ESC European Society of Cardiology

European Heart Journal (2024) **00**, 1–19
https://doi.org/10.1093/eurheartj/ehae082

STATE OF THE ART REVIEW
Valvular heart disease

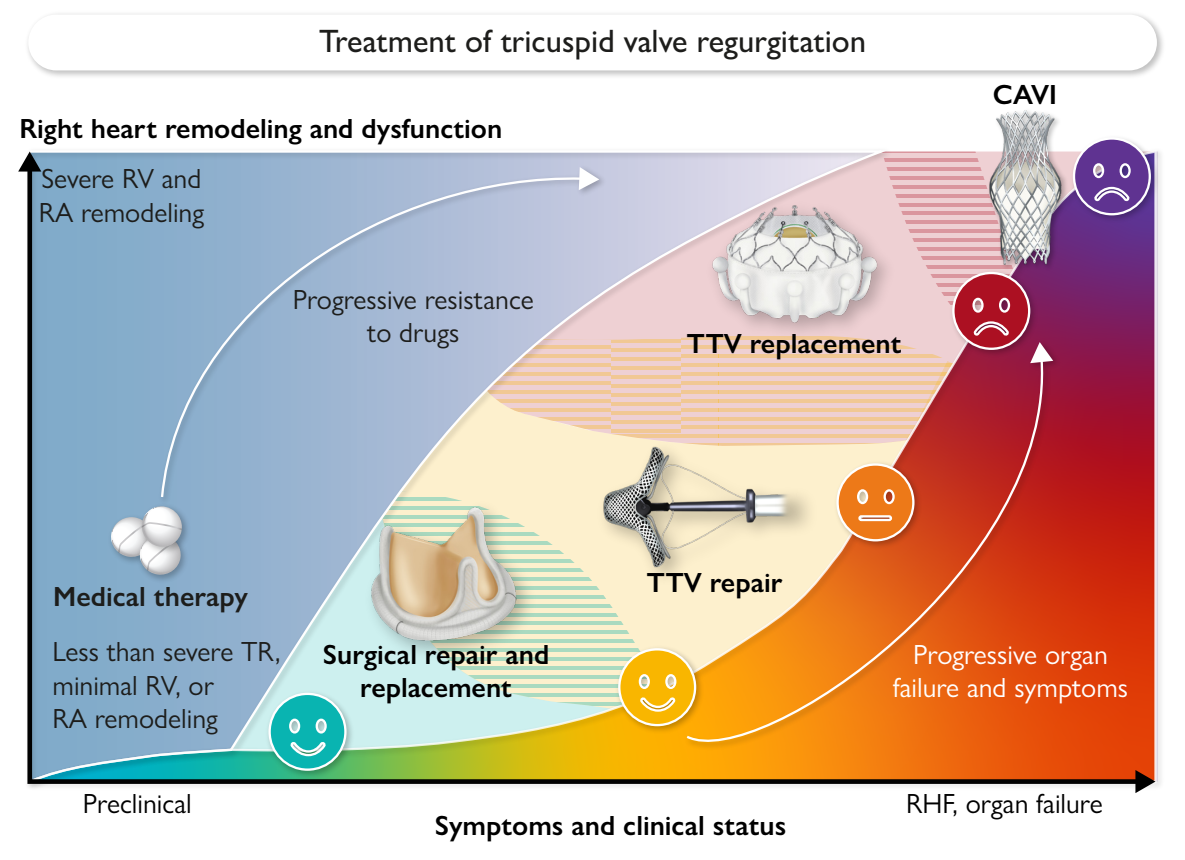
Transcatheter treatment of the tricuspid valve: current status and perspectives

Francesco Maisano [1]*, Rebecca Hahn [2], Paul Sorajja[3], Fabien Praz [4], and Philipp Lurz[5]

[1]Division of Cardiac Surgery and Valve Center, IRCCS Ospedale San Raffaele, Università Vita Salute, Via Olgettina 60, 20132 Milano, Italy; [2]Department of Medicine, Columbia University Irving Medical Center, New York, 161 Fort Washington Avenue, 10032 New York, NY, USA; [3]Minneapolis Heart Institute at Abbott Northwestern Hospital, 920 East 28th Street, Suite 100, 55407 Minneapolis, MN, USA; [4]Bern University Hospital, University of Bern, Anna-Seiler-Haus Freiburgstrasse 20, 3010 Bern, Switzerland; and [5]Department of Cardiology, Universitätsmedizin Johannes Gutenberg-University, Langenbeckstraße 1, 55131 Mainz, Germany

Received 2 August 2023; revised 13 January 2024; accepted 29 January 2024

Graphical Abstract



Disease stage and therapeutic strategies for tricuspid regurgitation. Tricuspid regurgitation evolves from undetectable early forms to advanced stages characterized by escalating symptoms, right heart failure, and organ impairment. While medical therapy is utilized throughout the disease course, its effectiveness wanes with progression. Surgery can play a role in the earlier stages, while transcatheter therapies are available for patients at high risk and in the more advanced stages of disease. Significant overlap between treatment options underscores the urgent need for precise, evidence-based

* Corresponding author. Email: francesco.maisano.personal@gmail.com

protocols. Overall, early intervention is crucial to prevent organ damage and avoid futility of late treatments (smileys becoming sad). CAVI, caval valve implantation; RHF, right heart failure; TR, tricuspid regurgitation; RA, right atrial; RV, right ventricular; TTV, transcatheter tricuspid valve.

Abstract

Transcatheter tricuspid valve interventions (TTVI) are emerging as alternatives to surgery in high-risk patients with isolated or concomitant tricuspid regurgitation. The development of new minimally invasive solutions potentially more adapted to this largely undertreated population of patients, has fuelled the interest for the tricuspid valve. Growing evidence and new concepts have contributed to revise obsolete and misleading perceptions around the right side of the heart. New definitions, classifications, and a better understanding of the disease pathophysiology and phenotypes, as well as their associated patient journeys have profoundly and durably changed the landscape of tricuspid disease. A number of registries and a recent randomized controlled pivotal trial provide preliminary guidance for decision-making. TTVI seem to be very safe and effective in selected patients, although clinical benefits beyond improved quality of life remain to be demonstrated. Even if more efforts are needed, increased disease awareness is gaining momentum in the community and supports the establishment of dedicated expert valve centres. This review is summarizing the achievements in the field and provides perspectives for a less invasive management of a no-more-forgotten disease.

Keywords Tricuspid regurgitation • Right heart • Heart failure • TTVI • Transcatheter interventions • Percutaneous • Repair • Replacement

Incipit: *'In the delicate chambers of the heart, where life's symphony finds its rhythm, a silent trouble lingers. A tricuspid valve, once a guardian of harmony, now whispers a discordant tune, signaling the presence of a hidden disease…'*
Anonimous Chatbot

The recent introduction of transcatheter tricuspid valve interventions (TTVI) has dramatically influenced the perception of the relevance of tricuspid valve (TV) disease. As more evidence becomes available, concepts and strategies are evolving (*Graphical Abstract*) and new challenges emerge in the quest to uncover the secrets of the right side of the heart. This state-of-the-art review is revisiting TV disease through the most up-to-date knowledge of its mechanisms, diagnostics, and treatment options, bringing to light the valve that is anything but forgotten.

Tricuspid valve regurgitation: a no-more-forgotten entity

The TV has long been disregarded and as a result remained relatively under-studied, leading to under-recognition, and under-treatment. For more than 50 years, tricuspid regurgitation (TR) has been classified as a signal rather than a causative prognostic factor, believed to be easily reversible with treatment of left heart disease, or surrogate of end-stage disease indicating an inoperable condition. Nina Braunwald, in a publication considered the manifesto of the 'forgotten valve', described TR as a secondary issue, 'seldom requiring an intervention'.[1] Several factors supported the theory that the right circulation is less impactful on survival than the left. As an example, children with surgically corrected congenital heart disease have survived with univentricular physiology. TV endocarditis has been treated with valvectomy with acceptable short-term results.[2] In addition, diuretics can efficiently control symptoms of venous congestion and reduce the degree of TR.[3] In the setting of nonspecific signs and symptoms as well as early diuretic responsiveness, there has been a tendency to delay interventions. Surgery for isolated TR has been associated with debatable prognostic impact[4] and high in-hospital mortality,[5] possibly related to the late referral but also influencing referral rates for this procedure.

Recent evidence challenges the belief that TV disease and, overall, right heart (RH) failure are of 'secondary' importance. In addition, recent advances in valvular interventions have broadened the spectrum of treatable patients to high risk or inoperable patients. The broad range of transcatheter treatment eligible patients, as well as less invasive nature of the procedures, will allow us to study the effect of TR reduction on prognosis and quality of life (QoL), but also, and probably more importantly, advance our understanding of the interaction between TV function and RH physiology, improving our detection of adaptive and maladaptive processes.

The burden of a misleading disease: from marker to culprit

The role of TR as a marker of disease severity is unquestioned. The development of TR as a consequence of left heart disease or pulmonary hypertension (PH) is associated with worsening prognosis in congestive heart failure,[6] primary PH,[7] and in patients undergoing aortic[8,9] or mitral valve interventions.[10–12] However, the absolute impact of isolated TR on prognosis has been long questioned. In addition, symptoms of isolated severe TR can be highly misleading and underestimated during its early stages or confounded with other conditions, particularly in the elderly. In a recent study, asthenia, ankle swelling, abdominal pain or distention, and/or anorexia have been found to be predictive of clinical outcomes in patients with TR.[13] With an aging population and improved left heart failure management, the prevalence of TR is increasing and these unconventional symptoms are red flags motivating further investigations.

The Framingham study reported a prevalence of 1.5% in men and 5.6% in women of at least moderate TR in the elderly (above 70 years) population.[14] A more recent community-based prospective study showed that 16% of patients ≥65 years old had previously undiagnosed moderate or severe valvular heart disease, with TR having the highest prevalence at 7.2%,[15] confirming the Framingham study. According to the Eurostat census, in 2001 there were 54 million elderly inhabitants in Europe, of which 21 million were male and 34 were million female

Table 1 New classification of TR according to mechanism and aetiology

	Mechanism of regurgitation	aetiology	Main imaging and staging	Typical patient journey (referral clinics)
Secondary (functional) tricuspid regurgitation				
Valve structures are anatomically normal, valve dysfunction is secondary to atrial or ventricular remodelling and dysfunction				
Ventricular TR	TR due to a combination of annular dilatation and leaflet tethering caused by RV remodelling and/or dysfunction	Pulmonary hypertension Left heart valvular disease HFrEF, HFpEF Right ventricular infarction Right ventricular cardiomyopathy Congenital anomalies	2D/3D echocardiography for TR grading, quantification of valve and ventricular remodelling, RV systolic function RH catheterization Biomarkers	Heart Failure clinic Cardiovascular surgery Pneumology GUCH
Atriogenic TR	TR is mainly driven by annular dilatation and dysfunction. Normal RV function and shape (conical shape preserved)	Atrial fibrillation HFpEF Aging	2D/3D echocardiography for TR grading, quantification of valve and ventricular remodelling, RV systolic function RH catheterization Biomarkers	Electrophysiology General cardiologist Family physician Internal Medicine Heart Failure clinic
Primary or mixed tricuspid regurgitation				
Valve structures are abnormal				
Primary	Chordal elongation/rupture Papillary muscle rupture (trauma) Excessive leaflet motion (myxomatous disease) Leaflet perforation (endocarditis) Leaflet retraction (rheumatic, inflammatory diseases)	Endocarditis Myxomatous disease Rheumatic disease Trauma NET tumours	2D/3D echocardiography for TR grading, quantification of valve and ventricular remodelling, RV systolic function	Internal medicine Infectivology Traumatology General Cardiologist Gastroenterology
CIED-related				
TR is caused by the interaction with intracavitary leads				
CIED-related	Leaflet impingement, chordal entanglement or rupture, leaflet adherence, perforation, laceration (post-extraction)	Implant of an intracardiac electrical device crossing the tricuspid valve. Implant of a leadless pacemaker Lead extraction	EP evaluation 2D/3D echocardiography for TR grading, quantification of valve and ventricular remodelling, RV systolic function Assessment of lead influence: CIED-related vs. CIED-associated TR)	Electrophysiology Heart failure clinic

The existence of multiple tricuspid regurgitation phenotypes, each with distinct regurgitation mechanisms and patient trajectories, indicates the necessity for personalized care strategies. This encompasses everything from diagnostic and therapeutic approaches to ongoing lifetime management.
RV, right ventricular; HFrEF, heart failure with reduced ejection fraction; HFpEF, heart failure with preserved ejection fraction; NET, neuroendocrine tumours; RH, right heart; EP, electrophysiology; CIED, cardiac implantable electronic device; GUCH, grown-up congenital heart disease; TR, tricuspid regurgitation.

(https://ec.europa.eu/eurostat/databrowser/view/CENS_HNMGA__custom_6714995/default/table? lang=en). This would predict a potential population of 2.2 million individuals with at least moderate TR in Europe. Topilsky *et al.*, in a population-based registry, found a 0.55% prevalence of at least moderate TR in the overall population, which increased with age and in women.[16] The most common cause of TR was left heart disease (valve disease or left ventricular dysfunction) and PH, while isolated, non-primary, TR was found in 8% of the population. The overall survival under medical management in patients with isolated TR was inferior to that of matched individuals with trivial TR (hazard ratio -HR-[15] 1.17; $P = .01$). Nath et al. reported an increased mortality risk [adjusted for age, left ventricular ejection fraction, inferior vena cava (IVC) size, and right ventricular (RV)[16] size and function] with moderate (HR 1.17) and severe TR (HR 1.31) in a retrospective analysis of 5223 patients.[17]

Data from the UK Biobank showed that, compared to patients with no valvular heart disease, the risk of all-cause death is more than 2.5 times higher for TR.[18] This is supported by a large population study of the National Echocardiography Database of Australia on 439 558 patients referred to echocardiographic examination[19] that revealed a prevalence of moderate and severe TR of 5.9% and 1.8%, respectively. Following adjustment for RV systolic pressure, atrial fibrillation, and left heart disease, severe TR was associated with 2.65 increased risk of mortality. Interestingly, increased risk was observed also in patients with mild (HR 1.24), or moderate TR (HR 1.72). Wang *et al.*[20] performed a systematic review and meta-analysis suggesting that TR is associated with increased mortality independently of pulmonary pressures and RH failure. The risk of mortality at a mean follow-up of 3.2 ± 2.1 years increased from 1.25 to 1.61 and 3.44-fold in patients

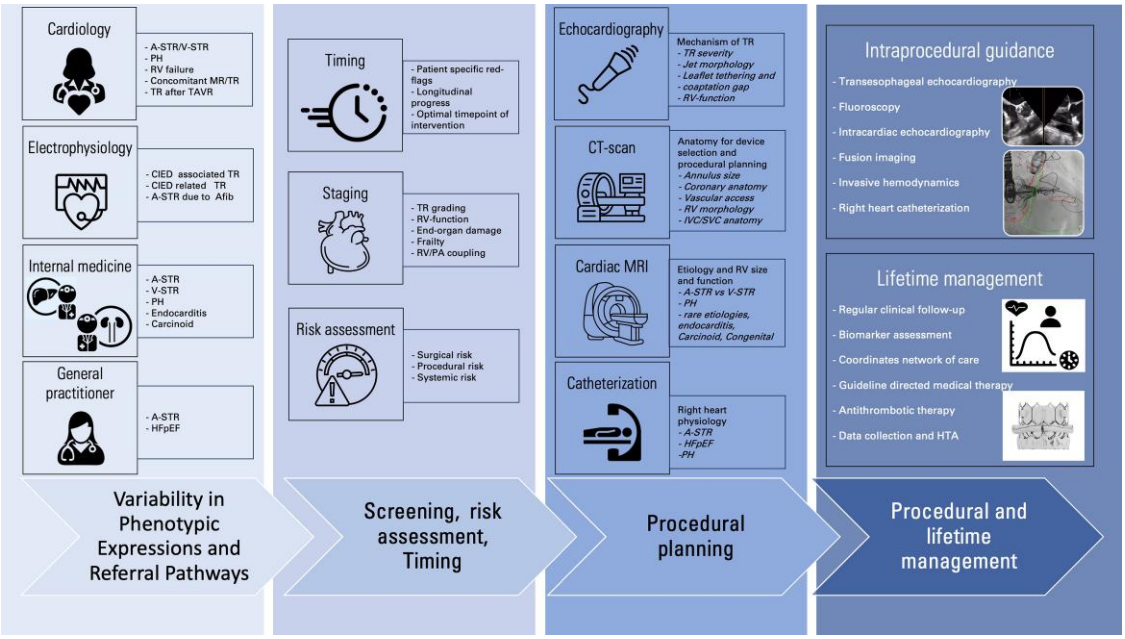


Figure 1 Patient journeys across different tricuspid regurgitation phenotypes. Patients with significant tricuspid regurgitation come from diverse disease journeys and may be referred to the Valve Team by different specialists. Following screening and risk stratification, if tricuspid regurgitation is deemed suitable for treatment, comprehensive multimodal imaging is essential for choosing the appropriate device, planning the procedure, and guiding the intervention. Post-intervention, patients enter a lifelong care program within a network that emphasizes seamless continuity of care and ongoing evaluation of their health outcomes. Abbreviations: A-STR, atrial secondary tricuspid regurgitation; V-STR, ventricular secondary tricuspid regurgitation; PH, pulmonary hypertension; RV, right ventricular; MR, mitral regurgitation; TR, tricuspid regurgitation; TAVR, transcatheter aortic valve replacement; CIED, cardiac implantable electronic device; AFib, atrial fibrillation; HFpEF, heart failure with preserved ejection fraction; PA, pulmonary artery; IVC, inferior vena cava; SVC, superior vena cava; HTA, health technology assessment

with mild, moderate, or severe TR, respectively. Patients with at least moderate TR had an overall 2.56-fold increased cardiac mortality and a 1.73-fold increased heart failure hospitalization rate.

These data challenge the misconception that TR is a benign condition and suggests us to refer patients presenting with at least moderate TR to a valve centre with dedicated expertise for further risk stratification and management.

Revised definitions unveiling different phenotypes and patient journeys

TR disease can develop under diverse circumstances, leading to a wide spectrum of phenotypes with different mechanisms and aetiology. The PCR Focus group (https://www.pcronline.com/Network/Tricuspid-Focus-Group) revised the TR classification[21,22] (*Table 1*) subdividing the formerly called functional TR into atrial secondary TR (A-STR) or ventricular secondary TR (V-STR), while primary TR encompasses a variety of subsets ranging from congenital malformation, traumatic lesions to endocarditis. Cardiac implantable electronic device (CIED)-related TR is considered a separate entity with distinctive disease mechanisms and management. In addition to the variability of valve morphology, mechanisms of regurgitation, and hemodynamics, clinical presentation seems to have prognostic relevance. This suggests different patient journeys and referral pathways (*Figure 1*). As an example, prognosis of A-STR treated conservatively[23] or following an intervention[24] is more favourable as compared to patients with V-STR, while the impact of TR treatment in patients with fixed pre-capillary PH is debatable. Such variability deserves further investigation and targeted therapies for a tailored approach. Recently, a comprehensive risk stratification based on pheno-clusters including aetiology and clinical presentation has been proposed.[25] RH function plays a major role in risk assessment with signs of RV failure indicating later stages of disease progression.[26,27]

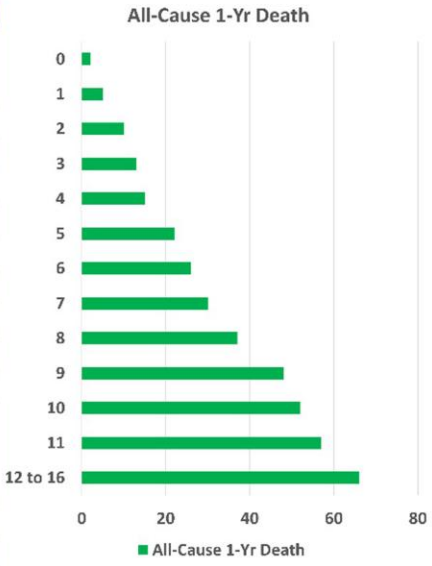
Risk scores for assessing short-term mortality both for medically treated[28] and surgically treated[29] patients have included both RV function and RH failure symptoms, in addition to a number of other clinical and laboratory parameters (*Figure 2*).

Function follows morphology, and in the spectrum of TR subsets, the anatomo-functional presentation of the valve and of the RH is highly variable.[30] Different mechanisms of regurgitation and disease progression imply the need for different types of interventions. Recent advances in three-dimensional (3D) echocardiography and the use of tomographic imaging modalities allow a comprehensive investigation of the morphology of the valve apparatus and guide device selection for valve repair and replacement.

All the components of the valve apparatus play a role: leaflet and subvalvar apparatus distribution, annular shape and function, as well as right atrial[31] and ventricular[32] function and morphology. To challenge the current nomenclature, TV has rarely three leaflets. Almost half of the valves with TR have more than three leaflets. This finding is highly relevant for leaflet devices, such as Triclip (Abbott Vascular, Menlo Park, CA,

A Risk Model for 1-Year All-Cause Mortality in Isolated Secondary TR

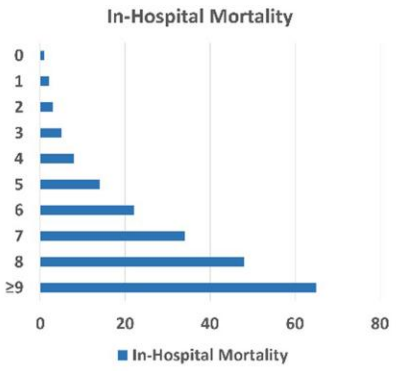
Parameter	Score
Age	
65-74 yrs	1
75+ yrs	2
Myocardial infarction	1
Peripheral vascular disease	1
Chronic lung disease	1
Chronic kidney disease (creatinine >1.4 mg/dL)	1
Loop diuretic use	1
Anemia (Hgb M10 g/dL	1
Thromocytopenia (plt <15 k/μL)	1
INR >1.5	1
Albumin <3.0 g/dL	2
RV Systolic Fx	
Mildly impaired	1
Moderately impaired	2
Severely impaired	3
Right ventricular systolic pressure >50 mmHg	1
TOTAL	16



Wang, TKM. et al. J Am Coll Cardiol Img. 2022:15(5):731-744

B Risk Model for In-Hospital Mortality after Isolated Tricuspid Valve Surgery

Parameter	Score
Age ≥70 years	1
NYHA Class III-IV	1
Right-sided Heart Failure Signs	2
Daily Dose Furosemide ≥ 125 mg	2
Glomerular filtration rate <30 ml/min	2
Elevated Total Bilirubin	2
LV ejection fraction <60%	1
Moderate/severe RV dysfunction	1
TOTAL	12



Dreyfus, J. et al. Eur Heart J. 2022 Feb 12;43(7):654-662

Figure 2 Risk models for all-cause mortality for conservative and surgical treatment. (*A*) Risk model for 1-year all-cause mortality in isolated secondary tricuspid regurgitation (adapted from Wang *et al.*[28]). (*B*) Surgical risk model for in-hospital mortality after isolated tricuspid regurgitation surgery (adapted from Dreyfus *et al.*[29])

USA) and Pascal (Edwards lifesciences, Irvine, CA, USA). A recent leaflet distribution classification[33] has been proposed as a guide for patient selection.[34]

Less invasive technologies to manage TR have ignited the need for a dedicated quantification model. Compared to mitral regurgitation (MR), the TR regurgitant volumes are larger, requiring a grading scheme taking into account more than severe TR.[35] The new grading scheme, which includes two more grades (massive and torrential TR) beyond severe is reliable for risk stratification in patients treated conservatively,[36] as well as for patient selection and to assess postprocedural outcomes.[37]

Imaging: a fundamental partner for valvular interventions

The fundamental role of imaging and dedicated imagers for structural heart interventions is well established.[38] Advanced imaging using two-dimensional (2D) and 3D echocardiography is instrumental in defining the morphologic characteristics that differentiate the TR subphenotypes.[31,39] State-of-the-art multi-modality imaging is required to appreciate the complexity of TV leaflet morphology,[33] provide a nuanced quantitation of TR severity[40] and to assess RH size and function.[41]

Because transcatheter devices can anchor at the leaflets, annulus, atrium, ventricle, and vena cavae, pre-procedural imaging is key for the assessment of device suitability, prediction of efficacy, and guarantee of technical success.[21] A comprehensive evaluation of the TV should be performed by transthoracic echocardiography to quantify the severity and aetiology of TR, assess left ventricular and RV size and function, and the presence of concomitant disease of other valves or PH. Transoesophageal echocardiography (TEE) should be performed in all patients considered for TTVI to further assess leaflet morphology and function (i.e. mobility, tethering, and coaptation gaps), TR jet number, size and location, annular morphology and size, and subvalvular anatomy (i.e. location and density of chordae, location/height of

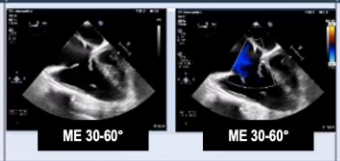
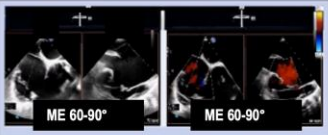
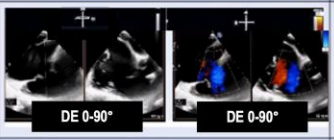
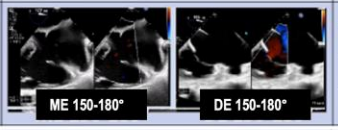
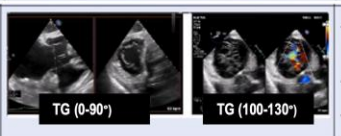
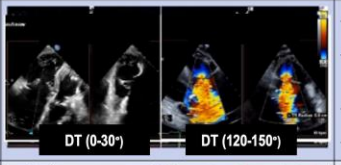
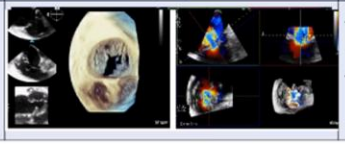
View	Imaging examples	Structures imaged	Potential role in procedural guidance
4-Chamber view, ME (0-30°)		– Tricuspid valve (A, S) – Right atrium/right ventricle/ outflow – Left atrium/ventricle – Aortic valve	– Septal and anterior tricuspid valve leaflets (for TEER) and annulus (for annular or replacement devices).
RV inflow/outflow view ME (60-90°)		– Tricuspid valve (A, P, S) – Right atrium/right ventricle	– Imaging sweep from anterior to posterior to localise regurgitant orifice along the septal coaptation line. – Biplane imaging used to visualise A-S or P-S coaptation zone or annulus.
2-Chamber view, DE (0-30°) and RV inflow/outflow view, DE (60-90°)		– Tricuspid valve (A or P, S) – Right atrium/right ventricle – Coronary sinus	– Septal and anterior (or posterior, depending on depth/flexion) tricuspid valve leaflets (for TEER) and annulus (for annular or replacement devices).
Reversed 4-chamber view, ME and DE (150-180°)		– Tricuspid valve (A, S) – Right atrium/right ventricle – Coronary sinus	– Septal and anterior tricuspid valve leaflets (for TEER) and annulus (for annular or replacement devices).
2-Chamber view, TG (0-90°) Short-Axis view TG (100-130°)		– Tricuspid valve SAX (A, S, P or atypical morphology) – Regurgitant orifice (SAX) – Right ventricular outflow	– Tricuspid coaptation gaps, regurgitant orifice location and chordal anatomy help guide TEER. – Posterior annulus well imaged for annular or replacement device.
Apical view DT (0-30° or 120-150°)		– Tricuspid valve (A, S) – Right atrium/right ventricle/ outflow – Left ventricular outflow – Aortic valve	– Septal and anterior tricuspid valve leaflets (for TEER) and annulus (for annular or replacement devices). – TR Doppler aligned for quantitative analysis.
3D volumes (any level)		– Tricuspid valve SAX (A, S, P or atypical morphology) – Regurgitant orifice (SAX)	– 3D multiplanar reconstruction allows simultaneous imaging of coaptation gaps, regurgitant orifice location and leaflet lengths/mobility for device implantation.

Figure 3 Transesophageal echocardiography imaging levels. Recent screening guidelines recommend a standardized imaging protocol for evaluating tricuspid valve structure and functionality. Three-dimensional imaging has become integral to the detailed assessment of the tricuspid valve, providing critical insights into its morphology and function. Abbreviations: ME, mid-esophageal; RV, right ventricular; DE, deep esophageal; TG, transgastric; DT, deep transgastric; SAX, short axis; A, anterior; P, posterior; S, septal; TEER, transcatheter edge-to-edge repair

papillary muscles). These anatomic parameters support optimal patient-specific device selection. Multi-modality imaging has also become the standard for the assessment of procedural eligibility.[34] Computed tomography (CT) allows comprehensive anatomical evaluation of the TV complex, right ventricle, and right coronary artery. In addition, CT is essential for pre-procedural planning of device delivery. Device-specific evaluation may include assessment of femoral or jugular vein diameters, cavo-atrial angulation, or detailed evaluation of caval anatomy.[42,43] Although currently underutilized for TR, cardiac magnetic resonance (CMR) imaging is helpful to quantify TR in case of discrepant echocardiographic findings[44] and is the reference method to quantify RV size and function.[41,45]

Intra-procedural imaging relies primarily on TEE and fluoroscopy.[34,46,47] New TEE screening guidelines have standardized TV imaging[48] and improved intra-procedural imaging protocols[46] (*Figure 3*). The use of echo-fluoro fusion imaging may improve intra-procedural communication between operators by the fusion of two modalities from nearly orthogonal points of view.[21] The recent introduction of 3D intracardiac echocardiography (ICE) catheters already had a significant impact on TTVI technical success when TEE is suboptimal.[49–52] Both TEE and ICE catheters have biplane imaging with both lateral and elevational tilt, and live 3D multi-planar reconstruction (MPR) which allows simultaneous visualization of three different (often orthogonal) 2D images, in addition to the 3D volume. Because of the innumerable ways in which the images can be manipulated, a dedicated, trained interventional imager is required for both TEE and ICE imaging during TTVI.[38]

Current treatment options: guidelines and real-world

The 2021 ESC/EACTS valvular heart disease guidelines recommend that interventional treatment of secondary TR may be considered in experienced Heart Valve Centers in symptomatic but inoperable patients, who are anatomically eligible and have the potential for a clinical

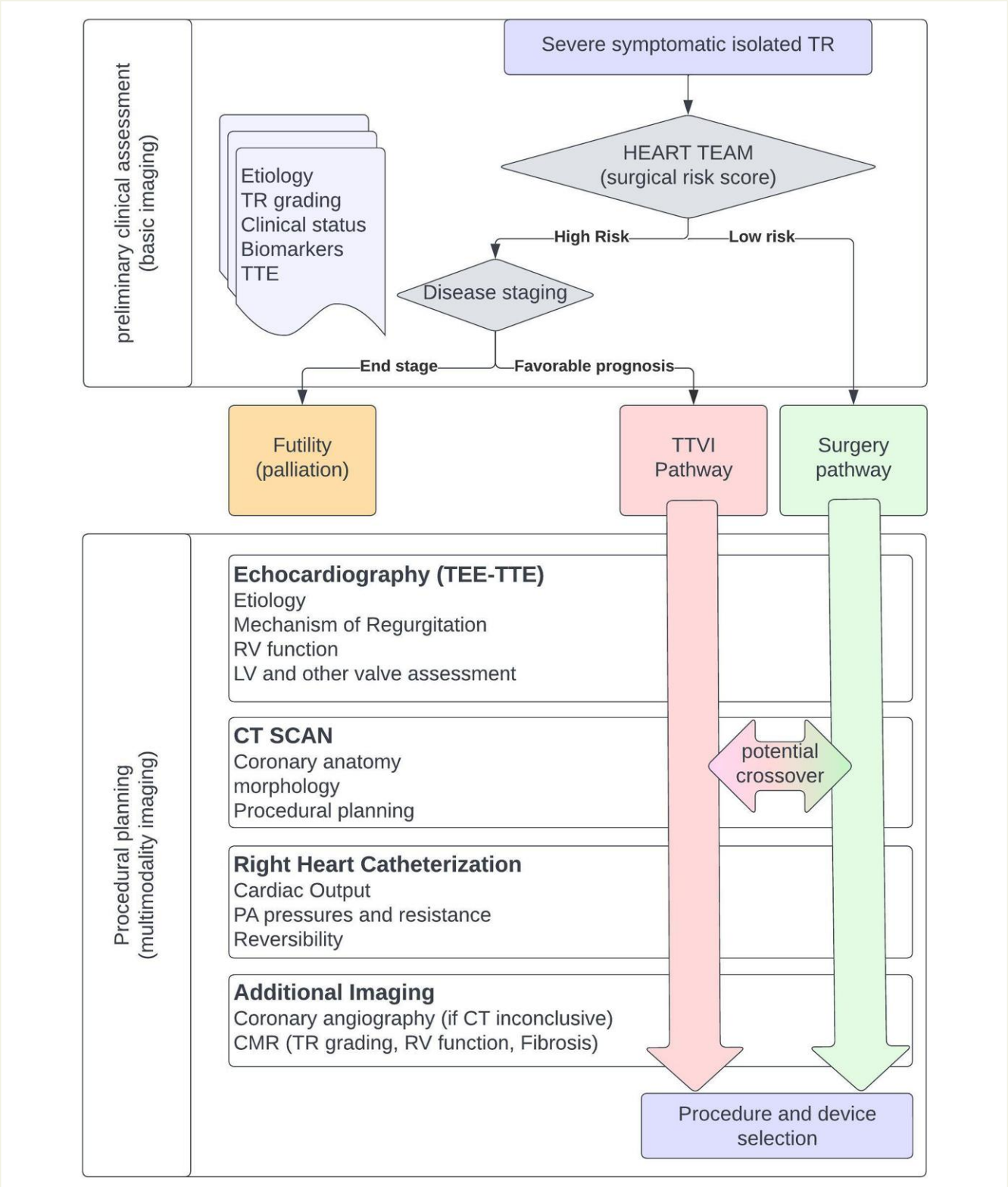


Figure 4 Imaging protocols for in-hospital tricuspid regurgitation screening and treatment planning. For patients with severe symptomatic tricuspid regurgitation, initial screening combines basic imaging techniques, predominantly transthoracic echocardiography, and right heart catheterization, with clinical assessments to stage the disease. Intervention candidates, whether for transcatheter or surgical approaches, require further comprehensive multimodal imaging to tailor the optimal treatment strategy and to support procedural and device selection

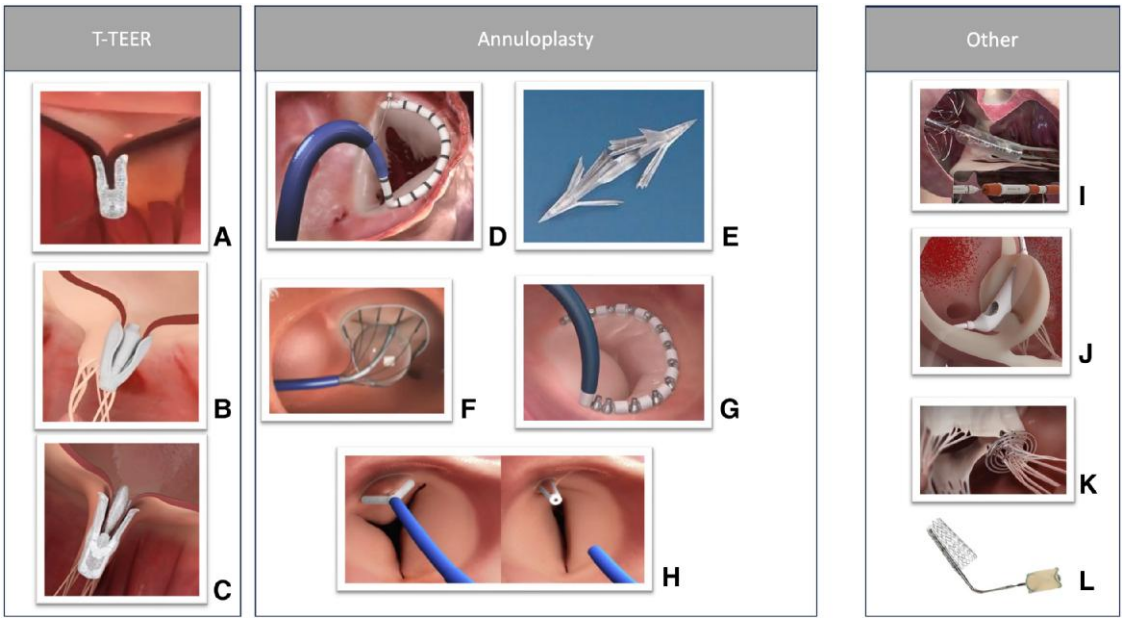


Figure 5 Repair technologies approved for clinical use in Europe or actively under investigation. (*A*) Triclip (CE marked); (*B*) PASCAL (CE marked); (*C*) Dragonfly; (*D*) Cardioband (CE marked); (*E*) MIA-T; (*F*) Cardiac Implants Tri-Ring; (*G*) Dragon Ring; (*H*) F-clip; (*I*) Coramaze; (*J*) PivotTR; (*K*) Mitrelix; (*L*) Croivalve Duo

benefit from the procedure.[53] While the exact timing for the procedure in both symptomatic and asymptomatic with RH dilation is still matter of debate, earlier referral is beneficial and supported by guidelines. As far as TTVI should be reserved for inoperable patients, surgical risk should be assessed using specific risk scores. The common simplification that surgery is high risk, should be demystified. Overall surgical risk in the Society of Thoracic Surgeons database is ~7%. However, hospital mortality is highly dependent on the disease stage and indication of treatment, being highest in patients with right-sided infective endocarditis.[54] When surgery is performed at earlier stages, mortality for isolated TR can be minimized.[55] The TRI-SCORE registry developed an additive scoring method to predict hospital mortality in patients undergoing surgery for isolated TR (*Figure 2*).[29] Lacking a reliable method to avoid futility, data from real-world registries[56–58] as well as local experience within the Heart Team should guide decisions within the in-hospital pathway (*Figure 4*).

Transcatheter valve repair techniques

Valve repair can be achieved with leaflet approximation devices, with annuloplasty, or with other devices including 'spacers' (devices filling the coaptation gap) and chordal approximation devices (*Figure 5*). The first transcatheter tricuspid valve repair (TTVr) has been performed with the MitraClip system (Abbott Vascular Inc, Santa Clara, CA, USA) in a corrected transposition patient with a morphologically tricuspid left atrio-ventricular valve.[59] Initially, tricuspid transcatheter edge-to-edge repair (T-TEER) with off-label MitraClip was broadly performed in Europe, usually as an adjunct to mitral interventions. To-date, T-TEER remains the most commonly performed TTVr procedure, with two approved devices. The TriClip is a dedicated multi-steering delivery system optimized for T-TEER, while PASCAL can be used indifferently for both atrio-ventricular valves. Both feature T-TEER devices of different sizes to accommodate for diverse leaflet anatomies and jet locations. The TriClip device features implants of four different sizes with an active closing mechanism. The most used device is the XTW, the longest and larger clip size, maximizing the amount of potential annular reduction.[60] The fourth-generation device allows independent grasping and continuous pressure monitoring. The PASCAL system is a nitinol-based device with a passive closing mechanism, incorporating two paddles and a spacer to fill the coaptation defect. The device has a unique elongation feature that minimize the risk of leaflet entanglement. Two sizes are available and continuous pressure monitoring is integrated in the steerable catheter. Additional devices are in early feasibility development and initial clinical trials. The Dragonfly[61] (Venus Medtec, Hangzhou, China) system is currently under first-in-man evaluation in China.

T-TEER addresses TR by a combination of leaflet approximation at the site of regurgitation and indirect annular reduction. Initial efforts have been challenged by anatomical complexity, lack of dedicated devices, and intra-procedural imaging complexity. Initially, most implants were confined in the anteroseptal commissure, because of the ease of approach and visualization by TEE. The anteroseptal coaptation line remains the main initial target, trying to approximate leaflet in the centre of the valve. The clover technique requires an additional device in the postero-septal coaptation line[62,63] to maximize leaflet approximation and annular reduction.[60] Safety and efficacy of T-TEER have been shown in several single-arm registries[64–67] and recently confirmed in pivotal trials.[68] The improvement of clinical outcomes follows TR reduction,[57,68] while the ideal cut-off for residual gradients remains debated.[69] Few non-randomized comparisons between devices show very comparable outcomes.[70] Several predictors of procedural success have been found. The

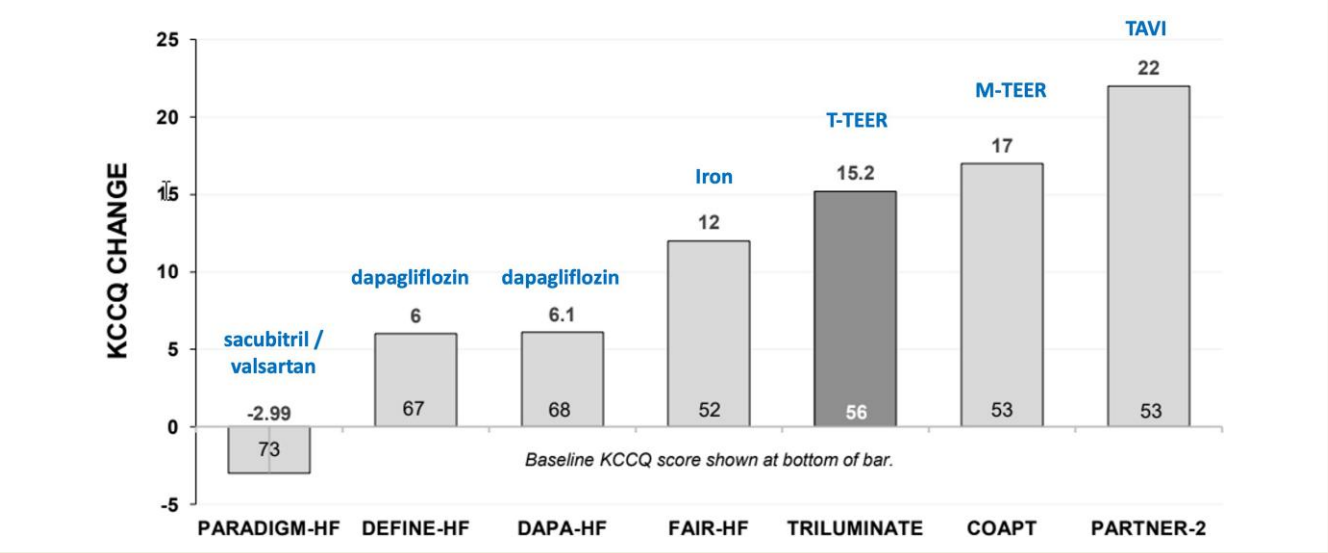


Figure 6 Quality of life improvement (as assessed by Kansas City Cardiomyopathy Questionnaire) in various heart failure randomized controlled trials. The quality of life improvements reported in the TRILUMINATE trial align with those seen in other structural heart disease studies and exceed the enhancements typically noted in heart failure drug trials. In these trials, various interventions were evaluated: sacubitril/valsartan in PARADIGM-HF;[103] dapagliflozin in DEFINE-HF[104] and DAPA-HF,[105] intravenous ferric carboxymaltose in FAIR-HF;[106] the MitraClip procedure for secondary mitral regurgitation in COAPT,[102] and transcatheter aortic valve implantation for intermediate-risk patients in PARTNER 2[107]

main anatomical determinants are the leaflet coaptation gap and the non-central or non-anteroseptal location of the jet.[71,72] A threshold for coaptation gap defining ineligibility for TEER is debatable, due to its load dependency. Leaflet-to-annulus index[72] is a promising alternative, derived from mitral interventions.[73,74] Complex valve morphologies, with multiple leaflets, in isolation,[33] or in combination with larger gaps,[75] are associated with residual TR. T-TEER is feasible in selected patients with CIED leads with short-term clinical outcomes comparable to patients without lead.[76]

Short and long-term outcomes are strongly affected by aetiology,[77] clinical presentation,[78] RH hemodynamics,[79,80] comorbidities, organ reserve, and stage of the disease.[81] Recent registries show an overall improvement in safety and efficacy of T-TEER even in anatomically challenging scenarios. In the post-approval bRIGHT post-approval study using the fourth-generation TriClip system, most patients were highly symptomatic [New York Heart Association (NYHA) class III–IV] and had more than severe TR. In this unselected population, hospital mortality and rate of adverse events were as low as 1% and 2.5%, respectively. Procedural success (reduction to ≤2+ TR) was obtained in 77% of patients, with early improvement of symptoms and QoL. Predictors of success were smaller tethering distance and smaller right atrial volumes at baseline.[58] Similarly, the CLASP TR trial reported a 3.1% 30 day-mortality, and sustained 1-year TR reduction (86% achieving ≤2+ TR),[82] associated with improved QoL and symptoms and comparable results were reported in the PASTE post-market registry including more than 230 patients.[66]

While T-TEER is the most performed intervention, annuloplasty replicates the most common surgical repair procedure, with the peculiarity of leaving all alternative options open. Cardioband system was the first TTVI device approved in Europe.[83] Cardioband is implanted under echocardiographic guidance with multiple anchoring screws, followed by echo-guided annular reduction. The TRI-REPAIR observational study enrolled 30 patients with symptomatic functional TR.[84] At 2 years, echocardiography showed a 16% reduction in septolateral annular diameter, and ≤2+ TR in 72% of patients. Six-minute walking distance and Kansas City Cardiomyopathy Questionnaire (KCCQ) score improved by 73 m and 14 points, respectively. Despite its strong rationale, Cardioband is implanted only in very experienced centres, because of the complexity of the procedure, and the potential risk of coronary lesions.[85] For the same reasons, several other direct and indirect annuloplasty devices have been discontinued or are in the early feasibility stage,[47,86–100] Second-generation devices are expected to simplify the procedure. The minimal effect on valve gradients, the minimal footprint of the implant, and the possibility of combining leaflet and annular repair imitating surgery[101] warrant further efforts in this field.

Emerging randomized controlled evidence: the impact of TR treatment

Although registries are key to explore the safety and feasibility of interventions, the fundamental question of whether TR treatment can influence survival remains to be answered. A propensity-matched analysis comparing survival of patients undergoing TTVI to a historical series of medically treated patients suggested a potential survival benefit in patients who received successful treatment.[56]

The TRILUMINATE pivotal trial[68] has a historical significance since it is the first randomized study investigating an isolated TR treatment strategy compared to medical therapy alone. The trial randomized 350 symptomatic patients with severe TR with a hierarchical composite primary endpoint at 1 year consisting of death or TV surgery, heart failure hospitalization, and improvement in QoL as measured with the KCCQ. A minimal 15 KCCQ points improvement was considered

Table 2 Comparison between the TRILUMINATE cohort and 'real-world' data from registries

	TRILUMINATE RCT arm (TriClip) $n = 350$	bRIGHT Study (TriClip) $n = 511$	PASTE Registry (PASCAL) $n = 603$	TRISCEND I (EVOQUE) $n = 176$
Demographics				
Age, years, mean ± SD	77.9 ± 7.3	78.9 ± 7.1	78 ± 9	78.7 ± 7.33
Male/female sex	45%/55%	44%/56%	47%/53%	39%/71%
Medical history				
NYHA class III/IV at baseline	57.5%	80%	89%	75.4%
Prior permanent pacemaker implantation	14.9%	22.5%	28%	32.4%
KCCQ score at baseline, mean ± SD	55.1 ± 23.8	44.5 ± 22.6		46.0 ± 21.8
Prior heart failure hospitalization lasts 12 months	25.1%	40.3%		40.9%
Baseline TR grade				
Moderate	1.8%	2.0%	6%	12.5%
Severe	27.5%	10.0%	38%	44.7%
Massive/torrential	70.7%	88%	56%	42.8%
Key procedural data				
Coaptation gap, mm, mean ± SD	5.4 ± 1.8	6.5 ± 2.7	6.3 ± 3.4	
TR ≤ moderate at 30 days	87%	77%	81%	100%
SLDA rate	7.0%	3.8%	3%	NA

KCCQ, Kansas City Cardiomyopathy Questionnaire; NYHA, New York Heart Association; SLDA, Single leaflet device attachment; RCT, randomized controlled trial; TR, tricuspid regurgitation; SD, standard deviation.

relevant. The patient population included elderly individuals (mean 78 years, 55% women), with reduced baseline QoL (mean KCCQ at baseline: 55.1 ± 23.8 points). However, only 25% of the patients were admitted for heart failure treatment in the year before enrolment, suggesting that, despite poor QoL, most TR patients remain managed in the ambulatory setting. At baseline, TR was severe or worse in almost all patients in both groups, while severe TR was still present in 95% of the control patients against 13% in the therapy arm at 1-year follow-up. This outcome contrasts with the COAPT trial, where MR was reduced significantly also in the medical arm at 2 years.[102] This finding confirms the efficacy of T-TEER and underlines the inefficacy of medical therapy to control TR in symptomatic patients. The procedure was safe, with 0.6% all-cause mortality at 30 days and only a few adverse events. At 1 year, there was no difference in mortality, surgery for TR, or hospitalization rate between the two groups, while KCCQ improved by 12.3 ± 1.8 points in the TEER group, in contrast to only .6 ± 1.8 points in the control group ($P < .001$).

The improvement in QoL is similar to that observed in the device group of the COAPT trial and larger than most of the heart failure trials (*Figure 6*). There was a direct correlation between QoL improvement and TR reduction, suggesting a dose-effect, although a placebo effect cannot be completely excluded due to trial design (patient-reported outcome, open-label trial). The TRILUMINATE trial is a matter of intensive debate, with all its intrinsic limitations, being the randomized study of a widely undefined field of interest. While observational studies were predicting a much higher treatment impact, the TRILUMINATE trial included patients with a lower burden of symptoms (NYHA class and KCCQ) and hospitalizations before entering the study, less advanced V-STR with smaller coaptation gaps and lower incidence of left-sided heart disease (particularly previous cardiac surgery) (*Table 2*). While QoL represents a relevant endpoint for elderly patients with TR, longer-term follow-up data are awaited to verify whether T-TEER can influence more objective outcomes. Unfortunately, the possibility to crossover without experiencing an event at one year by design has the potential to blunt this expectation.

Several additional randomized studies comparing different treatment strategies with conservative treatment are currently enrolling in different countries (e.g. TRISCEND II, CLASP TR, TRICI-HF in Germany and TRI-FR in France, TRICAV for heterotopic valve replacement with the TricValve system) and will provide further insights into the clinical impact of TR treatment.

Valve replacement

In the timeline of TR interventions, transcatheter tricuspid valve replacement (TTVR), as valve-in-valve[108] and valve-in-ring procedures, came first. The off-label implant of balloon-expandable aortic or pulmonary valves[109] efficiently restores failed surgical repair and replacements. The implanted prostheses function as fixation scaffold for the balloon-expandable valves. The VIVID (Valve-in-Valve International Database) registry reported outcomes of 306 patients undergoing valve-in-ring and valve-in-valve procedures, with an incidence of 17% mortality, 12% reintervention, and an 8% risk of valve-related complications at 3-year follow-up.[110] Valve-in-ring and valve-in-valve have been performed successfully also in patients with preexisting pacemaker leads without the need for lead extraction.[111] Valve-in-ring procedures have been sometimes unsuccessful due to device and patient selection, although few reports are available in the literature.[112] Patient selection,

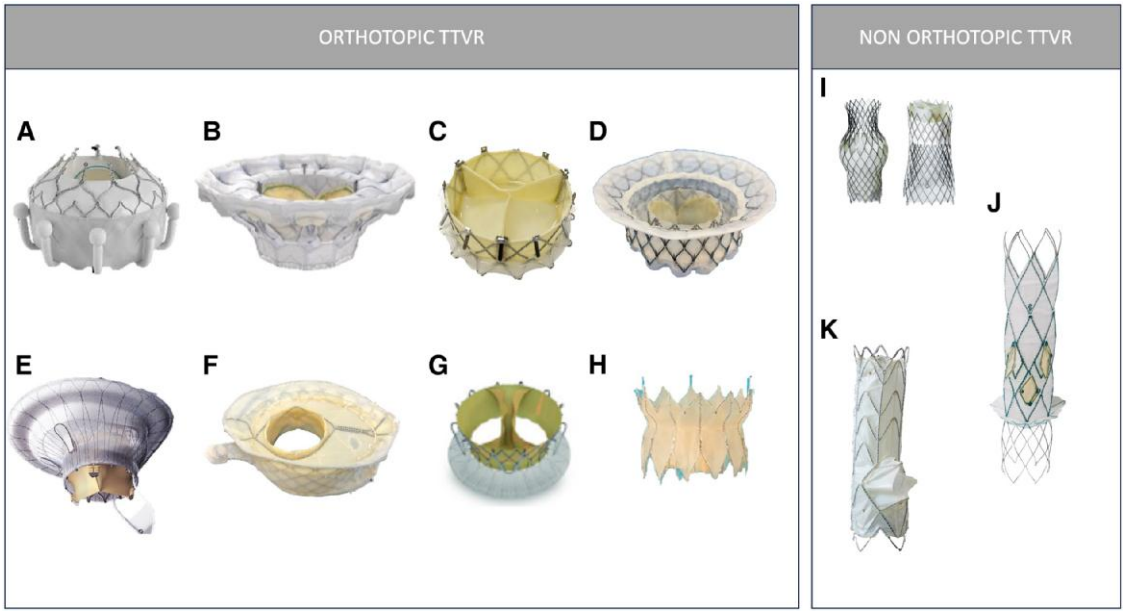


Figure 7 Transcatheter tricuspid valve replacement devices. Orthotopic devices: (*A*) Evoque; (*B*) Cardiovalve; (*C*) Gate; (*D*) Intrepid; (*E*) Lux valve; (*F*) V-Dyne, (*G*) Trisol; (*H*) Topaz Heterotopic devices; (*I*) Tric Valve; (*J*) Trillium; (*K*) Tricento

imaging screening, and device selection are key elements to perform a safe and simple procedure in most cases.

Balloon-expandable aortic valves have also been used as caval implants,[113,114] although this approach has been overcome by the development of dedicated devices.

Heterotopic or caval valve implantation (CAVI) has been attempted to protect organs from venous hypertension and reduce backflow-associated TR. CAVI (*Figure 7*) has been mainly used in patients who either had a failed or had anatomical contraindications for a 'conventional' transcatheter intervention. However, CAVI can be performed under local anaesthesia, solely fluoro-guided and non-constrained by TV anatomy. Dedicated prostheses are available with different fixation modalities, such as single bicaval implant,[115] or separated valves.[116] A recent registry reported significant improvements in QoL and symptoms despite no haemodynamic improvements following CAVI.[117] More recently, RH remodelling has been reported following CAVI, suggesting a potential prognostic value.[118] The exact role of CAVI in the field needs to be further developed, considering its simplicity and reproducibility, with the inherent limitation of an intervention that does not address the culprit lesion.

Several orthotopic valve devices (*Figure 7*) are under clinical investigation, most of them derived from a mitral valve design, while few are natively for the TV. The first TTVR with a dedicated device was performed using the Gate (NaviGate Cardiac Structures, Inc.) valve.[119] The large device, specifically designed to fit the large TV annulus, features a combination of leaflet and annular fixation. Limitations in the delivery system have confined this device to mainly direct transatrial access and have resulted in cases of malposition requiring surgical revision.

The experience with the Evoque system (Edwards Lifesciences Inc, Irvine, CA, USA), a self-expanding device using a mix of leaflet and annular fixation, with a dedicated delivery system is the largest so far. The safety-efficacy trial TRISCEND[120] collected data on 172 patients. Cardiovascular mortality was 1.7% and 9.4%, and major adverse events were observed in 18% and 30% of patients at 30 days and 1 year, respectively. New pacemaker implantation was needed in 13% of patients within 30 days (none thereafter). At 1 year, patients had significant improvement in NYHA class, QoL, and functional status. In addition, 2 years outcomes of patients implanted under compassionate use show superimposable outcomes[121] and reported a 37% increase of left ventricular forward stroke volume and improvement of hepatic function. The TRISCEND II (NCT04482062) pivotal trial comparing Evoque TTVR to medical therapy is recruiting.

Cardiovalve (Cardiovalve Inc., Or Yehuda, Israel), with leaflet fixation, requiring minimal radial force, therefore applicable to valves with large annulus, features a sealing cuff to minimize perivalvular leaks. The TARGET trial (NCT05486832) is collecting feasibility safety outcomes in an international registry. To date, more than 40 patients have been enrolled. Data from 30 compassionate-use patients report 6% mortality, 6% pacemaker implant rate, and 6% need for reintervention. At discharge, TR was less than moderate in 92% of patients (George Nickenig, PCR London Valves 2023, personal communication).

Other technologies are under investigation in an early phase, such as the Intrepid (Medtronic Inc, Minneapolis, MN, USA),[122] the LuX-Valve[123] (Jenscare Biotechnology, Ningbo, China), the Vdyne (VDyne, Minneapolis, MN, USA), the Topaz (TRiCares SAS, Paris, France) and Trisol Valve (TriSol Medical Ltd., Inc., Yokneam, Israel).

The Duo Valve (Croivalve, Dublin, Ireland) is a hybrid device implanted in the superior vena cava but acting as a coaptation device (either a valve or a spacer) at the valve level.

Spacers

Several attempts to treat atrio-ventricular valve regurgitation with spacers have been until now discouraging. These devices fill the regurgitant orifice to reduce backflow. The main limitation is the stability of fixation and efficacy in a complex 3D-shaped regurgitant orifice. The FORMA spacer was fixated at the subclavian vein and the apex of the

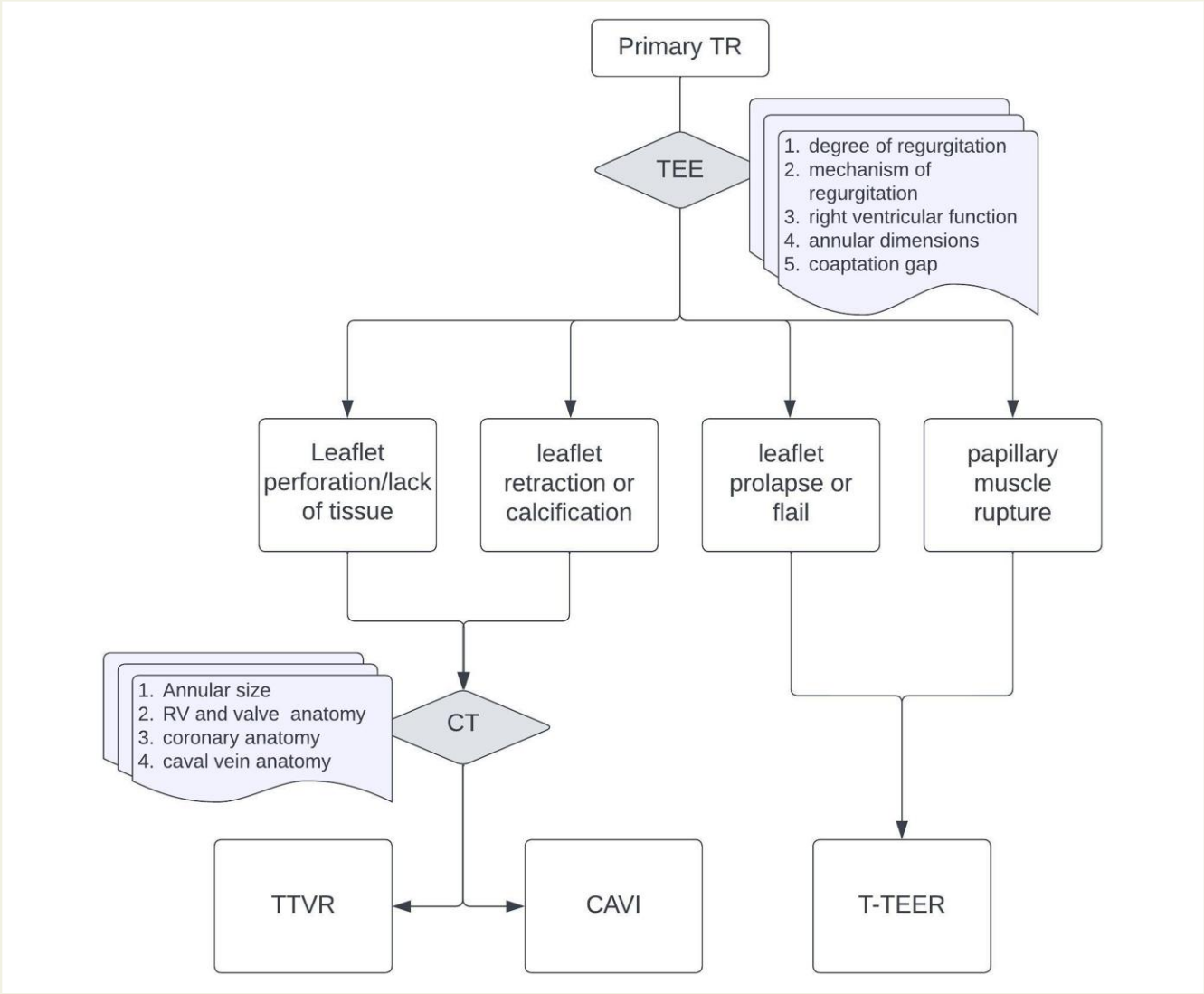


Figure 8 Decision-making and device selection algorithm for primary isolated tricuspid regurgitation. Initial echocardiographic screening, often via transoesophageal approach, is essential to evaluate the extent and cause of regurgitation and to examine right heart function and structure. If lesions are unsuitable for tricuspid transcatheter edge-to-edge repair, a cardiac computed tomography scan becomes crucial to scrutinize the anatomical details, determining suitability for alternative interventions like transcatheter tricuspid valve replacement or caval valve implantation (TEE, transoesophageal echocardiography; CT, computed tomography; TTVR, transcatheter tricuspid valve replacement; CAVI, caval valve implantation; T-TEER, tricuspid transcatheter edge-to-edge repair)

right ventricle. A multicenter registry demonstrated some reduction of regurgitation with improvement in QoL,[124] however, its production has been discontinued. A recent revival of spacers is observed,[125] regaining interest due to their independence from valve anatomy and simplicity of implant, but clinical outcomes are unavailable.[124–126]

Device selection and screening process: tailoring the therapy to patients

Once indication for TTVI is given, based on a predicted clinical benefit in high risk or inoperable patients, TTVI device and procedure selection is a key for success. Currently, T-TEER accounts for more than 90% of the indications. Future changes in this prevalence depend on ease of use, scalability, clinical outcomes, and availability of approved devices. Device selection is made by the Heart Team in a step-wise process that involves careful clinical and anatomical assessment. Multi-modality imaging help to assess the aetiology, mechanism of regurgitation, valve anatomy, deliverability and device eligibility, and to evaluate RV function and RH, physiology (to predict the tolerability of the procedure in end-stage patients).

In case of primary (organic) TR, T-TEER is an option for localized lesions (*Figure 8*). In patients with ruptured papillary muscles (usually post-traumatic), T-TEER may be considered but surgery is the most common solution.[127] Patients with restricted leaflet motion or with a lack of tissue (e.g. carcinoid disease) should be referred to TTVR

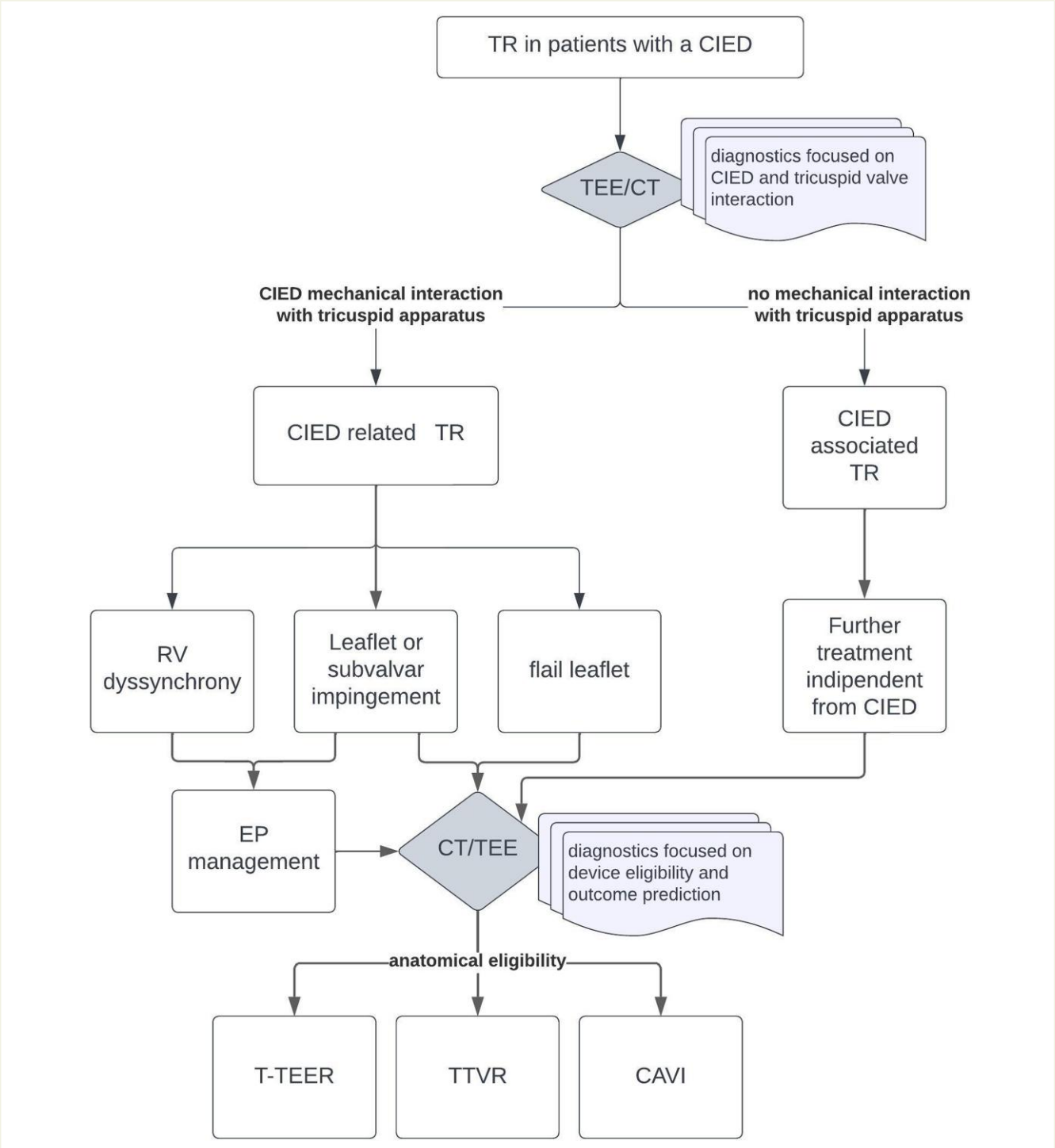


Figure 9 Decision-making and device selection algorithm for cardiac implantable electronic device-tricuspid regurgitation. Echocardiography, occasionally supplemented by CT imaging to better delineate the cardiac implantable electronic device pathway, is pivotal for evaluating how the cardiac implantable electronic device affects tricuspid valve functionality. Should the cardiac implantable electronic device be implicated in tricuspid regurgitation (cardiac implantable electronic device-related tricuspid regurgitation), interventions such as lead extraction, repositioning, or device replacement may be initiated by an electrophysiologist. Additionally, advanced imaging is indispensable for elucidating the regurgitation dynamics and for tailoring treatment to the patient's specific anatomical considerations (CIED, cardiac implantable electronic device; TEE, transoesophageal echocardiography; CT, computed tomography; EP, electrophysiology; T-TEER, tricuspid transcatheter edge-to-edge repair; TTVR, transcatheter tricuspid valve replacement; CAVI, caval valve implantation)

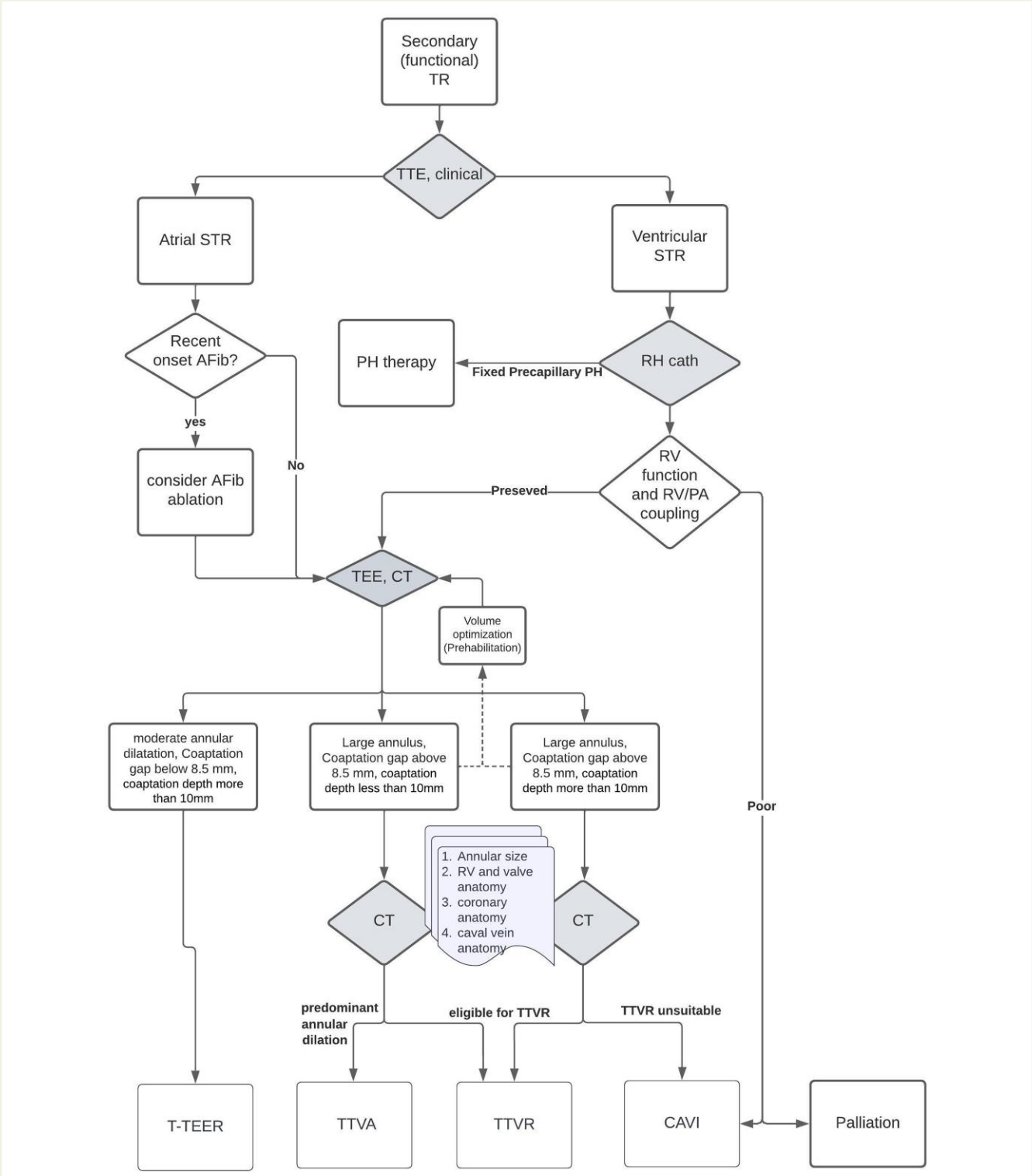


Figure 10 Decision-making and device selection algorithm for secondary isolated tricuspid regurgitation. The algorithm for decision-making in isolated secondary tricuspid regurgitation is intricate, requiring multiple steps. Initially, a distinction is made between atrial and ventricular tricuspid regurgitation based on clinical and echocardiographic data. Atrial secondary tricuspid regurgitation demands a collaborative approach with electrophysiology experts to devise rhythm management strategies. For ventricular secondary tricuspid regurgitation, especially in advanced stages, right heart catheterization is essential to gauge the severity and characteristics of pulmonary hypertension and to evaluate right heart function. The choice of intervention and device is then guided by detailed valve anatomy and cardiac function assessments through multimodal imaging (CIED, cardiac implantable electronic device; TEE, transoesophageal echocardiography; CT, computed tomography; EP, electrophysiology; T-TEER, tricuspid transcatheter edge-to-edge repair; TTVA, transcatheter tricuspid annuloplasty; TTVR, transcatheter tricuspid valve replacement; CAVI, caval valve implantation)

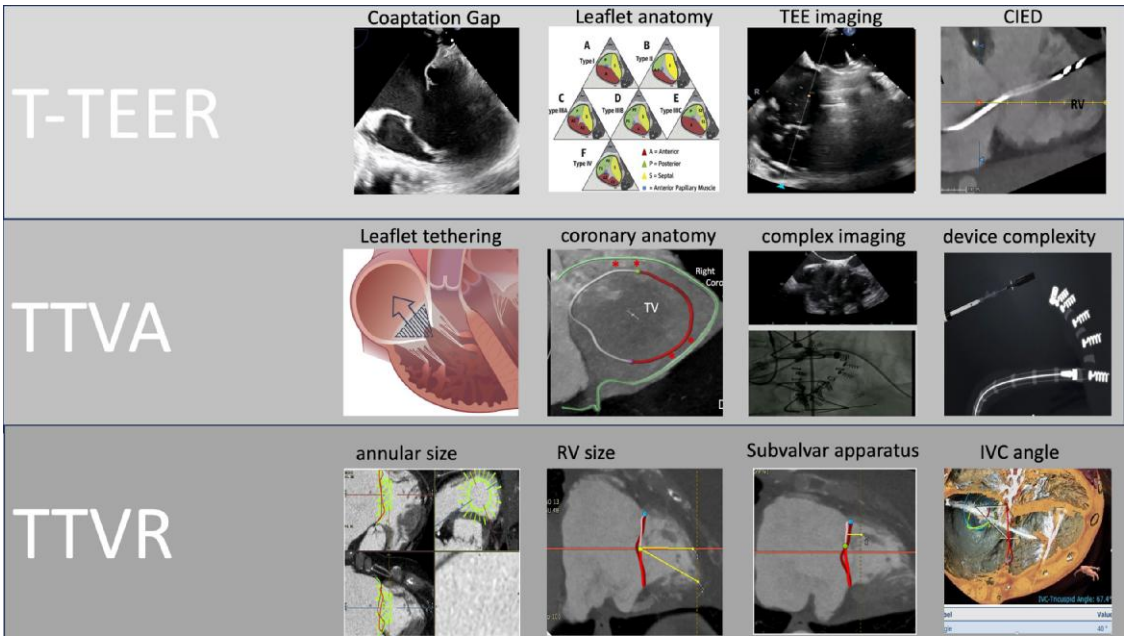


Figure 11 Device selection: key constraints of various tricuspid regurgitation treatment technologies. This figure outlines the technical obstacles for each tricuspid regurgitation treatment technology. Tricuspid transcatheter edge-to-edge repair effectiveness is constrained by factors such as the coaptation gap, leaflet number and distribution, transoesophageal echocardiography image quality, and the presence of transvalvular leads. Transcatheter tricuspid valve annuloplasty applicability is limited by the extent of right ventricular remodelling, leaflet tethering, proximity of the right coronary artery to the annulus, as well as device complexity and imaging requirements during the procedure. Transcatheter tricuspid valve replacement faces limitations due to the annulus size and shape, right ventricular dimensions, subvalvular apparatus anatomy, and the venous system's size and anatomy, with specific devices presenting unique anatomical contraindications (T-TEER, tricuspid transcatheter edge-to-edge repair; TTVA, transcatheter tricuspid valve annuloplasty; TTVR, transcatheter tricuspid valve replacement)

(when available) or CAVI. Obviously, surgery should be reconsidered in patients who are not eligible for any TTVI procedure, and is mandatory in most patients with active infective endocarditis.

Patients with CIED-related TR (*Figure 9*) can be challenging.[128] First, multi-modality imaging is required to determine whether TR is caused by the CIED (CIED-related TR) or the lead has no direct impact on the mechanism of regurgitation (CIED-associated TR). In very selected cases of CIED-related TR, a lead management strategy can be attempted by replacing, relocating,[129] or removing[130] the lead and implanting a valve-sparing pacemaker system (leadless pacemaker or coronary sinus lead). However, lead extraction, particularly in patients with leads entangled in the subvalvular apparatus, can worsen TR by generating additional lesions[131] (even in leadless pacemakers.[132]) In case of CIED-associated TR, T-TEER, and annuloplasty are not contraindicated and the presence of a CIED seems to have no impact on outcomes.[76] On the other hand, if the lead is actively involved and adherent to a valve structure, repair techniques should be used only in very experienced hands.

TTVR can be a good alternative, although the issue of lead management remains debated. Many patients have been treated by jailing the lead without acute effects,[110,133] but there are some cases of damaged leads and other complex situations (e.g. need for infected lead extraction following TTVR.[134])

In the case of secondary TR (*Figure 10*), the treatment options are wider.[21] Patients with A-STR can be successfully treated with either T-TEER or annuloplasty. Annuloplasty (eventually followed by TEER) can be very efficient in patients with larger coaptation gaps and minimal leaflet tethering, while T-TEER is more adequate for patients with moderate tethering, as seen in patients with late forms of A-STR and concomitant RV remodelling.

The main limitation of T-TEER (*Figure 11*) is the coaptation gap and the leaflet anatomy, while annuloplasty is limited by leaflet tethering, and the anatomy of the right coronary artery. In patients with V-STR, while T-TEER remains the most common treatment, TTVR and CAVI are a potential alternative, when the right ventricle is remodelled and the disease more advanced. CAVI is an option for end-stage untreatable patients in whom a palliative approach is needed, while its use in the earlier stages is still under evaluation.[117] Orthotopic TTVR is a very promising alternative to repair due to the predictability of TR reduction and to the ease of use. However, several anatomical limitations are excluding a large number of potential candidates. The eligibility anatomical criteria are strictly related to the delivery system and the mode of fixation of the different prostheses. They include the size and shape of the annulus, the size of the right ventricle, the quality of the leaflet tissue, and the deliverability (venous access and angle between the IVC and the valve). In addition, patients considered for TTVR undergo a more comprehensive evaluation of RV function. A suitable coupling between pulmonary resistance and RV function is considered a reliable method to exclude the risk of afterload mismatch.[80,135–137]

Future perspectives

To optimize outcomes, awareness, and early disease detection and management have to be further encouraged. In the era of individualized precision medicine, TTVI offers the opportunity to apply innovative

treatment approaches and gain systematic evidence in a largely under-investigated field of modern cardiology. Given the high disease complexity of TR, with several clinical phenotypes and crossing patient journeys, a one-size-fits-all approach is unlikely to succeed. Novel diagnostic and patient selection tools, including artificial intelligence, able to integrate multiple variables, analyze large datasets, harmonize layers of knowledge, and competence should be implemented to guide decision-making.

Combining multi-modality imaging with circulating biomarkers may inform about the biological mechanisms that contribute to disease progression and allow for future pathway-specific therapies and personalized treatments.[138] Moreover, they may help identifying early red flags, as well as late signs of futility.[139] Further basic and clinical research is needed to identify novel biomarkers that indicate early disease of the RH.

New imaging modalities integrating augmented reality and simulation will improve training, procedural planning, and outcomes, while dedicated imaging technologies may influence the way therapies are delivered to patients. Using ICE catheter producing image quality comparable to TEE general anaesthesia may be avoided.[50–52,140,141]

Continuous improvement of current devices and new technologies developed in a global market will also increase the treatment options and hopefully simplify the procedures. Simplicity and predictability of replacement will compete with the more physiological approach of repair. The choice depends on lifetime management perspectives with the index procedure representing only the beginning of the full patient journey.

A patient-centered approach requires therefore close collaboration between cardiology subspecialities to manage complex multimorbid patients and improve their outcomes. In an era of fragmentation and procedurally oriented medicine, a network of care dedicated to patients with RH disease integrating prevention, early diagnosis, optimal medical therapy, surgical and interventional treatments needs to come into existence.

Supplementary Data

Supplementary data are not available at *European Heart Journal* online.

Declarations

Disclosure of Interest

The authors declare the following: Francesco Maisano received grant and/or research Institutional Support from Abbott, Medtronic, Edwards Lifesciences, Biotronik, Boston Scientific Corporation, NVT, Terumo, Venus; personal and institutional consulting fees and honoraria from Abbott, Medtronic, Edwards Lifesciences, Xeltis, Cardiovalve, Occlufit, Simulands, Mtex, Venus, Squadra; Royalty Income/IP Rights Edwards Lifesciences. Is shareholder (including share options) of Magenta, 4Tech, Transseptalsolutions. Rebecca Hahn reports speaker fees from Abbott Structural, Baylis Medical, Edwards Lifesciences, Medtronic and Philips Healthcare, Siemens Healthineers; she has institutional consulting contracts for which she receives no direct compensation with Abbott Structural, Edwards Lifesciences, Medtronic and Novartis; she is Chief Scientific Officer for the Echocardiography Core Laboratory at the Cardiovascular Research Foundation for multiple industry-sponsored tricuspid valve trials, for which she receives no direct industry compensation. Paul Sorajja receives consulting fees from 4C Medical, Abbott Structural, Boston Scientific, Edwards Lifesciences, Foldax, GE Healthcare, Medtronic, Phillips, Siemens, vDyne, WL Gore Fabien Praz has been compensated for travel expenses from Abbott Vascular, Edwards Lifesciences, Polares medical, Medira, and Siemens Healthineers. Philipp Lurz has received institutional grants from Abbott Structural, ReCor and Edwards Lifesciences, Honoraria from ReCor and Innoventric and holds share options of Innoventric.

Data Availability

No data were generated or analysed for or in support of this paper.

Funding

Nothing to declare.

References

1. Braunwald NS, Ross J Jr, Morrow AG. Conservative management of tricuspid regurgitation in patients undergoing mitral valve replacement. *Circulation* 1967;**35**:I63–69. https://doi.org/10.1161/01.cir.35.4s1.i-63
2. Luc JGY, Choi JH, Kodia K, Weber MP, Horan DP, Maynes EJ, *et al.* Valvectomy versus replacement for the surgical treatment of infective tricuspid valve endocarditis: a systematic review and meta-analysis. *Ann Cardiothorac Surg* 2019;**8**:610–20. https://doi.org/10.21037/acs.2019.11.06
3. Konstam MA, Kiernan MS, Bernstein D, Bozkurt B, Jacob M, Kapur NK, *et al.* Evaluation and management of right-sided heart failure: a scientific statement from the American heart association. *Circulation* 2018;**137**:e578–622. https://doi.org/10.1161/cir.0000000000000560
4. Axtell AL, Bhambhani V, Moonsamy P, Healy EW, Picard MH, Sundt TM III, *et al.* Surgery does not improve survival in patients with isolated severe tricuspid regurgitation. *J Am Coll Cardiol* 2019;**74**:715–25. https://doi.org/10.1016/j.jacc.2019.04.028
5. 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
6. Neuhold S, Huelsmann M, Pernicka E, Graf A, Bonderman D, Adlbrecht C, *et al.* Impact of tricuspid regurgitation on survival in patients with chronic heart failure: unexpected findings of a long-term observational study. *Eur Heart J* 2013;**34**:844–52. https://doi.org/10.1093/eurheartj/ehs465
7. Chen L, Larsen CM, Le RJ, Connolly HM, Pislaru SV, Murphy JG, *et al.* The prognostic significance of tricuspid valve regurgitation in pulmonary arterial hypertension. *Clin Respir J* 2018;**12**:1572–80. https://doi.org/10.1111/crj.12713
8. Schwartz LA, Rozenbaum Z, Ghantous E, Kramarz J, Biner S, Ghermezi M, *et al.* Impact of right ventricular dysfunction and tricuspid regurgitation on outcomes in patients undergoing transcatheter aortic valve replacement. *J Am Soc Echocardiogr* 2017;**30**:36–46. https://doi.org/10.1016/j.echo.2016.08.016
9. Dahou A, Magne J, Clavel MA, Capoulade R, Bartko PE, Bergler-Klein J, *et al.* Tricuspid regurgitation is associated with increased risk of mortality in patients with low-flow low-gradient aortic stenosis and reduced ejection fraction: results of the multicenter TOPAS study (true or Pseudo-severe aortic stenosis). *JACC Cardiovasc Interv* 2015;**8**:588–96. https://doi.org/10.1016/j.jcin.2014.08.019
10. Calafiore AM, Gallina S, Iaco AL, Contini M, Bivona A, Gagliardi M, *et al.* Mitral valve surgery for functional mitral regurgitation: should moderate-or-more tricuspid regurgitation be treated? A propensity score analysis. *Ann Thorac Surg* 2009;**87**:698–703. https://doi.org/10.1016/j.athoracsur.2008.11.028
11. Schueler R, Ozturk C, Sinning JM, Werner N, Welz A, Hammerstingl C, *et al.* Impact of baseline tricuspid regurgitation on long-term clinical outcomes and survival after interventional edge-to-edge repair for mitral regurgitation. *Clin Res Cardiol* 2017;**106**:350–8. https://doi.org/10.1007/s00392-016-1062-1
12. Sagie A, Schwammenthal E, Newell JB, Harrell L, Joziatis TB, Weyman AE, *et al.* Significant tricuspid regurgitation is a marker for adverse outcome in patients undergoing percutaneous balloon mitral valvuloplasty. *J Am Coll Cardiol* 1994;**24**:696–702. https://doi.org/10.1016/0735-1097(94)90017-5
13. Gonzalez-Gomez A, Fernandez-Golfin C, Hinojar R, Monteagudo JM, Garcia A, Garcia-Sebastian C, *et al.* The 4A classification for patients with tricuspid regurgitation. *Rev Esp Cardiol (Engl Ed)* 2023;**76**:845–51. https://doi.org/10.1016/j.rec.2023.02.008
14. Singh JP, Evans JC, Levy D, Larson MG, Freed LA, Fuller DL, *et al.* Prevalence and clinical determinants of mitral, tricuspid, and aortic regurgitation (the Framingham heart study). *Am J Cardiol* 1999;**83**:897–902. https://doi.org/10.1016/s0002-9149(98)01064-9
15. Gössl M, Stanberry L, Benson G, Steele E, Garberich R, Witt D, *et al.* Burden of undiagnosed valvular heart disease in the elderly in the community: heart of new ULM valve study. *JACC Cardiovasc Imaging* 2023;**16**:1118–20. https://doi.org/10.1016/j.jcmg.2023.02.009
16. Topilsky Y, Maltais S, Medina Inojosa J, Oguz D, Michelena H, Maalouf J, *et al.* Burden of tricuspid regurgitation in patients diagnosed in the community setting. *JACC Cardiovasc Imaging* 2019;**12**:433–42. https://doi.org/10.1016/j.jcmg.2018.06.014

17. 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
18. Tung M, Nah G, Tang J, Marcus G, Delling FN. Valvular disease burden in the modern era of percutaneous and surgical interventions: the UK biobank. *Open Heart* 2022;**9**: e002039. https://doi.org/10.1136/openhrt-2022-002039
19. Offen S, Playford D, Strange G, Stewart S, Celermajer DS. Adverse prognostic impact of even mild or moderate tricuspid regurgitation: insights from the national echocardiography database of Australia. *J Am Soc Echocardiogr* 2022;**35**:810–7. https://doi.org/10.1016/j.echo.2022.04.003
20. Wang N, Fulcher J, Abeysuriya N, McGrady M, Wilcox I, Celermajer D, *et al.* Tricuspid regurgitation is associated with increased mortality independent of pulmonary pressures and right heart failure: a systematic review and meta-analysis. *Eur Heart J* 2019;**40**:476–84. https://doi.org/10.1093/eurheartj/ehy641
21. 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
22. Praz F, Enriquez-Sarano M, Wijns W, Maisano F, Taramasso M. Raising awareness of tricuspid valve disease and standardizing patient management. *JACC Case Rep* 2023; **12**:101795. https://doi.org/10.1016/j.jaccas.2023.101795
23. Galloo X, Dietz MF, Fortuni F, Prihadi EA, Cosyns B, Delgado V, *et al.* Prognostic implications of atrial vs. Ventricular functional tricuspid regurgitation. *Eur Heart J Cardiovasc Imaging* 2023;**24**:733–41. https://doi.org/10.1093/ehjci/jead016
24. Schlotter F, Dietz MF, Stolz L, Kresoja KP, Besler C, Sannino A, *et al.* Atrial functional tricuspid regurgitation: novel definition and impact on prognosis. *Circ Cardiovasc Interv* 2022;**15**:e011958. https://doi.org/10.1161/CIRCINTERVENTIONS.122.011958
25. Rao VN, Giczewska A, Chiswell K, Felker GM, Wang A, Glower DD, *et al.* Long-term outcomes of phenoclusters in severe tricuspid regurgitation. *Eur Heart J* 2023;**44**: 1910–23. https://doi.org/10.1093/eurheartj/ehad133
26. Galloo X, Stassen J, Butcher SC, Meucci MC, Dietz MF, Mertens BJA, *et al.* Staging right heart failure in patients with tricuspid regurgitation undergoing tricuspid surgery. *Eur J Cardiothorac Surg* 2022;**62**:ezac290. https://doi.org/10.1093/ejcts/ezac290
27. Dietz MF, Prihadi EA, van der Bijl P, Ajmone Marsan N, Delgado V, Bax JJ. Prognostic implications of staging right heart failure in patients with significant secondary tricuspid regurgitation. *JACC Heart Fail* 2020;**8**:627–36. https://doi.org/10.1016/j.jchf.2020.02.008
28. Wang TKM, Akyuz K, Mentias A, Kirincich J, Duran Crane A, Xu S, *et al.* Contemporary etiologies, outcomes, and novel risk score for isolated tricuspid regurgitation. *JACC Cardiovasc Imaging* 2022;**15**:731–44. https://doi.org/10.1016/j.jcmg.2021.10.015
29. 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
30. Utsunomiya H, Harada Y, Susawa H, Ueda Y, Izumi K, Itakura K, *et al.* Tricuspid valve geometry and right heart remodelling: insights into the mechanism of atrial functional tricuspid regurgitation. *Eur Heart J Cardiovasc Imaging* 2020;**21**:1068–78. https://doi.org/10.1093/ehjci/jeaa194
31. Muraru D, Addetia K, Guta AC, Ochoa-Jimenez RC, Genovese D, Veronesi F, *et al.* Right atrial volume is a major determinant of tricuspid annulus area in functional tricuspid regurgitation: a three-dimensional echocardiographic study. *Eur Heart J Cardiovasc Imaging* 2021;**22**:660–9. https://doi.org/10.1093/ehjci/jeaa286
32. Topilsky Y, Khanna A, Le Tourneau T, Park S, Michelena H, Suri R, *et al.* Clinical context and mechanism of functional tricuspid regurgitation in patients with and without pulmonary hypertension. *Circ Cardiovasc Imaging* 2012;**5**:314–23. https://doi.org/10.1161/CIRCIMAGING.111.967919
33. Hahn R, Weckbach LT, Noack T, Hamid N, Kitamura M, Bae R, *et al.* Proposal for a standard echocardiographic tricuspid valve Nomenclature. *JACC Cardiovasc Imaging* 2021;**14**:1299–305. https://doi.org/10.1016/j.jcmg.2021.01.012
34. Agricola E, Asmarats L, Maisano F, Cavalcante JL, Liu S, Milla F, *et al.* Imaging for tricuspid valve repair and replacement. *JACC Cardiovasc Imaging* 2021;**14**:61–111. https://doi.org/10.1016/j.jcmg.2020.01.031
35. Hahn RT, Badano LP, Bartko PE, Muraru D, Maisano F, Zamorano JL, *et al.* Tricuspid regurgitation: recent advances in understanding pathophysiology, severity grading and outcome. *Eur Heart J Cardiovasc Imaging* 2022;**23**:913–29. https://doi.org/10.1093/ehjci/jeac009
36. Santoro C, Marco Del Castillo A, Gonzalez-Gomez A, Monteagudo JM, Hinojar R, Lorente A, *et al.* Mid-term outcome of severe tricuspid regurgitation: are there any differences according to mechanism and severity? *Eur Heart J Cardiovasc Imaging* 2019;**20**:1035–42. https://doi.org/10.1093/ehjci/jez024
37. Miura M, Alessandrini H, Alkhodair A, Attinger-Toller A, Biasco L, Lurz P, *et al.* Impact of massive or torrential tricuspid regurgitation in patients undergoing transcatheter tricuspid valve intervention. *JACC Cardiovasc Interv* 2020;**13**:1999–2009. https://doi.org/10.1016/j.jcin.2020.05.011
38. Agricola E, Ancona F, Brochet E, Donal E, Dweck M, Faletra F, *et al.* The structural heart disease interventional imager rationale, skills and training: a position paper of the European association of cardiovascular imaging. *Eur Heart J Cardiovasc Imaging* 2021;**22**:471–9. https://doi.org/10.1093/ehjci/jeab005
39. Addetia K, Harb SC, Hahn RT, Kapadia S, Lang RM. Cardiac implantable electronic device lead-induced tricuspid regurgitation. *JACC Cardiovasc Imaging* 2019;**12**:622–36. https://doi.org/10.1016/j.jcmg.2018.09.028
40. Lancellotti P, Pibarot P, Chambers J, La Canna G, Pepi M, Dulgheru R, *et al.* Multi-modality imaging assessment of native valvular regurgitation: an EACVI and ESC council of valvular heart disease position paper. *Eur Heart J Cardiovasc Imaging* 2022;**23**:e171–232. https://doi.org/10.1093/ehjci/jeab253
41. Hahn RT, Lerakis S, Delgado V, Addetia K, Burkhoff D, Muraru D, *et al.* Multimodality imaging of right heart function: JACC scientific statement. *J Am Coll Cardiol* 2023;**81**: 1954–73. https://doi.org/10.1016/j.jacc.2023.03.392
42. Ranard LS, Vahl TP, Chung CJ, Sadri S, Khalique OK, Hamid N, *et al.* Impact of inferior vena cava entry characteristics on tricuspid annular access during transcatheter interventions. *Catheter Cardiovasc Interv* 2022;**99**:1268–76. https://doi.org/10.1002/ccd.30048
43. Volpato V, Badano LP, Figliozzi S, Florescu DR, Parati G, Muraru D. Multimodality cardiac imaging and new display options to broaden our understanding of the tricuspid valve. *Curr Opin Cardiol* 2021;**36**:513–24. https://doi.org/10.1097/HCO.0000000000000890
44. Zhan Y, Senapati A, Vejpongsa P, Xu J, Shah DJ, Nagueh SF. Comparison of echocardiographic assessment of tricuspid regurgitation against cardiovascular magnetic resonance. *JACC Cardiovasc Imaging* 2020;**13**:1461–71. https://doi.org/10.1016/j.jcmg.2020.01.008
45. Kresoja KP, Rommel KP, Lucke C, Unterhuber M, Besler C, von Roeder M, *et al.* Right ventricular contraction patterns in patients undergoing transcatheter tricuspid valve repair for severe tricuspid regurgitation. *JACC Cardiovasc Interv* 2021;**14**:1551–61. https://doi.org/10.1016/j.jcin.2021.05.005
46. Hahn RT, Kodali SK. State-of-the-art intra-procedural imaging for the mitral and tricuspid PASCAL repair system. *Eur Heart J Cardiovasc Imaging* 2022;**23**:e94–110. https://doi.org/10.1093/ehjci/jeab040
47. Wunderlich NC, Landendinger M, Arnold M, Achenbach S, Swaans MJ, Siegel RJ, *et al.* State-of-the-Art review: anatomical and imaging considerations during transcatheter tricuspid valve repair using an annuloplasty approach. *Front Cardiovasc Med* 2021;**8**: 619605. https://doi.org/10.3389/fcvm.2021.619605
48. Hahn RT, Saric M, Faletra FF, Garg R, Gillam LD, Horton K, *et al.* Recommended standards for the performance of transesophageal echocardiographic screening for structural heart intervention: from the American society of echocardiography. *J Am Soc Echocardiogr* 2022;**35**:1–76. https://doi.org/10.1016/j.echo.2021.07.006
49. Moller JE, De Backer O, Nuyens P, Vanhaverbeke M, Vejlstrup N, Sondergaard L. Transesophageal and intracardiac echocardiography to guide transcatheter tricuspid valve repair with the TriClip system. *Int J Cardiovasc Imaging* 2022;**38**:609–11. https://doi.org/10.1007/s10554-021-02448-0
50. Davidson CJ, Abramson S, Smith RL, Kodali SK, Kipperman RM, Eleid MF, *et al.* Transcatheter tricuspid repair with the use of 4-dimensional intracardiac echocardiography. *JACC Cardiovasc Imaging* 2022;**15**:533–8. https://doi.org/10.1016/j.jcmg.2021.01.029
51. Chadderdon SM, Eleid MF, Thaden JJ, Makkar R, Nakamura M, Babaliaros V, *et al.* Three-Dimensional intracardiac echocardiography for tricuspid transcatheter edge-to-edge repair. *Struct Heart* 2022;**6**:100071. https://doi.org/10.1016/j.shj.2022.100071
52. Eleid MF, Alkhouli M, Thaden JJ, Zahr F, Chadderdon S, Guerrero M, *et al.* Utility of intracardiac echocardiography in the early experience of transcatheter edge to edge tricuspid valve repair. *Circ Cardiovasc Interv* 2021;**14**:e011118. https://doi.org/10.1161/CIRCINTERVENTIONS.121.011118
53. Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, *et al.* 2021 ESC/EACTS guidelines for the management of valvular heart disease. *Eur Heart J* 2022;**43**: 561–632. https://doi.org/10.1093/eurheartj/ehab395
54. Taramasso M, Gavazzoni M, Pozzoli A, Dreyfus GD, Bolling SF, George I, *et al.* Tricuspid regurgitation: predicting the need for intervention, procedural success, and recurrence of disease. *JACC Cardiovasc Imaging* 2019;**12**:605–21. https://doi.org/10.1016/j.jcmg.2018.11.034
55. 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
56. Taramasso M, Benfari G, van der Bijl P, Alessandrini H, Attinger-Toller A, Biasco L, *et al.* Transcatheter versus medical treatment of patients with symptomatic severe tricuspid regurgitation. *J Am Coll Cardiol* 2019;**74**:2998–3008. https://doi.org/10.1016/j.jacc.2019.09.028
57. Taramasso M, Alessandrini H, Latib A, Asami M, Attinger-Toller A, Biasco L, *et al.* Outcomes after current transcatheter tricuspid valve intervention: mid-term results from the international TriValve registry. *JACC Cardiovasc Interv* 2019;**12**:155–65. https://doi.org/10.1016/j.jcin.2018.10.022
58. Lurz P, Besler C, Schmitz T, Bekeredjian R, Nickenig G, Mollmann 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

59. Franzen O, von Samson P, Dodge-Khatami A, Geffert G, Baldus S. Percutaneous edge-to-edge repair of tricuspid regurgitation in congenitally corrected transposition of the great arteries. *Congenit Heart Dis* 2011;**6**:57–9. https://doi.org/10.1111/j.1747-0803.2010.00428.x
60. Andreas M, Russo M, Taramasso M, Zuber M, Mascherbauer J. Novel transcatheter clip device (MitraClip XTR) enables significant tricuspid annular size reduction. *Eur Heart J Cardiovasc Imaging* 2019;**20**:1070. https://doi.org/10.1093/ehjci/jez032
61. Liu X, Chen M, Han Y, Pu Z, Lin X, Feng Y, *et al.* First-in-Human study of the novel transcatheter mitral valve repair system for mitral regurgitation. *JACC Asia* 2022;**2**:390–4. https://doi.org/10.1016/j.jacasi.2022.03.010
62. Alfieri O, De Bonis M, Lapenna E, Agricola E, Quarti A, Maisano F. The "clover technique" as a novel approach for correction of post-traumatic tricuspid regurgitation. *J Thorac Cardiovasc Surg* 2003;**126**:75–9. https://doi.org/10.1016/s0022-5223(03)00204-6
63. Hausleiter J, Braun D, Massberg S, Nabauer M. Percutaneous edge-to-edge tricuspid repair applying the 'clover' technique. *Eur Heart J Cardiovasc Imaging* 2017;**18**:1261. https://doi.org/10.1093/ehjci/jex151
64. Mehr M, Taramasso M, Besler C, Ruf T, Connelly KA, Weber M, *et al.* 1-Year outcomes after edge-to-edge valve repair for symptomatic tricuspid regurgitation: results from the TriValve registry. *JACC Cardiovasc Interv* 2019;**12**:1451–61. https://doi.org/10.1016/j.jcin.2019.04.019
65. Lurz P, Stephan von Bardeleben R, Weber M, Sitges M, Sorajja P, Hausleiter J, *et al.* Transcatheter edge-to-edge repair for treatment of tricuspid regurgitation. *J Am Coll Cardiol* 2021;**77**:229–39. https://doi.org/10.1016/j.jacc.2020.11.038
66. Wild MG, Low K, Rosch S, Gercek 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
67. Nickenig G, Weber M, Lurz P, von Bardeleben RS, Sitges M, Sorajja P, *et al.* Transcatheter edge-to-edge repair for reduction of tricuspid regurgitation: 6-month outcomes of the TRILUMINATE single-arm study. *Lancet* 2019;**394**:2002–11. https://doi.org/10.1016/S0140-6736(19)32600-5
68. Sorajja P, Whisenant B, Hamid N, Naik H, Makkar R, Tadros P, *et al.* Transcatheter repair for patients with tricuspid regurgitation. *N Engl J Med* 2023;**388**:1833–42. https://doi.org/10.1056/NEJMoa2300525
69. Coisne A, Scotti A, Taramasso M, Granada JF, Ludwig S, Rodes-Cabau J, *et al.* Prognostic value of tricuspid valve gradient after transcatheter edge-to-edge repair: insights from the TriValve registry. *JACC Cardiovasc Interv* 2023:S1936-8798(23)00452-1. https://doi.org/10.1016/j.jcin.2023.01.375
70. Sugiura A, Vogelhuber J, Ozturk C, Schwaibold Z, Reckers D, Goto T, *et al.* PASCAL versus MitraClip-XTR edge-to-edge device for the treatment of tricuspid regurgitation: a propensity-matched analysis. *Clin Res Cardiol* 2021;**110**:451–9. https://doi.org/10.1007/s00392-020-01784-w
71. Besler C, Orban M, Rommel KP, Braun D, Patel M, Hagl C, *et al.* Predictors of procedural and clinical outcomes in patients with symptomatic tricuspid regurgitation undergoing transcatheter edge-to-edge repair. *JACC Cardiovasc Interv* 2018;**11**:1119–28. https://doi.org/10.1016/j.jcin.2018.05.002
72. Tanaka T, Sugiura A, Kavsur R, Vogelhuber J, Ozturk C, Becher MU, *et al.* Leaflet-to-annulus index and residual tricuspid regurgitation following tricuspid transcatheter edge-to-edge repair. *EuroIntervention* 2022;**18**:e169–78. https://doi.org/10.4244/EIJ-D-21-00862
73. Maisano F, La Canna G, Grimaldi A, Vigano G, Blasio A, Mignatti A, *et al.* Annular-to-leaflet mismatch and the need for reductive annuloplasty in patients undergoing mitral repair for chronic mitral regurgitation due to mitral valve prolapse. *Am J Cardiol* 2007;**99**:1434–9. https://doi.org/10.1016/j.amjcard.2006.12.072
74. Colli A, Besola L, Montagner M, Azzolina D, Soriani N, Manzan E, *et al.* Prognostic impact of leaflet-to-annulus index in patients treated with transapical off-pump echo-guided mitral valve repair with NeoChord implantation. *Int J Cardiol* 2018;**257**:235–7. https://doi.org/10.1016/j.ijcard.2018.01.049
75. Sugiura A, Tanaka T, Kavsur R, Ozturk C, Vogelhuber J, Wilde N, *et al.* Leaflet configuration and residual tricuspid regurgitation after transcatheter edge-to-edge tricuspid repair. *JACC Cardiovasc Interv* 2021;**14**:2260–70. https://doi.org/10.1016/j.jcin.2021.07.048
76. Taramasso M, Gavazzoni M, Pozzoli A, Alessandrini H, Latib A, Attinger-Toller A, *et al.* Outcomes of TTVI in patients with pacemaker or defibrillator leads: data from the TriValve registry. *JACC Cardiovasc Interv* 2020;**13**:554–64. https://doi.org/10.1016/j.jcin.2019.10.058
77. Gavazzoni M, Heilbron F, Badano LP, Radu N, Cascella A, Tomaselli M, *et al.* The atrial secondary tricuspid regurgitation is associated to more favorable outcome than the ventricular phenotype. *Front Cardiovasc Med* 2022;**9**:1022755. https://doi.org/10.3389/fcvm.2022.1022755
78. 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
79. Schlotter F, Miura M, Kresoja KP, Alushi B, Alessandrini H, Attinger-Toller A, *et al.* Outcomes of transcatheter tricuspid valve intervention by right ventricular function: a multicentre propensity-matched analysis. *EuroIntervention* 2021;**17**:e343–52. https://doi.org/10.4244/EIJ-D-21-00191
80. Brener MI, Lurz P, Hausleiter J, Rodes-Cabau J, Fam N, Kodali SK, *et al.* Right ventricular-pulmonary arterial coupling and afterload reserve in patients undergoing transcatheter tricuspid valve repair. *J Am Coll Cardiol* 2022;**79**:448–61. https://doi.org/10.1016/j.jacc.2021.11.031
81. Anand V, Scott CG, Hyun MC, Lara-Breitinger K, Nkomo VT, Kane GC, *et al.* The 5 phenotypes of tricuspid regurgitation: insight from cluster analysis of clinical and echocardiographic variables. *JACC Cardiovasc Interv* 2023;**16**:156–65. https://doi.org/10.1016/j.jcin.2022.10.055
82. Kodali SK, Hahn RT, Davidson CJ, Narang A, Greenbaum A, Gleason P, *et al.* 1-year outcomes of transcatheter tricuspid valve repair. *J Am Coll Cardiol* 2023;**81**:1766–76. https://doi.org/10.1016/j.jacc.2023.02.049
83. Kuwata S, Taramasso M, Nietlispach F, Maisano F. Transcatheter tricuspid valve repair toward a surgical standard: first-in-man report of direct annuloplasty with a cardioband device to treat severe functional tricuspid regurgitation. *Eur Heart J* 2017;**38**:1261. https://doi.org/10.1093/eurheartj/ehw660
84. Nickenig G, Weber M, Schuler R, Hausleiter J, Nabauer M, von Bardeleben RS, *et al.* Tricuspid valve repair with the cardioband system: two-year outcomes of the multicentre, prospective TRI-REPAIR study. *EuroIntervention* 2021;**16**:e1264–71. https://doi.org/10.4244/EIJ-D-20-01107
85. Gercek M, Rudolph V, Arnold M, Beuthner BE, Pfister R, Landendinger M, *et al.* Transient acute right coronary artery deformation during transcatheter interventional tricuspid repair with the cardioband tricuspid system. *EuroIntervention* 2021;**17**:81–7. https://doi.org/10.4244/EIJ-D-20-00305
86. Rogers JH, Boyd WD, Bolling SF. Tricuspid annuloplasty with the millipede ring. *Prog Cardiovasc Dis* 2019;**62**:486–7. https://doi.org/10.1016/j.pcad.2019.11.008
87. Sanchez-Recalde A, Tahoces LS, Fernandez-Golfin C, Gonzalez A, Zamorano JL. Transcatheter tricuspid annuloplasty in a patient with very long segment of right coronary artery proximity. *JACC Case Rep* 2023;**12**:101774. https://doi.org/10.1016/j.jaccas.2023.101774
88. Lee AP, Ni Y, Lam YY. Imaging for transcatheter tricuspid annuloplasty using the K-clip device. *Circ Cardiovasc Imaging* 2023;**16**:e015033. https://doi.org/10.1161/CIRCIMAGING.122.015033
89. Nickenig G, Sugiura A. Transcatheter tricuspid Annulus reconstruction: compelling and Complex. *JACC Cardiovasc Interv* 2022;**15**:1933–5. https://doi.org/10.1016/j.jcin.2022.07.045
90. Bruoha S, Mangieri A, Ho EC, Goldberg Y, Chau M, Latib A. Transcatheter annular approaches for tricuspid regurgitation (cardioband and others). *Interv Cardiol Clin* 2022;**11**:67–80. https://doi.org/10.1016/j.iccl.2021.09.002
91. Greenbaum AB, Khan JM, Rogers T, Babaliaros VC, Eng MHK, Wang DD, *et al.* First-in-human transcatheter pledget-assisted suture tricuspid annuloplasty for severe tricuspid insufficiency. *Catheter Cardiovasc Interv* 2021;**97**:E130–4. https://doi.org/10.1002/ccd.28955
92. Fortuni F, Marques AI, Bax JJ, Ajmone Marsan N, Delgado V. Echocardiography-computed tomography fusion imaging for guidance of transcatheter tricuspid valve annuloplasty. *Eur Heart J Cardiovasc Imaging* 2020;**21**:937–8. https://doi.org/10.1093/ehjci/jeaa054
93. Miura M, Vicentini L, Taramasso M, Maisano F. Tangled wire in a dacron band during cardioband transcatheter tricuspid annuloplasty-how to solve the problem. *Catheter Cardiovasc Interv* 2021;**97**:E724–6. https://doi.org/10.1002/ccd.28845
94. Besler C, Meduri CU, Lurz P. Transcatheter treatment of functional tricuspid regurgitation using the trialign device. *Interv Cardiol* 2018;**13**:8–13. https://doi.org/10.15420/icr.2017:21:1
95. Khan JM, Rogers T, Schenke WH, Greenbaum AB, Babaliaros VC, Paone G, *et al.* Transcatheter pledget-assisted suture tricuspid annuloplasty (PASTA) to create a double-orifice valve. *Catheter Cardiovasc Interv* 2018;**92**:E175–84. https://doi.org/10.1002/ccd.27531
96. Gheorghe L, Swaans M, Denti P, Rensing B, Van der Heyden J. Transcatheter tricuspid valve repair with a novel cinching system. *JACC Cardiovasc Interv* 2018;**11**:e199–201. https://doi.org/10.1016/j.jcin.2018.09.019
97. Hahn RT, Meduri CU, Davidson CJ, Lim S, Nazif TM, Ricciardi MJ, *et al.* Early feasibility study of a transcatheter tricuspid valve annuloplasty: sCOUT trial 30-day results. *J Am Coll Cardiol* 2017;**69**:1795–806. https://doi.org/10.1016/j.jacc.2017.01.054
98. Taramasso M, Latib A, Denti P, Nietlispach F, Lynn K, Cesarovic N, *et al.* Percutaneous repair of the tricuspid valve using a novel cinching device: acute and chronic experience in a preclinical large animal model. *EuroIntervention* 2016;**12**:918–25. https://doi.org/10.4244/EIJV12I7A150
99. Latib A, Agricola E, Pozzoli A, Denti P, Taramasso M, Spagnolo P, *et al.* First-in-Man implantation of a tricuspid annular remodeling device for functional tricuspid regurgitation. *JACC Cardiovasc Interv* 2015;**8**:e211–214. https://doi.org/10.1016/j.jcin.2015.06.028
100. Zhu ZK, Zhao ZG, Zhang TC, Chen F, Wei X, Liang YJ, *et al.* First-in-human experience with a novel transcatheter direct annuloplasty system for severe atrial functional mitral

regurgitation. *EuroIntervention* 2023;**19**:e953–4. https://doi.org/10.4244/EIJ-D-23-00302
101. von Bardeleben RS, Ruf T, Schulz E, Muenzel T, Kreidel F. First percutaneous COMBO therapy of tricuspid regurgitation using direct annuloplasty and staged edge-to-edge repair in a surgical-like clover technique. *Eur Heart J* 2018;**39**:3621–2. https://doi.org/10.1093/eurheartj/ehy536
102. Stone GW, Lindenfeld J, Abraham WT, Kar S, Lim DS, Mishell JM, *et al.* Transcatheter mitral-valve repair in patients with heart failure. *N Engl J Med* 2018;**379**:2307–18. https://doi.org/10.1056/NEJMoa1806640
103. Lewis EF, Claggett BL, McMurray JJV, Packer M, Lefkowitz MP, Rouleau JL, *et al.* Health-Related quality of life outcomes in PARADIGM-HF. *Circ Heart Fail* 2017;**10**:e003430. https://doi.org/10.1161/CIRCHEARTFAILURE.116.003430
104. Nassif ME, Windsor SL, Gosch K, Borlaug BA, Husain M, Inzucchi SE, *et al.* Dapagliflozin improves heart failure symptoms and physical limitations across the full range of ejection fraction: pooled patient-level analysis from DEFINE-HF and PRESERVED-HF trials. *Circ Heart Fail* 2023;**16**:e009837. https://doi.org/10.1161/CIRCHEARTFAILURE.122.009837
105. Butt JH, Nicolau JC, Verma S, Docherty KF, Petrie MC, Inzucchi SE, *et al.* Efficacy and safety of dapagliflozin according to aetiology in heart failure with reduced ejection fraction: insights from the DAPA-HF trial. *Eur J Heart Fail* 2021;**23**:601–13. https://doi.org/10.1002/ejhf.2124
106. Comin-Colet J, Lainscak M, Dickstein K, Filippatos GS, Johnson P, Luscher TF, *et al.* The effect of intravenous ferric carboxymaltose on health-related quality of life in patients with chronic heart failure and iron deficiency: a subanalysis of the FAIR-HF study. *Eur Heart J* 2013;**34**:30–8. https://doi.org/10.1093/eurheartj/ehr504
107. Baron SJ, Arnold SV, Wang K, Magnuson EA, Chinnakondepali K, Makkar R, *et al.* Health Status benefits of transcatheter vs surgical aortic valve replacement in patients with severe aortic stenosis at intermediate surgical risk: results from the PARTNER 2 randomized clinical trial. *JAMA Cardiol* 2017;**2**:837–45. https://doi.org/10.1001/jamacardio.2017.2039
108. Hon JK, Cheung A, Ye J, Carere RG, Munt B, Josan K, *et al.* Transatrial transcatheter tricuspid valve-in-valve implantation of balloon expandable bioprosthesis. *Ann Thorac Surg* 2010;**90**:1696–7. https://doi.org/10.1016/j.athoracsur.2010.04.101
109. Cullen MW, Cabalka AK, Alli OO, Pislaru SV, Sorajja P, Nkomo VT, *et al.* Transvenous, antegrade melody valve-in-valve implantation for bioprosthetic mitral and tricuspid valve dysfunction: a case series in children and adults. *JACC Cardiovasc Interv* 2013;**6**:598–605. https://doi.org/10.1016/j.jcin.2013.02.010
110. McElhinney DB, Aboulhosn JA, Dvir D, Whisenant B, Zhang Y, Eicken A, *et al.* Mid-Term valve-related outcomes after transcatheter tricuspid valve-in-valve or valve-in-ring replacement. *J Am Coll Cardiol* 2019;**73**:148–57. https://doi.org/10.1016/j.jacc.2018.10.051
111. Anderson JH, McElhinney DB, Aboulhosn J, Zhang Y, Ribichini F, Eicken A, *et al.* Management and outcomes of transvenous pacing leads in patients undergoing transcatheter tricuspid valve replacement. *JACC Cardiovasc Interv* 2020;**13**:2012–20. https://doi.org/10.1016/j.jcin.2020.04.054
112. Noble S, Myers PO, Hachulla AL, Huber C. Unsuccessful transfemoral tricuspid valve-in-ring implantation: case report and literature review. *CJC Open* 2019;**1**:330–4. https://doi.org/10.1016/j.cjco.2019.09.005
113. Lauten A, Figulla HR, Unbehaun A, Fam N, Schofer J, Doenst T, *et al.* Interventional treatment of severe tricuspid regurgitation: early clinical experience in a multicenter, observational, first-in-man study. *Circ Cardiovasc Interv* 2018;**11**:e006061. https://doi.org/10.1161/CIRCINTERVENTIONS.117.006061
114. Lauten A, Figulla HR, Willich C, Laube A, Rademacher W, Schubert H, *et al.* Percutaneous caval stent valve implantation: investigation of an interventional approach for treatment of tricuspid regurgitation. *Eur Heart J* 2010;**31**:1274–81. https://doi.org/10.1093/eurheartj/ehp474
115. Wild MG, Lubos E, Cruz-Gonzalez I, Amat-Santos I, Ancona M, Andreas M, *et al.* Early clinical experience with the TRICENTO bicaval valved stent for treatment of symptomatic severe tricuspid regurgitation: a multicenter registry. *Circ Cardiovasc Interv* 2022;**15**:e011302. https://doi.org/10.1161/CIRCINTERVENTIONS.121.011302
116. Figulla HR, Kiss K, Lauten A. Transcatheter interventions for tricuspid regurgitation—heterotopic technology: tricValve. *EuroIntervention* 2016;**12**:Y116–118. https://doi.org/10.4244/EIJV12SYA32
117. Estevez-Loureiro R, Sanchez-Recalde A, Amat-Santos IJ, Cruz-Gonzalez I, Baz JA, Pascual I, *et al.* 6-Month outcomes of the TricValve system in patients with tricuspid regurgitation: the TRICUS EURO study. *JACC Cardiovasc Interv* 2022;**15**:1366–77. https://doi.org/10.1016/j.jcin.2022.05.022
118. Amat-Santos IJ, Estevez-Loureiro R, Sanchez-Recalde A, Cruz-Gonzalez I, Pascual I, Mascherbauer J, *et al.* Right heart remodelling after bicaval TricValve implantation in patients with severe tricuspid regurgitation. *EuroIntervention* 2023;**19**:e450–e452. https://doi.org/10.4244/EIJ-D-23-00077
119. Asmarats L, Dagenais F, Bedard E, Pasian S, Hahn RT, Navia JL, *et al.* Transcatheter tricuspid valve replacement for treating severe tricuspid regurgitation: initial experience with the NaviGate bioprosthesis. *Can J Cardiol* 2018;**34**:1370 e5–1370 e7. https://doi.org/10.1016/j.cjca.2018.07.481
120. Kodali S, Hahn RT, Makkar R, Makar M, Davidson CJ, Puthumana JJ, *et al.* Transfemoral tricuspid valve replacement and one-year outcomes: the TRISCEND study. *Eur Heart J* 2023;**44**:4862–73. https://doi.org/10.1093/eurheartj/ehad667
121. Stolz L, Weckbach LT, Hahn RT, Chatfield AG, Fam NP, von Bardeleben RS, *et al.* 2-Year outcomes following transcatheter tricuspid valve replacement using the EVOQUE system. *J Am Coll Cardiol* 2023;**81**:2374–6. https://doi.org/10.1016/j.jacc.2023.04.014
122. Blusztein DI, Hahn RT, Godoy Rivas C, George I, Kodali SK. Transcatheter tricuspid valve replacement with novel self-expanding valve: secure fixation in insecure anatomy. *JACC Case Rep* 2023;**12**:101773. https://doi.org/10.1016/j.jaccas.2023.101773
123. Zhang Y, Lu F, Li W, Chen S, Li M, Zhang X, *et al.* A first-in-human study of transjugular transcatheter tricuspid valve replacement with the LuX-valve plus system. *EuroIntervention* 2023;**18**:e1088–9. https://doi.org/10.4244/EIJ-D-22-00517
124. Asmarats L, Philippon F, Bedard E, Rodes-Cabau J. FORMA tricuspid repair system: device enhancements and initial experience. *EuroIntervention* 2019;**14**:1656–7. https://doi.org/10.4244/EIJ-D-18-00956
125. Chon MK, Lee SW, Hahn JY, Park YH, Kim HS, Lee SH, *et al.* A novel device for tricuspid regurgitation reduction featuring 3-dimensional leaflet and atraumatic anchor: pivot-TR system. *JACC Basic Transl Sci* 2022;**7**:1249–61. https://doi.org/10.1016/j.jacbts.2022.06.017
126. Fam NP. Return of the tricuspid spacer: filling an unmet clinical need. *JACC Basic Transl Sci* 2022;**7**:1262–3. https://doi.org/10.1016/j.jacbts.2022.08.004
127. Maisano F, Lorusso R, Sandrelli L, Torracca L, Coletti G, La Canna G, *et al.* Valve repair for traumatic tricuspid regurgitation. *Eur J Cardiothorac Surg* 1996;**10**:867–73. https://doi.org/10.1016/s1010-7940(96)80313-7
128. Vij A, Kavinsky CJ. The clinical impact of device lead-associated tricuspid regurgitation: need for a multidisciplinary approach. *Circulation* 2022;**145**:239–41. https://doi.org/10.1161/CIRCULATIONAHA.121.055019
129. Sorajja P, Chugh Y, Burns M, Hamid N, Bae R. Simple maneuver to improve TriClip eligibility in patients with cardiac implantable electronic device leads. *Circ Cardiovasc Interv* 2023;**16**:e012950. https://doi.org/10.1161/CIRCINTERVENTIONS.123.012950
130. Khor L, Madan K, Lee CH, Ng MKC. Pacing lead extraction in the management of tricuspid regurgitation: a case report. *Eur Heart J Case Rep* 2022;**6**:ytac170. https://doi.org/10.1093/ehjcr/ytac170
131. Hai T, Lerner AB, Khamooshian A. Severe tricuspid valve injury during right ventricular lead extraction. *J Cardiothorac Vasc Anesth* 2017;**31**:626–8. https://doi.org/10.1053/j.jvca.2016.08.014
132. Pingitore A, Calcagno S, Salvador L, Mennuni S, Cavarretta E. Tricuspid leaflet flail after Micra leadless pacemaker implantation: a case report. *Eur Heart J Case Rep* 2022;**6**:ytac154. https://doi.org/10.1093/ehjcr/ytac154
133. Mao Y, Liu Y, Meng X, Ma Y, Li L, Zhai M, *et al.* Treatment of severe tricuspid regurgitation induced by permanent pacemaker lead: transcatheter tricuspid valve replacement with the guidance of 3-dimensional printing. *Front Cardiovasc Med* 2023;**10**:1030997. https://doi.org/10.3389/fcvm.2023.1030997
134. Rios LH P, Alsaad AA, Guerrero M, Metzl MD. Tricuspid valve-in-valve jailing right ventricular lead is not free of risk. *Catheter Cardiovasc Interv* 2020;**96**:E758–60. https://doi.org/10.1002/ccd.28622
135. Stolz L, Doldi PM, Weckbach LT, Stocker TJ, Braun D, Orban M, *et al.* Right ventricular function in transcatheter mitral and tricuspid valve edge-to-edge repair. *Front Cardiovasc Med* 2022;**9**:993618. https://doi.org/10.3389/fcvm.2022.993618
136. Stolz L, Weckbach LT, Karam N, Kalbacher D, Praz F, Lurz P, *et al.* Invasive right ventricular to pulmonary artery coupling in patients undergoing transcatheter edge-to-edge tricuspid valve repair. *JACC Cardiovasc Imaging* 2023;**16**:564–6. https://doi.org/10.1016/j.jcmg.2022.10.004
137. Hagemeyer D, Merdad A, Ong G, Fam NP. Acute afterload mismatch after transcatheter tricuspid valve repair. *JACC Case Rep* 2022;**4**:519–22. https://doi.org/10.1016/j.jaccas.2022.02.008
138. Ho JE, Lyass A, Courchesne P, Chen G, Liu C, Yin X, *et al.* Protein biomarkers of cardiovascular disease and mortality in the community. *J Am Heart Assoc* 2018;**7**:e008108. https://doi.org/10.1161/JAHA.117.008108
139. Gardezi SK, Coffey S, Prendergast BD, Myerson SG. Serum biomarkers in valvular heart disease. *Heart* 2018;**104**:349–58. https://doi.org/10.1136/heartjnl-2016-310482
140. Hagemeyer D, Ali FM, Ong G, Fam NP. The role of intracardiac echocardiography in percutaneous tricuspid intervention: a new ICE age. *Interv Cardiol Clin* 2022;**11**:103–12. https://doi.org/10.1016/j.iccl.2021.09.006
141. Hammad TA, Abu-Omar Y, Shishehbor MH. Novel intracardiac echocardiography-guided catheter-based removal of inoperable tricuspid valve vegetation. *Catheter Cardiovasc Interv* 2022;**99**:508–11. https://doi.org/10.1002/ccd.29999