Relationship Between Tricuspid Annular Excursion and Velocity in Cardiac Surgical Patients

Raymond Hu, MBBS, FANZCA, C. David Mazer, MD, FRCPC, and Claude Tousignant, MD, FRCPC

Objectives: The primary objective of this study was to establish the relationship among tricuspid annular velocity (S'), tricuspid annular plane systolic excursion (TAPSE), and stroke volume (SV) in a cardiac surgical population with and without right ventricular (RV) dysfunction. The secondary objective was to assess the effect of ephedrine on these relationships in a population without RV dysfunction.

Design: Prospective, nonrandomized, unblinded study.

Setting: Single tertiary-level, university-affiliated hospital.

Participants: Twenty-seven patients undergoing elective coronary artery bypass grafting with no evidence of RV dysfunction (Group 1). Sixteen ventilated postcardiac surgical patients with suspected RV dysfunction (Group 2).

Interventions: Ten mg of intravenous ephedrine to Group 1 only.

Measurements and Main Results: Using transthoracic echocardiography, S' and TAPSE were measured using color tissue Doppler applied at the RV base in a 4-chamber view. SV was calculated using thermodilution. Six patients in Group 1 and 6 patients in Group 2 were excluded because of poor imaging or ineligibility.

The goal of this study was to assess the relationship among TAPSE, S', and SV using TTE and color-tissue Doppler imaging in elective cardiac surgical patients under general anesthesia before and after the administration of ephedrine, a weak inotrope. This relationship also was examined in a critically ill postoperative cardiac surgical population with RV dysfunction and elevated pulmonary artery pressures (PAP) who required inotropic support.

METHODS

The study protocol was approved by the St. Michael’s Hospital Research Ethics Board. There were 2 groups of patients. In Group 1, eligible patients undergoing elective coronary artery bypass graft surgery (CABG) were approached preoperatively, and a signed, informed consent was obtained before conducting any study-related procedures. Patients were excluded if they were not in sinus rhythm, if the LVEF by preoperative echocardiography was less than 45%, and if there was evidence of RV dysfunction or more than mild tricuspid regurgitation (TR). Each patient had an ECG and invasive monitoring, including indwelling radial arterial and pulmonary artery catheters (7.5-French PavePort, Edwards Lifesciences, Irvine, CA) as part of clinical routine. Approximately 15 minutes after the induction of anesthesia (sufentanil, midazolam, and rocuronium), a TTE was performed with the patient supine and tilted slightly to the left (GE Vivid 7 system, Milwaukee, WI). Echocardiography measurements were made simultaneously with hemodynamic measurements before and after the administration of ephedrine, 10 mg IV. No inhalation agents were used during the study period.

CONCLUSIONS

The comparison of S' and SV appears to be a more load-insensitive marker of RV function. The correlation between S' and SV has been variable. In the RV, IVA has become a popular surrogate marker for global RV systolic function because of its ease of application and good implications, especially in the presence of left ventricular (LV) dysfunction. Tricuspid annular plane systolic excursion (TAPSE) has become a popular surrogate marker for global RV systolic function because of its ease of application and good correlation with RV stroke volume (SV) in cardiac patients undergoing catheterization or surgery. It is measured using an M-mode technique.

Tissue-Doppler imaging allows for enhanced measurements of RV myocardial performance in the perioperative setting. Most studies have examined TAPSE, S', and IVA using transthoracic echocardiography (TTE) at the lateral wall of the RV. Good tissue Doppler alignment using transesophageal echocardiography (TEE) is only possible in the transgastric RV inflow–outflow view. However, there is no correlation between TAPSE and SV using this method. Using TTE, on the other hand, Uhrheim et al found a good correlation between TAPSE and SV. Furthermore, TAPSE could track SV changes associated with epoprostenol infusions. TTE, thus, appears to be the preferred modality to assess RV function by TAPSE, S', and IVA.

Both TAPSE and S' are influenced by loading conditions. Although knowledge of loading conditions remains important, the combination of TAPSE and annular velocity (S') may offer simultaneous insights into RV work and rate of work. Additionally, their relationship in each patient may prove superior to either one alone.

From the Department of Anaesthesia, St Michael’s Hospital, University of Toronto, Toronto, Ontario, Canada.

Address reprint requests to Claude Tousignant, MD, Department of Anaesthesia, St Michael’s Hospital, 30 Bond Street, Toronto, ON M5B 1W8, Canada. E-mail: tousignantc@smh.ca

© 2014 Elsevier Inc. All rights reserved.

KEY WORDS: right ventricular function, color-tissue Doppler, TAPSE, tricuspid annular velocity
Group 2 patients (with suspected RV dysfunction) were identified by the attending physician in the intensive care unit. They were included if the mPAP was above 25 mmHg and if they required inotropic support. They were excluded if the TAPSE on initial TTE examination was normal (>1.6 cm) or if there was more than mild TR. Written informed consent for the study was obtained from the next of kin. A TTE examination and hemodynamic measurements were performed simultaneously.

The following peak hemodynamic measurements were recorded in all groups: Heart rate (HR), mean arterial blood pressure (SBPm), and mean pulmonary artery pressure (PAPm). Cardiac output (CO) measurements were done using thermodilution and recorded as the average of 3 consecutive measurements from 10 mL saline boluses at room temperature. SV was calculated by dividing the CO by the HR and expressed in mL.

Using a GE Vivid 7 system (GE, Milwaukee, WI) with a phased array M4S or M3S TTE probe using harmonics, a 4-chamber view was obtained in which the RV annular motion was aligned with the Doppler plane. A color-tissue Doppler sector was applied to the RV annulus and basal segment, ensuring that the annulus remained within the sector throughout the cardiac cycle. The 2D sector was narrowed to optimize the tissue Doppler frame rate (>200 fps). Five consecutive beats were recorded digitally for offline analysis. Image acquisition was performed simultaneously with hemodynamic measurements.

Using Quantitative Analysis software (GE, Milwaukee, WI) a 6 × 6 mm sample volume was applied to the color-tissue Doppler sector at the basal segment of the RV as close to the annulus as possible. The sample volume was placed such that the highest possible velocity was ensured and that the sample volume remained within the myocardium at the base. The peak systolic velocity at the tricuspid annulus (S') was determined. Tissue tracking then was used to measure displacement (TAPSE). The average of 3 consecutive values was used.

The sample size was a convenience sample based on previous studies. All values were expressed as mean ± standard deviation (SD). Changes in hemodynamic and echocardiographic parameters were expressed as mean ± 95% confidence interval (CI). A paired Student's t-test was used to assess pre- and postephedrine values for echocardiographic and hemodynamic variables. An unpaired t test was used to assess between-group variables. A p value < 0.05 was considered significant. The relationship between TAPSE and SV as well as S' and SV was assessed using linear regression. The relationship between TAPSE and annular velocity (S') was examined using second order polynomial regression, because it was clear from examining the data that it would not fit a straight line. To examine the changes as a result of the administration of ephedrine, the TAPSE-S' relationship was log-transformed for TAPSE and linear regression was performed.

RESULTS

Twenty-seven patients were recruited in Group 1 (CABG patients), and 16 patients were recruited in Group 2 (critically ill patients). Six patients were excluded in Group 1: 3 due to poor images and 3 due to poor LV function (EF < 45%). Six patients were excluded in Group 2 due to poor imaging. The demographic characteristics for each group are presented in Table 1.

Patients in Group 2 were receiving various combinations of norepinephrine, vasopressin, dobutamine, and milrinone. There was a significant difference in HR and PAPm between Group 2 and the pre-ephedrine values in Group 1 (Table 2). There was no significant difference in SBPm and SV. The echocardiographic parameters TAPSE, IVA, and S' were significantly lower in Group 2 compared with Group 1 pre-ephedrine values (Table 3).

A modest correlation between TAPSE and SV was seen in Group 1 when all data were combined (R = 0.50, p < 0.001) (Fig 1A). There was no correlation between TAPSE and SV in Group 2 (R = 0.30, p = 0.39) (Fig 1A).

There was no significant relationship between S' and SV in Group 1 (R = 0.28, p = 0.08) or in Group 2 (R = 0.16, p = 0.66).

Ephedrine administration resulted in significant increases in all hemodynamic variables (Table 2). There were significant increases in S' and TAPSE as a result of ephedrine administration (Table 3, Fig 1B). However, ephedrine did not result in any appreciable rise in IVA; the 95% CI was larger than the mean IVA change (Table 3).

The relationship between TAPSE and S' for Group 1 described a curvilinear relationship, in which TAPSE increased along with S’ to a point at which no further appreciable increase in TAPSE was observed despite further increases in S' (Fig 2). Using second order polynomial regression, a good correlation was found in Group1, pre-ephedrine (R = 0.74, p < 0.001), and Group1, postephedrine (R = 0.64, p = 0.009) (Fig 2). In Group 2, increases in S' were not statistically significantly associated with any appreciable increase in TAPSE (Fig 2).

The postephedrine TAPSE versus S' relationship curve appeared shifted up when compared with the pre-ephedrine curve (Fig 2). Using linear regression of a log transformation of TAPSE vs S', a good correlation was found in both the pre- and postephedrine groups (R = 0.68, p < 0.001 and R = 0.55, p = 0.01, respectively). There was, however, significant

### Table 1. Demographic Data

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1 (CABG)</th>
<th>Group 2 (Critically Ill)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>64 ± 9</td>
<td>67 ± 12</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>20/1</td>
<td>5/5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173 ± 8.4</td>
<td>166 ± 13</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>89 ± 22</td>
<td>78 ± 20</td>
</tr>
</tbody>
</table>

NOTE. Values are expressed as means ± SD.

Abbreviations: CABG, coronary artery bypass graft surgery; F, female; M, male.

### Table 2. Hemodynamic Changes in Group 1 and Group 2

<table>
<thead>
<tr>
<th></th>
<th>Pre-ephedrine</th>
<th>Postephedrine</th>
<th>Change (±95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>58 ± 9</td>
<td>64 ± 11</td>
<td>6 ± 3</td>
</tr>
<tr>
<td>SBPm (mmHg)</td>
<td>78 ± 13</td>
<td>95 ± 14</td>
<td>17 ± 5</td>
</tr>
<tr>
<td>PAPm (mmHg)</td>
<td>20 ± 6</td>
<td>23 ± 3</td>
<td>4 ± 2</td>
</tr>
<tr>
<td>SV (mL)</td>
<td>75 ± 18</td>
<td>85 ± 21</td>
<td>10 ± 5</td>
</tr>
</tbody>
</table>

NOTE. Values are expressed as means ± SD. The changes in Group 1 are expressed as mean ± 95% CI.

Abbreviations: CI, confidence interval; HR, heart rate; bpm, beats per minute; PAPm, mean pulmonary artery pressure; SBPm, mean arterial blood pressure; SV, stroke volume.

*Denotes p < 0.001 compared with pre-ephedrine values.
†Denotes p < 0.001 compared with Group 1 pre-ephedrine values.
overlap of the 95% CI for both regression curves. Furthermore, the y intercepts (at $S' = 0$ cm/sec) were not significantly different between the pre- (1.04 mm, 95% CI [0.89, 1.19]) and postephedrine (1.18 mm, 95% CI [1.03, 1.33]) values.

### DISCUSSION

A reduced TAPSE has been associated with poor RV function and has been shown to predict depressed SV and RVFAC. Values less than 16 mm are considered abnormal. Normal values for $S'$ depend on the methodology. Using spectral pulsed-wave tissue Doppler, values less than 10 cm/sec are considered abnormal. Using color-tissue Doppler imaging, the reported normal values range from 8.3 cm/sec to 10.0 cm/sec. A depressed $S'$ has been shown to reveal RV dysfunction in a range of situations, similar to the differences seen between these 2 groups. Normal values for IVA using TTE in an anesthetized cardiac surgical population have been reported as 1.81 m/sec². The present study of elective cardiac surgical patients confirmed a modest correlation that has been found previously between TAPSE and SV. Similar to other studies, no significant relationship between $S'$ and SV was found. TAPSE may be more robust, because it correlates with geometric changes in RV size or length associated with the volume of blood that is moved during systole. On the other hand, the lack of a relationship between TAPSE and SV in the critically ill population shows that when TAPSE is indicative of depressed RV function, it does not necessarily mean depressed output performance. Other conformational changes may be responsible for the ejection volume. In an animal study, Leather et al found that RV longitudinal function correlated best with RV preload-recruitable stroke work. However, numerous studies suggested that in the abnormal RV (eg, congenital heart disease), longitudinal function may not fully represent global function; circumferential fibers and transverse motion appear to become more important.

The RV may be divided into 3 components: Inlet (sinus), apical trabecular, and outlet. The RV muscle fibers are predominantly longitudinal; however, circumferential fibers are found in the subepicardial layers. TAPSE is representative of the sum of the longitudinal function of the lateral wall that includes the inlet and apex. The function of the RV has been compared with that of a bellows, and the short-axis motion of the mid-RV wall likely contributes a significant portion of ejected RV volume. This may represent the function of the outlet, because it has been found to contribute up to 20% of the ejected volume. Septal and LV systolic function also are

### Table 3. Tissue Doppler Parameters for Group 1 and Group 2

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Post-ephedrine</th>
<th>Change (±95% CI)</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVA (m/sec²)</td>
<td>2.18 ± 0.80</td>
<td>2.45 ± 0.97</td>
<td>0.27 ± 0.38</td>
<td>0.95 ± 0.47</td>
</tr>
<tr>
<td>$S'$ (cm/sec)</td>
<td>9.59 ± 2.3</td>
<td>11.15 ± 2.3</td>
<td>1.55 ± 0.71</td>
<td>5.00 ± 1.42</td>
</tr>
<tr>
<td>TAPSE (mm)</td>
<td>19.18</td>
<td>22.32</td>
<td>3.14 ± 1.2</td>
<td>6.68 ± 1.43</td>
</tr>
</tbody>
</table>

NOTE. Values are expressed as mean ± SD. The changes in Group 1 are expressed as mean ± 95% confidence interval.

Abbreviations: CI, confidence interval; IVA, isovolumic acceleration; $S'$, peak systolic velocity at the tricuspid annulus; TAPSE, tricuspid annular plane systolic excursion.

*Denotes $p < 0.001$ compared with pre-ephedrine values.
†Denotes $p < 0.001$ compared with Group 1 pre-ephedrine values.

The relationship between TAPSE and $S'$ and corresponding second order polynomial regressions for Group 1 pre-ephedrine (empty circles, dotted line, $R = 0.50$, $p < 0.001$); Group 1 post-ephedrine (dark circles, solid line, $R = 0.64$, $p = 0.009$); and Group 2 (empty triangles, dashed line, $R = 0.74$, $p = 0.06$).
important contributors to RV function.\textsuperscript{29-31} The investigation of all these components (including tissue Doppler-derived values) should be undertaken in a complete assessment of RV function, especially in patients with abnormal function or loading conditions.

In a cardiac surgical population with normal RV function, the relationship between TAPSE and annular velocity (S') describes a concurrent rise in both values until a point is reached beyond which only minimal increases in TAPSE are observed. At this point, only efficiencies in annular velocity (S') are observed. This curve may provide useful information on the relationship between surrogates for work (TAPSE) and rate of work (S') and, by extension, power.\textsuperscript{10,11} Some patients may show a depressed TAPSE in response to abnormal loading conditions and disease. An associated depressed rate of annular descent (S') may reflect inadequate inotropic compensation in addition to a move away from optimal loading conditions.\textsuperscript{11} Knowing how this conceptual “work-rate” relationship changes and defining maximum values may be helpful in assessing the status of the RV and predicting how it will cope with further stress.

In the critically ill patients, TAPSE and S' were reduced significantly, and there was no relationship between TAPSE and S' (Fig 2). Patients with a depressed and fixed TAPSE due to various constraints, such as pulmonary hypertension or systolic dysfunction, may achieve efficiencies only through increases in rate of excursion (Fig 2). This may occur as a result of increased inotropic stimulation.\textsuperscript{10} In the Group 2 population, the use of inotropic drugs did not restore either the TAPSE or the S' velocity to normal values. This suggested both significant constraints and significantly depressed systolic function.

Induction of anesthesia frequently results in a decrease in sympathetic tone. In addition, the frequent use of β-blockers in cardiac patients results in a slower heart rate and a depressed inotropic state. These factors may contribute to an apparent depression of RV function when examined under echocardiography. Ephedrine, a weak inotrope, may help determine whether the depressed RV under anesthesia is recruitable or depressed. The authors previously have found that measurements of TAPSE using M mode and Speckle tracking with TEE could not reliably reflect changes following ephedrine administration.\textsuperscript{4} This is contrary to what was found in the present study at the lateral wall using TTE. Using color-tissue Doppler, Curren et al found that RV basal S' increased significantly from 8.3 ± 2.1 cm/sec to 12.7 ± 2.5 cm/sec after exercise.\textsuperscript{6} Using ephedrine, significant increases in S' as well as TAPSE were found in the CABG group (Table 3). However, ephedrine did not influence significantly the TAPSE-S' relationship (Fig 2). A clinically significant rise in PAPm was not observed (Table 2). However, interventions that would influence significantly the PAPm could certainly affect this relationship.

The IVA has been described as a load-independent measure of contractility.\textsuperscript{11} In an animal study using color-tissue Doppler, dobutamine 10 μg/kg/min, raised the IVA from 3.0 ± 1.4 m/sec\textsuperscript{2} to 4.7 ± 1.5 m/sec\textsuperscript{2}.\textsuperscript{11} In the present study, the administration of ephedrine did not result in any significant increase in IVA (Table 3). It is possible that ephedrine was not potent enough to effect a significant change in IVA. Alternatively, the variability in the measurement of IVA was due to measurement difficulties, a large interpatient variability or simply large beat-to-beat variability.\textsuperscript{18} The IVA was significantly lower in Group 2 compared with the pre-ephedrine patients in Group 1. This difference likely represented a significant reduction in RV inotropic state in this critically ill patient group despite the intravenous inotropic support.

There were several limitations in this study. The number of patients was small. Larger numbers may have resulted in a significant difference between the pre- and postephedrine data. Furthermore, ephedrine may not have had sufficient inotropic potency to elicit the response necessary to assess the echo changes in RV function. The effects of general anesthesia and cardiac medications also may have influenced the RV response. Modification of volume status was not undertaken; describing the TAPSE-S' relationship after volume modification would have been a useful adjunct to this study.

CONCLUSIONS

This study supported the utility of color-tissue Doppler-derived TAPSE, S', and IVA to distinguish between a cardiac surgical population with good RV function and one with significantly depressed RV requiring inotropic support. However, in patients with depressed RV function, TAPSE is not related closely to global RV cardiac output. Additional parameters of RV function should be investigated under these circumstances. The relationship between TAPSE and S' describes a curvilinear relationship, which may offer insight into baseline RV function and response to stimulation. This particular relationship is lost in patients with significant RV dysfunction.

REFERENCES


27. Ho SY, Nihoyannopoulos P: Anatomy, echocardiography, and normal right ventricular dimensions. Heart 92(suppl)i:12-i13, 2006


