

Evolution of treatment for isolated tricuspid regurgitation in the transcatheter era

Nicola Buzzatti ^{1,2,*}, Nicolò Azzola Guicciardi^{1,2}, Carlo Gaspardone^{2,3}, Paolo Denti ^{1,2}, Cristiano Sarais², Francesco Ancona ^{2,4}, Cosmo Godino^{2,3}, Eustachio Agricola ^{2,4}, Michele De Bonis ^{1,2}, Alberto Margonato^{2,3}, Ottavio Alfieri ^{1,2}, Marco Metra^{2,3}, and Francesco Maisano^{1,2}

¹Department of Cardiac Surgery, Vita-Salute San Raffaele University, IRCCS Ospedale San Raffaele, Via Olgettina 60, 20132 Milan, Italy; ²Heart Valve Center, Vita-Salute San Raffaele University, IRCCS Ospedale San Raffaele, Via Olgettina 60, 20132 Milan, Italy; ³Department of Cardiology, Vita-Salute San Raffaele University, IRCCS Ospedale San Raffaele, Milan, Italy; and ⁴Department of Cardiac Imaging, Vita-Salute San Raffaele University, IRCCS Ospedale San Raffaele, Milan, Italy

Received 21 October 2025; revised 31 December 2025; accepted after revision 12 January 2026; online publish-ahead-of-print 9 April 2026

Abstract

Background

Tricuspid regurgitation has historically been neglected or treated too late. Outcomes of tricuspid surgery have been plagued by high mortality. Recently, transcatheter therapies have emerged as a promising alternative.

Aims

To assess the changes in tricuspid regurgitation patients' referral, treatment, and in-hospital outcomes before and after transcatheter technologies became established at our centre.

Methods and results

We retrospectively reviewed our in-hospital data from patients with isolated $\geq$ moderate-to-severe tricuspid regurgitation referred for correction between January 2012 and December 2023. We compared two periods: before (2012–2017) and after (2018–2023) the widespread adoption of transcatheter procedures. A total of 348 patients were referred. Admissions rose from 108 (2012–2017) to 240 (2018–2023), reflecting a +12.4% annual growth ($P < .001$). Surgical treatment decreased from 68.5% to 37% ($P < .001$), while transcatheter interventions increased from 3.7% to 44% ($P < .001$) and indication to medical therapy alone declined from 27.8% to 19% ($P = .046$). Patients' risk profile remained similar over time (TriScore 7% vs 8%, $P = .64$). In-hospital mortality for tricuspid correction dropped from 10.3% to 3.6% ($P = .039$), but residual regurgitation $\geq 3+$ rose from 2.6% to 16.3% ($P < .001$).

Conclusions

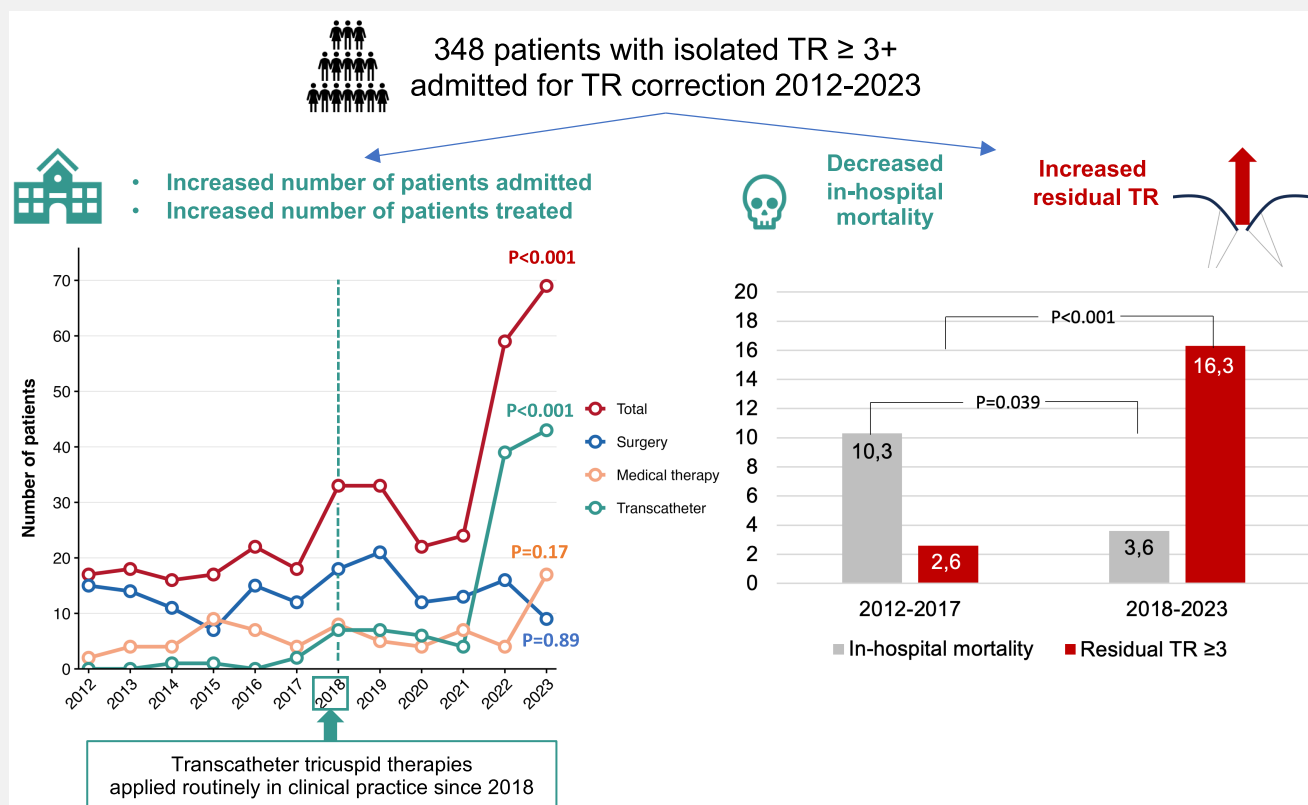
After the advent of transcatheter therapies, more patients with isolated tricuspid regurgitation were referred and received correction. In the last years, transcatheter therapies became the most used method to treat tricuspid regurgitation. Procedural mortality fell, however residual regurgitation was more common. Patients' risk profile remained similar.

* Corresponding author. Tel: +390226437102, Fax +390226437125, Email: buzzatti.nicola@hsr.it

© The Author(s) 2026. Published by Oxford University Press on behalf of the European Society of Cardiology.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Graphical Abstract



Twelve-year evolution of isolated tricuspid regurgitation treatment. After the advent of transcatheter therapies, more patients were admitted for tricuspid regurgitation correction and more patients received treatment, with reduced in-hospital mortality but increased residual tricuspid regurgitation.

Keywords

Tricuspid regurgitation • T-TEER • Triclip • TTVR • Tricuspid repair • Tricuspid replacement

Introduction

Tricuspid regurgitation (TR) has recently emerged from decades of neglect.¹⁻³ Its recognition has been a slow process, much like the gradual onset of its clinical consequences. Initially, TR is often well tolerated and easily managed with diuretics for an extended period.⁴ However, by the time symptoms persist despite escalating medical therapy, right ventricular dysfunction has often set in. Historically, patients were frequently referred for surgery at this late stage, where operative mortality becomes discouragingly high due to right ventricular failure. This, in turn, reinforced delayed and infrequent referral, perpetuating a vicious cycle that kept TR an underrated and undertreated condition.⁵

Over the past decade, transcatheter technologies have revolutionized TR management, rapidly increasing cardiological awareness on the matter. Indeed, early outcomes of transcatheter tricuspid interventions demonstrated excellent safety profiles, even in high-risk patients, offering the potential to shift the treatment paradigm⁶ and current guidelines now suggest transcatheter therapies for selected patients.⁷

The San Raffaele Hospital Valve Centre has been a tertiary referral centre for surgical treatment and, more recently, for transcatheter therapy of TR. It is therefore the ideal setting to analyse the impact of the introduction of transcatheter therapies on patients' referral, treatment choices for TR correction, and in-hospital outcomes. This study aims to evaluate the evolution of TR treatment before and after the introduction of transcatheter technologies and to assess the

changes of patients' in-hospital outcomes in the real-world clinical practice at the San Raffaele Hospital Valve Centre.

Methods

Patient selection

Case records of all patients admitted for TR treatment at the San Raffaele Hospital Valve Centre from January 2012 to December 2023 (12 years) with isolated moderate-severe or worse ($\geq 3+$) TR were reviewed. Patients with concomitant other valve pathology $\geq$ moderate-to-severe ($\geq 3+$) as well as with untreated severe coronary artery disease or other severe diseases requiring treatment were excluded (ascending aorta replacement, atrial fibrillation ablation, left atrial appendage closure, left ventricular assist device implantation, [Supplementary Figure S1](#)). Concomitant atrial septal defect ($n = 9$) and patent foramen ovalis ($n = 8$) closures were included.

Data collection

Data on patients' baseline characteristics, pre-procedural echocardiographic parameters, intra-procedural features, and post-procedural in-hospital outcomes were collected through the Department's prospectively filled in database and from patients' medical records for all patients.

Through retrospective analysis of each patient's medical record and echocardiogram, the recently developed TriScore⁸ was calculated and TR

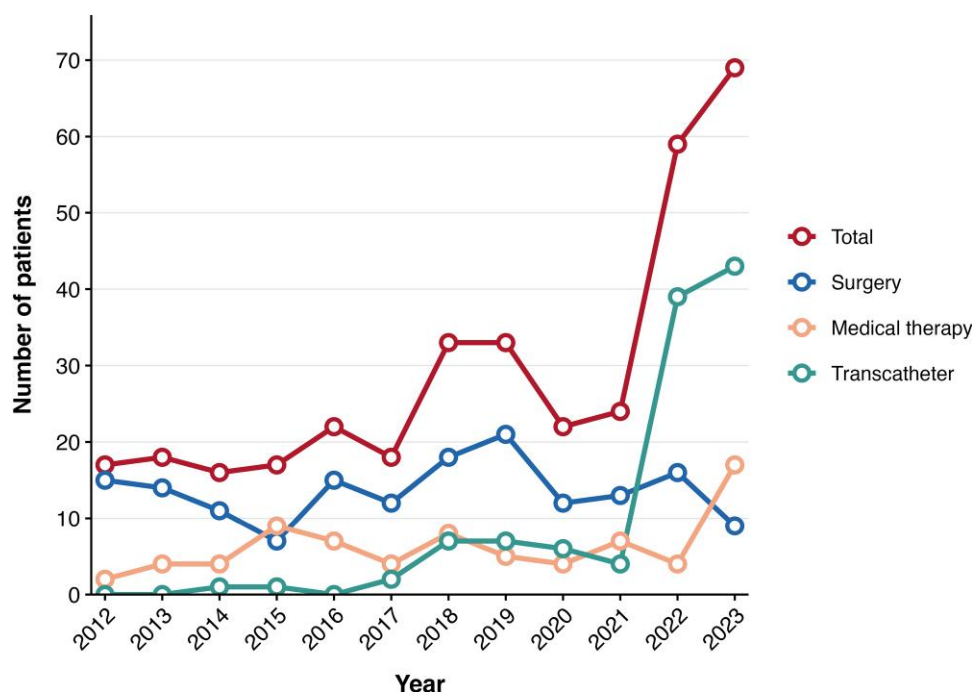


Figure 1 Annual number of admissions for correction of isolated tricuspid regurgitation (TR) $\geq 3+$ according to treatment received

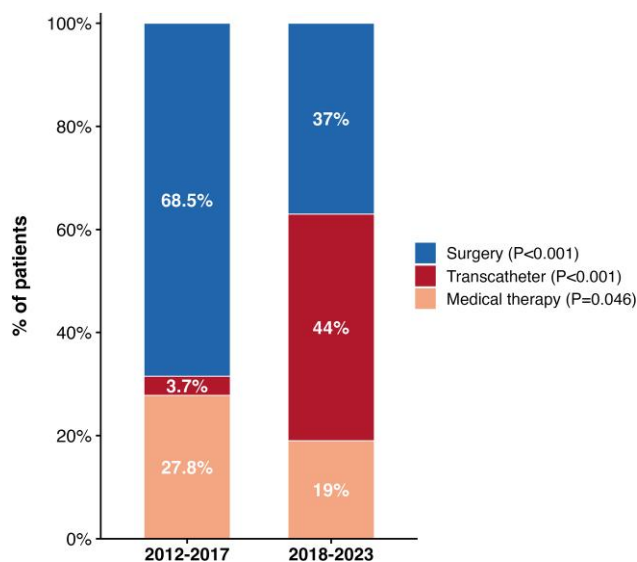


Figure 2 Percentages of treatments before (2012–2018) and after (2018–2023) transcatheter therapies introduction

mechanism was classified as primary, atrial, ventricular, and cardiac implantable electronic devices (CIED) related.⁹

TR was graded using a multiparametric approach as none, mild 1+, moderate 2+, moderate-to-severe 3+, and severe 4+ until 2017; from 2017 massive 5+ and torrential 6+ were added to the clinical practice.^{10,11} However, since TR grading beyond severe could not be retrospectively reliably re-adjudicated for all patients before 2017, for the purpose of the present manuscript we reclassified all 'massive' and 'torrential' cases into 'severe' to

avoid inconsistencies in grading over time. Post-procedural residual TR was measured after the procedure before discharge.

Right ventricle (RV) dimensions and contractile function are presented through mid-diameter, base diameter, tricuspid annular plane systolic excursion (TAPSE), tissue Doppler imaging (TDI), and free wall strain (FWS). According to Tricuspid Valve Academic Research Consortium Definitions, to help to describe right ventricular assessment, right ventricular dysfunction was also classified for all patients as absent, mild

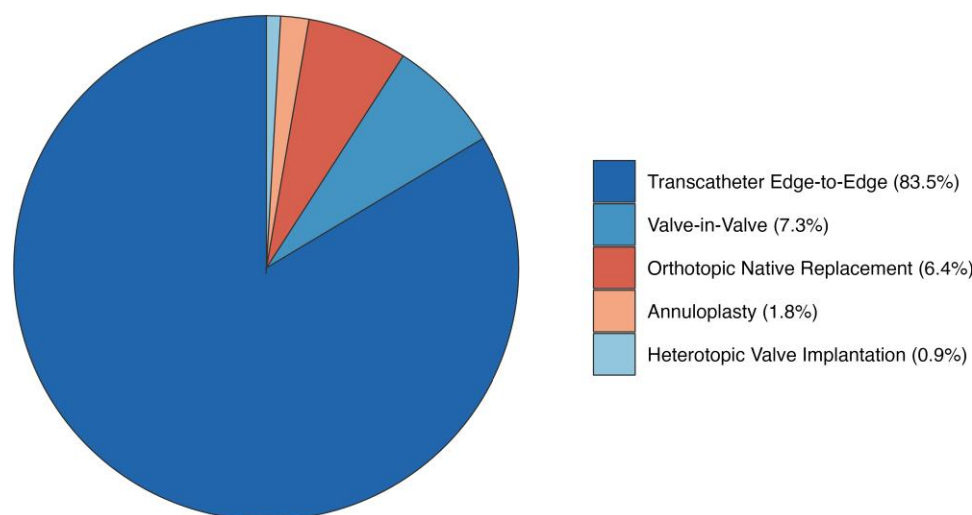


Figure 3 Proportions of transcatheter therapies applied during the study period

(TAPSE 14–17 mm, TDIs' 9–11 cm/sec, FWS 20–23%), moderate (TAPSE 10–13 mm, TDIs' 6–8 cm/s, FWS 15–19%), or severe (TAPSE <10 mm, TDIs' <6 cm/s, FWS <15%).¹¹

Data analysis

Before 2018, only rare attempts at transcatheter tricuspid treatment were performed. In 2018, transcatheter tricuspid edge-to-edge became routine clinical practice at our centre and was immediately applied consistently, making transcatheter treatment a real option for the patients. Therefore, we divided the study population into two groups: patients admitted during the 2012–2017 period (6 years) and those admitted from 2018 to 2023 (6 years). We then compared the characteristics and outcomes between these two groups. The study aims were to assess:

- The change in the number of patients admitted for TR correction.
- The change in the number of TR treatments performed (surgery, transcatheter, medical therapy).
- The change in in-hospital mortality after TR correction.

The study was approved by the competent Ethics Committee. Given the retrospective nature of the study and the use of completely anonymized data, the administration of informed consent was waived in accordance with the applicable regulations.

Statistical analysis

Statistical analysis was performed using RStudio (Posit Software, version 2023.09.1 + 494).

Continuous variables are presented as mean $\pm$ standard deviation for data with a normal distribution or as median (25th and 75th percentile limits in brackets) for data with a non-Gaussian distribution. Categorical variables are expressed as proportions. Univariable comparisons have been performed using the paired *t*-test for normally distributed data. For non-normally distributed data, Wilcoxon Signed Rank Test was used for paired continuous and Mann–Whitney test for unpaired continuous variables. The χ^2 test and Fisher's exact test were used for categorical data. Compound annual growth rates from 2012 to 2023 and the Jonckheere trend test were calculated to study temporal trends over time. A two-sided *P*-value < .05 was considered significant.

Results

A total of 348 patients (20% out of 1742 screened) were admitted for isolated TR correction and included in the study analysis; 163 treated surgically, 110 treated by transcatheter procedures, and 75 who remained on medical therapy.

Figure 1 illustrates the temporal trends of patients over 12 years (2012–2023). The annual number of admissions for isolated TR $\geq 3+$ increased from 17 in 2012 to 69 in 2023, with a compound annual growth rate of +12.4% ($P < .001$). Patient growth rates varied by treatment group: -4.17% per year for surgical intervention ($P = .89$), +45.6% per year for transcatheter therapy ($P < .001$), and +19.5% per year for medical therapy alone ($P = .174$).

Comparing the periods before and after 2018, the total number of patients increased from 108 to 240 (+122%). Absolute numbers rose across all treatment groups: surgery (74 to 89), transcatheter therapy (4 to 106), and medical therapy (30 to 45). Proportionally, surgical patients declined from 68.5% to 37% ($P < .001$), while transcatheter therapy cases grew from 3.7% to 44% ($P < .001$) and patients receiving medical therapy alone decreased from 27.8% to 19% ($P = .046$), **Figure 2**.

Figure 3 details tricuspid transcatheter interventions during the study period: the most frequently performed was edge-to-edge repair (83.5%) while orthotopic replacement in native anatomy was performed in 6.4% of cases. Before 2018, only four transcatheter procedures were performed (2014–2017); they were seldom attempts, each one different from the other, including compassionate and first-in-man cases: 1 Tricinch, 1 Navigate, 1 edge-to-edge, 1 Valve-in-Valve.

Tables 1 and **2** summarize the baseline clinical and echocardiographic characteristics of patients admitted during the 2012–2017 and 2018–2023 periods. Patients in the 2018–2023 cohort were older and had lower estimated glomerular filtration rate (eGFR). The mechanism of TR differed between the two periods, with atrial TR diagnosis increasing over time (from 17% to 38%) and ventricular TR decreasing (from 52% to 36%) ($P < .001$). Correspondingly, smaller left and right ventricular end-diastolic diameters were observed in the 2018–2023 cohort, though ventricular function remained unchanged.

In-hospital outcomes for patients undergoing surgical or transcatheter procedures in the two timeframes are summarized in **Table 3**. Overall, in-hospital mortality of treated patients declined from 10.3%

Table 1 Baseline patients features before and after the introduction of transcatheter therapies

	2012–2017 (n = 108)	2018–2023 (n = 240)	P value
Treatment, n (%)			<.001
Surgery	74 (68.5)	89 (37)	
Transcatheter	4 (3.7)	106 (44)	
Medical therapy	30 (27.8)	45 (19)	
Age, years	71 (61–76)	73 (64–78)	.043
Gender female, n (%)	71 (65.7)	165 (69)	.57
Triscore mortality, %	7 (2–22)	8 (3–14)	.64
Triscore class, (n %)			.18
Low (≤ 3)	54 (50)	113 (47)	
Medium 4–5	21 (19)	68 (28)	
High ≥ 6	33 (31)	59 (25)	
CAD, n (%)	22 (20)	44 (18)	.64
COPD, n (%)	13 (12)	24 (10)	.56
AFib	77 (71)	171 (70.8)	.99
Chronic AFib	61 (56)	124 (52)	.61
eGFR, ml/min	64 (46–88)	60 (40–78)	.02
eGFR < 60	40 (37)	121 (50)	.02
Previous cardiac surgery, n (%)	55 (51)	123 (51)	.95
Previous tricuspid surgery, n (%)	6 (5.6)	24 (10)	.17
Previous tricuspid transcatheter procedure, n (%)	1 (0.9)	4 (1.7)	.99
RV lead, n (%)	21 (19)	51 (21)	.70
NYHA $\geq$ III, n (%)	54 (50)	122 (51.4)	.99
Any sign of right failure, n (%)	44 (41)	85 (35)	.34
Ascites, n (%)	10 (9.3)	21 (8.8)	.87
Previous right HF hospitalization, n (%)	38 (35)	81 (34)	.81
Bilirubin >1.5	14 (13)	40 (17)	.36
Medications			
Furosemide daily mg	50 (24–125)	50 (25–100)	.34
MRA, n (%)	46 (44.2)	106 (44.9)	.91
Beta-blockers, n (%)	59 (56.7)	165 (69.9)	.018
ACEI/ARB, n (%)	43 (41.3)	104 (44.1)	.64
Sacubitril/valsartan, n (%)	0 (0)	4 (1.7)	.18
SGLT2 inhibitors, n (%)	0 (0)	13 (5.5)	.015
Inotropes, n (%)	24 (23.1)	32 (13.6)	.029

CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; AFib, atrial fibrillation; eGFR, estimated glomerular filtration rate; RV, right ventricle; NYHA, New York Heart Association; HF, heart failure; MRA, mineralocorticoid receptor antagonist; ACEI, angiotensin-converting-enzyme inhibitors; ARB, angiotensin receptor blockers; SGLT2, sodium-glucose co-transporter 2. Inotropes: any intravenous inotrope including dopamine, dobutamine, adrenaline, noradrenaline, enoximone.

(8/78) to 3.6% (7/195) ($P = .039$, [Figure 4](#)). The incidence of acute kidney injury decreased from 21% to 3.1% ($P < .001$), and post-procedural length of stay shortened from 9 (6–16) to 6 (4–8) days ($P < .001$). However, residual TR $\geq 3+$ was more common in the 2018–2023 period, rising from 2.6% to 16.3% ($P < .001$, [Figure 5](#)).

[Table 4](#) details the main reasons for procedural denial. Right ventricular failure was the leading cause of rejection in 2012–2017 (46.7%) and

remained the second most common in 2018–2023 (37.8%). On the other hand, unfavourable anatomy became the most frequent cause after 2018 (64.4%).

[Tables 5](#) and [6](#) compare the characteristics of patients treated surgically, via transcatheter therapy, or managed medically in the 2018–2023 period. Compared with surgical patients, those in the transcatheter and medical therapy groups were older ($P < .001$), had higher

Table 2 Baseline echocardiographic features before and after the introduction of transcatheter therapies

	2012–2017 (n = 108)	2018–2023 (n = 240)	P value
TR mechanism, n (%)			<.001
Primary	25 (33)	55 (23)	
Atrial	18 (17)	90 (38)	
Ventricular	56 (52)	87 (36)	
CIED related	9 (8.3)	8 (3.3)	
Infective endocarditis, n (%)	5 (4.6)	12 (5.0)	.88
TR vena contracta, mm	9 (8–10)	9 (8–13)	.79
Annulus diameter SL, mm	42 (40–49)	44 (40–48)	.25
RA volume, ml	124 (95–178)	100 (68–155)	.13
RV mid EDD	45 (44–50)	38 (34–43)	<.001
RV basal EDD	47 (43–50)	46 (42–51)	.96
TAPSE, mm	20 (16–23.8)	18 (16–21)	.18
S'-TDI, cm/s	10 (8–12)	10 (9–13)	.27
RV dysfunction			.74
None	64 (59)	134 (56)	
Mild	20 (19)	57 (24)	
Moderate	14 (13)	30 (12)	
Severe	10 (9.3)	19 (8)	
sPAP, mmHg	40 (35–48)	40 (35–50)	.91
LV EDD, mm	47 (43–52)	46 (40–50)	.01
LV EF, %	57 (55–60)	58 (53–62)	.08

TR, tricuspid regurgitation; CIED, cardiac implantable electrical devices; SL, septo-lateral; RA, right atrium; RV, right ventricle; EDD, end-diastolic diameter; TAPSE, tricuspid annular plane systolic excursion; S'-TDI, systolic wave at tissue doppler imaging; sPAP, systolic pulmonary artery pressure; LV, left ventricle; EF, ejection fraction.

Triscore-predicted mortality ($P < .001$), more comorbidities, more severe symptoms (New York Heart Association NYHA class $\geq$ III, $P = .016$), and worse right ventricular function (TAPSE, $P < .001$).

Nevertheless, transcatheter procedures resulted in fewer post-procedural complications and shorter hospital stays compared with surgery, with post-procedural mortality rates of 1.9% vs 5.6% respectively ($P = .25$), [Table 7](#). However, residual TR $\geq 3+$ was significantly more frequent after transcatheter treatment than after surgery (30% vs 0%, $P < .001$).

Changes in the characteristics and outcomes of surgical patients between the 2013–2017 and 2018–2022 periods are reported in [Supplementary Tables S1–3](#).

Clinical and echocardiographic data of the entire study population from 2012 to 2023 according to the treatment group are reported in [Supplementary Tables S4–5](#).

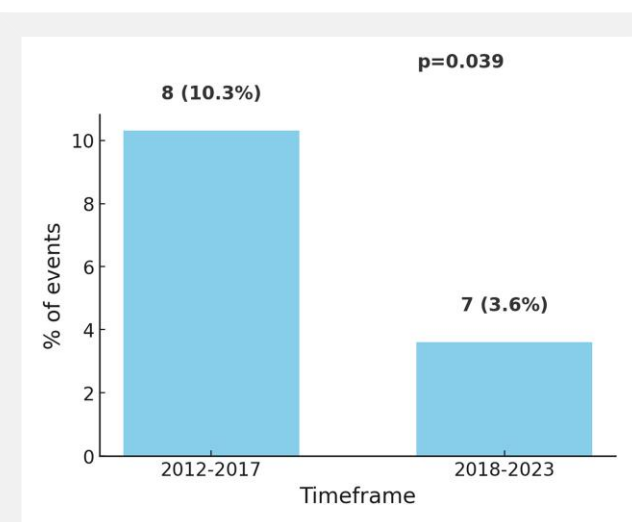
Discussion

To the best of our knowledge, this study is the first to analyse temporal trends in the treatment, both surgical and transcatheter, of isolated TR over the last 12 years, categorizing patients into surgical, transcatheter,

Table 3 Post-procedural outcomes in treated patients before and after the introduction of transcatheter therapies

	2012–2017 (n = 78)	2018–2023 (n = 195)	P value
Death, n (%)	8 (10.3)	7 (3.6)	.039
LCOS, n (%)	38 (49)	70 (36)	.054
AKI, n (%)	16 (21)	6 (3.1)	<.001
Stroke, n (%)	5 (6.6)	4 (2.1)	.12
Bleeding, n (%)	11 (14)	15 (7.8)	.10
Prolonged ventilatory support, n (%)	29 (38)	43 (22)	.01
PM implantation, n (%)	6 (7.8)	9 (4.6)	.38
Residual TR, n (%)			<.001
0	59 (81)	79 (41)	
1	5 (6.3)	44 (22.7)	
2	8 (10)	40 (20)	
3	2 (2.6)	18 (9.2)	
4	0 (0)	14 (7.1)	
Post-procedural LOS, days	9 (6–16)	6 (4–8)	<.001
ICU LOS, days	3 (1–6)	1 (1–3)	<.001

LCOS, low cardiac output syndrome; AKI, acute kidney injury; PM, pacemaker; TR, tricuspid regurgitation; LOS, length of stay; ICU, intensive care unit.

**Figure 4** Post-procedural observed mortality of treated patients during the study timeframes 2012–2017 vs 2018–2023

or medical therapy groups. The cohort includes all consecutive patients admitted for isolated TR correction at a high-volume valve centre.

The key findings are: (i) after the introduction of transcatheter therapies, the overall number of patients admitted for TR correction increased; (ii) the number of patients who actually received TR

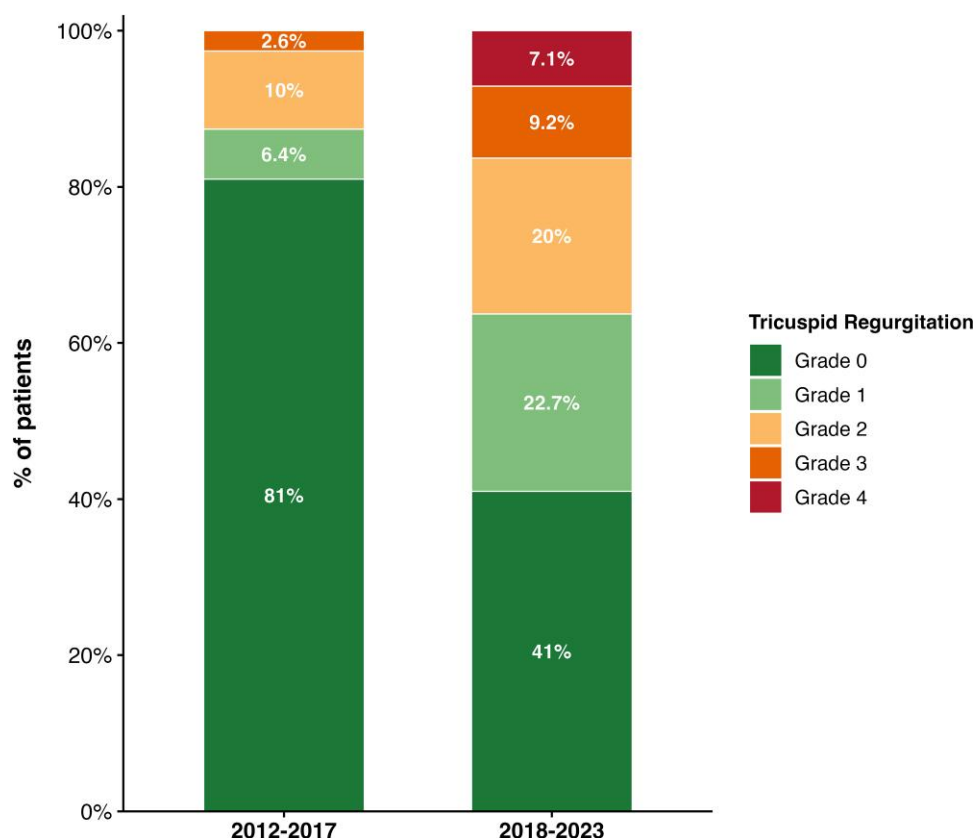


Figure 5 Residual tricuspid regurgitation (TR) among treated patients in the study timeframes 2012–2017 vs 2018–2023

Table 4 Main reasons for procedure denial before and after the introduction of transcatheter therapies

	2012–2017 (n = 30)	2018–2023 (n = 45)	P value
RV dysfunction, n (%)	14 (46.7)	17 (37.8)	.46
Pulmonary hypertension	5 (16.7)	2 (4.4)	.07
LV dysfunction, n (%)	5 (16.7)	7 (15.5)	.53
TR $\leq 3+$ without triggers for intervention	13 (43.3)	8 (17.8)	.002
Medical therapy not optimized	1 (3.3)	6 (13.3)	.44
Unfavourable anatomy	4 (13.3)	29 (64.4)	.014

RV, right ventricle; LV, left ventricle; TR, tricuspid regurgitation.

correction increased with fewer patients left on medical therapy alone; (iii) in-hospital mortality among treated patients declined, albeit with a higher incidence of residual TR. All of these findings were driven primarily by the rise in transcatheter therapy, which became the most frequent treatment performed in the last years.

Isolated TR remains a clinical challenge due to subtle symptoms, frequent underdiagnosis, and complex, still-debated treatment algorithms.¹² TR has been historically an undertreated condition,¹³ largely

due to a lack of awareness regarding its prognostic impact^{14,15} and the self-perpetuating cycle of late referral to intervention—poor outcomes—late referral to intervention.^{16,17} Despite these challenges, our data demonstrate a growing recognition of TR and an evolving approach to its management over the past decade.

Interesting trends emerge comparing the two study periods (2012–2017 vs 2018–2023). Patients in the later cohort showed a trend towards older age and lower eGFR, suggesting they could be people who would have not been referred for TR correction before transcatheter procedures became available. They also exhibited a changing TR mechanism, with atrial TR becoming more prevalent while ventricular TR declined. This shift likely reflects the increasing recognition of atrial functional TR as a distinct clinical entity and possibly an initial increase in the referral of patients with atrial TR.^{18,19} Concordantly, smaller left and right ventricular end-diastolic diameters were observed in the 2018–2023 period, although no significant differences in ventricular function were noted. Of note, a role may also have been played by new heart failure medications (Sacubitril/Valsartan and Sodium-Glucose co-transporter 2 inhibitors), which were only used in the more recent timeframe.

From a procedural perspective, overall in-hospital mortality among patients undergoing surgical or transcatheter treatment significantly declined (from 10.3% to 3.6%). Post-procedural complications, such as acute kidney injury (AKI), also decreased, and hospital stays were notably shorter in the later cohort. The reduction in observed mortality after TR correction is long-awaited good news, since TR treatment has been historically associated with high mortality in the past surgical era.²⁰ Notably, latest data from the Society of Thoracic Surgeons

Table 5 Clinical features of surgical, transcatheter, and medical therapy patients in the 2018–2023 timeframe

	Surgery (n = 89)	Transcatheter (n = 106)	Medical therapy (n = 45)	P value
Age, years	64 (53–74)	76 (68–80)	75 (69–79)	<.001
Gender female, n (%)	64 (72)	73 (69.0)	28 (62.0)	.52
Triscore mortality	3 (2–14)	8 (5–22)	8 (3–22)	<.001
Triscore class, (n %)				<.001
Low (≤ 3)	61 (69)	32 (30)	20 (44)	
Medium 4–5	17 (19)	40 (38)	11 (24)	
High ≥ 6	11 (12)	34 (32)	14 (31)	
CAD, n (%)	12 (13)	20 (19)	12 (27)	.17
COPD, n (%)	3 (3.4)	12 (11)	9 (20)	.006
AFib	54 (61.1)	91 (89.5)	26 (58)	<.001
Chronic AFib	37(42)	67 (63)	20 (44)	<.001
eGFR, ml/min	74 (61–91)	44 (32–65)	53 (39–73)	<.001
eGFR < 60	20(22)	74 (70)	27 (60)	<.001
Previous cardiac surgery, n (%)	45 (51)	55 (52)	23 (51)	.98
Previous tricuspid surgery, n (%)	9 (10)	11 (10)	4 (8.9)	.99
RV lead, n (%)	14 (16)	26 (25)	11 (24)	.27
NYHA $\geq$ III, n (%)	34 (39.1)	63 (59)	24 (53)	.016
Any sign of right failure, n (%)	21 (24)	45 (42)	19 (42)	.01
Ascites, n (%)	4 (4.5)	14 (13)	3 (6.7)	.09
Previous right HF hospitalization, n (%)	22 (25)	43 (41)	16 (36)	.07
Bilirubin >1.5	14 (16)	19 (18)	7 (16)	.87
Medications				
Furosemide daily mg	25 (0–75)	50 (25–106)	50 (25–100)	<.001
MRA, n (%)	32 (37)	56 (53)	18 (41)	.06
Beta-blockers, n (%)	58 (67)	75 (71)	32 (73)	.70
ACEI/ARB, n (%)	44 (51)	38 (36)	22 (50)	.09
Sacubitril/valsartan, n (%)	1 (1)	2 (2)	1(2)	.87
SGLT2 inhibitors, n (%)	1 (1)	11 (10.5)	1 (2)	.01
Inotropes, n (%)	22 (25)	6 (6)	4 (9)	<.001

CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; AFib, atrial fibrillation; eGFR, estimated glomerular filtration rate; RV, right ventricle; NYHA, New York Heart Association; HF, heart failure; MRA, mineralocorticoid receptor antagonist; ACEI, angiotensin-converting-enzyme inhibitors; ARB, angiotensin receptor blockers; SGLT2, sodium-glucose co-transporter 2. Inotropes: any intravenous inotrope including dopamine, dobutamine, adrenaline, noradrenaline, enoximone.

database confirm a similar trend: after years of disappointingly steadiness,²¹ mortality after TR surgery has been decreasing over the last few years.²² This reduction likely reflects improvements in patient selection, perioperative management, and the availability of less invasive transcatheter alternatives, like in our experience.

On the other hand, the rate of residual TR $\geq 3+$ increased in the 2018–2023 period is disappointing, particularly among patients treated with transcatheter therapies. This underscores the need for further advancements in device technology, patient selection, and earlier referral to optimize long-term outcomes. Indeed, as highlighted by the similar baseline Triscore, NYHA class, heart failure hospitalizations, tricuspid annulus diameter, and RV function over time, many patients still presented at a late stage of disease. At this time advanced tricuspid apparatus remodelling frequently presents an unfavourable anatomy for

repair techniques, which cannot achieve optimal TR reduction, while at the same time RV dysfunction increases the risk of afterload mismatch after replacement with consequent increased post-procedural mortality and complications.⁷ These concepts remain true for surgery and transcatheter technologies alike.

Patients who were denied intervention diminished from 2012–2017 to 2018–2023, therefore not only more patients were admitted for TR correction after the introduction of transcatheter therapies, but more patients actually received treatment compared with the past. The evolving criteria for procedural denial provide further insights into the shifting landscape of TR management. Right ventricular failure, historically the primary reason for rejection, remained a key factor but was surpassed by unfavourable anatomy in the later cohort. This shift likely reflects the expansion of transcatheter interventions, where anatomical

Table 6 Echocardiographic features of surgical, transcatheter, and medical therapy patients in the 2018–2023 timeframe

	Surgery (n = 89)	Transcatheter (n = 106)	Medical therapy (n = 45)	P value
TR mechanism, n (%)				.13
Primary	24 (27)	23 (23)	8 (18)	
Atrial	38 (43)	35 (33)	17 (38)	
Ventricular	23 (26)	46 (43)	18 (40)	
CIED related	4 (4.5)	2 (1.9)	2 (4.4)	
TR degree, n (%)				.01
Moderate-to-Severe	9 (10)	10 (9.6)	12 (26.5)	
Severe	80 (90)	95 (90.4)	33 (73.5)	
TR vena contracta, mm	10 (8–12.3)	9 (7–13.5)	10 (8–15)	.36
TR EROA, cm ²	0.60 (0.40–0.81)	0.60 (0.44–0.72)	0.60 (0.5–0.85)	.73
Coaptation gap, mm	12.0 (9.8–13.5)	8.0 (6.0–11.0)	6.5 (4.1–10.3)	.09
Leaflets coaptation depth, mm	9.3 (7–11.8)	10.5 (8.0–11.8)	12.0 (10.0–12.5)	.26
Annulus diameter SL, mm	43 (40–47)	44 (41–48)	45 (42–48)	.18
RA volume, ml	95 (70–150)	108 (60–239)	100 (81–112)	.87
RV mid EDD, mm	36 (33–41)	50 (35–43)	41 (36–50)	.059
RV basal EDD, mm	45 (42–50)	46 (42–51)	47 (44–56)	.06
TAPSE, mm	20 (17–23)	18 (15–19)	18 (16–20.8)	<.001
S'-TDI, cm/s	10.4 (9–13)	10 (8.1–11.8)	10.4 (9–13)	.06
RV FWLS	−22 (−26, −17)	−20 (−24, −14)	−22 (−24, −17)	.19
RV dysfunction				<.001
None	61 (69)	50 (47)	23 (51)	
Mild	20 (22)	28 (26)	9 (20)	
Moderate	5 (5.6)	21 (20)	4 (8.9)	
Severe	3 (3.4)	7 (6.7)	9 (20)	
sAPP, mmHg	40 (31–45)	41 (35–50)	50 (38–60)	.001
LV EDD, mm	45 (40–48)	46 (40–52)	47 (40–50)	.27
LV EF, %	60 (55–65)	58 (52–62)	56 (50–60)	.01

TR, tricuspid regurgitation; CIED, cardiac implantable electrical devices; EROA, effective regurgitant orifice area; SL, septo-lateral; RA, right atrium; RV, right ventricle; EDD, end-diastolic diameter; TAPSE, tricuspid annular plane systolic excursion; S'-TDI, systolic wave at tissue doppler imaging; FWLS, free wall longitudinal strain; sAPP, systolic pulmonary artery pressure; LV, left ventricle; EF, ejection fraction.

feasibility plays a crucial role in patient selection. All patients left in medical therapy were by definition not eligible for neither surgery or transcatheter therapies, typically with multiple reasons present at the same time (e.g. bad anatomy for transcatheter and high risk for surgery due to right ventricle failure).

When comparing surgical, transcatheter, and medically managed patients in the 2018–2023 period, those undergoing transcatheter or medical therapy were older, had higher Triscore-predicted mortality, more comorbidities, symptoms, and severe right ventricle dysfunction. Despite these baseline differences, transcatheter interventions confirmed a favourable safety profile, similar to previously reported experiences^{23–25} with fewer post-procedural complications and shorter hospital stays compared with surgery. However, the significantly higher rate of residual TR $\geq 3+$ after transcatheter treatment once again highlights the need for improvement. Of note, while most surgical patients received replacement because, due to late referral, the disease was too advanced for repair,

the majority of transcatheter cases were repaired because replacement was not widely available. The EVOQUE Transcatheter Tricuspid Valve Replacement system (Edwards Lifesciences, Irvine, CA, US) received CE mark only in October 2023 and was therefore not available during the study period. It is worth to underline that with the expansion of emerging transcatheter replacement options more patients who present with unfavourable anatomy for transcatheter repair may be treated with replacement, leading to reduced residual TR. On the other hand, it must also be remembered that the presence of right ventricle dysfunction at the late stages of the disease may limit the applicability of replacement technologies. Once again, earlier intervention when anatomy is still favourable for effective repair and the right ventricle is still good enough for safe replacement will be needed to really improve the outcomes of TR treatment.

In summary, our findings highlight a profound transformation in the approach to isolated TR, characterized by increased recognition, evolving treatment strategies, and improved in-hospital survival. While

Table 7 Comparison of outcomes between surgery and transcatheter therapies in the 2018–2023 period

	Surgery 2018–2023 (n = 89)	Transcatheter 2018–2023 (n = 106)	P value
Repair, n (%)	26 (29)	91 (86)	<.001
Replacement, n (%)	63 (71)	15 (14)	
Death, n (%)	5 (5.6)	2 (1.9)	.25
LCOS, n (%)	41 (46)	29 (28)	.008
AKI, n (%)	3 (3.4)	3 (2.9)	.99
Stroke, n (%)	2 (2.2)	2 (1.9)	.99
Bleeding, n (%)	9 (10)	6 (5.8)	.27
Prolonged ventilatory support, n (%)	36 (40)	7 (6.8)	<.001
PM implantation, n (%)	5 (5.6)	4 (3.8)	.73
Residual TR, n (%)			<.001
0	67 (57)	12 (11)	
1	19 (21)	25 (24)	
2	3 (3.4)	37 (35)	
3	0 (0)	18 (17)	
4	0 (0)	14 (13)	
Post-procedural LOS, days	7 (5–11)	5 (4–6.2)	<.001
ICU LOS, days	2 (1–4)	1 (0–2)	<.001

LCOS, low cardiac output syndrome; AKI, acute kidney injury; PM, pacemaker; TR, tricuspid regurgitation; LOS, length of stay; ICU, intensive care unit.

transcatheter therapies offer a promising alternative to surgery, optimizing long-term results remains an important challenge that will require earlier treatment as well as refined patient selection and improved procedural techniques.

Study limitations

Several limitations of the present work should be acknowledged.

First, its retrospective and 'historical' nature, encompassing a wide timespan in the past, undermined the quality of some data, especially echocardiographic. Indeed, despite careful re-adjudication of TR mechanisms based on available data, it remains difficult to fully judge the increased diagnosis of atrial TR after 2018. Similarly, the current TR grading with the addition of 'massive' and 'torrential' was only proposed in 2017 and could not be reliably re-adjudicated in the previous years of the study for all patients. Other parameters, like right ventricle strain, fractional area change, and pro-BNP were also not routinely used in the early years of the study. Moreover, we acknowledge that some cut-offs for right ventricle dysfunction that we used based on the 2023 Tricuspid Valve Academic Research Consortium Definitions slightly differ from those recently adopted by the current 2025 ESC/EACTS Guidelines.^{7,11}

Second, the present analysis focused only on patients who were admitted to the valve centre department to undergo a TR correction procedure. Patients evaluated at the outpatient clinic or admitted to other departments of the hospital not referred to the valve centre for TR correction were not captured. Therefore, the purpose of the present

work cannot be to give information about the entire population of TR patients but only on those patients who were referred and admitted for TR correction.

Moreover, the analysis of follow-up outcomes was beyond the purpose of the present study and remains an important objective of future work.

Furthermore, since the very early experience with transcatheter technologies is included into the present analysis, its learning curve is to be taken into account.

Also, the COVID pandemic did alter the number of all patients referred during 2020 and 2021 years, likely with a rebound in 2023.

Finally, this was a single-centre study whose results may not be generalizable and the small number of patients and events limit the statistical power of the analyses. After cleaning the study population removing concomitant diseases, only 348 patients with isolated TR were included out of the 1742 screened with TR (20%).

Conclusions

Over the past decade, the introduction of transcatheter tricuspid therapies has led to increased referrals for the correction of isolated TR and a higher number of treated patients compared with previous years. Transcatheter procedures have recently become the most used method to treat these patients. This shift has also resulted in reduced post-procedural mortality; however, it has come at the expense of a higher incidence of residual TR.

Despite this progress, TR patients are still not being referred early enough, with many reaching treatment at an advanced stage of disease. To further improve outcomes, a dual approach is necessary: continuous technological advancements in transcatheter therapies and a shift towards earlier intervention.

Acknowledgements

None.

Author contributions

Nicola Buzzatti (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing—original draft, Writing—review & editing [lead]), Nicolò Azzola Guicciardi (Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing—original draft, Writing—review & editing [supporting]), Carlo Gaspardone (Data curation, Validation, Writing—review & editing [supporting]), Paolo Denti (Data curation, Validation, Writing—review & editing [supporting]), Cristiano Sarais (Data curation, Validation, Writing—review & editing [supporting]), Francesco Ancona (Data curation, Validation, Writing—review & editing [supporting]), Cosmo Godino (Data curation, Validation, Writing—review & editing [supporting]), Eustachio Agricola (Data curation, Resources, Validation, Writing—review & editing [supporting]), Michele De Bonis (Resources, Validation, Writing—review & editing [supporting]), Alberto Margonato (Resources, Validation, Writing—review & editing [supporting]), Ottavio Alfieri (Resources, Validation, Writing—review & editing [supporting]), Marco Metra (Writing—review & editing [supporting]), and Francesco Maisano (Project administration, Resources, Validation, Writing—original draft, Writing—review & editing [supporting]).

Supplementary data

Supplementary data are available at [European Heart Journal – Valvular and Structural Heart Disease](#) online.

Declarations

Disclosure of Interest

Nicola Buzzatti: Consultant for Biosensors and Meril. Nicolò Azzola Guicciardi: none. Carlo Gaspardone: none. Paolo Denti: Speaker Honoraria from Abbott; Consultant: Approxima, HVR, InnovaHeart, Picardia, Simulands. Cristiano Sarais: none. Francesco Ancona: Speaker Honoraria from Abbott and GE. Cosmo Godino: none. Eustachio Agricola: none. Michele De Bonis: CMO, co-founder and stakeholder of Startric. Alberto Margonato: none. Ottavio Alfieri: none. Marco Metra: consulting honoraria from Abbott Structural Heart, Astra-Zeneca, Bayer, Boehringer-Ingelheim, Edwards LifeSciences, NovoNordisk, Roche Diagnostics. Francesco Maisano: Grant and/or Research Institutional Support from Abbott, Medtronic, Edwards Lifesciences, Biotronik, Boston Scientific Corporation, NVT, Terumo, Venus, Roche; Consulting fees, Honoraria personal and Institutional from Abbott, Boston Scientific, Medtronic, Edwards Lifesciences, Xeltis, Cardiovalve, Occlufit, Simulands, Mtex, Venus, Squadra, Valgen, Croivalve, Meril; Royalty Income/IP Rights: Edwards Lifesciences; Shareholder (including share options) of Magenta, Transseptalsolutions, 4Tech.

Data Availability

The data underlying this article will be shared on reasonable request to the corresponding author.

Funding

None.

References

- Dreyfus GD, Corbi PJ, Chan KM, Bahrami T. Secondary tricuspid regurgitation or dilation: which should be the criteria for surgical repair? *Ann Thorac Surg* 2005;**79**:127–32. <https://doi.org/10.1016/j.athoracsur.2004.06.057>
- Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. *J Am Coll Cardiol* 2004;**43**:405–9. <https://doi.org/10.1016/j.jacc.2003.09.036>
- Enriquez-Sarano M, Messika-Zeitoun D, Topilsky Y, Tribouilloy C, Benfari G, Michelena H. Tricuspid regurgitation is a public health crisis. *Prog Cardiovasc Dis* 2019;**62**:447–51. <https://doi.org/10.1016/j.pcad.2019.10.009>
- Hahn RT. Tricuspid regurgitation. *N Engl J Med* 2023;**388**:1876–91. <https://doi.org/10.1056/NEJMr2216709>
- Sala A, Lorusso R, Alfieri O. Isolated tricuspid regurgitation: a plea for early correction. *Int J Cardiol* 2022;**353**:80–5. <https://doi.org/10.1016/j.ijcard.2022.01.069>
- Taramasso M, Hahn RT, Alessandrini H, Latib A, Attinger-Toller A, Braun D, et al. The International Multicenter TriValve Registry: which patients are undergoing transcatheter tricuspid repair? *JACC Cardiovasc Interv* 2017;**10**:1982–90. <https://doi.org/10.1016/j.jcin.2017.08.011>
- Praz F, Borger MA, Lanz J, Marin-Cuartas M, Abreu A, Adamo M, et al. 2025 ESC/EACTS guidelines for the management of valvular heart disease. *Eur Heart J* 2025;**46**:4635–736. <https://doi.org/10.1093/eurheartj/ehaf194>
- Dreyfus J, Audureau E, Bohbot Y, Coisne A, Lavie-Badie Y, Bouchery M, et al. TRI-SCORE: a new risk score for in-hospital mortality prediction after isolated tricuspid valve surgery. *Eur Heart J* 2022;**43**:654–62. <https://doi.org/10.1093/eurheartj/ehab679>
- Praz F, Muraru D, Kreidel F, Lurz P, Hahn RT, Delgado V, et al. Transcatheter treatment for tricuspid valve disease. *EuroIntervention* 2021;**17**:791–808. <https://doi.org/10.4244/EIJ-D-21-00695>
- Hahn RT, Zamorano JL. The need for a new tricuspid regurgitation grading scheme. *Eur Heart J Cardiovasc Imaging* 2017;**18**:1342–3. <https://doi.org/10.1093/ehjci/jex139>
- Hahn RT, Lawlor MK, Davidson CJ, Badhwar V, Sannino A, Spitzer E, et al. Tricuspid valve academic research consortium definitions for tricuspid regurgitation and trial endpoints. *Eur Heart J* 2023;**44**:4508–32. <https://doi.org/10.1093/eurheartj/ehad653>
- Adamo M, Chioncel O, Pagnesi M, Bayes-Genis A, Abdelhamid M, Anker SD, et al. Epidemiology, pathophysiology, diagnosis and management of chronic right-sided heart failure and tricuspid regurgitation. A clinical consensus statement of the Heart Failure Association (HFA) and the European Association of Percutaneous Cardiovascular Interventions (EAPCI) of the ESC. *Eur J Heart Fail* 2024;**26**:18–33. <https://doi.org/10.1002/ehfj.3106>
- Agarwal S, Tuzcu EM, Rodriguez ER, Tan CD, Rodriguez LL, Kapadia SR. Interventional cardiology perspective of functional tricuspid regurgitation. *Circ Cardiovasc Interv* 2009;**2**:565–73. <https://doi.org/10.1161/CIRCINTERVENTIONS.109.878983>
- Arbulu A, Holmes RJ, Asfaw I. Tricuspid valvectomy without replacement. Twenty years' experience. *J Thorac Cardiovasc Surg* 1991;**102**:917–22. [https://doi.org/10.1016/S0022-5223\(19\)33944-3](https://doi.org/10.1016/S0022-5223(19)33944-3)
- Braunwald NS, Ross J, Morrow AG. Conservative management of tricuspid regurgitation in patients undergoing mitral valve replacement. *Circulation* 1967;**35**:163–9. <https://doi.org/10.1161/01.CIR.35.451.I-63>
- Sala A, Lorusso R, Bargagna M, Ruggeri S, Buzzatti N, Scandroglio M, et al. Complicated postoperative course in isolated tricuspid valve surgery: looking for predictors. *J Card Surg* 2021;**36**:3092–9. <https://doi.org/10.1111/jocs.15739>
- Sala A, Lorusso R, Bargagna M, Ascione G, Ruggeri S, Meneghin R, et al. Isolated tricuspid valve surgery: first outcomes report according to a novel clinical and functional staging of tricuspid regurgitation. *Eur J Cardiothorac Surg* 2021;**60**:1124–30. <https://doi.org/10.1093/ejcts/ezab228>
- Russo G, Badano LP, Adamo M, Alessandrini H, Andreas M, Braun D, et al. Characteristics and outcomes of patients with atrial versus ventricular secondary tricuspid regurgitation undergoing tricuspid transcatheter edge-to-edge repair—results from the TriValve registry. *Eur J Heart Fail* 2023;**25**:2243–51. <https://doi.org/10.1002/ehfj.3075>
- Stolz L, Kresoja KP, von Stein J, Fortmeier V, Koell B, Rottbauer W, et al. Atrial secondary tricuspid regurgitation: insights into the EuroTR registry. *JACC Cardiovasc Interv* 2024;**17**:2781–91. <https://doi.org/10.1016/j.jcin.2024.10.028>
- Kilic A, Saha-Chaudhuri P, Rankin JS, Conte JV. Trends and outcomes of tricuspid valve surgery in North America: an analysis of more than 50,000 patients from the Society of Thoracic Surgeons database. *Ann Thorac Surg* 2013;**96**:1546–52; discussion 52. <https://doi.org/10.1016/j.athoracsur.2013.06.031>
- Zack CJ, Fender EA, Chandrashekar P, Reddy YNV, Bennett CE, Stulak JM, et al. National trends and outcomes in isolated tricuspid valve surgery. *J Am Coll Cardiol* 2017;**70**:2953–60. <https://doi.org/10.1016/j.jacc.2017.10.039>
- Thourani VH, Bonnell L, Wyler von Ballmoos MC, Mehaffey JH, Bowdish M, Kurlansky P, et al. Outcomes of isolated tricuspid valve surgery: a society of thoracic surgeons analysis and risk model. *Ann Thorac Surg* 2024;**118**:873–81. <https://doi.org/10.1016/j.athoracsur.2024.04.014>
- Lurz P, Besler C, Schmitz T, Bekerdejian R, Nickenig G, Möllmann H, et al. Short-term outcomes of tricuspid edge-to-edge repair in clinical practice. *J Am Coll Cardiol* 2023;**82**:281–91. <https://doi.org/10.1016/j.jacc.2023.05.008>
- Kodali S, Hahn RT, George I, Davidson CJ, Narang A, Zahr F, et al. Transfemoral tricuspid valve replacement in patients with tricuspid regurgitation: TRISCEND study 30-day results. *JACC Cardiovasc Interv* 2022;**15**:471–80. <https://doi.org/10.1016/j.jcin.2022.01.016>
- Wild MG, Löw K, Rosch S, Gerçek M, Higuchi S, Massberg S, et al. Multicenter experience with the transcatheter leaflet repair system for symptomatic tricuspid regurgitation. *JACC Cardiovasc Interv* 2022;**15**:1352–63. <https://doi.org/10.1016/j.jcin.2022.05.041>