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REPORTS OF ORIGINAL INVESTIGATIONS

Evaluation of TAPSE as a measure of right ventricular output
Évaluation du TAPSE comme mesure du débit ventriculaire droit

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Abstract

Purpose *This study was designed to show the relationship between tricuspid annular plane systolic excursion (TAPSE) and stroke volume (SV) by thermodilution using three different methods and also to assess whether TAPSE can track hemodynamic changes associated with volume loading and ephedrine administration.*

Methods *This was an observational study in 61 elective patients with a pulmonary artery catheter who were undergoing coronary artery bypass graft surgery in a cardiac surgical centre. We measured TAPSE by three methods using transesophageal echocardiography: M mode, speckle tracking at the lateral wall, and tissue tracking at the inferior wall. There were two interventions: leg raising (volume recruitment) or administration of ephedrine 5 mg iv. Echo and hemodynamic measurements were performed before and after each intervention.*

Results *Eleven patients were excluded due to poor imaging. There were 26 patients in the leg raising group and 24 patients in the ephedrine group. The correlation coefficient between stroke volume (SV) and TAPSE by M mode, speckle tracking, and tissue tracking was 0.48, 0.44, and 0.09, respectively. There was a significant increase in SV following each intervention; however, the changes in TAPSE by any method and velocity were not large enough to reach statistical significance.*

Conclusion *Tricuspid annular plane systolic excursion by M mode and by speckle tracking correlates modestly with SV. There was no correlation between TAPSE and SV by tissue tracking at the inferior wall of the right ventricle. Tricuspid annular plane systolic excursion by M mode and by speckle tracking does not track changes in SV following either volume loading or ephedrine administration.*

Résumé

Objectif *Cette étude a été conçue pour montrer le rapport entre le déplacement systolique du plan de l'anneau tricuspidien (TAPSE) avec le volume d'éjection systolique (SV) par thermodilution en utilisant trois méthodes différentes et aussi pour déterminer si le TAPSE peut suivre les modifications hémodynamiques associées à une charge volumique et à une administration d'éphédrine.*

Méthodes *Il s'agit d'une étude observationnelle menée chez 61 patients sélectionnés porteurs d'un cathéter de l'artère pulmonaire qui devaient subir un pontage coronarien dans un centre de chirurgie cardiaque. Nous avons mesuré le TAPSE par trois méthodes différentes à l'aide d'une échocardiographie transœsophagienne: mode M;suivi de granularités (speckle tracking) sur la paroi latérale; et suivi de tissu (tissue tracking) sur la paroi inférieure. Il y a eu deux interventions: jambes relevées*

Author contributions *Claude Tousignant* made a significant contribution toward the study design, the acquisition and interpretation of data, as well as the drafting and revision of all versions prior to submission. He also approved the final draft. *Han Kim* made a significant contribution toward the study design, the acquisition and interpretation of data, as well as the drafting and revision of all versions prior to submission. He also approved the final draft. *Fabio Papa* made a significant contribution toward the study design, the acquisition and interpretation of data, as well as the drafting and revision of all versions prior to submission. He also approved the final draft. *C. David Mazer* made a significant contribution toward the study design, the acquisition and interpretation of data, as well as the drafting and revision of all versions prior to submission. He also approved the final draft.

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(recrutement volumique) ou administration d'éphédrine 5 mg IV. L'échographie et les mesures hémodynamiques ont été réalisées avant et après chaque intervention.

Résultats *Onze malades ont été exclus en raison de la mauvaise qualité des images. Il y a eu 26 patients dans le groupe « jambes relevées » et 24 patients dans le groupe « éphédrine ». Les coefficients de corrélation entre le volume d'éjection systolique (SV) et le TAPSE évalués en mode M, par suivi de granularité et suivi de tissu ont été, respectivement, 0,48, 0,44, et 0,09. Il y a eu une augmentation significative du SV après chaque intervention; toutefois, les variations de vélocité et du TAPSE par l'une ou l'autre méthode n'ont pas été assez importantes pour atteindre la signification statistique.*

Conclusion *Le TAPSE en mode M et en suivi de granularité est modestement corrélé au SV. Il n'y a pas eu de corrélation entre le TAPSE et le SV par le suivi de tissu au niveau de la paroi inférieure du ventricule droit. Le TAPSE ne suit pas, en mode M et avec le suivi de granularité, les variations du SV après une charge volumique ou une administration d'éphédrine.*

Right ventricular (RV) function is an important component of overall heart function. Indeed, RV dysfunction assessed using RV ejection fraction (RVEF), RV stroke work, RV fractional area of change, or tricuspid annular systolic plane excursion (TAPSE) is a predictor of outcome in cardiac surgery, transplantation, and patients with pulmonary hypertension.[1–3] Due to its simplicity and ease of application, TAPSE has become a commonly measured variable in the assessment of RV function, however, it remains one dimensional. Tricuspid annular systolic plane excursion is commonly measured using M mode, but it can be measured using speckle tracking (tracking of B mode markers) or tissue tracking (TT) [integrating annular velocity (S') measured by colour tissue Doppler]. Contrary to M mode, speckle tracking and TT allow for the measurement of S'. Most studies examining TAPSE have used transthoracic echocardiography (TTE). Aligning tricuspid annular motion in transesophageal echocardiography (TEE) using M mode or TT remains problematic. In the four-chamber view using TEE, a floating M mode cursor must be used. On the other hand, tissue tracking cannot be performed in the four-chamber view.

Assessing RV responsiveness to volume or inotropes may also be helpful in predicting risk or outcome. A good correlation has been found between TAPSE by TT using TTE at the lateral wall of the RV and SV by thermodilution or the Fick technique ($r = 0.63$).[4] The study results showed that changes in TAPSE (by TT) correlated well with changes in the stroke volume index (SVI) in patients with idiopathic pulmonary hypertension following the administration of epoprostenol infusions.

The main focus of our study was to compare TAPSE with thermodilution-derived SV using three different methodologies in patients undergoing coronary artery bypass grafting (CABG) and, secondly, to determine whether TAPSE and S' can track induced hemodynamic changes.

Methods

The protocol was approved by the St. Michael's Hospital Research Ethics Board (REB#08-367, February 12, 2008). Eligible patients were approached preoperatively, and signed informed consent was obtained prior to conducting any study-related procedures. Sixty-one elective CABG patients were recruited sequentially to receive either a volume load through passive leg raising (during leg prepping for surgery) or administration of ephedrine 5 mg. Patients were excluded if they had contraindications to TEE, if they were not in sinus rhythm, or if the left ventricular (LV) ejection fraction by preoperative echo was inferior to 45%. As part of clinical routine, each patient had an electrocardiogram and invasive monitoring, including an indwelling radial arterial line and a 7.5 Fr Swan-Ganz Paceport catheter (Edwards Lifesciences, Irvine, CA, USA). Following induction of anesthesia using sufentanil, midazolam, and rocuronium, a TEE probe was inserted (GE Vivid 7 system, Milwaukee, WI, USA). All measurements were taken approximately 15 min after induction of anesthesia with patients in the supine position. Echocardiography measurements were taken simultaneously with hemodynamic measurements before and after each intervention. Measurements were taken after 30 sec of leg raising or after a rise in systolic blood pressure following the administration of ephedrine. Each patient underwent only one intervention. No inhalational anesthesia was used during the study period.

Hemodynamic measurements

The following peak hemodynamic measurements were recorded before and after each intervention: heart rate (HR), central venous pressure, and mean pulmonary artery pressure (PAPm). Cardiac output measurements were taken using thermodilution and recorded as the average of three consecutive measurements.

Echocardiographic measurements

Using a GE Vivid 7 system with an omniplane TEE probe at 5 MHz, a mid-esophageal four-chamber view was obtained, and the RV was placed in the centre of the sector. The sector was narrowed to optimize frame rate while taking great care

to include the whole free wall of the RV and to avoid tricuspid annular migration outside the sector during atrial contraction. The focus position was adjusted at the basal level of the RV wall. Five consecutive beats were recorded digitally for later analysis. The probe was then introduced into the patient's stomach, and a modified transgastric RV inflow-outflow was visualized aligning the motion of the inferior wall with the right edge of the sector.[5] A colour tissue Doppler sector was applied to the inferior wall, including the tricuspid annulus. The two-dimensional sector was minimized to obtain a colour Doppler frame rate over 200 fps. A minimum of five consecutive beats was recorded digitally for later analysis. Image acquisition for all methods was performed over approximately two to three minutes simultaneously with invasive measurements.

Tricuspid annular plane systolic excursion measurement M mode

In the mid-esophageal four-chamber view, a floating M mode cursor was applied to the tricuspid annulus and aligned with its motion (Fig. 1). Tricuspid annular systolic plane excursion was measured as the maximum systolic excursion in millimetres. The average of three beats was used.

Tricuspid annular systolic plane excursion measurement using speckle tracking

Using quantitative two-dimensional analysis software (GE, Milwaukee WI, USA), a region of interest was applied to the

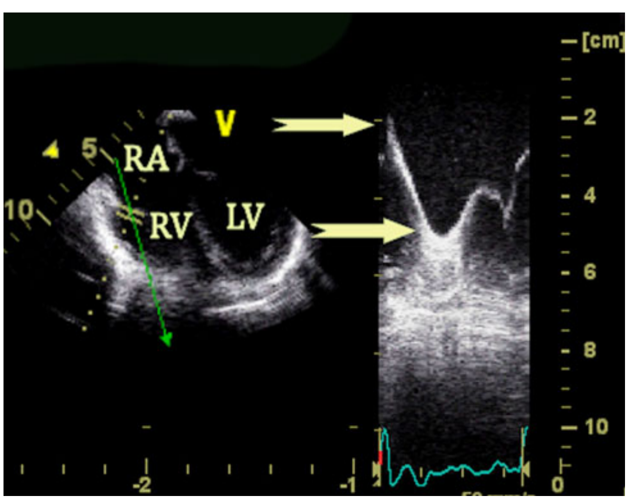

Fig. 1 Mid-esophageal four-chamber view (left) with application of floating M mode cursor (green arrow) to the tricuspid annulus. The corresponding M mode trace is displayed on the right. The annular descent corresponds with the segment between the yellow arrows, which corresponds with the tricuspid annular systolic excursion. The scale in cm is displayed to the right. RA = right atrium; RV = right ventricle; LV = left ventricle

lateral wall of the right ventricle beginning at the tricuspid annulus in the mid-esophageal four-chamber view. Anchor points and width were adjusted to provide the best possible tracking of the basal segment. Images were checked to ensure proper tracking of the annulus. A maximum of three attempts was made per cardiac cycle to ensure a passing score on tracking at the level of the RV basal segment. If all three attempts failed, the next heart beat was used. Tricuspid annular plane systolic excursion and velocity were measured by sampling at the annulus (Fig. 2). The average of three heart beats was used for the TAPSE and velocity measurements.

Tricuspid annular systolic plane excursion measurement by tissue tracking

Using quantitative analysis software (GE, Milwaukee WI, USA), a 6 x 6 mm sample volume was applied to the colour tissue Doppler sector at the basal segment of the RV as close to the annulus as possible. Using TT, the sample volume was positioned in a manner to obtain the largest annular excursion (Fig. 3). The average of three values was used for TAPSE.

Data analysis and statistics

The sample size was a convenience sample based on previous study sample sizes.[5,6] The observers were not blinded to the intervention. An unpaired Student's t test was used to compare both groups. Using linear correlation, we examined the association between three different methods of measuring TAPSE and SV. Using a paired Student's t test, we then examined whether TAPSE values could be modified as a result of volume administration or ephedrine. Values are expressed as mean, standard deviations, and 95% confidence intervals (CI). A $P < 0.05$ was considered significant.

Results

Sixty-one CABG patients were recruited, and 11 patients were excluded for failure of speckle tracking or excessive noise on TT. There were 24 patients in the ephedrine group (Group E) and 26 patients in the volume group (Group V). The demographics are presented in Table 1.

There was a modest correlation between TAPSE by M mode and SV ($r = 0.48$; $P < 0.001$) (Fig. 4). In contrast, TAPSE by speckle tracking yielded a poorer correlation with SV ($r = 0.44$; $P = 0.001$). There was no correlation between TAPSE by TT and SV ($r = 0.09$; $P = 0.065$).

There was no significant difference in hemodynamic variables between the two groups prior to the intervention (Table 2). The mean arterial pressure, PAPm, cardiac

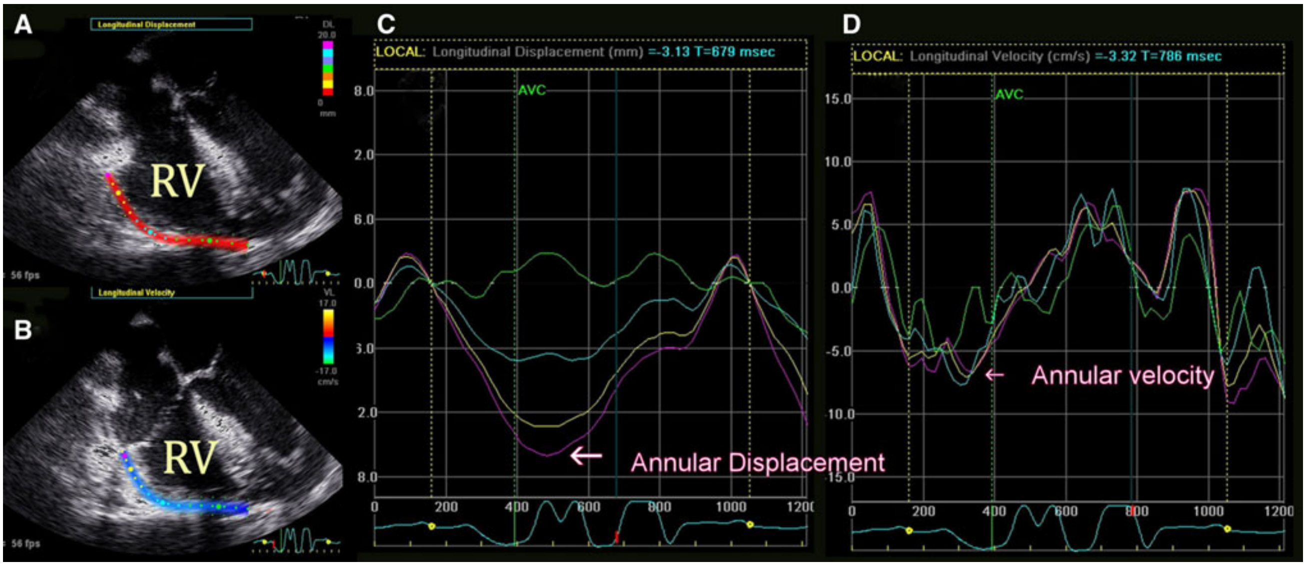

Fig. 2 Speckle tracking for the measurement of displacement (A) and velocity (B). An area of interest is applied to the lateral wall of the right ventricle (RV) (A and B). The colour superimposed on the lateral wall corresponds with the displacement (A) or velocity (B) for that particular frame. The lateral wall is divided into three equal segments, and mean displacement (C) or velocity (D) is colour coded for each segment and displayed graphically. A sample volume is placed at the annulus, and the displacement (C) or velocity (D) is displayed as a pink trace. Peak measurements are shown by the arrows in C and D

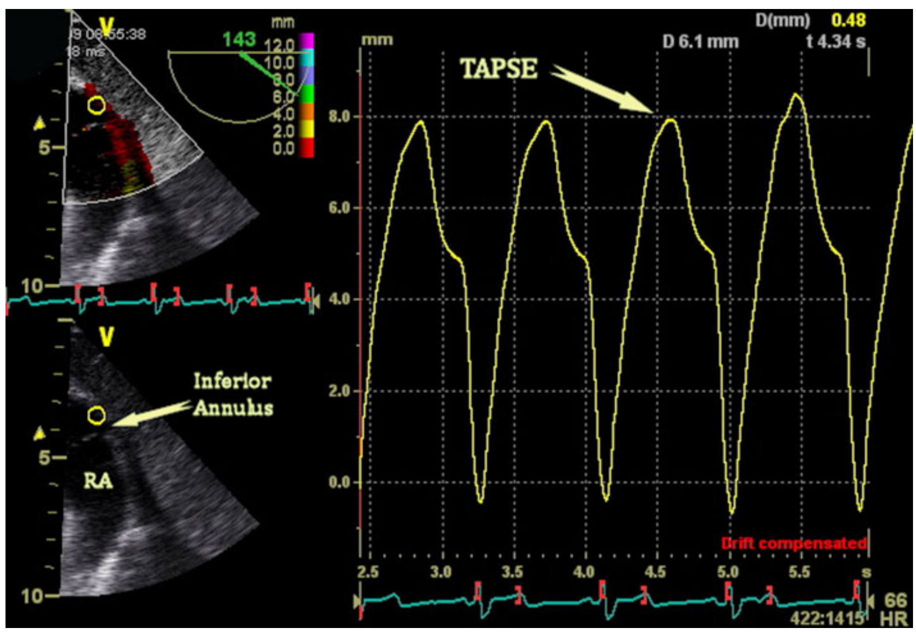

Fig. 3 A modified transgastric right ventricular long axis view focusing on the annulus is shown on the left. A colour tissue Doppler sector is applied (upper left) and a sample volume (yellow circle) is applied to the region near the annulus. Velocity information in the sample volume is integrated over time and shown graphically on the right as displacement (tissue tracking). The tricuspid annular systolic excursion (TAPSE) (arrow) corresponds with the maximum excursions derived from velocity data

output, and SV increased in response to both interventions (Table 2). The central venous pressure increased only in Group V. The HR did not change. When all patients were pooled, all variables rose except the HR (Table 2).

Tricuspid annular systolic plane excursion by M mode increased significantly in Group V [18 (4) mm to 20 (4) mm] with a mean change of 2 mm (95% CI 0 to 4]. The pre-intervention value was lower in Group V when compared with Group E [18 (4) mm *vs* 21 (4) mm, respectively] (Table 3). When all results were pooled, TAPSE by M mode did not change following the intervention.

Tricuspid annular systolic plane excursion by speckle tracking did not change in response to intervention in either group or when the data were pooled (Table 3).

Peak S' by speckle tracking increased significantly in Group E [7.25 (1.34) cm·sec^{-1} to 7.70 (0.84) cm·sec^{-1}] with a mean change of 0.45 cm·sec^{-1} (95% CI −0.10 to 0.80) (Table 3).

Table 1 Demographics

	Group E (n = 24)	Group V (n = 26)	All (n = 50)
Age (yr)	61 (10)	62 (9)	62 (9)
M/F	18/6	21/5	39/11
Height (cm)	170 (9)	165 (10)	168 (10)
Weight (kg)	84 (16)	76 (16)	80 (16)
BSA (m^2)	1.98 (0.23)	1.86 (0.23)	1.92 (0.23)

Values are mean (standard deviation). Group E = ephedrine; Group V = volume. BSA = body surface area

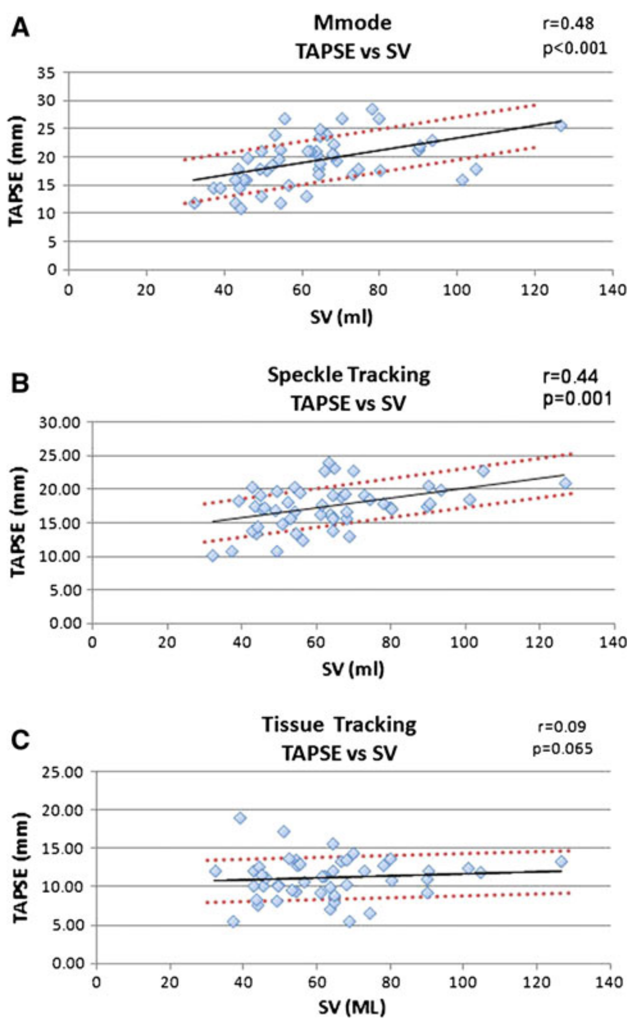

Fig. 4 Relationship between tricuspid annular systolic excursion (TAPSE) by M mode (A), speckle tracking (B), and tissue tracking (C) and SV (stroke volume) in all patients pre-intervention. The solid line represents the regression line with R value displayed. The dashed lines represent the 95% confidence interval for the regression line

Discussion

Our study suggests that the intraoperative assessment of RV function and response using TEE may not be reliable using TAPSE. Tricuspid annular systolic plane excursion by M mode showed a modest correlation with SV (r = 0.48); TAPSE by speckle tracking correlated poorly with SV (r = 0.44), and TAPSE by TT at the inferior wall of the RV was unrelated to SV (r = 0.09). Although ephedrine and volume each increased the SV, PAPm, and mean arterial pressure, TAPSE by either method did not significantly track these changes. The S' velocity by speckle tracking increased in response to ephedrine administration.

The longitudinal contribution to total RV output has been shown to be approximately 80% owing to a predominantly longitudinal muscle fibre orientation.[7-9] For this reason, TAPSE, a measure of longitudinal displacement, has become popular in the rapid and simple assessment of RV function.[10-12] Tricuspid annular systolic plane excursion is independent of age, sex, and body size[11]; however, it remains dependent on LV function.[12,13] It is affected by tricuspid regurgitation and is reduced in the presence of atrial fibrillation.[14,15]

There has been a wide range of correlations between TAPSE and other measures of RV function. Good correlations were obtained comparing TAPSE with RVEF,[16-20] and better correlations were obtained comparing TAPSE with RV fractional area of change[6,12] and global RV strain.[21] Correlations were more modest when compared with RVEF using magnetic resonance imaging.[16] Theoretically, RV annular displacement should be related to SV. Comparisons with SV have yielded good results (r = 0.63).[4] A TAPSE of < 1.8 cm predicted a SVI of < 29 mL·m^{-2}.[1] We found a modest correlation between TAPSE by M mode and SV (r = 0.48).

Tricuspid annular systolic plane excursion by speckle tracking offers the advantage of reducing user bias; however, the correlation was lower (r = 0.44).

Tissue tracking of the RV free wall using TTE has previously shown a good correlation with RV SVI (r = 0.63).[4] Using TEE, the tricuspid annular motion aligns with the Doppler plane only in the modified transgastric inflow-outflow view.[7] Tricuspid annular systolic plane excursion by TT measured in this area did not result in any correlation with SV (r = 0.09). This may be the result of its proximity to the septum and left ventricle or simply that longitudinal annular motion in this location does not fully represent RV function. An accurate assessment of RV function using annular motion in this area of the RV is likely not possible using this method.

The peak velocity of annular descent (peak S' velocity) has also been suggested as an indicator of RV performance. The S' velocity has been shown to be load and inotropic dependent in an animal model.[22] In humans, S' velocity has been found to be stable under load alterations in

Table 2 Pre and post hemodynamics

	Group E ($n = 24$)		Group V ($n = 26$)		All ($n = 50$)	
	Pre	Post	Pre	Post	Pre	Post
MAP (mmHg)	73 (12)	88* (11)	73 (11)	82* (13)	73 (11)	85* (12)
PAPm (mmHg)	18 (3)	21* (4)	18 (3)	22* (3)	18 (3)	21* (4)
CVP (mmHg)	11 (2)	11 (2)	11 (3)	13* (3)	11 (2)	12* (3)
CO ($L \cdot min^{-1}$)	3.82 (0.94)	4.31* (0.87)	3.47 (0.84)	3.96* (0.79)	3.64 (0.90)	4.13* (0.84)
HR ($beats \cdot min^{-1}$)	58 (9)	59 (8)	60 (9)	59 (6)	59 (9)	59 (7)
SV (mL)	67 (20)	74* (18)	59 (18)	67* (15)	63 (19)	70* (16)

Values are mean (standard deviation). Hemodynamics in the ephedrine (Group E) and volume (Group V) groups as well as all data combined. * Denotes $P < 0.05$ from pre value. MAP = mean arterial pressure; PAPm = mean pulmonary artery pressure; CVP = central venous pressure; CO = cardiac output; HR = heart rate; SV = stroke volume

healthy subjects.[6] On the other hand, S' velocity was reduced following preload reduction in healthy subjects.[23] It is likely that the S' velocity is an indicator of performance in relation to the speed at which a certain amount of work is performed, which is dependent on both load and inotropy. In our study, the S' velocity was measured using speckle tracking. Ephedrine, a weak inotrope, resulted in a small increase in S' velocity ($0.45\ cm \cdot sec^{-1}$) (95% CI −0.10 to 0.80), whereas volume loading did not. It is also possible that the mild increase in PAPm (18 to 22 mmHg) (95% CI of difference 5.0 to 3.0) may have mitigated any increase in S' velocity gained by the weak effect of volume loading.

The measurement of TAPSE is not a complete assessment of work. It does not take into account the load against which the RV is working. Under prevailing conditions, a response to either volume loading or inotropic stimulation would add valuable information to RV function assessment and possibly risk stratification. Although TAPSE by M mode and speckle tracking correlated reasonably well with SV overall, it was unable to track changes in SV. The literature is also conflicting in this matter. In a study by Kjaergaard *et al.*, TAPSE by TT was found to be relatively stable under preload and afterload modification.[6] On the other hand, Urheim *et al.* found an increase in TAPSE using TT along with an increase in SVI in patients receiving epoprostanol.[4] In our study, changes in TAPSE by whichever method overall did not correlate with modifications of SV. In Group V, a small increase in TAPSE by M mode was observed. This may have been the result of a lower TAPSE starting value in Group V compared with Group E (18 mm *vs* 21 mm, respectively); however, an increase of 2 mm with 95% CI 0 to 0.4 would not be considered clinically significant. These interventions may have more value in patients with a depressed RV function (lower TAPSE).

Assessing RV function has become an important factor in predicting survival and outcome in the perioperative period.[2,3,24] Assessing RV reserve in the presence of abnormal constraints may further help to predict outcome and survival. Rapid and easy methods (i.e., leg raising and ephedrine administration), which can be applied in the operating room, could provide the interventions necessary to assess RV recruitment. Unfortunately, TAPSE by M mode or by speckle tracking at the lateral wall was not sensitive enough to track output changes induced by these two interventions. Alternatively, it is possible that the interventions did not produce a large enough response to assess recruitment properly in these elective patients. Our study did not include patients with depressed RV function; patients with reduced TAPSE may have responded differently to these interventions. We did not measure RV size in this study so it is also possible that our volume loading resulted in geometric changes in the RV, resulting in an increase in SV without changes in annular descent. The inclusion of other geometric measurements, especially in the presence of dysfunction or disease, may enhance the relationship.[25]

Both TAPSE by speckle tracking and M mode were gross measures of RV output as measured by thermodilution-derived SV. Annular motion at the inferior wall of the RV using TT did not correlate with SV. Tricuspid annular systolic plane excursion by whichever method was insensitive to changes in SV induced by either volume loading or ephedrine administration. In a perioperative cardiac surgical population with normal RV function, the assessment of RV function and reserve using TAPSE may not be appropriate using these methods.

Table 3 Echo variables

	Group E ($n = 24$)			Group V ($n = 26$)			All ($n = 50$)		
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
TAPSE Mm (mm)	21 (4)	21 (5)	0 (4) (−2 to 2)	18† (4)	20* (4)	2 (5) (0 to 4)	19 (4)	20 (5)	1 (4) (0 to 2)
TAPSE ST (mm)	17.1 (3.0)	18.1 (3.4)	1 (2.4) (0.0 to 2.0)	17.7 (3.5)	18.2 (3.7)	0.6 (3.4) (−0.8 to 2)	17.4 (3.2)	18.2 (3.5)	0.8 (2.9) (0 to 1.6)
S' ST ($cm \cdot sec^{-1}$)	7.25 (1.34)	7.7* (0.84)	0.45 (0.84) (−0.10 to 0.8)	7.82 (2.0)	8.1 (1.4)	0.28 (1.80) (0.44 to 1.00)	7.55 (1.71)	7.91 (1.3)	0.36 (1.41) (−0.04 to 0.76)

TAPSE (tricuspid annular systolic excursion) measured by M mode (Mm) and speckle tracking (ST) as well as annular velocity (S') by ST for the ephedrine group (Group E), the volume group (Group V), and all patients combined. * Denotes significantly different from pre-value ($P < 0.05$); † Denotes significant difference in pre-values between volume and ephedrine groups ($P < 0.05$). Mean changes are displayed for each group. Values are mean (standard deviation) and 95% confidence interval

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