DOI: 10.1111/jocs.14672

ORIGINAL ARTICLE

JOURNAL OF CARDIAC SURGERY WILEY

Right ventricular assessment can improve prognostic value of Euroscore II

Michele Di Mauro MD, PhD[1] | Roberto Scrofani MD[2] | Carlo Antona MD[2] | Francesca Nicolò MD[2] | Giangiuseppe Cappabianca MD[3] | Cesare Beghi MD[3] | Giuseppe Santarpino MD[4,5] | Renato Gregorini MD[4] | Luca Di Marco MD, PhD[6] | Davide Pacini MD[6] | Antonio Salsano MD[7] | Francesco Santini MD[7] | Luca Weltert MD[8] | Ruggero De Paulis MD[8] | Marco Pano MD[9] | Salvatore Zaccaria MD[9] | Alessandro D'Alfonso MD[10] | Marco Di Eusanio MD[10] | Francesco Massi MD[11] | Michele Portoghese MD[11] | Erik Cura Stura MD[12] | Mauro Rinaldi MD[12] | Vito Margari MD[13] | Massimiliano Foschi MD[14] | Alessandro Parolari MD[15] | Domenico Paparella MD[13]

[1]Cardio-Thoracic Surgery Unit, Heart and Vascular Centre, Cardiovascular Research Institute Maastricht (CARIM), Maastricht University Medical Centre (MUMC), Maastricht, The Netherland

[2]Department of Cardiac Surgery, "Fatebenefratelli-Sacco" Hospital, University of Milan, Milan, Italy

[3]Division of Cardiac Surgery, U.O. Cardiochirurgia Ospedale di Circolo e Fondazione Macchi, Varese, Italy

[4]Dipartimento di Cardiochirurgia, Città di Lecce Hospital-GVM Care & Research, Lecce, Italy

[5]Department of Cardiothoracic Surgery, Paracelsus Medical University, Nuremberg, Germany

[6]Cardiac Surgery Unit, Cardio-Thoracic-Vascular Deptartment, S.Orsola Hospital, University of Bologna, Bologna, Italy

[7]Department of Cardiac Surgery, IRCCS "S. Martino" University of Genova, Genova, Italy

[8]Department of Cardiac Surgery, European Hospital, Rome, Italy

[9]Department of Cardiac Surgery, "Vito Fazzi" Hospital, Lecce, Italy

[10]Department of Cardiac Surgery, Torrette-Riuniti Hospital, Ancona, Italy

[11]Department of Cardiac Surgery, AOU Sassari, Sassari, Italy

[12]Department of Cardiac Surgery, AOU "Città della Salute e della Scienza" Hospital, Turin, Italy

[13]Dipartimento dell'Emergenza e Trapianti d'Organo, Sezione di Cardiochirurgia, Università di Bari Aldo Moro. Ospedale Santa Maria, GVM Care & Research, Bari, Italy

[14]Heart Department, SS Annunziata Hospital, Chieti, Italy

[15]UOC Cardiac Surgery and Translational Research, IRCCS San Donato and University of Milan, San Donato Milanese, Italy

Correspondence
Michele Di Mauro, MD, PhD, Cardio-Thoracic Surgery Unit, Heart and Vascular Centre, Maastricht University Medical Centre (MUMC), Cardiovascular Research Institute Maastricht (CARIM), P. Debyelaan 25, 6202 AZ Maastricht, The Netherlands.
Email: mdimauro1973@gmail.com

Abstract

Background: The aim of this multicenter prospective study was to evaluate the prognostic weight of preoperative right ventricular assessment on early mortality in cardiac surgery.

Methods: This is a multicenter prospective observational study performed by the Italian Group of Research for Outcome in Cardiac Surgery (GIROC) including 11 centers. From October 2017 to March 2019, out of 923 patients undergoing cardiac surgery, 28 patients with some missing data were excluded and 895 patients were enrolled in the study right ventricular dilatation was defined as a basal end-diastolic diameter >42 mm. The right ventricle (RV) function was assessed using the combination of three parameters: fractional area changing (FAC), tricuspid annular plane systolic excursion (TAPSE), and S'-wave using tissue Doppler imaging (TDI-S'); RV dysfunction was defined as the presence of at least two of the following cutoffs: FAC <35%, TAPSE <17 mm, and TDI S' <9.5 mm

Results: Among the entire cohort, 624 (70%) showed normal RV, 92 (10%) isolated RV dilatation, 154 (17%) isolated RV dysfunction, and 25 (3%) both RV dilatation and dysfunction. Non-surviving patients showed a significantly higher rate of RV alteration at multivariable analysis, RV status was found to be an independent predictor for higher in-hospital mortality beside Euroscore II.

Conclusions: This prospective multicenter observation study shows the importance to assess RV preoperatively and to include both RV function and dimension in a risk score model such as Euroscore II to implement its predictivity, since PH cannot always mirror the status of the right ventricle.

KEYWORDS

Euroscore II, right ventricle, right ventricular dilatation, right ventricular dysfunction

1 | INTRODUCTION

The prognostic role of right ventricle has been clearly demonstrated in patients with myocardial infarction (MI),[1,2] heart failure (HF), either ischemic or not,[3,4] receiving cardiac resynchronization therapy,[5] and in small cohorts of patients undergoing cardiac surgery.[6-10] In last decades several risk score models were introduced to estimate perioperative risk in cardiac surgery, mainly Euroscore I and Euroscore II[11,12] and STS score.[13,14] However, while left ventricular function has been considered as risk factor in all of them, the right ventricle function and size have not been included.

Ghio et al[15] demonstrated in a heart failure model that certain patients have normal pulmonary pressure and low right ventricular ejection fraction (RVEF); they reported as this subset accounted for roughly 6% if patients with HF and their prognosis was similar to those patients with high pulmonary pressure but normal RVEF. In a cohort of patients undergoing mitral and tricuspid surgery, Di Mauro et al,[16] reported a subset of patients with normal systolic pulmonary artery pressure (sPAP) and abnormal right ventricle (RV) accounting for roughly 3%. Similarly in this study, the prognostic impact of RV on in-hospital mortality was independent from pulmonary hypertension (PH), and the presence of both PH and RV alteration showed the worst outcome.

So, although many surgeons and cardiologists consider systolic pulmonary pressure as mirror of right ventricular condition, there are some evidence that this is not particularly true.[15,16]

Hence, the aim of this multicenter study was to evaluate the weight of preoperative right ventricular assessment as add-on to implement Euroscore II.

2 | MATERIALS AND METHODS

2.1 | Study population

This is a multicenter prospective observational study performed by the Italian Group of Research for Outcome in Cardiac Surgery (GIROC), endorsed by The Italian Society for Cardiac Surgery (SICCH), including 11 centers. Inclusion criteria were: (a) patients undergoing cardiac surgery; (b) elective or urgent surgery; (c) complete preoperative echocardiogram with data regarding RV. Patients undergoing surgery on emergency or patients with technical difficulty to assess the right ventricle with 2D-TT echocardiogram were excluded. All the data were prospectively collected using SICCH database. The study was approved by IRB and ethical committee of all participating centers (Prot. 0086656|07/11/2017 Principal Ethical Committee). From October 2017 to March 2019, out of 923 patients undergoing cardiac surgery, 28 patients with some missing data were excluded and 895 patients were enrolled in the study

2.2 | Definition of terms, end-points, and echocardiography

All the variables collected in the dataset were defined according to Euroscore II.[13] The primary end-points were in-hospital mortality.

The right ventricle was assessed from a right ventricle-focused apical four-chamber view[17]: RV basal dimension is best estimated at end-diastole; right ventricular dilatation was defined as a basal end-diastolic diameter >42 mm. The RV function was assessed using the combination of three parameters: fractional area changing (FAC), tricuspid annular plane systolic excursion (TAPSE) and S'-wave using tissue Doppler imaging (TDI-S'); RV dysfunction was defined as the presence of at least two of the following cutoffs: FAC <35%, TAPSE <17 mm, and TDI S' <9.5 mm.[17]

Thus, RV status was classified as: 0 no dilatation and dysfunction; 1 isolated dilatation; 2 isolated dysfunction; 3 dilatation and dysfunction; RV alteration was defined as RV status from 1 to 3

Systolic pulmonary artery pressure was estimated using tricuspid regurgitation (TR) velocity using the simplified Bernoulli equation and combining this value with an estimate of the right atrium (RA) pressure. PH was defined as the presence of sPAP equal or higher than 31 mm Hg.[12]

2.3 | Statistics

The normal distribution of continuous variables was assessed by Kolmogorov-Smirnov test. Normally distributed variables are reported as mean and standard deviation; conversely non-normally distributed variables are reported as median and quartiles. Pairwise comparison was performed with i-test or the Mann-Whitney *U*-test in case of continuous variables and χ^2 with Fisher exact test in case of categorical variables. To verify the impact of RV-status beside Euroscore II, these two variables were tested using a parsimonious logistic regression model was built to identify the best predictors for early outcome. Results are reported as odds ratio (OR), 95% confidence limits (95CLs) and *P*-value. The final model was internally validated using bootstrapping. Receiver operating characteristic (ROC) curve was used to estimate the discrimination power of Euroscore II and Euroscore II plus RV dysfunction and/or dilatation (Euroscore + RV). The ROC curves were compared by DeLong test. Calibration of both risk model was assessed with Brie score. The effect on risk classification of adding anemia to the reference model was evaluated with the use of net reclassification improvement (category-free NRI)[18]

All the analyses were performed with SPSS (IBM Corp. IBM SPSS Version 24.0. Armonk, NY), Med-Calc (MedCalc Software bv, Ostend, Belgium) and R-project (Core Team 2013. R Foundation for Statistical Computing, Vienna, Austria); $P < .05$ was considered as the threshold for statistical significance.

3 | RESULTS

The mean age was 67 ± 12 (19-89 years) and 35% were females. Isolated coronary artery bypass grafting (CABG) was performed in 234 (31%), isolated non-CABG procedure in 313 (35%), two procedures in 234 (26%), and three procedures in 70 (8%) cases. All preoperative data are summarized in the Table 1.

Among the entire cohort, 624 (70%) showed normal RV, 92 (10%) isolated RV dilatation, 154 (17%) isolated RV dysfunction, and 25 (3%) both RV dilatation and dysfunction. Non-surviving patients showed a significantly higher rate of RV alteration as shown in the Figure 1.

Stratifying the entire cohort according to the presence of PH and RV status, 422 (47%) patients showed neither PH nor RV alteration, 202 (23%) showed PH but not RV alteration, 145 (16%) showed RV alteration but not PH, and 126 (14%) showed both conditions.

TABLE 1 Preoperative data

Age, y	67 ± 12
Female gender	311 (35%)
Smoker	291 (33%)
Hypertension	555 (62%)
Dyslipidemia	376 (42%)
NIDDM	141 (16%)
IDDM	70 (8%)
ECV	156 (17%)
Previous stroke	33 (4%)
CRF	
Moderate	127 (14%)
Severe	23 (3%)
Dialysis	7 (1%)
COPD	
Mild	25 (3%)
Moderate	39 (4%)
Severe	4 (0.5%)
Previous cardiac surgery	49 (6%)
NYHA class	
I	320 (36%)
II	286 (32%)
III	273 (31%)
IV	16 (2%)
CCS class	
1	54 (6%)
2	95 (11%)
3	104 (12%)
4	70 (8%)
EF (%)	56 ± 10
Moderate impairment	148 (17%)
Severe impairment	30 (3%)
PH	
Moderate	202 (23%)
Severe	43 (5%)
Elective surgery	668 (75%)
Urgent surgery	227 (25%)
Euroscore II	1.7 (1.0-3.1)

Abbreviations: CCS, Canadian Cardiovascular Society; COPD, chronic obstructive pulmonary disease; CRF, chronic renal failure; ECV, extracardiac vasculopathy; EF, ejection fraction; IDDM, insulin-dependent diabetes mellitus; NIDDM, non-insulin dependent diabetes mellitus; NYHA, New York Heart Association; PH, pulmonary hypertension.

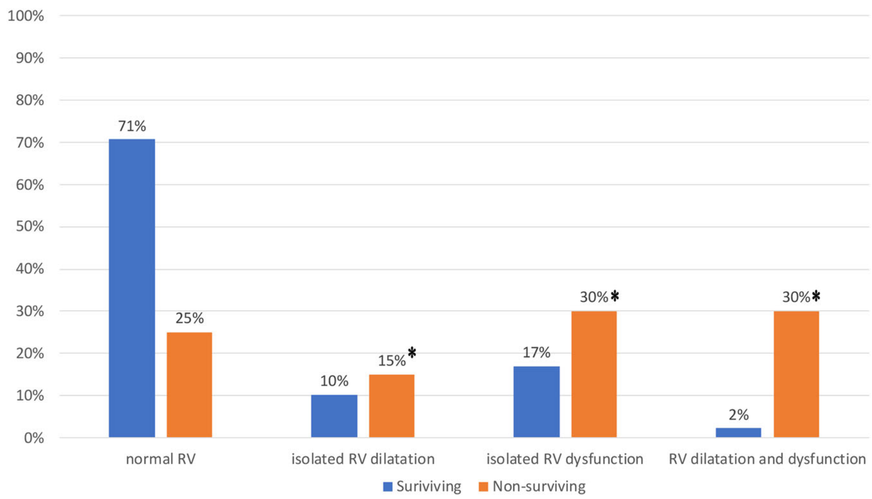

FIGURE 1 The rate of right ventricular (RV) dilatation and/or dysfunction between surviving (blue columns) and non-surviving (orange columns) patients

In-hospital mortality was 2.2% (20 cases). Surviving patients showed significantly higher TAPSE [22 mm (19-24) vs 19 mm (15-21); $P = .001$), TDI S' [14 cm/s (13-16) vs 11 cm/s (9-14), $P < .001$) and FAC [44% (39-49) vs 34% (32-39); $P < .001$) along with significantly less dilated RV [36 mm (33-40) vs 40 mm (35-43); $P = .025$) (Figures 2-3).

At multivariable analysis, RV status was found to be an independent predictor for higher in-hospital mortality (Table 2), beside Euroscore II. The Euroscore II showed an area under the curve (AUC) significantly lower than Euroscore II + RV (0.86, 0.84-0.88 vs 0.96, 0.94-0.97, difference 0.095, $P = .045$) (Figure 4). The net reclassification index was 0.5126 (0.0706-0.9545); P-value, .023. Calibration was similar: Brier score was 0.0197 for Euroscore II and 0.0196 Euroscore II + RV

The predicted mortality by Euroscore II + RV is closer to observed mortality than Euroscore II (Figure 5). This finding was confirmed also in subgroups: isolated CABG, isolated non-CABG, two or more procedures (Figure 6).

4 | DISCUSSION

The estimation of RV dimensions and function can be well achieved with cardiac magnetic resonance (CMR),[17] but preoperative evaluation cannot include routine CMR due to its cost, availability, and technical issues (PMK/ICD, claustrophobia, etc). In most of centers, even 3D echocardiography cannot be considered as a routine preoperative exam, since it is performed in

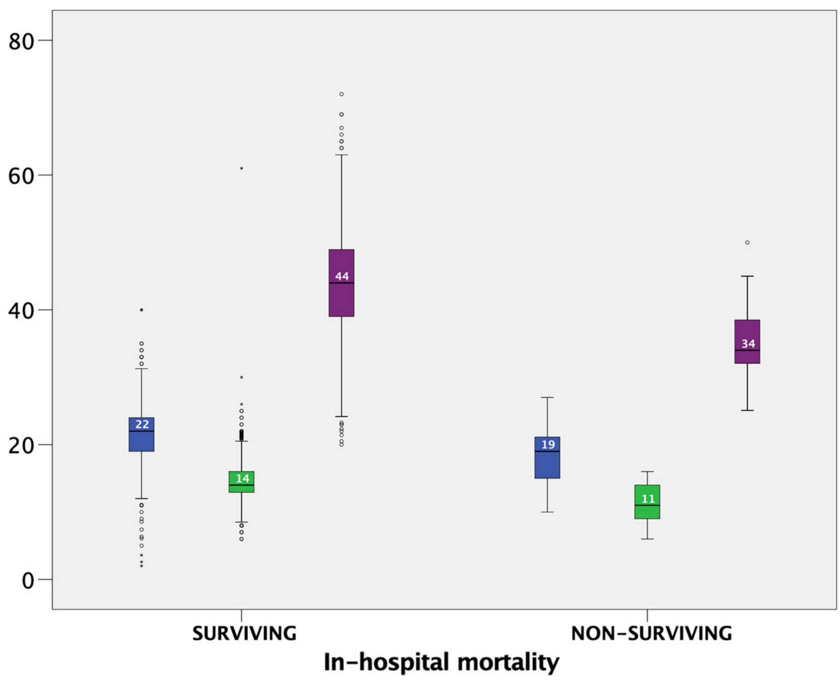

FIGURE 2 Preoperative right ventricular function comparing surviving and non-surviving patients; tricuspid annular plane systolic excursion (TAPSE, red box); tricuspid annular plane velocity by tissue Doppler pulse wave (TDI S', green box); fractional area change (FAC%, purple box)

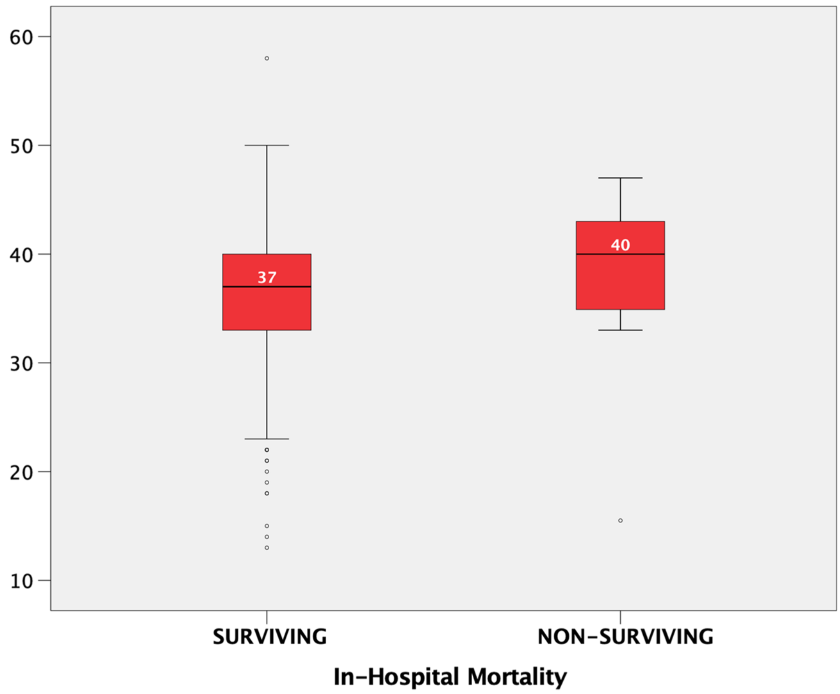

FIGURE 3 Preoperative right ventricular diameter comparing surviving and non-surviving patients; basal right ventricular diameter (red box)

TABLE 2 Multivariable analysis

	Beta-coefficient	OR	Lower 95%CL	Upper 95%CL	*P*-value
Euroscore II	0.053	1.054	1.024	1.085	<.001
Normal RV (ref.)					
Isolated RV dilatation	1.678	5.355	1.174	24.417	.030
Isolated RV dysfunction	1.790	5.991	1.679	21.383	.006
RV dilatation and dysfunction	3.813	45.298	11.840	173.311	<.001
Constant	−5.211				

Abbreviations: CL, confidence limits; OR, odds ratio; RV, right ventricle.

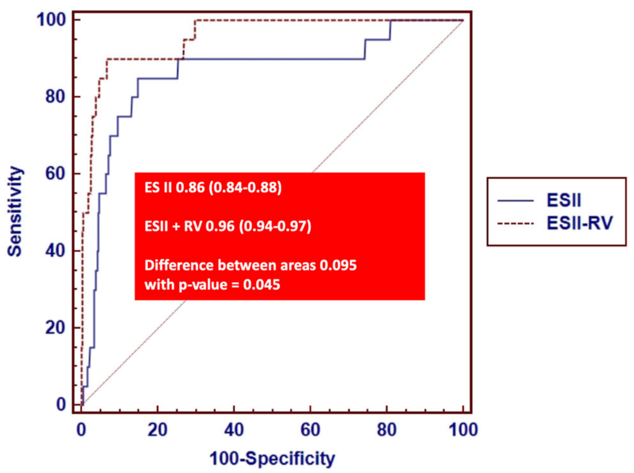

FIGURE 4 The Euroscore II showed an AUC significantly lower than Euroscore II + RV. AUC, area under the curve; RV, right ventricle

the operating room where hemodynamic conditions is somehow altered by the anesthesia. So, actually, 2D-echocardiography remains the easiest tool to assess RV function and size, playing a paramount role using surrogate index as TAPSE, FAC, or TDI S',[19] even with the limitation of a poor sonographic windows in some cases.

The importance of the right ventricle in cardiac surgery has been demonstrated in a variety of clinical settings such as CABG or valvular heart disease, congenital heart disease, heart transplantation, in patients requiring ventricular assist devices.[6-10] However, almost all the studies focusing on prognostic role of RV are retrospective with a small sample size, so the independent prognostic role of RV has not been well evidenced.

The present multicenter study account for roughly 900 cases, exploring the usefulness to add RV function and size to Euroscore II to avoid underestimation of the risk.

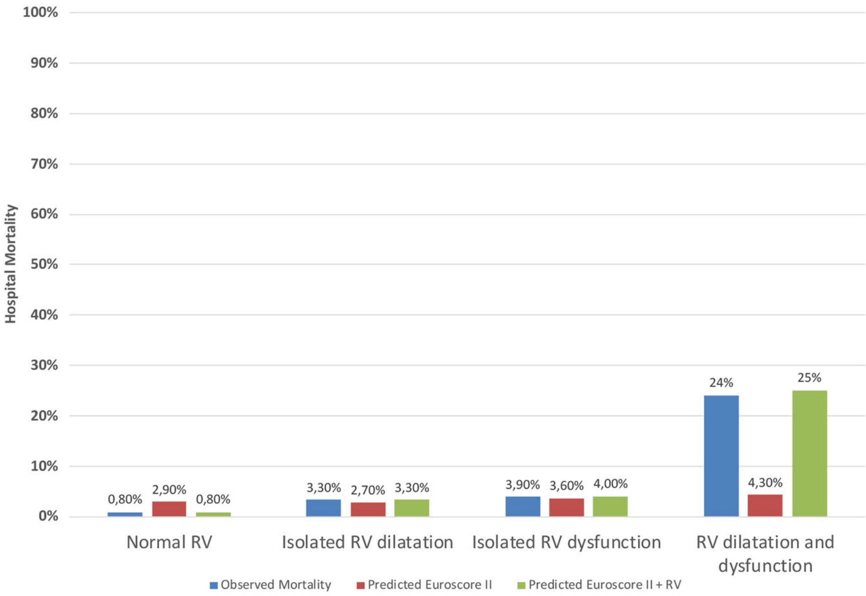

FIGURE 5 Observed (blue columns) versus predicted mortality by either Euroscore II (red columns) and Euroscore II + RV (green columns), stratified by right ventricular status. RV, right ventricle

In fact, in presence of a reduction of RV function or of low forward RV stroke volume, as in case of tricuspid regurgitation, pulmonary pressure can be normal or low, even in presence of high pulmonary resistances[20] Moreover, in case of RV volume overload and dilatation, the primary involvement of RV by myocardial disease or overtreatment with diuretic can reduce pulmonary pressure, but not necessarily influence the right ventricle prognostic role. In this condition, the actual predictive models underestimate the perioperative risk. Conversely, some patients show good RV function despite high pulmonary pressure; in fact, despite similar RV afterload not all the patients develop maladaptive RV hypertrophy, characterized by dilatation, ischemia, fibrosis, and then RV failure.[21] So, considering pulmonary hypertension strictly linked to right ventricular dysfunction and dilatation and vice versa is not always true, and this is particularly important in the case of prognosis assessment, even in cardiac surgery.[16]

In our series, PH and RV dilatation and/or dysfunction were present only in 14% of cases, while in 23% of cases patients had PH without any alteration of RV as well as in 16% of cases RV alteration was not associated with PH.

Longitudinal RV excursion is the major contributor to RV ejection, accounting for 80% of RV stroke volume.[22] Some reports demonstrated as patients undergoing cardiac surgery show a reduction of longitudinal RV contraction up to 40% that can persist even for

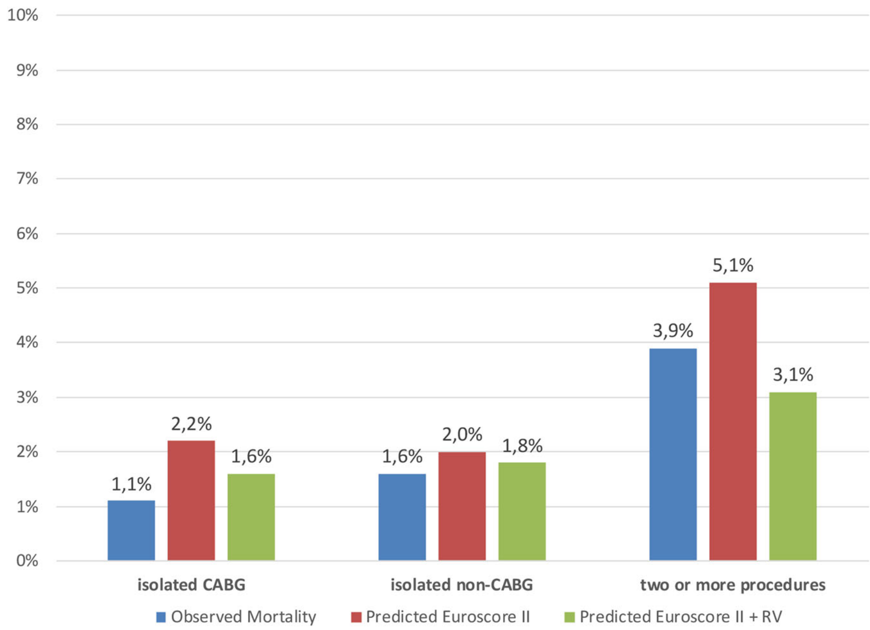

FIGURE 6 Observed (blue columns) vs predicted mortality by either Euroscore II (red columns) and Euroscore II + RV (green columns), stratified by weight of procedure: isolated CABG, isolated non-CABG, two or more procedures. CABG, coronary artery bypass grafting; RV, right ventricle

months after surgery.[23-25] Singh et al[26] have recently demonstrated in a cohort of 109 patients as the RV function reduction starts soon after CPB discontinuation, with the greatest change after chest closure, regardless of the procedure and the chest access; TAPSE decreased from 2.2 to 1.4 and FAC from 46% to 38%. This reduction seems to be CPB-correlated or due to cardioplegic arrest.[25-27] However, the real correspondence between surrogate echocardiographic indexes and RVEF in postoperative period remains still largely controversial. Some studies[24,28] reported preserved RVEF despite reduced echocardiographic TAPSE and TDI S', but, conversely, others defined TAPSE as a robust measure well correlating with RVEF[29]

Nevertheless, the reduction of RV function is well-tolerated in almost the patients with preoperative normal RV size and function, and normal RV afterload. Though, in presence of pre-existing RV alteration, surgery can be so deleterious to compromise the outcome. Therefore, the present study support the necessity to add RV assessment to actual risk models such as Euroscore II, showing a significant improvement of both calibration and discrimination power of the model.

The strength of the present study was to identify RV dilatation as well as RV dysfunction as risk factors independently from other pathological conditions already included into Euroscore II such as PH or COPD. This new stratification tool could be helpful to identify those patients with normal pulmonary pressure but RV dilatation and dysfunction, not only to merely establish the perioperative risk, but also to adopt all that strategies to prevent a further impairment of the right ventricle (off-pump surgery, lung protection, pulmonary vasodilatation, volume management) to be willing to treat postoperative RV failure (pulmonary vasodilatation, ventilatory management, ECLS).

4.1 | Practical implication

Using beta-coefficient and constant reported in the Table 2, Euroscore II + RV score model should become according to the following formula: exp[-5.211 + (EuroSCORE II x 0.53)+ 1.678 (in case of isolated RV dilatation) or +1.790 (in case of isolated RV dysfunction) or +3.813 in case of contemporary RV dilatation and dysfunction).

4.2 | Study limitations

The right ventricular dysfunction was assessed by TAPSE, FAC, and TDI S' that, although are well correlated with RVEF,[30] ignores the outlet portion and the septal contribution to RV ejection, which may become important to maintain overall RV function. Moreover, neither 3D echocardiographic RV assessment nor novel echocardiographic indexes as speckle tracking was used. Another limitation is the small number of events (only 20) is a limitation for the multivariable analysis according to the role of thumb 1:10. Finally, the most important limitation of the study is the use of the internal rather than an external validation, as consequent we have such an extremely high discrimination value (0.96) for the new ES II + RV model. So, this model deserves to be validated in a larger and different cohort of patients undergoing cardiac surgery.

5 | CONCLUSIONS

Although the above-mentioned limitations, this prospective multicenter observational study confirms the importance to assess RV preoperatively and to include both RV function and dimension in a risk score model such as Euroscore II to implement its predictivity, since PH cannot always mirror the status of the right ventricle.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ORCID

Michele Di Mauro http://orcid.org/0000-0003-2611-5626
Francesca Nicolò http://orcid.org/0000-0003-0377-8638
Giuseppe Santarpino http://orcid.org/0000-0002-4913-9834
Luca Weltert http://orcid.org/0000-0001-6094-8280
Domenico Paparella http://orcid.org/0000-0003-2261-7098

REFERENCES

1. Zornoff LA, Skali H, Pfeffer MA, et al. Right ventricular dysfunction and risk of heart failure and mortality after myocardial infarction. *J Am Coll Cardiol*. 2002;39:1450-1455.
2. Larose E, Ganz P, Reynolds HG, et al. Right ventricular dysfunction assessed by cardiovascular magnetic resonance imaging predicts poor prognosis late after myocardial infarction. *J Am Coll Cardiol*. 2007;49: 855-862.
3. Ghio S, Recusani F, Klersy C, et al. Prognostic usefulness of the tricuspid annular plane systolic excursion in patients with congestive heart failure secondary to idiopathic or ischemic dilated cardiomyopathy. *Am J Cardiol*. 2000;85:837-842.
4. Kjaergaard J, Akkan D, Iversen KK, Køber L, Torp-Pedersen C, Hassager C. Right ventricular dysfunction as an independent predictor of short- and long-term mortality in patients with heart failure. *Eur J Heart Fail*. 2007;9:610-616.
5. Scuteri L, Rordorf R, Marsan NA, et al. Relevance of echocardiographic evaluation of right ventricular function in patients undergoing cardiac resynchronization therapy. *Pacing Clin Electrophysiol*. 2009;32: 1040-1049.
6. Di Mauro M, Calafiore AM, Penco M, Romano S, Di Giammarco G, Gallina S. Mitral valve repair for dilated cardiomyopathy: predictive role of right ventricular dysfunction. *Eur Heart J*. 2007;28:2510-2516.
7. Maslow AD, Regan MM, Panzica P, Heindel S, Mashikian J, Comunale ME. Pre cardiopulmonary bypass right ventricular function is associated with poor outcome after coronary artery bypass grafting in patients with severe left ventricular systolic dysfunction. *Anesth Analg*. 2002;95:1507-1518.
8. Haddad F, Denault AY, Couture P, et al. Right ventricular myocardial performance index predicts perioperative mortality or circulatory failure in high-risk valvular surgery. *J Am Soc Echocardiogr*. 2007;20: 1065-1072.
9. Chrustowicz A, Gackowski A, El-Massri N, Sadowski J, Piwowarska W. Preoperative right ventricular function in patients with organic mitral regurgitation. *Echocardiography*. 2010;27:282-285.

10. Garatti A, Castelvecchio S, Di Mauro M, Bandera F, Guazzi M, Menicanti L. Impact of right ventricular dysfunction on the outcome of heart failure patients undergoing surgical ventricular reconstruction†. *Eur J Cardiothorac Surg*. 2015;47(2):333-340.
11. Nashef SA, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R. European system for cardiac operative risk evaluation (EuroSCORE). *Eur J Cardiothorac Surg*. 1999;16:9-13.
12. Chalmers J, Pullan M, Fabri B, et al. Validation of EuroSCORE II in a modern cohort of patients undergoing cardiac surgery. *Eur J Cardiothorac Surg*. 2013;43:688-694.
13. Shahian DM, O'Brien SM, Filardo G, et al. The society of thoracic surgeons 2008 cardiac surgery risk models: Part 1—coronary artery bypass grafting surgery. *Ann Thorac Surg*. 2009;88(1 suppl):S2-S22.
14. O'Brien SM, Shahian DM, Filardo G, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: Part 2—isolated valve surgery. *Ann Thorac Surg*. 2009;88(1 suppl):S23-S42.
15. Ghio S, Gavazzi A, Campana C, et al. Independent and additive prognostic value of right ventricular systolic function and pulmonary artery pressure in patients with chronic heart failure. *J Am Coll Cardiol*. 2001;37:183-188.
16. Di Mauro M, Foschi M, Tancredi F, et al. Additive and independent prognostic role of abnormal right ventricle and pulmonary hypertension in mitral-tricuspid surgery. *Int J Cardiol*. 2018;252:39-43.
17. Kossaify A. Echocardiographic assessment of the right ventricle, from the conventional approach to speckle tracking and three-dimensional imaging, and insights into the "right way" to explore the forgotten chamber. *Clin Med Insights Cardiol*. 2015;9:65-75.
18. Pencina MJ, D'Agostino RB Sr, Steyerberg EW. Extensions of net reclassification improvement calculations to measure usefulness of new biomarkers. *Stat Med*. 2011;30:11-21.
19. Mooij CF, de Wit CJ, Graham DA, Powell AJ, Geva T. Reproducibility of MRI measurements of right ventricular size and function in patients with normal and dilated ventricles. *J Magn Reson Imaging*. 2008;28:67-73.
20. Ling LF, Marwick TH. Echocardiographic assessment of right ventricular function: how to account for tricuspid regurgitation and pulmonary hypertension. *JACC Cardiovasc Imaging*. 2012;5:747-753.
21. Rich S, Pogoriler J, Husain AN, Toth PT, Gomberg-Maitland M, Archer SL. Long-term effects of epoprostenol on the pulmonary vasculature in idiopathic pulmonary arterial hypertension. *Chest*. 2010;138:1234-1239.
22. Brown SB, Raina A, Katz D, Szerlip M, Wiegers SE, Forfia PR. Longitudinal shortening accounts for the majority of right ventricular contraction and improves after pulmonary vasodilator therapy in normal subjects and patients with pulmonary arterial hypertension. *Chest*. 2011;140:27-33.
23. Raina A, Vaidya A, Gertz ZM, Susan C, Forfia PR. Marked changes in right ventricular contractile pattern after cardiothoracic surgery: implications for postsurgical assessment of right ventricular function. *J Heart Lung Transplant*. 2013;32:777-783.
24. Tamborini G, Muratori M, Brusoni D, et al. Is right ventricular systolic function reduced after cardiac surgery? A two- and three-dimensional echocardiographic study. *Eur J Echocardiogr*. 2009;10:630-634.
25. Schuuring MJ, Bolmers PP, Mulder BJ, et al. Right ventricular function declines after cardiac surgery in adult patients with congenital heart disease. *Int J Cardiovasc Imaging*. 2012;28:755-762.
26. Singh A, Huang X, Dai L, et al. Right ventricular function is reduced during cardiac surgery independent of procedural characteristics, reoperative status, or pericardiotomy. *J Thorac Cardiovasc Surg*. 2019;(19):30930-30934. https://doi.org/10.1016/j.jtcvs.2019.04.035. pii: S0022-5223.
27. Bitcon CJ, Tousignant C. The effect of pericardial incision on right ventricular systolic function: a prospective observational study. *Can J Anaesth*. 2017;64:1194-1201.
28. Maffessanti F, Gripari P, Tamborini G, et al. Evaluation of right ventricular systolic function after mitral valve repair: a two-dimensional Doppler, speckle-tracking, and three-dimensional echocardiographic study. *J Am Soc Echocardiogr*. 2012;25:701-708.
29. Garcia Gigorro R, Renes Carreño E, Mayordomo S, et al. Evaluation of right ventricular function after cardiac surgery: the importance of tricuspid annular plane systolic excursion and right ventricular ejection fraction. *J Thorac Cardiovasc Surg*. 2016;152:613-620.
30. Ueti OM, Camargo EE, Ueti Ade A, de Lima-Filho EC, Nogueira EA. Assessment of right ventricular function with Doppler echocardiographic indices derived from tricuspid annular motion: comparison with radionuclide angiography. *Heart*. 2002;88:244-248.

How to cite this article: Di Mauro M, Scrofani R, Antona C, et al. Right ventricular assessment can improve prognostic value of Euroscore II. *J Card Surg*. 2020;1–8.
https://doi.org/10.1111/jocs.14672