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Comparative analysis of different risk prediction tools after mitral Transcatheter edge-to-edge repair

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ABSTRACT

Background: Transcatheter edge-to-edge repair (TEER) has become an established treatment for primary and secondary mitral regurgitation (PMR and SMR). The objective of this study was to compare the accuracy of different risk scores for predicting 1-year mortality and the composite endpoint of 1-year mortality and/or heart failure (HF) hospitalization after TEER.

Methods: We analyzed data from 206 patients treated for MR at a tertiary European center between 2011 and 2023 and compared the accuracy of different mitral and surgical risk scores: EuroSCORE II, GRASP, MITRALITY, MitraScore, TAPSE/PASP-MitraScore, and STS for predicting 1-year mortality and the composite of 1-year mortality and/or HF hospitalization in PMR and SMR. A subanalysis of SMR-only patients with the addition of COAPT Risk Score and baseline N-Terminal pro-Brain Natriuretic Peptide (NT-proBNP) list was also performed.

Results: MITRALITY had the best discriminative ability for 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization, with an area under the curve (AUC) of 0.74 and 0.74, respectively, in a composed group of PMR and SMR. In a SMR-only population, MITRALITY also presented the best AUC for 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization, with values of 0.72 and 0.72, respectively.

Conclusion: MITRALITY was the best mitral TEER risk model for both 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization in a population of PMR and SMR patients, as well as in SMR patients only. Surgical risk scores, MitraScore, TAPSE/PASP-MitraScore and NT-proBNP alone showed poor predictive values.

1. Introduction

Mitral regurgitation (MR) is a common heart valvular disorder with impaired quality of life and overall survival. [1,2] MR is classified as primary (PMR), when its etiology is attributable to a structural or degenerative change in the mitral leaflets; and secondary (SMR), when MR occurs in the absence of primary mitral valve disease, usually as a consequence of left ventricular or atrial dysfunction [3]. Transcatheter edge-to-edge repair (TEER) is a minimally invasive procedure that has emerged as an effective treatment option for selected patients with PMR and SMR [4,5].

However, not all MR patients respond in the same way to TEER [6,7]. The validity of traditional surgical risk scores, such as STS and EuroSCORE II, in predicting outcomes post-TEER remains uncertain, with modest predictive accuracy for 1-year mortality [8]. Hence, a major effort has been made to develop accurate risk stratification scores to improve TEER patient selection. Multiple models have been developed for this purpose, including COAPT, GRASP, MITRALITY, and MitraScore [9–12]. Furthermore, novel models with additional echocardiographic data emerged to improve the accuracy of established scores, such as the

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addition of tricuspid annular plane systolic excursion (TAPSE) and pulmonary artery systolic pressure (PASP) ratio to MitraScore [13]. Finally, N-Terminal pro-Brain Natriuretic Peptide (NT-proBNP) has also been shown to have valuable predictive ability for mortality and heart failure (HF) hospitalization after TEER and is a core variable in some risk score models [10,11].

The objective of this study was to compare the accuracy of different risk prediction tools for 1-year mortality and the composite endpoint of 1-year mortality and/or heart failure (HF) hospitalization in patients after TEER for MR at a European tertiary center.

2. Methods

2.1. Study population and protocol

This single-center retrospective study included consecutive patients treated for MR at Erasmus University Medical Center between 2011 and 2023. Indications for TEER included PMR and SMR. The choice of device (MitraClip and PASCAL), and strategy was left at the discretion of the operators. All procedures were executed by the same first operator (N.M. V.M.). Details regarding MitraClip and PASCAL generations are available in **Supplemental Table 1**. Exclusion criteria for the present study were as follows: (1) previous surgical mitral valve repair or replacement, (2) prior mitral TEER, (3) age < 18 years, (4) mixed MR etiology and (5) no information on MR etiology. The study was approved by the Medical

Table 1
Mitral transcatheter edge-to-edge repair risk scores analyzed.

Risk score	Authors	Population	Outcome and AUC	Variables
Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients with Functional Mitral Regurgitation (COAPT) risk score, *JACC Cardiovascular Interventions*, 2022 [9]	Shah N, Madhavan MV, Gray WA, Brener SJ, Ahmad Y, Lindenfeld J, et al	Secondary MR patients	2-year mortality and/or HF hospitalization AUC: 0.74	- Chronic kidney disease (CKD): estimated glomerular filtration rate (eGFR) < 60 mL/min/1.73m^2 or lower - New York Heart Association (NYHA) class III or higher - Chronic obstructive pulmonary disease (COPD) - Atrial fibrillation or flutter history - Right ventricular systolic pressure (RVSP) > 45 mmHg or higher - Left ventricle ejection fraction (LVEF): if ≤35% or lower - Left ventricular end-systolic diameter (LVESD) > 5.5 cm or higher - Tricuspid regurgitation (TR) > mild or greater Guideline-directed medical therapy (GDMT) alone
Getting Reduction of mitrAl inSufficiency by Percutaneous clip implantation (GRASP) Risk Score, *American Journal of Cardiology*, 2017 [10]	Buccheri S, Capodanno D, Barbanti M, Popolo Rubbio A, Di Salvo ME, Scandura S, et al	Primary and secondary MR	1-year mortality AUC: 0.78	- N-terminal pro–brain natriuretic peptide (NT-proBNP) - Mean arterial pressure (MAP) - NYHA class IV - Hemoglobin
MITRALITY score, *JACC Cardiovascular Interventions*, 2021 [11]	Zweck E, Spieker M, Horn P, Iliadis C, Metze C, Kavsur R, et al	Primary and secondary MR	1-year mortality AUC: 0.78	- Blood urea nitrogen (BUN) - Body mass index (BMI) - Hemoglobin - NT-proBNP - Creatinine
MitraScore, *Journal of the American College of Cardiology*, 2022 [12]	Raposeiras-Roubin S, Adamo M, Freixa X, Arzamendi D, Benito-González T, Montefusco A, et al	Primary and secondary MR	1-year mortality AUC All MR: 0.70 AUC Functional MR: 0.69 1-year mortality and/or HF hospitalization AUC All MR: 0.67 AUC Functional MR: 0.65	- Age ≥ 75 years or older - LVEF <40% - Anemia - CKD: if eGFR <60 mL/min/1.73m^2 or lower - Peripheral artery disease - COPD - High dose of diuretic: if ≥80 mg of furosemide/daily or use of ≥2 diuretic agents excluding antialdosteronic drugs - No therapy with renin-angiotensin system (RAS) drugs
TAPSE/PASP-MitraScore, *Journal of the American Society of Echocardiography*, 2023 [13]	Shechter A, Vaturi M, Kaewkes D, Koren O, Koseki K, Solanki A, et al	Primary and secondary MR	1-year mortality and/or HF hospitalization AUC All MR: 0.71 AUC Functional MR: 0.69 1-year mortality AUC All MR: 0.70 AUC Functional MR: 0.67	- TAPSE/PASP ratio of 0.37 added to MitraScore

COAPT = Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients with Functional Mitral Regurgitation; CKD = chronic kidney disease; eGFR = estimated glomerular filtration rate; COPD = chronic obstructive pulmonary disease; RVSP = right ventricular systolic pressure; LVEF = left ventricle ejection fraction; LVESD = left ventricular end-systolic; TR = tricuspid regurgitation;
GDMT = guideline-directed medical therapy; GRASP = Getting Reduction of mitrAl inSufficiency by Percutaneous clip implantation; NT-proBNP = N-terminal pro–brain natriuretic peptide; MAP = mean arterial pressure; BUN = blood urea nitrogen; BMI = body mass index; RAS = renin-angiotensin system.

Ethics Committee of the Erasmus University Medical Center and the need for individual informed consent was waived due to the retrospective and anonymous nature of the study. The following dedicated scores for mitral TEER were evaluated: COAPT Risk Score [9], GRASP [10], MITRALITY [11], MitraScore [12] and TAPSE/PASP-MitraScore [13], as summarized in Table 1. Two general surgical risk scores were examined: EuroSCORE II and STS [14–16]. Pre-intervention NT-proBNP was analyzed by electrochemical luminescent immunoassay (Cobas 8000; Roche Diagnostics GmbH, Mannheim, Germany). The endpoints of interest were 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization. Clinical outcomes were defined according to M-VARC criteria [17,18]. HF hospitalization was defined by the Universal Definition of HF [19]. Data was obtained from hospital and administrative records from the Dutch National Register of Deceased Persons. Clinical follow-up was assessed at 1 year.

2.2. Doppler echocardiographic measurements

Transthoracic echocardiographic (TTE) examination was performed before mitral intervention and upon hospital discharge. All patients had at least one pre-intervention TTE showing moderate-to-severe or severe MR. Echocardiographic parameters were measured using the methods recommended by the American Society of Echocardiography guidelines [20,21]. MR severity was assessed by TTE using a combination of both qualitative and quantitative parameters, such as effective regurgitant orifice area (EROA), regurgitant volume (RVol), and regurgitant fraction (RF) [22,23].

2.3. Statistical analysis

Categorical variables are reported as n (%). Continuous variables are expressed as mean and standard deviation or median and 25th - 75th percentiles, depending on distribution normality, which was assessed by Kolmogorov-Smirnov test and kernel density plots. All mitral TEER risk scores were reconstructed from baseline variables, based on their description in the original reports [9–16]. To assess the discriminative abilities of the analyzed risk scores and cardiac biomarkers, area under the curves (AUC) were calculated using the R package "pROC" version 1.18.0. All analyzes were performed using R Statistical Software (version 4.3.0, Foundation for Statistical Computing, Vienna, Austria).

3. Results

A total of 237 consecutive patients who received mitral TEER in our center between 2011 and 2023 were evaluated for inclusion. 31 patients were excluded, of which 10 had previous surgical mitral valve repair or replacement, another 10 had undergone prior mitral TEER, 10 had mixed MR, and 1 was under 18 years old. The study population consisted of the remaining 206 patients. Clinical, echocardiographic, procedural characteristics and outcomes of the overall study population and the SMR-only population are shown in Table 2. MitraClip was used in 188 (91%) cases and PASCAL in 18 (9%). PMR was present in 60 (29%) patients and SMR in 146 (71%).

3.1. Clinical outcomes and predictive accuracy of risk prediction tools

After 1 year, 45 patients (22%) in the overall population died. The cumulative endpoint of 1-year mortality and/or HF hospitalization occurred in 69 (33.5%) of the available patients. In the SMR-only population, there were 34 (23%) deaths after 1 year. The composite endpoint of 1-year mortality and/or HF hospitalization occurred in 54 (37%) of the available patients.

ROC curves of the analyzed risk scores for 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization are shown in Fig. 1.**A** and Fig. 1.**B**, respectively. EuroSCORE II score displayed an area under the curve (AUC) value of 0.61 (95% CI: 0.51–0.71)

Table 2
Clinical, echocardiographic, and procedural characteristics of the study population.

	Overall population ($n = 206$)	SMR-only ($n = 146$)
Clinical variables		
Age, years	74.5 [67–81.3]	72.9 [65.1–77.6]
Male	134 (65)	96 (66)
Mitral dysfunction etiology		
Primary	60 (29)	
Secondary	146 (71)	146 (100)
NYHA functional class		
II	41 (20)	30 (21)
III-IV	165 (80)	116 (80)
Diabetes mellitus	47 (23)	39 (27)
Hypertension	142 (69)	100 (68)
Prior percutaneous coronary intervention	80 (39)	62 (42)
Prior coronary artery bypass graft	45 (22)	37 (25)
Atrial fibrillation	125 (60)	88 (60)
Cerebrovascular disease	14 (7)	7 (5)
Peripheral vascular disease	26 (13)	20 (14)
Chronic obstructive pulmonary disease	33 (16)	24 (17)
eGFR, mL/min	45 [32–59]	44 [30–57]
Clinical Frailty	85 (41)	55 (38)
STS-PROM score, %	2.8 [1.8–5.5]	2.8 [1.7–5.7]
EuroSCORE II, %	4.8 [2.9–8.3]	5.7 [3.1–9.9]
Hemoglobin (g/dl)	12.7 ± 1.9	12.7 ± 1.8
N-terminal B-type natriuretic peptide (pg/ml)	358 [192–684]	449.3 [240–807]
Echocardiographic variables pre-procedure		
Left atrium size, cm	5.1 [4.7–5.7]	5.1 [4.7–5.7]
Left atrium volume, mm^2	137 [111.9–175.2]	137 [112.5–176.5]
LVEF, %	37 [27–55]	32 [24.2–44.7]
LVESD, cm	5.2 [4.2–6.3]	5.6 [4.7–6.5]
LVEDD, cm	6.2 [5.5–7]	6.4 [5.7–7.2]
LVESV, mL	130 [85–177]	135 [101–194]
LVEDV, mL	189 [146–242]	205 [165–247]
PASP >55, mmHg	32 (19)	25 (21)
TAPSE	18 [14–21]	18 [14–20]
Right ventricle systolic pressure, mmHg	43 [32–58]	41 [32.7–56]
RVPA coupling, ratio	0.41 [0.28–0.57]	0.38 [0.27–0.55]
Procedural characteristics and outcomes*		
Device		
MitraClip	188 (91)	133 (91)
PASCAL	18 (9)	13 (9)
Technical success	192 (93)	137 (94)
Moderate or less mitral regurgitation at discharge	181 (88)	124 (85)
Periprocedural death	10 (5)	5 (3)
Acute Kidney Injury		
Stage 1	16 (8)	9 (6)
Stage 2	4 (2)	3 (2)
New atrial fibrillation	6 (3)	4 (3)
Vascular Complications		
Major	6 (3)	2 (1)
Minor	3 (2)	2 (1)
Stroke	1 (1)	1 (1)

Values are n (%), mean ± SD or median [IQR].
SMR = secondary mitral regurgitation; STS-PROM = Society of Thoracic Surgeons Predicted Risk of Mortality; EuroSCORE II = European System for Cardiac Operative Risk Evaluation predicted risk of in-hospital mortality; LVEDD = left ventricular end-diastolic diameter; LVESV = left ventricular end-systolic volume; LVEDV = left ventricular end-diastolic volume; PASP = pulmonary artery systolic pressure; TAPSE = tricuspid annular plane systolic excursion; RVPA = right ventricle to pulmonary artery. Other abbreviations as in Table 1.
* Following M-VARC criteria [17,18].

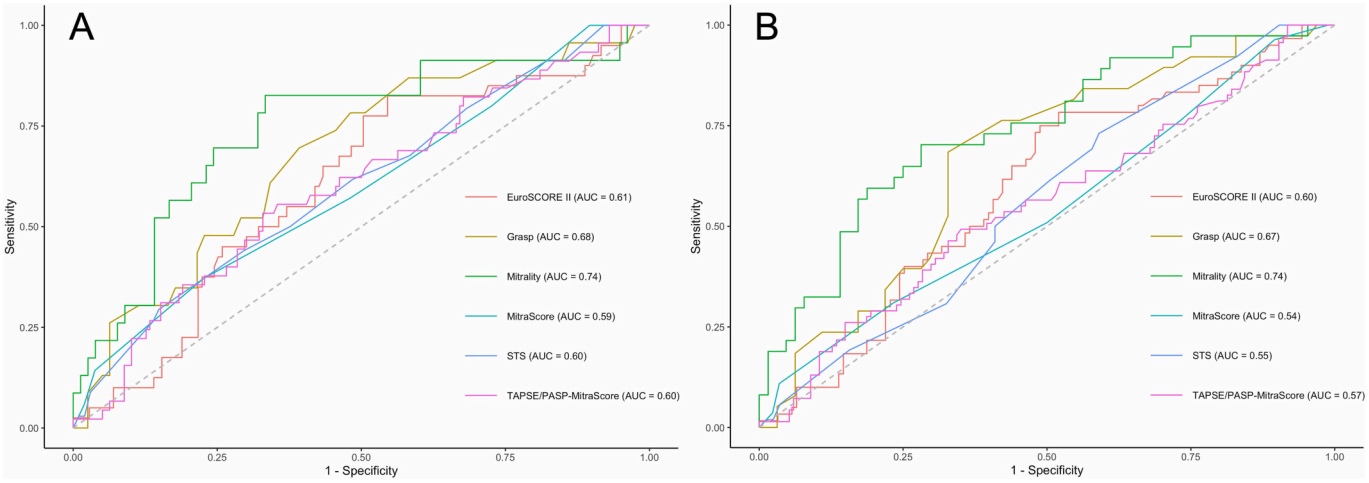

Fig. 1. ROC curves of different risk models for 1-year mortality (A) and for the composite endpoint of 1-year mortality and/or HF hospitalization (B). Confidence interval (CI); area under the curve (AUC).

for 1-year mortality and 0.60 (95% CI: 0.51–0.69) for the composite endpoint of 1-year mortality and/or HF hospitalization. GRASP presented an AUC value of 0.68 (95% CI: 0.56–0.81) and 0.67 (95% CI: 0.56–0.78), respectively. MITRALITY showed an AUC value of 0.74 (95% CI: 0.62–0.87) and 0.74 (95% CI: 0.64–0.84), respectively. MitraScore had an AUC value of 0.59 (95% CI: 0.49–0.71) and 0.54 (95% CI: 0.45–0.64), respectively. TAPSE/PASP-MitraScore had an AUC value of 0.60 (95% CI: 0.50–0.72) and 0.57 (95% CI: 0.47–0.67), respectively. Finally, STS showed an AUC value of 0.60 (95% CI: 0.51–0.69) and 0.55 (95% CI: 0.47–0.64), respectively.

Analyses of 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization for SMR after TEER, with additional inclusion of the COAPT Risk Score and baseline NT-proBNP, are shown in Fig. 2.**A and 2.B**, respectively. COAPT Risk Score showed an AUC value of 0.59 (95% CI: 0.47–0.72) for 1-year mortality and 0.66 (95% CI: 0.56–0.76) for the composite endpoint of 1-year mortality and/or HF hospitalization. EuroSCORE II score displayed an AUC value of 0.62 (95% CI: 0.52–0.73) and 0.61 (95% CI: 0.52–0.72), respectively. GRASP presented an AUC value of 0.65 (95% CI: 0.51–0.79) and 0.63 (95% CI: 0.51–0.76), respectively. MITRALITY showed an AUC value of 0.72 (95% CI: 0.58–0.86) and 0.72 (95% CI: 0.61–0.84), respectively. MitraScore had an AUC value of 0.53 (95% CI: 0.45–0.68) and 0.52 (95% CI: 0.42–0.63), respectively. TAPSE/PASP-MitraScore had an AUC value of 0.56 (95% CI: 0.45–0.70) and 0.54 (95% CI: 0.43–0.64), respectively. Baseline NT-proBNP presented an AUC value of 0.59 (95% CI: 0.45–0.73) and 0.58 (95% CI: 0.45–0.70) for both 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization in SMR. Finally, STS displayed an AUC value of 0.64 (95% CI: 0.54–0.74) and 0.59 (95% CI: 0.49–0.68), respectively.

4. Discussion

The present study evaluated the discriminative ability of multiple risk scores for TEER in patients with MR. The main findings were as follows: (1) the MITRALITY model showed the best accuracy for mortality or the composite of 1-year mortality and/or HF hospitalization in a composed population of PMR and SMR; (2) in a SMR-only population, MITRALITY remained the best predictive models for 1-year mortality or the composite of 1-year mortality and/or HF hospitalization; and (3) surgical risk scores, MitraScore, TAPSE/PASP-MitraScore and NT-proBNP alone showed poor discriminative ability for both 1-year mortality and the composite of 1-year mortality and/or HF hospitalization in a composed population of PMR and SMR.

TEER is an established option for symptomatic patients with MR who

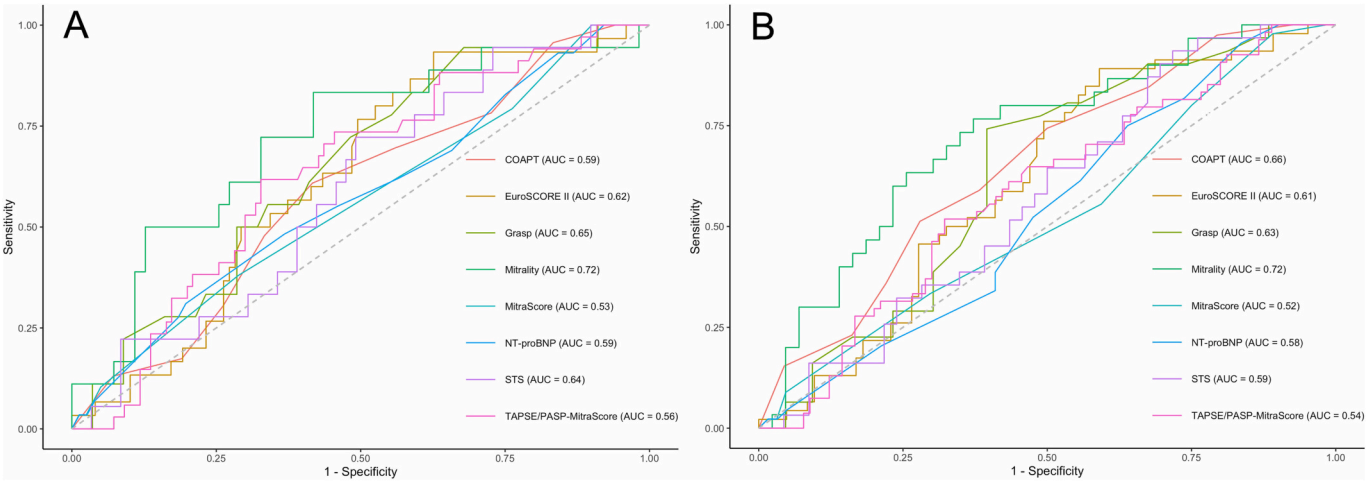

Fig. 2. ROC curves of different risk models for secondary MR for 1-year mortality (A) and for the composite endpoint of 1-year mortality and/or HF hospitalization (B).
N-terminal pro-Brain Natriuretic Peptide (NT-proBNP). Other abbreviations as in Fig. 1.

fulfill the eligibility echocardiographic criteria, and are deemed inoperable or at high surgical risk by the Heart Team [5]. Recent data have found TEER to be safe and result in lower hospitalization for HF rates and decreased mortality compared with medical therapy alone over a 5-year follow-up period [24]. In recent years, TEER eligible patients presented with lower surgical risk scores, higher prevalence of NYHA III, and lower NT-pro-BNP baseline level when compared to patients in the first years of TEER experience [25]. This shift indicates TEER uptake is expanding towards patients with longer life expectancy [26]. Therefore, accurate risk stratification is important to ensure proper patient selection.

4.1. Risks scores for overall TEER

We compared the accuracy of different baseline risk stratification tools in our cohort of 206 mitral TEER patients. The MITRALITY score displayed the best discriminative capability for both 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization, with acceptable AUC values of 0.74 and 0.74, respectively. In its original paper MITRALITY likewise outperformed other compared scores, with a 1-year mortality AUC of 0.78 [11]. This risk score also performed best in an external validation article [27]. In the original MITRALITY paper, machine-learning was applied to create a 1-year mortality score based on six variables derived from univariable analysis: baseline levels of hemoglobin, urea, creatinine, NT-proBNP, body mass index (BMI) and mean arterial pressure (MAP) [11]. The GRASP model for 1-year mortality was the second best model in our cohort, and displayed an AUC value of 0.68 as compared with 0.78 in its original publication [10]. The same AUC value of 0.68 for 1-mortality has also been reported in an external validation paper [27]. GRASP is based on four variables: NT-proBNP, MAP, NYHA class IV and hemoglobin [10].

Although MitraScore is simple to calculate, it exhibited no statistically significant discriminative value in our population, with an AUC value of 0.59 for 1-year mortality and 0.54 for 1-year mortality and/or HF hospitalization. These findings are lower than the 0.70 and 0.67 in the original study [12]. It is important to note the different risk profile in the MitraScore paper, yielding higher mortality rates of 31.9% after 1.6 years of follow-up in the original paper, as compared to 22% at 1-year in the present study. The addition of right ventricular-pulmonary artery coupling through the ratio of TAPSE and PASP only slightly improved the model's performance, to an AUC of 0.60 for 1-year mortality and 0.57 for 1-year mortality and/or HF hospitalization, as opposed to an AUC of 0.71 for 1-year mortality and/or HF hospitalization in its original publication [13]. It is important to consider that these scores were derived from both PMR and SMR cohorts, which are known to have heterogenous clinical outcomes [2]. Conventional surgical risk scores such as EuroSCORE II and STS have never been well validated for 1-year mortality prediction and showed an AUC of 0.61 and 0.60, respectively. This is similar to other studies published in the literature, with AUC values of 0.67 for EuroSCORE II and 0.61 for STS [8].

4.2. Risks scores for SMR

In our cohort of SMR only, MITRALITY outperformed the other scores, with an AUC of 0.72 for 1-year mortality and 0.72 for 1-year mortality or HF hospitalization. GRASP was the second-best model for 1-year mortality, but presented a lower AUC for the composed endpoint of 1-year mortality or HF hospitalization. COAPT Risk Score, which was derived from a strictly SMR population, has a reported AUC value of 0.74 for 2-year mortality or HF hospitalization [9]. In an external validation paper, *Adamo* et al. found a lower AUC value of 0.62 for the composite endpoint of 2-year mortality or HF hospitalization [28]. In our cohort, we found an AUC value of 0.59 for 1-year mortality and of 0.66 for 1-year mortality or HF hospitalization in SMR patients using COAPT Risk Score. A possible explanation for COAPT's underperformance is that HF hospitalizations can be underreported in real-life registries [28]. Finally, the COAPT Risk Score was designed for a 2-year follow-up; and, as our analysis was restricted to 1-year follow-up, this might have underestimated the score's predictive ability. MitraScore also had poor AUC in SMR-only, with values of 0.53 and 0.52 for 1-year mortality and for 1-year mortality or HF hospitalization, respectively.

TAPSE/PASP-MitraScore displayed a slight improvement, with AUC values of 0.56 and 0.54 for 1-year mortality and for 1-year mortality or HF hospitalization. The original validation paper reported an AUC value of 0.69 for 1-year mortality or HF hospitalization in SMR [13]. The lower AUC value in our population may be explained by different patient populations in both studies. EuroSCORE II showed an AUC of 0.63 and 0.61 for 1-year mortality and for 1-year mortality or HF hospitalization, respectively, performing better than some dedicated TEER scores in our analysis for SMR. STS demonstrated a similar performance in a SMR-only population, with AUC values of 0.64 and 0.59 for 1-year mortality and for 1-year mortality or HF hospitalization, respectively.

4.3. NT-proBNP for predicting outcomes

NT-proBNP correlated well with mortality in several publications [10,11,29,30]. Interestingly, despite successful TEER, NT-proBNP has been shown to remain fairly unchanged during follow-up and changes in NT-proBNP levels appeared poor predictors of functional improvement or clinical outcomes after MitraClip treatment [31]. In our cohort, we found an AUC of 0.59 for 1 year mortality and an AUC of 0.58 for 1-year mortality and/or HF hospitalization using baseline NT-proBNP, which corroborates NT-proBNP as a poor predictor for clinical outcomes after TEER.

5. Limitations

Our study has limitations. First, it is a single-center observational analysis with inherent selection bias and a relatively small sample size. Nevertheless, it is important to emphasize that the study population reflects contemporary clinical practice, with similar outcomes to those reported in the literature. Second, both the analyzed clinical outcomes and the echocardiographic measures were not adjudicated by a central committee and a core laboratory. Third, our analysis was limited to 1-year of follow-up, which is shorter than the 2-year follow-up time frame of some of the risk scores. Finally, HF hospitalizations may have been underreported whereas mortality checks were derived from and confirmed in the Dutch civil registry. Nonetheless, this limitation is commonly encountered in real-life research.

6. Conclusion

MITRALITY was the best mitral TEER risk model for both 1-year mortality and the composite endpoint of 1-year mortality and/or HF hospitalization in a population of PMR and SMR patients as well as SMR patients only.

Disclosures

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All other authors have reported that they have no relationship relevant to the content of this paper to disclose.

CRediT authorship contribution statement

Mauricio Felippi de Sá Marchi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Mark van den Dorpel:** Data curation, Investigation, Writing – original draft. **Pedro Calomeni:** Formal analysis, Writing – review & editing. **Sraman Chatterjee:** Data curation, Writing – review & editing. **Rik Adrichem:** Data curation, Writing – review & editing. **Sarah Verhemel:** Data curation, Writing – review & editing. **Antoon J.M. Van Den Enden:** Data curation, Writing – review & editing. **Joost Daemen:** Resources, Writing – review & editing. **Isabella Kardys:** Formal analysis, Methodology, Writing – review & editing. **Henrique Barbosa Ribeiro:** Supervision, Writing – review & editing. **Nicolas M. Van Mieghem:** Conceptualization, Project administration, Resources, Supervision, Writing – review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2024.131768.

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