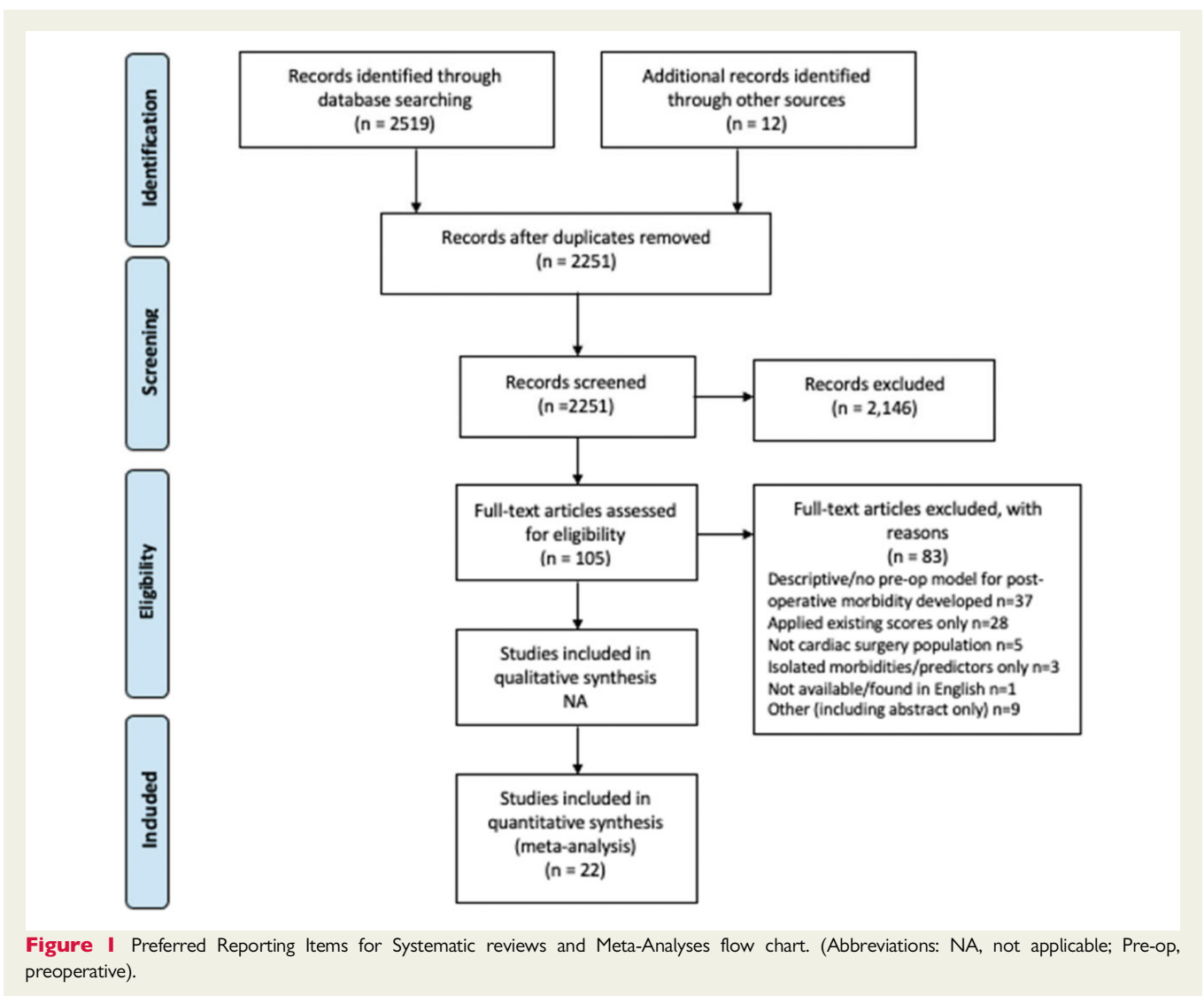


**Figure 1** Preferred Reporting Items for Systematic reviews and Meta-Analyses flow chart. (Abbreviations: NA, not applicable; Pre-op, preoperative).

**Table I** The study characteristics of each included model (*n* = 22): model name, year of publication, country, design, data collection period, and population

| Study (author, reference, and *model name* (where stated)) | Year published | Country | Design *(includes validation design where conducted)* | Data collection period | Population (surgery type) |
|---|---|---|---|---|---|
| Parsonnet[39] | 1989 | USA | Retrospective | 1982–1987 | Open heart surgery |
| Higgins[58] *Cleveland Clinic score* | 1992 | USA | Development: Retrospective Validation: Prospective | 1986–1988 | CABG |
| Tuman[40] | 1992 | Canada | Prospective | Not stated | Isolated cardiac surgery |
| Geraci[59] | 1993 | USA | Retrospective | 1985–1986 | CABG |
| Hattler[41] | 1994 | USA | Prospective | 1991–1993 | CABG |
| Roques[33] *Ontario Province Risk Score (French score)* | 1995 | France | Prospective | 1993 | Cardiac surgery |
| Kurki and Kataja[34] *CABDEAL score* | 1996 | Finland | Retrospective | 1990–1991 | CABG |
| Magovern[31] | 1996 | USA | Retrospective | Development 1991–1992 Validation: 1993–1994 | CABG |
| Staat[32] | 1999 | France | Retrospective | 1996 | CABG |
| Pitkanen[36] | 2000 | Finland | Development: Retrospective Validation: Prospective | Development 1992–1996 Validation: 1998–1999 | Cardiac surgery |
| Dupuis[37] *Cardiac Anaesthesia Risk Evaluation Score (CARE)* | 2001 | Canada | Prospective | Development: 1996–1998 Validation: 1998–1999 | Cardiac surgery |
| Fortescue[35] *Quality Measurement and Management Initiative (QMMI) score* | 2001 | USA | Prospective | 1993–1995 | CABG |
| Wouters[30] *CORRAD score* | 2002 | Netherlands | Retrospective | Development: 1998 Validation: 1999–2000 | CABG |
| Huijskes[60] *Amphibia score* | 2003 | Netherlands | Retrospective | 1997–2001 | CABG ± valve surgery |
| Hsieh[27] | 2007 | Taiwan | Retrospective | 2004–2006 | Cardiac surgery (>80 years old) |
| Grinberg[22] *Valve, myocardial function, coronary artery disease, and pulmonary artery pressure (VMCP) score* | 2009 | Brazil | Retrospective | Not stated | Heart valve surgery |
| Afilalo[26] | 2012 | USA and Canada | Prospective | 2008–2010 | CABG ± valve replacement or repair (>70 years old) |
| Heringlake[28] | 2013 | Germany | Prospective | Development: 2009 Validation: 2008 | Cardiac surgery |
| Schoe[29] | 2014 | Netherlands | Prospective | 2006–2010 | Elective cardiac surgery |
| Tan[23] | 2015 | USA and Canada | Retrospective | USA: 2008–2010 Canada: 2010–2012 | Surgical AVR ± CABG. Also included aortic surgery |

*Continued*

**Table I** *Continued*

| Study (author, reference, and *model name* (where stated)) | Year published | Country | Design *(includes validation design where conducted)* | Data collection period | Population (surgery type) |
| --- | --- | --- | --- | --- | --- |
| LaPar[24] | 2018 | USA | Retrospective | 2002–2014 | Isolated tricuspid valve operations |
| O'Brien[25] *STS Adult Cardiac Surgery Risk Model* | 2018 | USA and Canada | Retrospective | Development: 2011–2014 Validation: 2014–2016 | Considered separately: CABG, Valve, and CABG and Valve |

that described the development of a preoperative risk assessment tool for postoperative morbidity after cardiac surgery. A complete reference list of all included studies is presented in Supplementary material online, *Table S1*.

## Study characteristics

The study characteristics of the 22 included studies are detailed in *Tables 1* and *2*. The majority of studies were conducted in the USA or Canada [$n = 12$ (54.5%)] (*Table 1*), with just over a quarter [$n = 6$ (27.3%)] published in the last 10 years. Equal proportions of tools were developed in mixed cohorts of cardiac surgery patients and those specifically undergoing CABG [$n = 9$ (40.9%)], four (18.2%) were developed specifically in valve surgery patients[22–25] and two focused on risk assessment in the elderly (>70 years;[26] >80 years[27]). More recently, focus has been on adapting existing models, for example, combining tools,[26] and adding biomarkers[28,29] and echo parameters.[23] Overall, development set sample sizes ranged from 152[26] to 670 830,[25] while almost all defined outcome within the in-hospital postoperative period [$n = 20$ (90.9%)]. Only one study included morbidity outcome up to 6 months after surgery.[30]

## Risk of bias

*Figure 2* demonstrates the risk of bias across studies. While the vast majority conducted the development of the models in an appropriate cohort of patients, just under half did not validate the model in a different group of patients. Furthermore, in almost three-quarters of studies performance or detection bias was detected or unclear, although the clinical prediction rule was clearly defined in over 75% of studies. Considering studies individually (*Figure 3*), only three studies demonstrated no bias in any category,[25,31,32] one study demonstrated bias in all categories and another was unclear in all but the sample population bias category.[33]

## Definition of postoperative morbidity

Across studies four broad types of definition of morbidity were used (*Table 2*). Two studies defined morbidity using a surrogate marker (LOS >12 days,[34] LOS >10 days[22]), while the majority ($n = 10$), and all studies pre-1996, defined morbidity and mortality separately but combined them to develop one model. Similarly, three further studies included death within the morbidity definition.[31,32,35] The construction of separate models for mortality and morbidity was first reported in 2000[36] with 7 of 12 studies (58.3%) from this time

defining and constructing a separate model for postoperative morbidity. However, within these models only two studies used the same definition of morbidity (Hsieh *et al.* 2007[27] used that of Dupuis *et al.* 2001[37]) (Supplementary material online, *Table S1*), highlighting the variation of morbidity definitions. The majority defined morbidity as severe morbidity, including a range of variables of varying definitions/criteria, while only Magovern *et al.*[31] defined morbidity as either a major or minor complication.

## Incidence of postoperative operative morbidity

Overall, the majority of studies ($n = 9$, 40.9%) reported postoperative morbidity incidence between 20% and 30%, although the range across studies was 4.3%[35] to 52%.[27,31] However, it is important to note that Hsieh *et al.*[27] only included those >80 years old and is considerably higher than that reported by Dupuis *et al.*[37] using the same morbidity definition but in a younger cohort. Equally, as highlighted previously, Magovern *et al.*[31] was the only study to include both major and minor complications (36% minor complication, 16% major complication). The reverse is true for Fortescue *et al.*[35] where only five serious adverse events were included in the morbidity definition (death, renal failure, myocardial infarction, cardiac arrest, stroke, and coma), which are uncommonly experienced after cardiac surgery.[38]

## Preoperative risk assessment model

Six models either used statements or categories to assess risk[22,37] or, as detailed previously, combined or modified existing scores.[23,26,28,29] Of the newly developed models, including those using EuroSCORE, the number of variables included in a model ranged from 6[32] to 50.[25] Overall, 94 variables were included across studies with the highly common variables identified as age ($n = 16$), emergency surgery ($n = 14$), left ventricular dysfunction/ejection function ($n = 14$), reoperation/previous cardiac surgery ($n = 13$), renal dysfunction/failure (including creatinine level categories) ($n = 11$), and gender ($n = 10$), where female gender was consistently identified as higher risk ($n = 8$) (Supplementary material online, *Table S1*). However, despite some variables being commonly included in the models, considerable variations in the definitions of the variables existed. For example, where categorized, eight different age, seven different left ventricular dysfunction/ejection function, and eight different renal function definitions were identified. Considering those models defining and measuring postoperative morbidity only ($n = 7$), the common

**Table 2** The model characteristics of each included model (*n* = 22): sample size, morbidity definition, timing of morbidity outcome, number of variables in the score, and morbidity rate

| Study (author and reference) | Sample size (development and validation) | [a]Morbidity definition for model development | Timing of morbidity outcome (e.g. in-hospital, 1 week) | [b]Number of variables in score (taken from text, where stated, otherwise counted from results table) | Morbidity rate (%) |
|---|---|---|---|---|---|
| Parsonnet[39] | Development: 3500 Validation: 300 | 2 | In-hospital[c] | 15 | 23.5 |
| Higgins[58] | Development: 5051 Validation: 4069 | 2 | In-hospital | 13 | 13.5 |
| Tuman[40] | Development: 3156 Validation: 394 | 2 | In-hospital[c] | 12 | 22.2 development 19.8 validation |
| Geraci[59] | Development: 2213 (split in half for development and validation) | 2 | Postoperative | 11 | 33 |
| Hattler[41] | Development: 728 No validation | 2 | Unclear—some done post-discharge | 17 | Not stated |
| Roques[33] | Development: 7181 No validation | 2 | In-hospital[c] | 8 | Not stated |
| Kurki[34] | Development: 386 No validation | 1 | In-hospital | 7 | Not stated |
| Magovern[31] | Development: 1567 Validation: 1235 | 3 | In-hospital[c] | 20 | 16 (major) 36 (minor) |
| Staat[32] | Development: 679 Validation: 226 | 3 | Postoperative | 6 | 23 |
| Pitkanen[36] | Development: 4592 Validation: 821 | 4 | Postoperative | 14 | 22.0 development 18.4 validation |
| Dupuis[37] | Development: 2000 Validation: 1548 | 1 and 2 | In-hospital | 6 (statements) | 20.7 development 22.2 validation |
| Fortescue[35] | Development: 6237 Validation: 3261 | 3 | Postoperative | 16 | 4.3 |
| Wouters[30] | Development: 653 Validation: 969 | 4 and 3 | Up to 6 months after surgery | 20 | 19.1 development 21 validation |
| Huijskes[60] | 7282 (split 2/3 for development and 1/3 for validation) | 4 and 3 | In-hospital | 8 | 17 |
| Hsieh[27] | Development: 199 Validation: 423 | 4 | In-hospital[c] | 13 | 51.6 |
| Grinberg[22] | Development: 768 No validation | 1 | In-hospital[c] | 4 categories each with 4 categories/statements in each | Not stated |
| Afilalo[26] | Development: 152 No validation | 2 | In-hospital | Not stated specifically but combines 5 metre-gait speed, STS-PROMM and Nagi scales | 24.3 |
| Heringlake[28] | Pooled datasets due to some loss of samples, and low event rate (3.4% mortality): 1452 | 4 | In-hospital[c] | 16[d] | 14.4 |

*Continued*

**Table 2** *Continued*

| Study *(author and reference)* | Sample size *(development and validation)* | [a]Morbidity definition for model development | Timing of morbidity outcome *(e.g. in-hospital, 1 week)* | [b]Number of variables in score *(taken from text, where stated, otherwise counted from results table)* | Morbidity rate (%) |
|---|---|---|---|---|---|
| Schoe[29] | Development: 679 No validation | 4 and 3 and 1 | In-hospital[c] | 16[d] | 27.5 |
| Tan[23] | Development: 432 No validation | 2 | In-hospital[c] | STS model (version or number of variables not stated) and echo parameters (3) | 20.4 |
| LaPar[24] | Development: 2050 No validation | 4 | Postoperative | 9 | 42% |
| O'Brien[25] | Development: 670 830 Validation: 579 335 | 2 | In-hospital[c] | CABG: 50 Valve: 45 CABG and Valve: 47 | All: 17.4 CABG: 15.0 Valve: 18.4 CABG and Valve: 28.3 |

[a]Morbidity definition codes: (1) morbidity defined using surrogate marker (all were hospital LOS); (2) specifically defined morbidity and mortality separately but included all outcomes in developing one model; (3) included death in the morbidity definition; and (4) defined mortality and morbidity separately and constructed separate models for each.
[b]The specific variables included for each model are available in Supplementary material online, *Table S1*.
[c]In-hospital outcome only inferred but not explicitly stated.
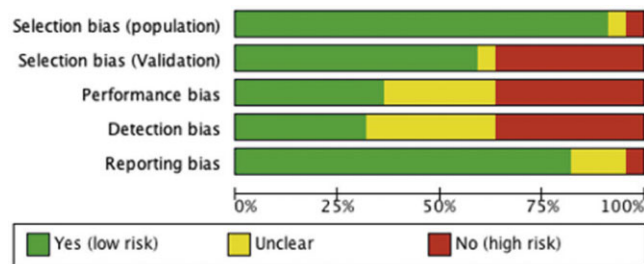[d]EuroSCORE used was additive/model 1[61] containing 15 variables.



**Figure 2** A summary of the overall risk of bias across all 22 studies included in *Tables 1* and *2*. Red = high risk of bias; Yellow = unknown risk of bias; Green = low risk of bias.

variables were similar and included age ($n = 7$), left ventricular dysfunction/ejection function ($n = 6$), renal dysfunction/failure (including creatinine level categories) ($n = 4$), combined surgery ($n = 4$), lung disease ($n = 4$), and gender ($n = 4$).

The discriminatory power of each model is shown in *Figure 4*, excluding three early models that did not report the area under the receiver operating characteristic curve (area under the ROC) or C-statistic.[39–41] Four studies demonstrated poor discriminatory power (0.6–0.7), while fair (0.7–0.8) or good (0.8–0.9) discriminatory power was demonstrated in two-thirds of the models [fair $n = 12$ (54.5%); good $n = 3$ (13.6%)]. No models demonstrated excellent discriminatory power (0.9–1.0).

# Discussion

The impact of postoperative morbidity after cardiac surgery, on in-hospital,[4] postdischarge,[8] physical health, and quality of life,[9] and the associated financial burden,[12] means that strategies to identify, predict and reduce morbidity after cardiac surgery are needed. Our systematic review identified 22 models of preoperative risk assessment of morbidity after cardiac surgery. There are several findings of note from these studies. Firstly, there is a recognition of a shift over time in how postoperative morbidity has been defined and measured as the relevance, impact, and importance of postoperative morbidity has heightened. Secondly, there remains ongoing challenges relating to varying morbidity definitions resulting in a multitude of prediction
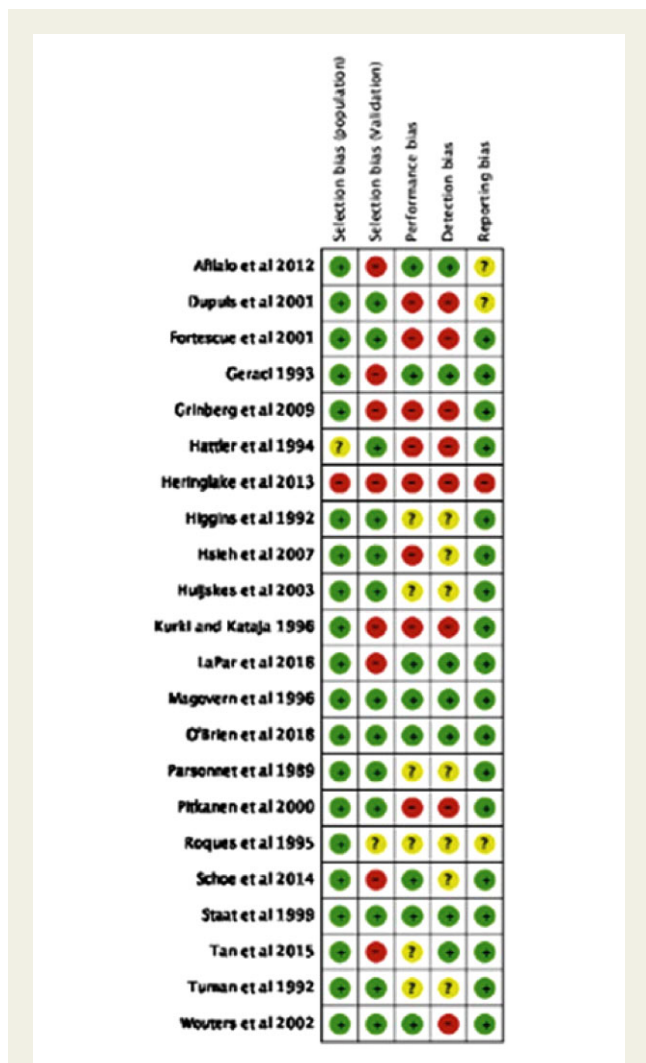
**Figure 3** The risk of bias of the 22 individual studies included in *Tables 1* and *2*. Red (−) = high risk of bias; Yellow (?) = unknown risk of bias; Green (+) = low risk of bias.



**Figure 4**

For the models listed in *Tables 1* and *2* [excluding three that studies that did not report the area under the receiver operating characteristic curve (area under the ROC) or C-statistic], the individual effect sizes (squares), and their confidence intervals (95%) are shown. The size of the square reflects the random effect weight assigned to each study. There is significant heterogeneity between the studies so the random effects estimate for the overall effect is 0.72 (0.69–0.75) (diamond). ROC, receiver operating characteristic curve.

models using different outcomes. Thirdly, there is still an overwhelming focus on in-hospital morbidity outcome despite the evidence supporting impact beyond discharge and potentially for several years and finally, only three models demonstrated 'good' discriminatory power while only one of the 22 models considered both major and minor complications. However, it is also interesting to note that morbidity outcome for those undergoing valve surgery is beginning to be considered separately from CABG with four models now available focusing on this patient group.

## Increasing age and risk profile

Cardiac surgery is experiencing an increasing age and risk profile of patients although mortality has continued to fall.[42] Despite this, considerable postoperative morbidity was reported in those over 70 years old (24.3%)[26] and 80 years old (51.6%).[27] Clearly, the differences in definition influence interpretation of these figures but there are two noteworthy points. Firstly, Hsieh *et al.* used the same
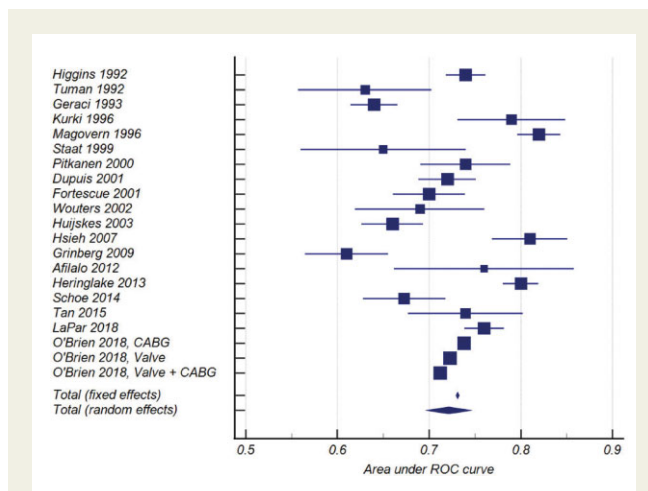
morbidity definition as the Cardiac Anaesthesia Risk Evaluation Score model,[37] which included all cardiac surgery patients and identified a morbidity rate of 20.7% in the development and 22.2% in the validation dataset. Secondly, Afilalo *et al.*[26] added frailty and disability scales to known mortality prediction tools and reported improved model discrimination (compared to mortality prediction alone) for postoperative morbidity. This suggests that elderly patients experience greater postoperative morbidity and that consideration of preoperative frailty and disability may be useful in predicting postoperative morbidity risk. As it is expected that any life expectancy gains over the next 20 years will be spent living with multiple complex morbidities, efforts on prevention and efficient service provision are needed.[43]

## Utility in practice

A fundamental challenge of clinical risk prediction scores is their utility in practice.[44] Since operative mortality has been found to be associated with both the number and severity of complications after cardiac surgery,[45] and operative mortality risk tools are routinely used in practice, it is not unreasonable to consider whether existing mortality risk prediction tools may also have value in morbidity prediction. Certainly, EuroSCORE, developed to predict operative mortality risk and used widely across Europe, has been applied to explore postoperative morbidity risk prediction. Indeed, two tools identified in this review[28,29] added biomarkers to the EuroSCORE to create new models. Unsurprisingly, due to its discriminatory power in predicting operative mortality, EuroSCORE appears to perform reasonably well in predicting overall in-hospital major morbidity incidence.[36,46] However, EuroSCORE only predicts some, but not all, major (e.g. stroke, acute renal failure, respiratory infection, bleeding, myocardial infarction) postoperative complications[46–49]

and these results are also inconsistent across studies. Equally, previous work has highlighted that different risk factors are associated with morbidity outcome as time from surgery progresses. Thus, accepted risk factors and models for operative mortality may only be useful for predicting morbidity risk in the first few critical days of recovery.[50] This principle may also be applied to the vast majority of models in this review, since almost all only considered in-hospital morbidity and major morbidities.

The 'holy grail' of prognostic factor research is to improve patient outcomes by providing a personalized approach to healthcare and risk prediction[51] and how these factors can be used to improve patient or treatment outcomes.[52] Clinical risk prediction scores are an important driver for person-centred care,[44] at a time when shared decision-making to meaningfully improve outcomes that are important to patients[53] is advocated. Specifically, in the UK, these currently include improving the outcomes of frail heart surgery patients and those with chronic conditions, including long-term outcomes.[54] Enhanced Recovery After Surgery cardiac programmes recognize the culture-shift to a person-centred system of care and the importance of the multidisciplinary team in this to optimize patient outcomes and experience.[55] Certainly, nurses and allied professionals working in primary care, optimization or preoperative clinics are ideally placed to use clinical risk prediction scores to provide this level of personalized care prior to surgery.[56]

Although few countries to date have reliably recorded postoperative morbidity after cardiac surgery,[14] efforts to do so are being progressed.[42,57] This provides the opportunity for more detailed and accurate identification, prediction, and subsequent reduction of postoperative morbidity in the future.

## Study limitations

This review has three main limitations. Firstly, no studies were excluded on the basis of the quality assessment. This was to enable full exploration of all the models available, although as the results detail, the studies were of varying quality. Secondly, we purposefully only included preoperative risk assessment tools, excluding those that included intraoperative (and postoperative) variables. If strategies to predict, and then subsequently reduce, postoperative morbidity after cardiac surgery are to be implemented, then preoperative risk assessment is necessary. Thirdly, due to the heterogeneity of the outcome definition and variations in methodological detail direct comparisons or undertaking a meta-analysis are not feasible. Despite this, our review, conducted with considerable methodological rigour (e.g. not employing any date restrictions, undertaking double independent searching, data extraction and quality assessments), is valuable in describing and summarizing the current evidence in this area to enable subsequent work to be undertaken to improve morbidity burden after cardiac surgery.

## Conclusion

In conclusion, this review identified 22 preoperative risk prediction tools for morbidity outcome after cardiac surgery. Those including minor morbidities, focusing on the elderly and including Growth Differentiation Factor 15 biomarker performed well. However, due to the methodological heterogeneity of studies, the lack of ability to undertake direct comparisons or a meta-analysis does limit the scope of conclusion that can be made as they all measure and predict

different factors. Certainly, obtaining consensus, both nationally and internationally, would be beneficial for future work. Despite this current lack of standardization, the review has highlighted that strategies to identify, predict and reduce morbidity after cardiac surgery should consider minor, as well as major morbidities, the impact of in-hospital complications on longer-term recovery and the increasing age, with accompanying multiple complex morbidities, of the current and future cardiac surgery population.

## Supplementary material

Supplementary material is available at *European Journal of Cardiovascular Nursing* online.

## Data Availability

There are no new data associated with this article.

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