Changes in Right Ventricular Volume and Function After Tricuspid Valve Surgery
– Tricuspid Annuloplasty vs. Tricuspid Valve Replacement –

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Background: There is a concern that clinical outcome of tricuspid valve replacement (TVR) is inferior compared with tricuspid annuloplasty (TAP). The aim of this study was therefore to compare changes in right ventricular (RV) volume and function following TAP with that following TVR on cardiac magnetic resonance imaging (CMR) in patients with severe functional tricuspid regurgitation (TR).

Methods and Results: Forty patients who underwent surgery for severe functional TR and who underwent CMR preoperatively and on postoperative follow-up (24.8±13.3 months after surgery) were enrolled. Thirteen patients underwent TAP (TAP group) and 27 patients underwent TVR (TVR group). Both RV end-diastolic and end-systolic volume indices decreased significantly after surgery (from 178.9±53.9 to 116.3±26.7 ml/m², P<0.001, and from 95.7±36.1 to 67.3±28.0 ml/m², P<0.001, respectively), without intergroup differences. In the TAP group, RV ejection fraction (EF) was preserved following surgery (from 43.3±9.5 to 46.9±10.9%, P=0.312). In the TVR group, however, it decreased significantly following surgery (from 51.8±9.2 to 42.4±12.3%, P<0.001). In addition, postoperative RVEF was lower in the TVR than TAP group, with a marginal significance (mean difference, –6.967; 95% confidence interval: –14.529 to 0.595; P=0.070).

Conclusions: For patients with severe functional TR, both TAP and TVR are beneficial for reduction of RV volume indices. TAP, however, might be superior to TVR, because RVEF is well preserved following surgery. (Circ J 2016; 80: 1142–1147)

Key Words: Cardiac magnetic resonance imaging; Right ventricle; Tricuspid valve
patients underwent TVR (the TVR group). Thirty-two patients (80.0%) had a history of previous cardiac surgery. There were no statistically significant differences in preoperative characteristics between the 2 groups, except for a higher proportion of worse New York Heart Association (NYHA) functional class in the TAP group than in the TVR group (Table 1).

### Surgical Procedures and Operative Data

The surgical techniques for TAP and TVR have been described previously. All operations were performed through a median

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**Table 1. Subject Preoperative Characteristics**

| Variables                        | Total (n=40) | TAP group (n=13) | TVR group (n=27) | P-value |
|----------------------------------|--------------|------------------|------------------|---------|
| Age (years)                      | 59.3±9.1     | 60.8±7.7         | 58.6±9.8         | 0.496   |
| M/F                              | 5/35         | 2/11             | 3/24             | >0.999  |
| Preoperative patient status      |              |                  |                  |         |
| Smoking                          | 1 (2.5)      | 1 (7.7)          | 0 (0)            | 0.325   |
| Diabetes mellitus                | 4 (10)       | 1 (7.7)          | 3 (11.1)         | >0.999  |
| Hypertension                     | 5 (12.5)     | 2 (15.4)         | 3 (11.1)         | >0.999  |
| History of stroke                | 5 (12.5)     | 1 (7.7)          | 4 (14.8)         | >0.999  |
| Dyslipidemia                     | 2 (5)        | 1 (7.7)          | 1 (3.7)          | >0.999  |
| Overweight (BMI >25 kg/m²)       | 2 (5)        | 1 (7.7)          | 1 (3.7)          | >0.999  |
| COPD                             | 3 (7.5)      | 1 (7.7)          | 2 (5)            | >0.999  |
| Chronic renal failure            | 1 (2.5)      | 1 (7.7)          | 0 (0)            | 0.325   |
| CAD                              | 2 (5)        | 1 (7.7)          | 1 (3.7)          | >0.999  |
| Atrial fibrillation              | 36 (90)      | 11 (84.6)        | 25 (92.6)        | 0.584   |
| NYHA class ≥3                    | 19 (47.5)    | 10 (76.9)        | 9 (33.3)         | 0.001   |
| Previous cardiac surgery ≥2      | 13 (32.5)    | 3 (23.0)         | 10 (37.0)        | 0.484   |
| Echocardiographic data           |              |                  |                  |         |
| LVEF (%)                         | 55.8±9.7     | 52.8±12.7        | 57.3±7.7         | 0.256   |
| SPAP (mmHg)                      | 41.6±12.1    | 42.3±16.6        | 41.1±9.5         | 0.713   |
| Right heart catheterization data |              |                  |                  |         |
| Right atrial pressure (mmHg)     | 13.7±5.8     | 13.0±5.2         | 14.2±6.3         | 0.577   |
| SPAP (mmHg)                      | 42.7±16.1    | 42.5±17.2        | 42.8±16.0        | 0.712   |
| MPAP (mmHg)                      | 28.1±10.8    | 27.2±11.1        | 28.8±10.9        | 0.755   |

Data given as mean±SD or n (%). BMI, body mass index; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; MPAP, mean pulmonary artery pressure; NYHA, New York Heart Association; SPAP, systolic pulmonary artery pressure; TAP, tricuspid annuloplasty; TVR, tricuspid valve replacement.
sternotomy under routine aorto-bicaval cannulation, moderate hypothermia, and cold cardioplegic arrest. Choice of TAP or TVR was at the discretion of the operating surgeons. Extent of tricuspid annular enlargement or RV dilatation was not considered as a contraindication for TAP. TAP was preferred in the early study period. During the latter study period, however, TVR was frequently performed due to a concern about risk of future reoperation for recurrent TR following TAP. In the TAP group, 10 patients underwent TAP using prosthetic rings and 3 patients underwent De Vega suture annuloplasty. In the TVR group, 8 patients underwent TVR using a mechanical valve and 19 patients underwent bioprosthetic TVR. During TVR, all TV leaflets were preserved, whenever possible. Concomitant arrhythmia surgery were performed in 8 patients. Left-sided valve procedure was performed in 8 patients. Mean cardiopulmonary bypass and aortic cross-clamp times were 177.4±53.7 and 93.8±29.2 min, respectively. There were no significant differences in operative data between the 2 groups (Table 2).

CMR CMR was performed before surgery and during the follow-up period (24.8±13.3 months after surgery). The protocols for CMR have been described previously.15 Briefly, CMR was carried out using a 1.5-T system (Sonata Magnetom, Siemens, Erlangen, Germany). Images were acquired using a phased-array body surface coil during breath-holding and were electrocardiogram-triggered. True fast imaging with steady-state free precession cine images (repetition time/echo time, 2.2/1.1 ms; flip angle, 80°; matrix, 256×169; field of view, 330×330 mm; slice thickness, 6 mm; slice gap, 4 mm; temporal resolution, 44 ms) were taken in 2-, 3-, and 4-chamber views of the heart. Short-axis cine images covering the entire ventricle were obtained for volumetric analysis. RV end-diastolic volume, RV end-systolic volume, and RV ejection fraction (RVEF) were measured using a software program (Siemens Medical Systems, Iselin, NJ, USA). RV end-diastolic volume index (RVEDVI) and RV end-systolic volume index (RVESVI) were calculated using body surface area.

Statistical Analysis Statistical analysis was performed using SAS version 9.2 (SAS Institute, Cary, NC, USA) and IBM SPSS statistic version 21.0 (IBM Inc, Armonk, NY). Data are expressed as mean±SD, median (range), or proportion. Comparisons between the 2 groups were carried out using chi-squared test or Fisher’s exact test for the categorical variables, and Student’s t-test or Mann-Whitney test for the continuous variables. The mixed models for repeated measures before and after operation were used to compare changes in the CMR variables (RVESVI, RVEDVI, and RVEF) between the 2 groups. Because the NYHA functional class was significantly different between the 2 groups, this variable was included in the mixed-model analyses; fixed effects in all models were type of operation, time of CMR, interaction between type of operation and time of CMR, and functional class, while study subjects were treated as random effects. Normality assumption of model residuals was checked on histograms and normal quantile-quantile plots of residuals.

| Table 2. Operative Data and Echocardiographic Results |
|------------------------------------------------------|
| Variables                                             | Total (n=40) | TAP group (n=13) | TVR group (n=27) | P-value |
| Operative data                                        |             |                 |                  |        |
| CPB time (min)                                       | 177.4±53.7  | 170.7±60.6      | 180.7±51.0       | 0.589   |
| ACC time (min)                                       | 100.9±34.0  | 93.9±23.6       | 103.2±36.7       | 0.998   |
| Concomitant arrhythmia surgery                        | 8 (20)      | 3 (23.1)        | 5 (18.5)         | <0.009  |
| Concomitant left-side valve procedure                 | 8 (20)      | 4 (30.8)        | 4 (14.8)         | 0.340   |
| Echocardiographic results                             |             |                 |                  |        |
| LVEF (%)                                              | 56.7±10.6   | 55.5±10.0       | 57.2±11.0        | 0.644   |
| SPAP (mmHg)                                          | 40.6±8.4    | 41.1±9.4        | 40.2±7.8         | 0.805   |
| Residual tricuspid regurgitation                      |             |                 |                  |        |
| None                                                  | 18 (45.0)   | 1 (7.7)         | 17 (63.0)        |        |
| Trivial                                               | 10 (25.0)   | 3 (23.1)        | 7 (25.9)†        |        |
| Mild                                                  | 12 (30.0)   | 9 (69.2)        | 3 (11.1)†        |        |

| Table 3. Mixed-Effect Regression Model of Change in RVEDVI |
|-----------------------------------------------------------|
| Variables                                                 | Mean difference in RVEDVI | 95% CI         | P-value |
| Type of surgery (reference: TAP)                          |                         |                |        |
| TVR                                                       | 2.582                    | −22.819 to 27.982 | 0.838 |
| Time (reference: before operation)                        |                         |                |        |
| After operation                                           | −62.568                  | −79.439 to −45.696 | <0.001 |
| NYHA class (reference: NYHA <3)                           |                         |                |        |
| NYHA ≥3                                                   | 9.187                    | −14.637 to 33.011 | 0.440 |

Data given as mean±SD or n (%). †Physiologic regurgitation across the prosthesis. ACC, aortic cross-clamp; CPB, cardiopulmonary bypass. Other abbreviations as in Table 1.
RV Volume and Function After TV Surgery

RV Volume and Function After TV Surgery

56.9 ml/m² to 111.9 ± 24.7 ml/m² in the TAP group, and from 175.8 ± 53.2 ml/m² to 118.4 ± 27.9 ml/m² in the TVR group). On mixed-effect modeling there was no statistically significant difference in improvement of RVEDVI between the TAP and TVR groups (mean difference, 2.582; 95% CI: −22.819 to 27.982; P = 0.838; Table 3; Figure 2A).

RVESVI also significantly improved from 95.7 ± 36.1 ml/m² to 67.3 ± 28.0 ml/m² after TV operation (P < 0.001; from 106.3 ± 44.6 ml/m² to 61.5 ± 26.1 ml/m² in the TAP group, and from 90.6 ± 31.0 ml/m² to 70.1 ± 28.9 ml/m² in the TVR group). On mixed-effect regression modeling, there was no statistically significant difference in change of RVESVI between the 2 groups (mean difference, 1.560; 95% CI: −17.022 to 20.141; P = 0.866; Table 4; Figure 2B).

Change in RV Function

Because there was a statistically significant interaction between type of surgery and time of CMR (P = 0.005), it was included in the mixed-effect model for RVEF analysis. Results of mixed effects model were as follows. First, in the TAP group, RVEF was preserved postoperatively (from 43.3 ± 9.5% to 47.0 ± 10.9%,
function following surgery.

Previous studies have demonstrated favorable results after TAP,\textsuperscript{16–18} and others showed better clinical outcomes after TAP such as overall survival and freedom from cardiac death compared with TVR.\textsuperscript{4,6,19} Controversial data, however, also exist: on comparison of TAP and TVR using propensity score-matching analysis, there were no significant differences in either operative mortality or long-term survival between the 2 groups.\textsuperscript{8} Another study also showed that long-term survival following TV surgery in patients with severe TR was not affected by the type of procedure on propensity score-adjusted multivariate analysis.\textsuperscript{20} The present study was inspired by our previous study, which found inferior results for TVR compared with TAP.\textsuperscript{6} In that study, we demonstrated, using propensity score models, that TVR was associated with a higher rate of long-term cardiac death compared with TAP in patients with severe functional TR. In the present study we evaluated changes in RV volume and function using CMR, which has been accepted as the gold standard for evaluating both RV structure and function, because echocardiography is limited in its ability to evaluate RV volume and function due to the complex shape and retrosternal position of the RV.\textsuperscript{21,22} To the best of our knowledge, the present study is the first to compare the changes in RV volume and function following TAP with those following TVR using CMR. In the present study both TAP and TVR were effective for reduction of RV volumes in patients with severe functional TR, but there were differences in RVEF change after surgery between the 2 groups. On mixed-effect regression modeling, RVEF was preserved in the TAP group, but decreased significantly in the TVR group. In addition, postoperative RVEF was higher in the TAP than TVR group with a marginal significance. The impact of decreased RVEF on clinical outcome has been well demonstrated in other clinical settings.\textsuperscript{23,24} Similarly, preserved RVEF could be a reason why patients who undergo TAP have better clinical outcome compared with TVR, as demonstrated in our previous study.\textsuperscript{6} It is possible that the characteristics of TVR patients differ from TAP patients, such as with regard to extent of right heart dilatation or presence of TV leaflet pathology. At the present institution, TAP was preferred in the early study period. As mentioned previously, extent of tricuspid annular enlargement or RV dilatation was not considered as a contraindication of TAP; preoperative RVEDVI and RVESVI were even larger in the TAP group than in the TVR group. But, due to a concern

\begin{table}
\centering
\begin{tabular}{|l|c|c|c|}
\hline
Variable & Mean difference in RVEF & 95% CI & P-value$^\dagger$ \\
\hline
Type of operation (reference: TAP) & & & \\
TVR & Before & 6.144 & −1.418 to 13.706 & 0.108 \\
& After & −6.967 & −14.529 to 0.595 & 0.070 \\
Time (reference: before operation) & & & \\
& After operation & & \\
& TAP & 3.677 & −3.7397 to 11.0935 & 0.312 \\
& TVR & −9.434 & −14.474 to −4.394 & <0.001 \\
NYHA class (reference: NYHA <3) & & & \\
& NYHA ≥3 & −5.526 & −11.281 to 0.228 & 0.059 \\
\hline
\end{tabular}
\caption{Mixed-Effect Regression Model of Changes in RVEF}
\end{table}

$^\dagger$Adjusted for interaction between the type of surgery and CMR time because this interaction was significant (P=0.005). CMR, cardiac magnetic resonance imaging; RVEF, right ventricular ejection fraction. Other abbreviations as in Table 1.

In contrast, in the TVR group, RVEF significantly decreased from 51.8±9.2% to 42.4±12.3% after TVR (P<0.001). Second, there was no statistically significant difference in preoperative RVEF in the TVR group when compared with the TAP group (mean difference, 6.144; 95% CI: −1.418 to 13.706; P=0.108). RVEF, however, was lower after surgery in the TVR than in the TAP group, with a marginal significance (mean difference, −6.967; 95% CI: −14.529 to 0.595; P=0.070; Table 5; Figure 3).

\section*{Discussion}

This study had 2 main findings. First, in patients with severe functional TR, RV volume improved significantly after TR correction, regardless of type of TV surgery. Second, TAP is beneficial compared with TVR in terms of preservation of RV function following surgery.

Figure 3. Changes in right ventricular ejection fraction (RVEF) following tricuspid annuloplasty (TAP) and tricuspid valve replacement (TVR). RVEF was preserved in the TAP group but was significantly decreased in the TVR group (P<0.001). Central box, lower-upper quartile; middle line, median; whiskeys, minimum and maximum values).
about risk of future reoperation after failed TAP, TVR was used even in patients with functional TR in the latter study period.

In the present study, several efforts were made to minimize selection bias: (1) we included only patients with functional TR without any evidence of organic pathology; (2) we excluded 2 patients who had more than mild TR after TAP, because TVR patients have a higher chance of afterload mismatch than TAP patients if there is significant residual TR after TAP, and it could lead to overestimation of postoperative RVEF in the TAP group; and (3) we compared all preoperative characteristics and hemodynamic data between the groups, and NYHA functional class was included in the mixed models, because it was significantly different between the TAP and TVR groups. Other hemodynamic data such as LVEF, pulmonary artery pressure and right atrial pressure, however, were not entered into the models because these were not significantly different between the 2 groups.

After minimization of selection bias, TAP was still shown to be superior to TVR. In addition, postoperative outcomes that could affect RVEF such as postoperative LVEF, pulmonary artery pressure and presence of AF were also similar between the 2 groups. The insertion of a large and rigid prosthetic object into a deformable and low-pressure chamber may be an obstacle to remodeling of the right heart chambers and cause progressive RV dysfunction, as suggested in the previous studies.4-5

In conclusion, for patients with severe functional TR, both TVR and TAP are beneficial for reduction of RV volume indices. TAP, however, might be superior to TVR, because RVEF is well preserved after surgery.

Study Limitations
The present study had several limitations that must be noted. First, it was a retrospective, observational study conducted at a single institution. Second, not all of the patients who underwent TV surgery were enrolled in the study. Third, the number of patients enrolled was relatively small with regard to statistical analysis and the drawing of definite conclusions.

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Disclosures
None.

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