Alternation of Right Ventricular Contraction Pattern in Healthy Children
– Shift From Radial to Longitudinal Direction at Approximately 15 mm of Tricuspid Annular Plane Systolic Excursion –
Ikuo Hashimoto, MD; Kazuhiro Watanabe, MD

Background: Many studies have investigated tricuspid annular plane systolic excursion (TAPSE) as a longitudinal right ventricular (RV) contraction. The aim of this study was to clarify the mechanism of RV systolic function compared with longitudinal and radial RV contractions in healthy children.

Methods and Results: A total of 815 consecutive healthy children and adolescents were enrolled. We measured TAPSE on M-mode echocardiography as a longitudinal RV contraction. RV wall displacement (RVWD) toward the center of the left ventricle (LV) was measured in the short-axis view on M-mode echocardiography. RV stroke volume (RVSV) was obtained using pulse Doppler echocardiography as an indicator of RV global systolic function. RVSV and TAPSE had a positive but non-linear correlation with a definite inflection point around 15 mm of TAPSE. Subjects were stratified into 2 groups according to TAPSE (≤15 mm or >15 mm). In subjects with TAPSE ≤15 mm, RVWD and TAPSE were identified as independent predictors of RVSV. In contrast, in subjects with TAPSE >15 mm, TAPSE were identified as an independent predictor of RVSV.

Conclusions: Normal RV contraction pattern shifts from radial to longitudinal directions at approximately 15 mm of TAPSE. RVSV is primarily generated by longitudinal contraction, but in neonates, RVSV is supported not only by longitudinal contraction but also by radial contraction. (Circ J 2014; 78: 1967–1973)

Key Words: Echocardiography; Myocardial contraction; Pediatrics

Although many studies involving right ventricular (RV) function have been reported, the complex geometry of the RV precludes the understanding of its function. Many studies have shown that tricuspid annular plane systolic excursion (TAPSE) – represented as a longitudinal RV contraction – is important for evaluating RV systolic function. The role of radial RV contraction, however, has not been well documented. Pettersen et al reported that a longitudinal RV contraction was predominant under normal conditions, but that circumferential RV contraction was predominant in response to increased afterload. The RV contraction pattern is therefore expected to change in response to the changing RV hemodynamics, particularly in the neonatal period because RV hemodynamics undergoes great change during this period.

The aim of this study was to elucidate the mechanism underlying RV systolic function compared with that of longitudinal and radial RV contraction in healthy neonates and children.

Methods

Subjects
We examined 815 consecutive children and adolescents without heart disease, ranging from newborns to 22.2 years of age (mean age, 4.4±4.0 years). All subjects who were referred for heart murmur, chest pain, or those with a history of Kawasaki disease underwent complete physical examination, electrocardiogram, and routine echocardiography. Exclusion criteria in this study were as follows: (1) irregular heart rhythm; (2) intraventricular conduction disturbance such as complete or incomplete right bundle branch block; (3) coronary arterial involvement in patients with a history of Kawasaki disease; (4) pulmonary stenosis with peak-flow velocity >2.0 m/s; (5) moderate-severe pulmonary or tricuspid regurgitation; or (6) history of open-heart surgery. Patients with a history of Kawasaki disease who were within 6 months after onset of disease were also excluded from this study even if they did not have any cardiac involvement because we were concerned about pro-
tion to TAPSE, mitral annular systolic excursion (MAPSE) was
together. Radial RV Wall Displacement (RVWD) as Radial RV
contraction was measured in the same short-axis view as the LV
at the papillary muscle level, using the M-mode. RVWD is the
RV anterior wall (RVAW) displacement toward the center of
the LV and is in the orthogonal direction of TAPSE. We set
the M-mode scan line on the center of the LV avoiding the RV
outflow tract. We measured RVWD as the distance between
the peak and the bottom of the M-mode tracing curve of RVAW,
averaging at least 4–5 consecutive beats (Figure 1B). The
ratio of radial to longitudinal RV contractions was calculated
as RVWD/TAPSE.

RV/LV Diameter Ratio
The ratio of RV/LV diameter was measured for evaluating RV
size among children with various body sizes (Figure 1B).5,6

Standard RV Performance and Pulmonary Vascular Resistance
We used RV stroke volume (RVSV) as a geometry-independent indicator of RV performance. RVSV was determined as the

General Echocardiography and TAPSE
We used EUB-6000 (Hitachi Medical, Tokyo, Japan) for echocardiography with a 7–3-MHz or 4–2-MHz phased array sec-
tor probe. All subjects underwent echocardiography in the su-
pine position. If subjects were uncooperative, sedation was
provided as oral 10% triclofos sodium syrup. After obtaining
routine echocardiographic data, we measured TAPSE as a lon-
gitudinal RV contraction.5

We used M-mode scanning to measure tricuspid lateral an-
nulus through several cycles (Figure 1A). TAPSE was mea-
sured as the distance between the peak and the bottom of the M-mode tracing curve, and at least 4–5 consecutive beats were
averaged. To investigate the influence of LV longitudinal mo-

tion to TAPSE, mitral annular systolic excursion (MAPSE) was
measured.

Radial RV Wall Displacement (RVWD) as Radial RV
Contraction
RVWD was measured in the same short-axis view as the LV
at the papillary muscle level, using the M-mode. RVWD is the
RV anterior wall (RVAW) displacement toward the center of
the LV and is in the orthogonal direction of TAPSE. We set
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RV/LV Diameter Ratio
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size among children with various body sizes (Figure 1B).5,6

Standard RV Performance and Pulmonary Vascular Resistance
We used RV stroke volume (RVSV) as a geometry-independent indicator of RV performance. RVSV was determined as the
In all subjects, body length and body weight were measured and body surface area (BSA) was calculated using the Haycock formula.

**Statistical Analysis**

Statistical analysis was done using Stat View 5.01 (SAS Institute, Cary, NC, USA). All data are expressed as mean ± SD. Linear regression was used to evaluate the correlation between RVSV and TAPSE or BSA. A change point regression analysis was used to identify the optimal splitting point of the linear regression line. Analysis of covariance was used to compare 2 re-
tion with a definite inflection point at approximately 15 mm of TAPSE (arrow; Figure 3B). On change point regression analysis the optimal TAPSE splitting point was 14.5 mm for right- and left-side linear correlations. There was a linear relationship between RVSV and TAPSE $\leq 14.5$ mm $(RVSV=1.12 \times TAPSE–2.06, r=0.63, P<0.0001)$. And there was also a linear relationship between RVSV and TAPSE $>14.5$ mm $(RVSV=3.08 \times TAPSE–30.51, r=0.73, P<0.0001)$. The slopes of these regression lines were significantly different $(P<0.001)$. Subjects were stratified into 2 groups according to TAPSE ($\leq15.0$ mm or $>15.0$ mm). Fifteen millimeters of TAPSE corresponded to approximately 4 months of age regression slopes. To study the strongest predictors for RVSV, variables such as TAPSE, MAPSE, RV/LV ratio and PA Act/ET were examined using multiple regression analysis. $P<0.05$ was considered significant.

**Results**

There was no gender difference of TAPSE (male, 19.1±4.2 mm; female, 19.0±4.6 mm). RVSV ranged from 4.4 to 136.6 ml (mean, 29.3±14.6 ml) and had a strong linear relationship with BSA $(RVSV=39.8\times BSA+2.6, r=0.89, P<0.0001; Figure 3A)$. In contrast, RVSV and TAPSE had a non-linear correla-

**Table. Multivariate Predictors of RVSV**

<table>
<thead>
<tr>
<th>Variables</th>
<th>$\leq15$ mm</th>
<th>$&gt;15$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta$</td>
<td>P-value</td>
</tr>
<tr>
<td>TAPSE (mm)</td>
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<tr>
<td>MAPSE (mm)</td>
<td>0.125</td>
<td>0.334</td>
</tr>
<tr>
<td>RVWD (mm)</td>
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<td>&lt;0.05</td>
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<tr>
<td>RV/LV</td>
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<td>0.405</td>
</tr>
<tr>
<td>PA Act/ET</td>
<td>0.045</td>
<td>0.588</td>
</tr>
</tbody>
</table>

AcT, acceleration time; ET, ejection time; LV, left ventricle; MAPSE, mitral annular plane systolic excursion; PA, pulmonary artery; RV, right ventricle; RVSV, right ventricular stroke volume; RVWD, right ventricular wall displacement; TAPSE, tricuspid annular plane systolic excursion.

Figure 4. Age-dependent change of (A) TAPSE, (B) RVWD and (C) RVWD/TAPSE. RVWD, right ventricular wall displacement toward the center of the left ventricle; TAPSE, tricuspid annular plane systolic excursion.
Multivariate analysis identified predominant predictors for RVSV in subjects with TAPSE ≤15.0 mm and subjects with TAPSE >15.0 mm, respectively (Table). In subjects with TAPSE ≤15.0 mm, RVWD and TAPSE were identified as independent predictors of RVSV. In contrast, the influence of RVWD on RVSV became smaller and TAPSE predominated in subjects with TAPSE >15.0 mm. Figure 4 shows age-dependent change of TAPSE, RVWD and RVWD/TAPSE. TAPSE increased rapidly after birth until approximately 4 months of age, and after that increased slowly and linearly with age (Figure 4A). RVWD remained constant, between 0 and 8 mm, independent of aging (Figure 4B). RVWD/TAPSE was high at birth and showed a rapid decrease until approximately 4 months of age. After that, RVWD/TAPSE remained constant, between 0 and 0.5, independent of aging (Figure 4C).

Figure 5A shows the relationship between RVWD and TAPSE. RVWD ranged from 3.35 to 11.6 mm in subjects with TAPSE ≤15.0 mm (5.56±1.3 mm) and from 0.15 to 11.8 mm in subjects with TAPSE >15.0 mm (4.40±1.79 mm). There was a significant mean difference of RVWD between them (P<0.0001). The RVWD/TAPSE ratio was inversely related to TAPSE (Figure 5B). The predominance of radial RV contraction in small TAPSE shifts to predominance of longitudinal RV contraction with increasing TAPSE.

**Interobserver Variability in TAPSE and RVWD**

Interobserver variability was tested for TAPSE and RVWD on 10 random patients between the first observer (I.H.) and second observer (K.W.). The mean interobserver difference was 0.67±2.7 mm for TAPSE and 0.39±1.6 mm for RVWD. There was no significant difference in TAPSE and RVWD between 2 observers.

**Discussion**

Kawut et al recently reported that RV volume and hypertrophy are associated with the risk of heart failure and cardiovascular death. Although evaluating RV function and structure is important, the complex geometry of RV precludes accurate analysis. Three-dimensional analysis using magnetic resonance imaging (MRI) is geometry independent and has been regarded as the gold standard for RV studies. Echocardiography is not as accurate as MRI, but gives us a real-time image for diagnosis with a high frame rate and is, furthermore, applicable at the bedside. Among many parameters for assessing RV function, such as TAPSE, RV ejection fraction (RVEF), and myocardial performance index, TAPSE proved to be the most reliable and reproducible index. Although some investigators have reported that TAPSE significantly correlates with RVEF and contributes to approximately 80% of RV output, others have reported that TAPSE was affected by LV function and also by pulmonary condition – resulting in a lower correlation with RVEF. We therefore hypothesized that RVSV was generated by longitudinal and radial RV contraction with changes of myocardial fiber structure and contraction pattern.

Despite the strong linear correlation of RVSV with BSA, RVSV did not linearly correlate with increasing TAPSE. A
Conclusions

Normal RV contraction pattern shifts from radial to longitudinal directions at approximately 15 mm of TAPSE, which corresponds to approximately 4 months of age. RVSV is primarily generated by longitudinal contraction, but, in neonates, RVSV is supported not only by longitudinal but also by radial contraction.

Acknowledgments

No conflicts of interest to disclose.

References

RV Contraction Pattern in Healthy Children


