# Concomitant Tricuspid Repair in Patients with Degenerative Mitral Regurgitation

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Abstract: Background: Tricuspid regurgitation is common in patients with severe degenerative mitral regurgitation. However, the evidence base is insufficient to inform a decision about whether to perform tricuspid-valve repair during mitral-valve surgery in patients who have moderate tricuspid regurgitation or less-than-moderate regurgitation with annular dilatation. Methods: We randomly assigned 401 patients who were undergoing mitral-valve surgery for degenerative mitral regurgitation to receive a procedure with or without tricuspid annuloplasty (TA). The primary 2-year end point was a composite of reoperation for tricuspid regurgitation, progression of tricuspid regurgitation by two grades from baseline or the presence of severe tricuspid regurgitation, or death. Results: Patients who underwent mitral-valve surgery plus TA had fewer primary-end-point events than those who underwent mitral-valve surgery alone (3.9% vs. 10.2%) (relative risk, 0.37; 95% confidence interval [CI], 0.16 to 0.86; P = 0.02). Two-year mortality was 3.2% in the surgery-plus-TA group and 4.5% in the surgery-alone group (relative risk, 0.69; 95% CI, 0.25 to 1.88). The 2-year prevalence of progression of tricuspid regurgitation was lower in the surgery-plus-TA group than in the surgery-alone group (0.6% vs. 6.1%; relative risk, 0.09; 95% CI, 0.01 to 0.69). The frequencies of major adverse cardiac and cerebrovascular events, functional status, and quality of life were similar in the two groups at 2 years, although the incidence of permanent pacemaker implantation was higher in the surgery-plus-TA group than in the surgery-alone group (14.1% vs. 2.5%; rate ratio, 5.75; 95% CI, 2.27 to 14.60). Conclusions: Among patients undergoing mitral-valve surgery, those who also received TA had a lower incidence of a primary-end-point event than those who underwent mitral-valve surgery alone at 2 years, a reduction that was driven by less frequent progression to severe tricuspid regurgitation. Tricuspid repair resulted in more frequent permanent pacemaker implantation. Whether reduced progression of tricuspid regurgitation results in long-term clinical benefit can be determined only with longer follow-up. (Funded by the National Heart, Lung, and Blood Institute and the German Center for Cardiovascular Research; ClinicalTrials.gov number, NCT02675244.).

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ORIGINAL ARTICLE

# Concomitant Tricuspid Repair in Patients with Degenerative Mitral Regurgitation

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## ABSTRACT

### BACKGROUND

Tricuspid regurgitation is common in patients with severe degenerative mitral regurgitation. However, the evidence base is insufficient to inform a decision about whether to perform tricuspid-valve repair during mitral-valve surgery in patients who have moderate tricuspid regurgitation or less-than-moderate regurgitation with annular dilatation.

### METHODS

We randomly assigned 401 patients who were undergoing mitral-valve surgery for degenerative mitral regurgitation to receive a procedure with or without tricuspid annuloplasty (TA). The primary 2-year end point was a composite of reoperation for tricuspid regurgitation, progression of tricuspid regurgitation by two grades from baseline or the presence of severe tricuspid regurgitation, or death.

### RESULTS

Patients who underwent mitral-valve surgery plus TA had fewer primary-end-point events than those who underwent mitral-valve surgery alone (3.9% vs. 10.2%) (relative risk, 0.37; 95% confidence interval [CI], 0.16 to 0.86; P=0.02). Two-year mortality was 3.2% in the surgery-plus-TA group and 4.5% in the surgery-alone group (relative risk, 0.69; 95% CI, 0.25 to 1.88). The 2-year prevalence of progression of tricuspid regurgitation was lower in the surgery-plus-TA group than in the surgery-alone group (0.6% vs. 6.1%; relative risk, 0.09; 95% CI, 0.01 to 0.69). The frequencies of major adverse cardiac and cerebrovascular events, functional status, and quality of life were similar in the two groups at 2 years, although the incidence of permanent pacemaker implantation was higher in the surgery-plus-TA group than in the surgery-alone group (14.1% vs. 2.5%; rate ratio, 5.75; 95% CI, 2.27 to 14.60).

### CONCLUSIONS

Among patients undergoing mitral-valve surgery, those who also received TA had a lower incidence of a primary-end-point event than those who underwent mitral-valve surgery alone at 2 years, a reduction that was driven by less frequent progression to severe tricuspid regurgitation. Tricuspid repair resulted in more frequent permanent pacemaker implantation. Whether reduced progression of tricuspid regurgitation results in long-term clinical benefit can be determined only with longer follow-up. (Funded by the National Heart, Lung, and Blood Institute and the German Center for Cardiovascular Research; ClinicalTrials.gov number, NCT02675244.)

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*A complete list of investigators in the Cardiothoracic Surgical Trials Network is provided in the Supplementary Appendix.

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Tricuspid regurgitation is common among patients undergoing mitral-valve surgery for degenerative mitral regurgitation.[1-3] The recommendations for management of tricuspid regurgitation during mitral-valve surgery are based largely on observational data.[4,5] There is broad agreement that severe tricuspid regurgitation may not predictably improve after left-sided cardiac surgery and should be addressed during the index procedure. Late reoperation for severe tricuspid regurgitation in patients with right heart failure is associated with high perioperative mortality.[6,7]

However, the operative management of lesser degrees of tricuspid regurgitation is widely debated. Surgical and medical treatments of left-sided cardiac disease often result in a progressive reduction in the degree of tricuspid regurgitation, with favorable right ventricular reverse remodeling, a decrease in pulmonary-artery pressures, or both.[8,9] Mild or moderate tricuspid regurgitation that is not corrected at the time of left-sided cardiac surgery may progress in approximately 25% of patients and result in poorer late survival and functional outcomes. Risk factors for the progression of tricuspid regurgitation include annular dilation measuring 40 mm or more (or 21 mm per square meter) in diameter on preoperative transthoracic echocardiography, the magnitude of right ventricular dysfunction, and the presence of leaflet tethering, pulmonary hypertension, atrial fibrillation, or transvalvular pacing or defibrillator leads.[10-14]

Several single-center observational studies and a small randomized trial with an unblinded endpoint assessment have suggested that concomitant tricuspid-valve repair in patients with moderate tricuspid regurgitation or less-than-moderate (i.e., none, trace, or mild) regurgitation with annular dilatation is associated with less disease progression and better outcomes than conservative management.[11-13,15-19] Enthusiasm for uniform adoption of tricuspid-valve repair under these circumstances is tempered by concern regarding the excess risk of postoperative conduction disturbances resulting in permanent pacemaker implantation, an increase in cardiopulmonary bypass times, the small chance that tricuspid-valve replacement (rather than annuloplasty repair) may be needed, and the reality that tricuspid regurgitation does not progress in all patients.[1,9,20-26]

Accordingly, there are wide practice variations in the management of less-than-severe tricuspid regurgitation at the time of left-sided cardiac surgery. The frequency of tricuspid-valve repair at the time of mitral-valve surgery ranges from 5 to 75%.[1,27] To inform decision making, the Cardiothoracic Surgical Trials Network (CTSN) conducted a multicenter, randomized trial to assess the benefits and risks of tricuspid-valve repair at the time of mitral-valve surgery in patients with moderate or less-than-moderate tricuspid regurgitation who were undergoing surgery for degenerative mitral regurgitation.

## Methods

### Trial Design and Oversight

The trial was conducted at 39 clinical centers in the United States, Canada, and Germany. The progress of the trial was overseen by a coordinating center, an echocardiographic core laboratory, an independent event-adjudication committee, and a data and safety monitoring board appointed by the National Institutes of Health. The review board at each participating center approved the protocol, available with the full text of this article at NEJM.org. All the patients provided written informed consent.

All the investigators were responsible for the trial design and data collection; coordinating center investigators vouch for the completeness and accuracy of the data and for the fidelity of the trial to the protocol.

### Randomization and Treatment

Among patients who were scheduled for mitral-valve surgery, we randomly assigned those with either moderate tricuspid regurgitation or less-than-moderate regurgitation with annular dilatation in a 1:1 ratio to undergo the surgery with or without tricuspid annuloplasty (TA). Randomization was stratified according to the severity of tricuspid regurgitation and the clinical center. The trial was designed to enroll 400 patients; 1 additional patient underwent randomization before the completion of enrollment. The investigators were unaware of the overall out-

come data. End points were assessed at 30 days and at 6, 12, 18, and 24 months; after 24 months, survival was to be evaluated annually up to 60 months.

### PATIENTS AND INTERVENTIONS

The target population included adults undergoing mitral-valve surgery for degenerative mitral regurgitation with either moderate tricuspid regurgitation or less-than-moderate regurgitation with annular dilatation of 40 mm or more (or 21 mm per square meter).[2] The degree of tricuspid regurgitation was assessed by means of transthoracic echocardiography and verified by the central echocardiographic core laboratory. The selection of the most effective medical therapy was at the discretion of the heart team at each site. Exclusion criteria included evidence of secondary mitral regurgitation, primary tricuspid-valve disease, and suboptimal volume management.

All the patients underwent mitral-valve surgery with the use of a sternotomy or right minithoracotomy. Decisions regarding the use of surgical techniques — including suture placement and the type of prosthetic annuloplasty ring or valve — were at the surgeon's discretion. However, the protocol specified the use of an approved rigid, incomplete, nonplanar, and undersized (26, 28, or 30 mm) TA ring. (Details regarding surgical techniques are provided in the Supplementary Appendix, available at NEJM.org.)

### END POINTS

The primary end point at 2 years was a composite of reoperation for tricuspid regurgitation, progression of tricuspid regurgitation from baseline by two grades or the presence of severe tricuspid regurgitation, or death, with imputation of missing data. Secondary end points were death, major adverse cardiac and cerebrovascular events (MACCE; a composite of death, stroke, or serious heart-failure events), permanent pacemaker implantation, length of hospital stay, residual tricuspid regurgitation, echocardiographic indexes of right ventricular size and function, New York Heart Association (NYHA) classification, diuretic use, results on a 6-minute walk test, results on a gait-speed test for frailty, quality of life (as measured on the 12-Item Short Form Survey [SF-12], the Kansas City Cardiomyopathy Questionnaire [KCCQ], and EuroQol [EQ-5D]), serious adverse events, rehospitalizations, and cost-effectiveness. The cost-effectiveness analysis and additional echocardiographic studies are ongoing.

### STATISTICAL ANALYSIS

The trial used a parallel design with patients randomly assigned to undergo mitral-valve surgery alone or surgery plus TA, with 90% power to detect a 52% relative reduction in the primary end point among those in the surgery-plus-TA group as compared with the surgery-alone group. A two-sided P value of 0.05 was considered to indicate statistical significance. We assumed a 25% failure rate for mitral-valve surgery and 12% for surgery plus TA. One interim analysis was planned but not performed, according to the recommendation of the data and safety monitoring board, since enrollment had been completed and assessments of the primary end point were close to finalization.

All end points were evaluated in the intention-to-treat population. There was no correction of the type I error rate for multiple testing across secondary end points, as prespecified. As such, reported 95% confidence intervals have not been adjusted for multiplicity and do not imply definitive treatment effects.

The primary hypothesis was tested with the use of a log binomial regression model of treatment failure and randomization assignment that was stratified according to the severity of tricuspid regurgitation at baseline. Missing data regarding the primary end point at 2 years were imputed by means of multiple imputation on the assumption that data were missing at random. The imputation model was stratified according to randomization assignment and included age, sex, baseline severity of tricuspid regurgitation, and the degree of tricuspid regurgitation at 6 months and at 12 months. Details regarding the statistical analysis of the primary end point are provided in the Supplementary Appendix.

We used Cox proportional-hazards regression models to analyze the incidence of MACCE and death from any cause at 2 years. Secondary end points, including 30-day mortality, NYHA class, diuretic use, and categorical echocardiographic

end points, are reported descriptively. Results on 6-minute walk and gait-speed testing and continuous echocardiographic end points are also reported descriptively as means and standard deviations or medians and interquartile ranges. We assessed the patients' quality of life during the 2-year trial period using longitudinal linear mixed-effects models. The lengths of stay in the hospital and in the intensive care unit during the index hospitalization were compared separately according to geographic region with the use of the Hodges–Lehmann estimate of location shift. We performed Poisson regression with a robust variance estimate to calculate group differences in the frequencies of serious adverse events and readmissions through 2 years. All analyses were performed with the use of SAS software, version 9.4 (SAS Institute).

## RESULTS

### PATIENTS

From 2016 through 2018, a total of 5208 patients were screened; 885 were eligible to participate in the trial, and 401 underwent randomization (203 to undergo mitral-valve surgery alone and 198 to undergo surgery plus TA) (Fig. S1 and Tables S1 and S2 in the Supplementary Appendix). The two groups had similar preoperative characteristics at baseline (Table 1). The core laboratory confirmed moderate tricuspid regurgitation in 149 of 399 patients (37.3%). Right ventricular systolic function was normal in 360 of 398 patients (90.5%), and 121 of 400 patients (30.3%) had NYHA class III or IV heart failure.

Of the 401 patients, mitral-valve repair was performed in 360 (89.8%) and mitral-valve replacement in 41 (10.2%). In TA recipients, the average annuloplasty ring size was 29.0±1.9 mm in men and 27.8±1.6 mm in women. The mean cardiopulmonary bypass time was longer by 33.5 minutes (95% confidence interval [CI], 20.9 to 46.1) in the surgery-plus-TA group than in the surgery-alone group (166.1±69.3 minutes vs. 132.6±58.8 minutes). On the basis of surgeon judgment and logistics, 4 patients crossed over to undergo the other procedure in the operating room. More than 50% of the patients underwent concomitant procedures, including coronary-artery bypass grafting, atrial fibrillation ablation, left atrial appendage closure, and oversewing of a patent foramen ovale.

### PRIMARY END POINT

The primary end point was significantly more frequent among patients in the surgery-alone group (10.2%) than in the surgery-plus-TA group (3.9%) (relative risk, 0.37; 95% CI, 0.16 to 0.86; P=0.02) (Table 2). Death occurred in 9 of 199 patients (4.5%) in the surgery-alone group and in 6 of 190 (3.2%) in the surgery-plus-TA group (relative risk, 0.69; 95% CI, 0.25 to 1.88). No patients underwent tricuspid-valve reoperation within 2 years after randomization. The percentage of patients who had progression of tricuspid regurgitation at 2 years was higher in the surgery-alone group than in the surgery-plus-TA group (6.1% vs. 0.6%; relative risk, 0.09; 95% CI, 0.01 to 0.69). Most of the patients with progression had severe tricuspid regurgitation, which was present in 10 of 179 patients (5.6%) in the surgery-alone group and in 1 of 179 (0.6%) in the surgery-plus-TA group (relative risk, 0.10; 95% CI, 0.01 to 0.77).

In a post hoc analysis stratified according to the degree of tricuspid regurgitation at baseline, the incidence of a primary-end-point event was higher among the patients in the surgery-alone group than in the surgery-plus-TA group when moderate tricuspid regurgitation was present at baseline but not when tricuspid regurgitation was less than moderate. This difference in outcomes was driven by the progression to severe tricuspid regurgitation at 2 years in the surgery-alone group (Table S4).

### MACCE AND DEATH

In the time-to-event analysis of death during the 2-year trial period, we observed no substantial difference in cumulative mortality between the surgery-alone group and the surgery-plus-TA group (hazard ratio, 0.69; 95% CI, 0.24 to 1.93) (Fig. 1). Death within 30 days after surgery (perioperative mortality) occurred in 1 of 203 patients (0.5%) in the surgery-alone group and in 2 of 197 (1.0%) in the surgery-plus-TA group. The risk of a MACCE end point within 2 years was also similar in the two groups (hazard ratio, 0.89; 95% CI, 0.49 to 1.63) (Fig. S2).

### ECHOCARDIOGRAPHIC END POINTS

The degree of tricuspid regurgitation during a 2-year period is shown in Figure 2A. Moderate or severe tricuspid regurgitation occurred in 45 of

179 patients (25.1%) in the surgery-alone group and in 6 of 179 (3.4%) in the surgery-plus-TA group. The median peak diastolic transtricuspid pressure gradient was 1 mm Hg (interquartile range [IQR], 1 to 2) in the surgery-alone group and 3 (IQR, 2 to 4) in the surgery-plus-TA group. More than 90% of the patients in both groups had normal right ventricular systolic function, which occurred in 163 of 178 patients (91.6%) in the surgery-alone group and in 162 of 178 (91.0%) in the surgery-plus-TA group. The median left ventricular ejection fraction was 60% (IQR, 56 to 64) in the surgery-alone group and 61% (IQR, 56 to 64) in the surgery-plus-TA group. At 2 years, moderate or severe mitral regurgitation was present in 18 of 178 patients (10.1%) in the surgery-alone group and in 15 of 179 (8.4%) in the surgery-plus-TA group (Fig. 2B). Post hoc analyses of these end points with reasons for missingness of data and estimates of treatment effect on the basis of multiple imputation are provided in the Supplementary Appendix.

### ADVERSE EVENTS AND HOSPITALIZATIONS

The overall incidence of serious adverse events was similar in the two groups at 2 years (Table 3). The rate of heart-failure events was 0.11 per 24 patient-months in the surgery-alone group and 0.07 per 24 patient-months in the surgery-plus-TA group (rate ratio, 0.68; 95% CI, 0.25 to 1.85). Sustained supraventricular arrhythmias requiring drug therapy or cardioversion were more frequent in the surgery-alone group than in the surgery-plus-TA group (rate ratio, 0.70; 95% CI, 0.43 to 1.12). However, cardiac-conduction abnormalities resulting in permanent pacemaker implantation were more frequent in the surgery-plus-TA group than in the surgery-alone group (rate ratio, 5.75; 95% CI, 2.27 to 14.60). The majority of these events occurred during the index hospitalization, with 4 of 5 permanent pacemakers (80.0%) implanted in the surgery-alone group and 22 of 28 (78.6%) implanted in the surgery-plus-TA group before hospital discharge. The most common indication for permanent pacemaker implantation was complete or high-grade atrioventricular block (in 19 of 33 patients [57.6%]).

The median length of stay during the index hospitalization was 2 days shorter in the surgery-alone group than in the surgery-plus-TA group in the United States (6 days [IQR, 5 to 8] vs. 8 days [IQR, 6 to 9]) and in Canada (7 days [IQR, 6 to 11] vs. 9 days [IQR, 7 to 14]). In Germany, the length of stay was longer than that in either the United States or Canada and similar in the two treatment groups (11.5 days [IQR, 9 to 15] vs. 12 days [IQR, 9 to 16]) (Fig. S3). The overall hospital readmission rate per 24 patient-months was 0.65 in the surgery-alone group and 0.56 in the surgery-plus-TA group (rate ratio, 0.86; 95% CI, 0.58 to 1.27) (Table S5), with similar incidences of readmissions for cardiovascular events (rate ratio, 0.87; 95% CI, 0.52 to 1.43) and heart-failure events (rate ratio, 0.71; 95% CI, 0.18 to 2.71). Post hoc analyses of the time until the first readmission with death as a competing risk also showed similar outcomes in the two groups.

### QUALITY OF LIFE AND FUNCTIONAL STATUS

The outcomes with respect to any measures of quality of life or functional status for patients at 2 years were similar in the two groups (Figs. S4, S5, and S6). Among survivors, the median improvement in heart-failure symptoms over baseline, as measured on the KCCQ, was 27.2% (IQR, 4.3 to 70.0) in the surgery-alone group and 21.4% (IQR, 6.1 to 57.1) in the surgery-plus-TA group. Figure 2C shows the NYHA classification, which includes data regarding death, over time. Diuretic use at 24 months was similar in the two groups (in 55 of 185 patients [29.7%] in the surgery-alone group and in 41 of 182 [22.5%] in the surgery-plus-TA group).

## DISCUSSION

The best treatment approach for patients with moderate or less-than-moderate tricuspid regurgitation at the time of surgery for degenerative mitral regurgitation is uncertain. Current guideline recommendations are based largely on observational data from studies conducted at single surgical centers.[28-30] In this international, randomized trial, we found that patients with moderate or less-than-moderate tricuspid regurgitation who were receiving TA at the time of mitral-valve surgery for degenerative mitral regurgitation had a significantly lower 2-year incidence of a composite end point of reoperation

**Table 1. Characteristics of the Patients at Baseline.***

| Characteristic | Mitral-Valve Surgery Alone (N=203) | Mitral-Valve Surgery plus TA (N=198) |
|---|---|---|
| **Demographic** | | |
| Age — yr | 68.2±9.7 | 66.6±10.7 |
| Male sex — no. (%) | 153 (75.4) | 147 (74.2) |
| Race or ethnic group — no./total no. (%)† | | |
| White | 184/197 (93.4) | 182/189 (96.3) |
| Hispanic or Latino | 0 | 6/193 (3.1) |
| **Clinical** | | |
| Body-mass index‡ | 26.3±4.5 | 26.6±4.5 |
| Coexisting condition — no. (%) | | |
| Atrial fibrillation | 90 (44.3) | 87 (43.9) |
| Ventricular arrhythmia | 14 (6.9) | 17 (8.6) |
| Myocardial infarction | 12 (5.9) | 7 (3.5) |
| Hypertension | 124 (61.1) | 111 (56.1) |
| Left ventricular ejection fraction — % | 64.3±7.4 | 64.1±7.1 |
| Left ventricular end-diastolic volume — ml | 165.0±48.8 | 160.3±50.4 |
| Left ventricular end-systolic volume — ml | 60.7±27.4 | 58.4±25.8 |
| Severe mitral regurgitation — no./total no. (%) | 187/202 (92.6) | 178/193 (92.2) |
| Moderate tricuspid regurgitation — no./total no. (%) | 76/202 (37.6) | 73/197 (37.1) |
| Tricuspid-valve annulus dimension — mm§ | 42.2±4.7 | 42.0±4.6 |
| Right ventricular basal diameter — mm | 44.7±5.9 | 43.2±6.2 |
| Right ventricular fractional area of change — %¶ | 42.6±7.6 | 43.1±7.4 |
| Normal right ventricular function — no./total no. (%) | 181/202 (89.6) | 179/196 (91.3) |
| NYHA functional class III or IV — no./total no. (%) | 68/203 (33.5) | 53/197 (26.9) |
| Score on SF-12‖ | | |
| Physical health | 41.9±10.8 | 43.4±11.5 |
| Mental health | 51.3±9.6 | 51.4±10.3 |
| Score on EQ-5D visual analogue scale** | 72.8±18.1 | 73.7±18.3 |
| Overall summary score on KCCQ†† | 68.0±22.4 | 69.4±23.7 |
| **Surgical** | | |
| Cardiopulmonary bypass time — min | 132.6±58.8 | 166.1±69.3 |
| Type of procedure — no. (%)‡‡ | | |
| Sternotomy | 103 (50.7) | 108 (54.5) |
| Mitral-valve repair | 178 (87.7) | 182 (91.9) |
| Tricuspid-valve repair | 1 (0.5) | 196 (99.0) |
| Any concomitant procedure§§ | 109 (53.7) | 105 (53.0) |

* Plus–minus values are means ±SD. NYHA denotes New York Heart Association, and TA tricuspid annuloplasty.
† Race and ethnicity were reported as two separate variables by the patient. Details regarding the distribution of patients according to race or ethnic group are provided in Table S7 in the Supplementary Appendix.
‡ The body-mass index is the weight in kilograms divided by the square of the height in meters.
§ The annulus of the tricuspid valve was measured on the apical four-chamber view.
¶ The right ventricular fractional area of change is calculated as the difference between the end-diastolic area and the end-systolic area divided by the end-diastolic area.
‖ The physical and mental health scores on the 12-Item Short Form Survey (SF-12) are reported as T scores (mean, 50±10), with higher scores indicating better health status.
** Scores on the EuroQol (EQ-5D) visual analogue scale range from 0 (worst imaginable health) to 100 (best imaginable health).
†† Scores on the Kansas City Cardiomyopathy Questionnaire (KCCQ) overall summary range from 0 to 100, with higher scores indicating a better quality of life and fewer symptoms and physical limitations associated with heart failure.
‡‡ Patients who did not undergo sternotomy received a right minithoracotomy; those who did not undergo mitral-valve repair received mitral-valve replacement. Four patients (2 in each group) did not receive their assigned treatment. In the surgery-alone group, 1 patient underwent tricuspid-valve repair and 1 patient underwent tricuspid-valve replacement. In the surgery-plus-TA group, 2 patients did not undergo a tricuspid-valve procedure.
§§ In the surgery-alone group, concomitant procedures that were performed included coronary-artery bypass grafting (CABG) in 22 patients (10.8%), maze procedure for atrial fibrillation ablation in 49 (24.1%), left atrial appendage closure in 50 (24.6%), and closure of the patent foramen ovale in 25 (12.3%). In the surgery-plus-TA group, CABG was performed in 21 patients (10.6%), maze procedure in 56 (28.3%), left atrial appendage closure in 58 (29.3%), and closure of the patent foramen ovale in 29 (14.6%).

**Table 2. Primary End Point.***

| Composite End Point | Mitral-Valve Surgery Alone (N=203) | Mitral-Valve Surgery plus TA (N=198) | Relative Risk (95% CI) | P Value |
|---|---|---|---|---|
| Imputed calculation — % (95% CI) | 10.2 (6.0–14.5) | 3.9 (1.1–6.7) | 0.37 (0.16–0.86) | 0.02 |
| Observed calculation — no./total no. (%) | 20/188 (10.6) | 7/185 (3.8) | 0.35 (0.15–0.81) | — |
| Reoperation for tricuspid regurgitation | 0 | 0 | — | — |
| Progression of tricuspid regurgitation | 11/179 (6.1) | 1/179 (0.6) | 0.09 (0.01–0.69) | — |
| Death | 9/199 (4.5) | 6/190 (3.2) | 0.69 (0.25–1.88) | — |

* The primary 2-year end point was a composite of reoperation for tricuspid regurgitation, progression of tricuspid regurgitation by two grades from baseline or the presence of severe tricuspid regurgitation, or death. Data regarding the primary end point were missing for 15 patients in the group undergoing mitral-valve surgery alone and for 13 in the group undergoing mitral-valve surgery plus TA, so values were imputed for the primary analysis. Denominators indicate the number of patients who were observed for each portion of the composite end point. For data regarding death within 2 years, excluded were all the patients who had been lost to follow-up or who had withdrawn from the trial by 2 years. Also excluded is a patient in the surgery-plus-TA group who attended the 2-year visit at 23.1 months and missed the 3-year visit. For data regarding tricuspid-valve surgery, excluded were all the patients who had been excluded from the analysis of death in addition to any patients who had died within 2 years. For data regarding the progression of tricuspid regurgitation at 2 years, included were patients who had 2-year results on echocardiography that could be interpreted by the core laboratory. Included in the "observed" analyses were the patients who had died and those who had a readable result on the 2-year echocardiographic evaluation.

for tricuspid regurgitation, progression of tricuspid regurgitation, or death than those undergoing mitral-valve surgery alone (3.9% vs. 10.2%; P=0.02). This difference was driven by a substantially lower incidence of progression of tricuspid regurgitation among patients assigned to receive TA.

Although our trial was not powered to analyze the primary end point according to the severity of tricuspid regurgitation at baseline, in a post hoc analysis, we found that the progression of tricuspid regurgitation occurred almost exclusively in patients with moderate tricuspid regurgitation at baseline and not in those with less-than-moderate regurgitation with annular dilatation. This observation calls into question reliance on the measurement of the tricuspid annular diameter to inform surgical decision making in patients with less-than-moderate tricuspid regurgitation — a question that can be answered only with additional research over a longer time period.

The status with respect to MACCE, functional status, quality of life, heart-failure events, diuretic use, and hospital readmission at 2 years was similar in the two groups, although the rate of permanent pacemaker implantation was substantially higher in recipients of TA, an outcome that should be factored into shared decision making with patients. Moreover, patients who were undergoing mitral-valve surgery alone were more likely to have moderate or severe tricuspid regurgitation at 2 years (25.1%) than those who also received TA (3.4%). However, we observed similar incidences of NYHA class III or IV heart failure (2.8% in the surgery-alone group and 1.1% in the surgery-plus-TA group), as compared with incidences of 33.5% and 26.9%, respectively, at baseline. Overall summary scores for quality of life on the KCCQ, the SF-12 physical and mental health scores, and scores on the EQ-5D and 6-minute walk test were also similar in the two groups. Notably, the 2-year KCCQ scores showed average increases from baseline in both groups that were indicative of clinical improvement that was "large to very large."[31] Readmission rates, including for cardiovascular and heart-failure events, were also similar in the two groups.

Although the much higher prevalence of moderate or severe tricuspid regurgitation among the patients who underwent mitral-valve surgery alone did not affect clinical or functional outcomes at 2 years, differences may emerge with longer-term follow-up. Observational studies have suggested that moderate or severe functional tricuspid regurgitation in patients with degenerative mitral regurgitation is an independent long-term risk factor for death.[2] The incidence of severe tricuspid regurgitation may increase over

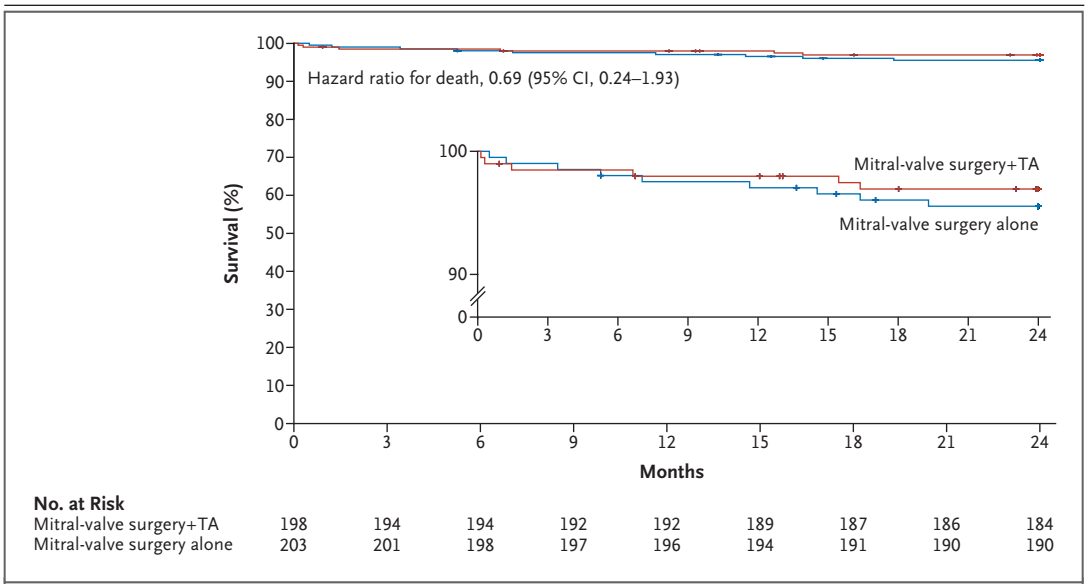


**Figure 1. Overall Survival.**

Shown are Kaplan–Meier estimates of overall survival during the 2 years after randomization among patients with moderate or less-than-moderate tricuspid regurgitation who were undergoing mitral-valve surgery alone or surgery with placement of a tricuspid annuloplasty (TA) ring. The inset shows the same data on an expanded y axis. The tick marks indicate censored data.

time after isolated mitral-valve surgery and adversely affect right ventricular function.[18] The long life expectancy of our relatively young trial population underscores the importance of longer-term follow-up.

The addition of TA increased cardiopulmonary bypass time by 34 minutes on average. However, this difference was not associated with a higher risk of perioperative death, as has been reported in other studies.[23] Mitral-valve surgery plus TA was associated with a length of stay during the index hospitalization that was 2 days longer than the length of stay with surgery alone in both the United States and Canada. In Germany, the length of hospital stay was generally longer than those in both the United States and Canada but similar in the two treatment groups, which reflects the different incentives embedded in the three health care systems.

An important finding in this trial was the higher incidence of permanent pacemaker implantation in the TA group (14.1% vs. 2.5%), with nearly 80% of procedures occurring during the index hospitalization. The frequency of surgery for atrial fibrillation, a potential confounder, was similar in the two treatment groups. Permanent pacemaker implantation has been associated with the risks of device malfunction, thrombosis, infection, recurrent or progressive tricuspid regurgitation, right ventricular remodeling, and reduced survival.[32,33] The use of leadless pacemakers and evolving transcatheter approaches may circumvent some of these issues, and additional study may help in the identification of procedural factors associated with permanent pacemaker implantation. Although the clinical effect of pacemaker implantation was not evident during the 2-year period, longer-term follow-up is needed to gain further insight. In the two treatment groups, recurrent mitral regurgitation could also contribute to late outcomes.

Our trial has several limitations. First, we did not meet our target in recruiting a sufficiently diverse patient population with respect to race or ethnic group. A recent national registry study

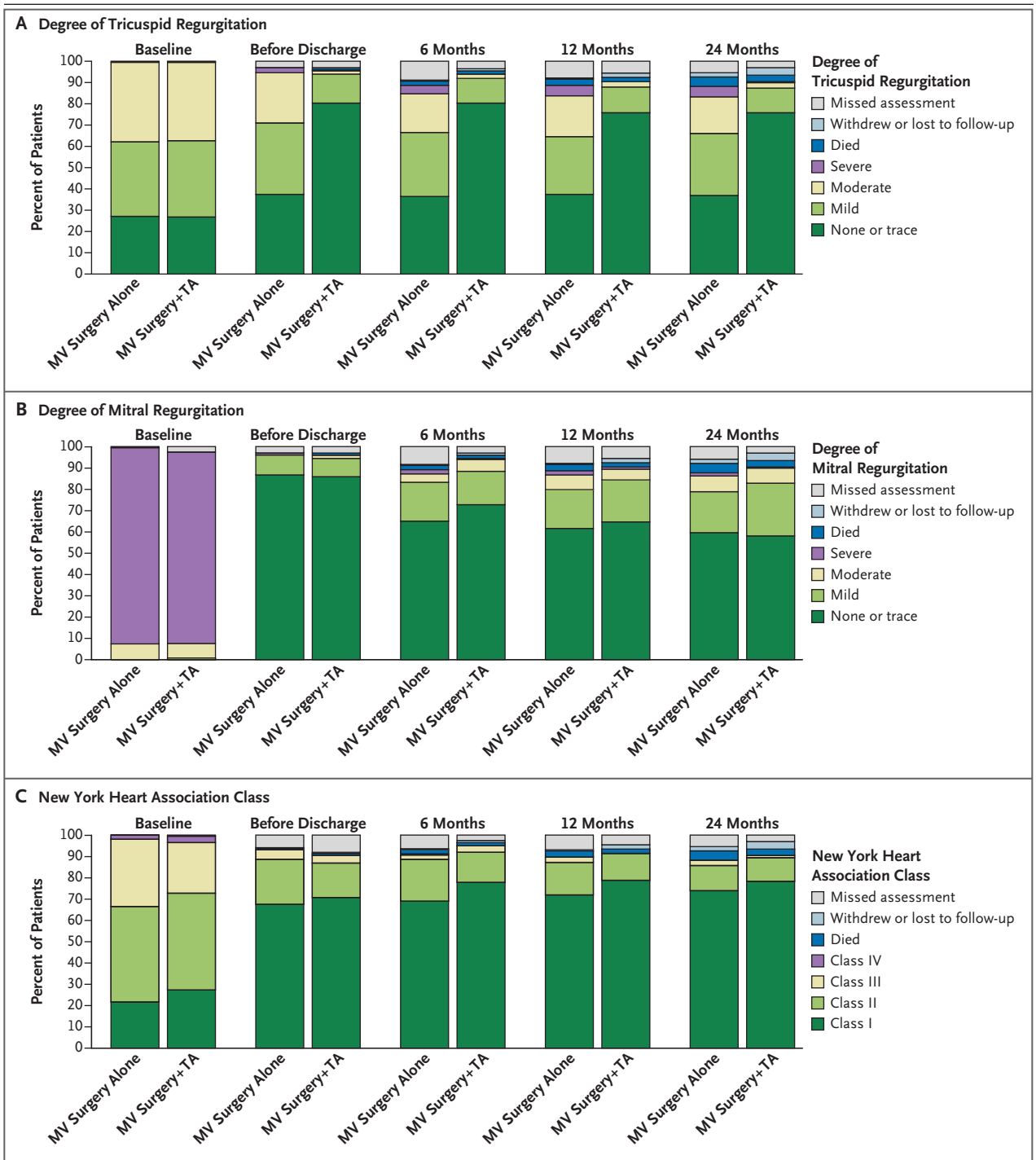


**Figure 2. Echocardiographic and Functional Status.**

Shown are the distributions of the degree of tricuspid regurgitation (Panel A), the degree of mitral regurgitation (Panel B), and the New York Heart Association class (Panel C) among the patients who were undergoing mitral-valve (MV) surgery alone or MV surgery plus TA during the 2 years after randomization.

**Table 3. Serious Adverse Events.***

| Variable | Mitral-Valve Surgery Alone (N=203) | | | Mitral-Valve Surgery plus TA (N=198) | | | Rate Ratio (95% CI) |
|---|---|---|---|---|---|---|---|
| | Patients | Events | Rate | Patients | Events | Rate | |
| | *no. (%)* | *no.* | *no./24 patient-mo* | *no. (%)* | *no.* | *no./24 patient-mo* | |
| All serious adverse events | 109 (53.7) | 259 | 1.323 | 109 (55.1) | 216 | 1.133 | 0.86 (0.61–1.20) |
| Bleeding | 12 (5.9) | 13 | 0.066 | 7 (3.5) | 8 | 0.042 | 0.63 (0.24–1.64) |
| Sustained ventricular arrhythmia leading to defibrillation or cardioversion | 2 (1.0) | 2 | 0.010 | 2 (1.0) | 2 | 0.010 | 1.03 (0.15–7.22) |
| Sustained supraventricular arrhythmia requiring drug treatment or cardioversion | 45 (22.2) | 56 | 0.286 | 30 (15.2) | 38 | 0.199 | 0.70 (0.43–1.12) |
| New-onset atrial fibrillation | 19 (9.4) | 22 | 0.112 | 17 (8.6) | 19 | 0.100 | 0.89 (0.45–1.74) |
| Cardiac conduction abnormalities or sustained bradycardia leading to permanent pacemaker implantation | 5 (2.5) | 5 | 0.026 | 28 (14.1) | 28 | 0.147 | 5.75 (2.27–14.60) |
| Atrioventricular block | 1 (0.5) | 1 | 0.005 | 15 (7.6) | 15 | 0.079 | 15.41 (2.05–115.52) |
| Pericardial fluid collection | 3 (1.5) | 3 | 0.015 | 3 (1.5) | 3 | 0.016 | 1.03 (0.21–5.02) |
| Pleural effusion | 16 (7.9) | 20 | 0.102 | 8 (4.0) | 10 | 0.052 | 0.51 (0.21–1.25) |
| Pneumothorax | 3 (1.5) | 3 | 0.015 | 5 (2.5) | 5 | 0.026 | 1.71 (0.41–7.07) |
| Hepatic dysfunction | 2 (1.0) | 2 | 0.010 | 0 | 0 | — | — |
| Major infection | | | | | | | |
| Localized | 15 (7.4) | 18 | 0.092 | 15 (7.6) | 16 | 0.084 | 0.91 (0.44–1.92) |
| Endocarditis | 1 (0.5) | 1 | 0.005 | 2 (1.0) | 2 | 0.010 | 2.05 (0.19–22.50) |
| Sepsis | 11 (5.4) | 12 | 0.061 | 5 (2.5) | 5 | 0.026 | 0.43 (0.15–1.24) |
| Myocardial infarction | | | | | | | |
| Not related to procedure | 2 (1.0) | 2 | 0.010 | 2 (1.0) | 2 | 0.010 | 1.03 (0.15–7.26) |
| Related to CABG | 1 (0.5) | 1 | 0.005 | 0 | 0 | — | — |
| Transient ischemic attack | 1 (0.5) | 1 | 0.005 | 2 (1.0) | 2 | 0.010 | 2.05 (0.19–22.46) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Stroke | | | | | | | |
| Ischemic | 3 (1.5) | 3 | 0.015 | 9 (4.5) | 9 | 0.047 | 3.08 (0.84–11.23) |
| Hemorrhagic | 1 (0.5) | 1 | 0.005 | 1 (0.5) | 1 | 0.005 | 1.03 (0.06–16.44) |
| Toxic metabolic encephalopathy | 3 (1.5) | 3 | 0.015 | 4 (2.0) | 4 | 0.021 | 1.37 (0.31–6.06) |
| Seizure | 2 (1.0) | 3 | 0.015 | 3 (1.5) | 3 | 0.016 | 1.03 (0.16–6.45) |
| Renal failure | 5 (2.5) | 5 | 0.026 | 3 (1.5) | 3 | 0.016 | 0.62 (0.15–2.59) |
| Respiratory failure | 5 (2.5) | 7 | 0.036 | 5 (2.5) | 7 | 0.037 | 1.03 (0.28–3.82) |
| Heart failure | 13 (6.4) | 21 | 0.107 | 9 (4.5) | 14 | 0.073 | 0.68 (0.25–1.85) |
| Arterial non-CNS thromboembolism | 2 (1.0) | 2 | 0.010 | 0 | 0 | — | — |
| Venous thromboembolic event | 2 (1.0) | 2 | 0.010 | 0 | 0 | — | — |
| Wound dehiscence | 0 | 0 | — | 2 (1.0) | 2 | 0.010 | — |
| Unexpected other serious adverse event | 47 (23.2) | 71 | 0.363 | 37 (18.7) | 52 | 0.273 | 0.75 (0.47–1.21) |

* CNS denotes central nervous system.

involving patients who were undergoing mitral-valve surgery indicated that 5.9% were Hispanic and 9.9% were Black, as compared with 2.5% and 4.2%, respectively, among the patients in the United States in our trial (Tables S6 and S7).[34] Efforts to understand why minorities are underrepresented in the surgical population and in clinical trials in general and how to overcome these limitations have become a priority for the CTSN. Second, the composite primary end point included both echocardiographic and clinical outcomes so that a manageable sample size to allow for efficient trial completion could be achieved. However, our choice of progression of tricuspid regurgitation was driven by observational evidence correlating it with the long-term risk of adverse clinical outcomes. Third, the trial was designed to address surgical decision making for patients with either moderate tricuspid regurgitation or less-than-moderate regurgitation with annular dilatation, but it was not powered to draw inferences about these groups individually. Finally, measuring the primary end point at 24 months may not fully capture the clinical effect of progression of tricuspid regurgitation or permanent pacemaker implantation over time. The trial is designed to follow patients for 5 years to assess longer-term clinical outcomes.

The inclusion of TA at the time of mitral-valve surgery resulted in a lower risk of a primary-end-point event at 2 years than surgery alone, a reduction that was driven by less frequent progression to severe tricuspid regurgitation. This reduction in disease progression came at the cost of a higher risk of permanent pacemaker implantation. Otherwise, patients in the two treatment groups had similar outcomes with respect to MACCE, quality of life, functional status, hospital readmission, and death. Follow-up through 5 years to assess net clinical benefit is ongoing.

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## APPENDIX

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## REFERENCES

1. Badhwar V, Rankin JS, He M, et al. Performing concomitant tricuspid valve repair at the time of mitral valve operations is not associated with increased operative mortality. Ann Thorac Surg 2017;103:587-93.
2. Essayagh B, Antoine C, Benfari G, et al. Functional tricuspid regurgitation of degenerative mitral valve disease: a crucial determinant of survival. Eur Heart J 2020;41:1918-29.
3. Topilsky Y, Maltais S, Medina Inojosa J, et al. Burden of tricuspid regurgitation in patients diagnosed in the community setting. JACC Cardiovasc Imaging 2019;12:433-42.
4. Vahanian A, Beyersdorf F, Praz F, et al. 2021 ESC/EACTS guidelines for the management of valvular heart disease. Eur J Cardiothorac Surg 2021;60:727-800.
5. Otto CM, Nishimura RA, Bonow RO, et al. 2020 ACC/AHA guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation 2021;143(5):e35-e71.
6. Jeganathan R, Armstrong S, Al-Alao B, David T. The risk and outcomes of reoperative tricuspid valve surgery. Ann Thorac Surg 2013;95:119-24.
7. Pfannmüller B, Moz M, Misfeld M, et al. Isolated tricuspid valve surgery in patients with previous cardiac surgery. J Thorac Cardiovasc Surg 2013;146:841-7.
8. Desai RR, Vargas Abello LM, Klein AL, et al. Tricuspid regurgitation and right ventricular function after mitral valve surgery with or without concomitant tricuspid valve procedure. J Thorac Cardiovasc Surg 2013;146(5):1126-1132.e10.
9. Sordelli C, Lancellotti P, Carlomagno G, et al. Tricuspid annular size and regurgitation progression after surgical repair for degenerative mitral regurgitation. Am J Cardiol 2016;118:424-31.
10. Benedetto U, Melina G, Angeloni E, et al. Prophylactic tricuspid annuloplasty in patients with dilated tricuspid annulus undergoing mitral valve surgery. J Thorac Cardiovasc Surg 2012;143:632-8.
11. Bertrand PB, Koppers G, Verbrugge FH, et al. Tricuspid annuloplasty concomitant with mitral valve surgery: effects on right ventricular remodeling. J Thorac Cardiovasc Surg 2014;147:1256-64.
12. Chikwe J, Itagaki S, Anyanwu A, Adams DH. Impact of concomitant tricuspid annuloplasty on tricuspid regurgitation, right ventricular function, and pulmonary artery hypertension after repair of mitral valve prolapse. J Am Coll Cardiol 2015;65:1931-8.
13. Dreyfus GD, Corbi PJ, Chan KM, Bahrami T. Secondary tricuspid regurgitation or dilatation: which should be the criteria for surgical repair? Ann Thorac Surg 2005;79:127-32.
14. McCarthy PM, Szlapka M, Kruse J, et al. The relationship of atrial fibrillation and tricuspid annular dilation to late tricuspid regurgitation in patients with degenerative mitral repair. J Thorac Cardiovasc Surg 2021;161(6):2030-2040.e3.
15. Brescia AA, Ward ST, Watt TMF, et al. Outcomes of guideline-directed concomitant annuloplasty for functional tricuspid regurgitation. Ann Thorac Surg 2020;109:1227-32.
16. Calafiore AM, Gallina S, Iacò AL, 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.
17. Calafiore AM, Iacò AL, Romeo A, et al. Echocardiographic-based treatment of functional tricuspid regurgitation. J Thorac Cardiovasc Surg 2011;142:308-13.
18. Goldstone AB, Howard JL, Cohen JE, et al. Natural history of coexistent tricuspid regurgitation in patients with degenerative mitral valve disease: implications for future guidelines. J Thorac Cardiovasc Surg 2014;148:2802-9.
19. Van de Veire NR, Braun J, Delgado V, et al. Tricuspid annuloplasty prevents right ventricular dilatation and progression of tricuspid regurgitation in patients with tricuspid annular dilatation undergoing mitral valve repair. J Thorac Cardiovasc Surg 2011;141:1431-9.
20. David TE, David CM, Fan CS, Manl-

hiot C. Tricuspid regurgitation is uncommon after mitral valve repair for degenerative diseases. J Thorac Cardiovasc Surg 2017;154(1):110-122.e1.
**21.** Helmers MR, Shin M, Iyengar A, et al. Permanent pacemaker implantation following mitral valve surgery: a retrospective cohort study of risk factors and long-term outcomes. Eur J Cardiothorac Surg 2021;60:140-7.
**22.** Jouan J, Mele A, Florens E, et al. Conduction disorders after tricuspid annuloplasty with mitral valve surgery: implications for earlier tricuspid intervention. J Thorac Cardiovasc Surg 2016;151:99-103.
**23.** LaPar DJ, Mulloy DP, Stone ML, et al. Concomitant tricuspid valve operations affect outcomes after mitral operations: a multiinstitutional, statewide analysis. Ann Thorac Surg 2012;94:52-7.
**24.** Lee JW, Song JM, Park JP, Lee JW, Kang DH, Song JK. Long-term prognosis of isolated significant tricuspid regurgitation. Circ J 2010;74:375-80.
**25.** Ro SK, Kim JB, Jung SH, Choo SJ, Chung CH, Lee JW. Mild-to-moderate functional tricuspid regurgitation in patients undergoing mitral valve surgery. J Thorac Cardiovasc Surg 2013;146:1092-7.
**26.** Yilmaz O, Suri RM, Dearani JA, et al. Functional tricuspid regurgitation at the time of mitral valve repair for degenerative leaflet prolapse: the case for a selective approach. J Thorac Cardiovasc Surg 2011;142:608-13.
**27.** Dion RA. Is the air in Toronto, Rochester, and Cleveland different from that in London, Monaco, Leiden, Genk, Milan, and New York? J Thorac Cardiovasc Surg 2015;150:1040-3.
**28.** Chan V, Burwash IG, Lam BK, et al. Clinical and echocardiographic impact of functional tricuspid regurgitation repair at the time of mitral valve replacement. Ann Thorac Surg 2009;88:1209-15.
**29.** Kim JB, Yoo DG, Kim GS, et al. Mild-to-moderate functional tricuspid regurgitation in patients undergoing valve replacement for rheumatic mitral disease: the influence of tricuspid valve repair on clinical and echocardiographic outcomes. Heart 2012;98:24-30.
**30.** Navia JL, Brozzi NA, Klein AL, et al. Moderate tricuspid regurgitation with left-sided degenerative heart valve disease: to repair or not to repair? Ann Thorac Surg 2012;93:59-67.
**31.** Spertus JA, Jones PG, Sandhu AT, Arnold SV. Interpreting the Kansas City Cardiomyopathy Questionnaire in clinical trials and clinical care: JACC state-of-the-art review. J Am Coll Cardiol 2020;76:2379-90.
**32.** Mar PL, Angus CR, Kabra R, et al. Perioperative predictors of permanent pacing and long-term dependence following tricuspid valve surgery: a multicentre analysis. Europace 2017;19:1988-93.
**33.** McCarthy PM, Bhudia SK, Rajeswaran J, et al. Tricuspid valve repair: durability and risk factors for failure. J Thorac Cardiovasc Surg 2004;127:674-85.
**34.** Vemulapalli S, Grau-Sepulveda M, Habib R, Thourani V, Bavaria J, Badhwar V. Patient and hospital characteristics of mitral valve surgery in the United States. JAMA Cardiol 2019;4:1149-55.