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Short title: The association between TAPSE and right atrial contractile strain

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WHAT'S NEW?

The changes in tricuspid annular plane systolic excursion (TAPSE) curve configuration represents the changes in atrial contractile phase. If the right atrial contractile strain (RAS_{ct}) is above −19 %, it is observed that there is a notch which corresponds to late diastole during the atrial contraction, at the descending arm of the TAPSE. So, this notch formation of the TAPSE curve indicates the RAS_{ct} phase as whether it is preserved or not. TAPSE and right atrial strain have similar courses when RAS_{ct} remains preserved. Therefore, instead of right atrial strain analyses as a cutting-edge technique, an easier, more applicable, and more effortless tool TAPSE can be an indicator of atrial contractile phase. We suggest that TAPSE curve configuration can be used to estimate the RAS_{ct} practically in daily routine.

ABSTRACT

Background: In the descending arm of tricuspid annular plane systolic excursion (TAPSE) there is a notch formation which corresponds to the contractile phase of the atrial strain curve. Theoretically, this notch formation stands for atrial contraction.

Aims: We aim to characterize the notch formation on the TAPSE, the predictors of its existence, its relationship with the right ventricle and right atrial strain (RAS) parameters.

Methods: Retrospectively selected 240 patients were investigated for the determinants of the notch formation on TAPSE and the relation between RAS and TAPSE. RAS was analyzed using 2D speckle tracking in a dedicated mode for atrial analysis and reported separately for the reservoir, conduit, and contractile phases.

Results: 71.7% (n = 172) of patients had the notch formation on the TAPSE and 70.4% (n = 169) had a normal value of right atrial contractile strain (RAS_{ct}). Most of the patients with a notch formation also had preserved RAS_{ct} (95.9%; P <0.001). In multivariable analysis, RAS_{ct} (odds ratio [OR], 1.45; 95% confidence interval [CI]: 1.13–1.77; P = 0.020) remained significant with the notch formation. Receiver operator characteristic (ROC) analysis demonstrated that a RAS_{ct} of –19% was found as a cut-off for presence of notch formation. ROC area was 0.897 (95% CI 0.844–0.951; P <0.001).

Conclusions: The changes in TAPSE configuration represents the changes in atrial contractile phase. The descending arm of the TAPSE indicates the RAS_{ct} as whether it is preserved or not. The notch formation persists if the RAS_{ct} is above –19%. So, an easier, more applicable, and more effortless tool TAPSE can be used as an indicator of atrial contractile phase by its configuration in daily routine.

Key words: atrial contractile strain, right atrial strain, tricuspid annular plane systolic excursion

INTRODUCTION

In recent years, a growing number of studies have focused on the data of investigating the right atrium (RA), its mechanics, and normal reference values of the diameters, area, and other metric values, functions, and the role during the cardiac phases after the recognition of diagnostic and prognostic impact on different cardiovascular diseases, such as pulmonary embolism, pulmonary hypertension (PH), and heart failure (HF) [1–4].

Formerly, the atrial cavities were assigned to the minimalistic role of a "transit chamber", but the atriums serve three distinct functions during the cardiac cycle. RA works as a reservoir during ventricular systole against closed tricuspid valve, after opening of the tricuspid valve it serves as a passive conduit during early diastole, and finally it has a booster pump role during atrial contraction in late diastole until the tricuspid valve closure [5, 6]. All of these phases are modulated by the loading conditions, heart rate and the intrinsic contractility of the atria [7]. Concerning the RA strain, the American Society of Echocardiography (ASE) and European Association of Cardiovascular Imaging (EACVI) have published a consensus document addressing standards for two-dimensional (2D) speckle tracking echocardiography (STE) of the RA that is a useful non-invasive tool for the assessment of the atrial function [8].

On the other hand, tricuspid annular plane systolic excursion (TAPSE) is the traction of the lateral annulus of the tricuspid valve toward the apex during ventricular systole. The incline of the TAPSE represents the traction of the right ventricular (RV) lateral wall during ventricular systole- RV contractility in the long axis and it corresponds atrial diastole that RA works as a reservoir also called atrial reservoir phase. The first part of the descending arm of the TAPSE curve represents the passive part — conduit phase in early ventricle diastole and the second part of the decline of the TAPSE represents atrial booster phase in the late ventricle diastole [9].

When the atrial strain curves are examined, it is easy to realize the resemblance between the TAPSE curve. The TAPSE curve shows the formation of a notch in the descending arm, while the atrial strain curve shows the contractile phase when atrial contraction occurs (Figure 1). Theoretically, this notch formation on the TAPSE curve stands for atrial contraction. But somehow in our daily practice, it has been observed that some patients have a smooth formation on the descending arm while others have a notch on it (Figure 2). Currently there is a paucity of data on the impact of the notch formation on TAPSE and interrelation between TAPSE and right atrial strain (RAS). In this study, we aim to characterize the notch formation on the TAPSE curve, the predictors of its existence, and its relationship with the RV and RA strain patterns.

METHODS

Study population

We retrospectively selected 290 patients with sinus rhythm without previous cardiac surgery. All subjects were enrolled who referred to our Echocardiography Laboratory for examination due to routine follow-up of underlying stable coronary artery disease, compensated and clinically stable heart failure, hypertension, diabetes, hyperlipidemia, chronic kidney disease, and healthy individuals as well to be investigated for possible cardiac pathology, between March 2021 and March 2022. Since we have planned to investigate the determinants of the notch formation on TAPSE and the relation between RAS and TAPSE, a sample with a wide range of patients has been created to investigate the effect of different pathologies on the outcome. It was considered important to include a wide range of different cardiac disorders to better examine the possible difference between different scenarios. However, patients with one or more of the following 'specific cardiovascular diseases' were excluded: atrial fibrillation, primary pulmonary hypertension, severe tricuspid regurgitation and/or stenosis, pericardial diseases, restrictive or hypertrophic cardiomyopathies, or paced rhythms. 50 patients were excluded out of the study whom it was difficult to assess cause of poor imaging quality, frequent extrasystoles.

Echocardiography

Echocardiography was performed using EPIQ ultrasound system equipped with a matrix-array S-4 transducer (Philips Medical Systems, Andover, MA, US) by a single sophisticated sonographer. All images were recorded between 08:00-10:00 am on an empty stomach at least after 6 hours fasting in order to provide standardization in volume status. Care was taken to include the entire RV with the images. TAPSE, systolic excursion velocity (RV S'), and right ventricular global longitudinal strain (RVGLS) were measured according to the recommendations by the ASE and EACVI [10]. RA strain was analyzed using 2D speckle tracking in a dedicated mode for atrial analysis and reported separately for the reservoir, conduit, and contractile phases as recommended in the EACVI/ASE consensus report [8]. For RAS analyses, we used vendor-specific software originally designed for the left atrium and the endocardial border of the RA was manually traced, beginning, and ending at the tricuspid annulus, and the width of the region of interest (ROI) was manually adjusted to include the whole endocardium, but not the pericardium, as recommended. For RV strain analyses, we used vendor-specific software originally designed for the RV. RASs and RVGLS were measured by speckle tracking echocardiography using frame rates from 40 to 80/s. Measurements were averaged over three cardiac cycles when the patient had sinus rhythm. The time reference used to define the zero-baseline for the RAS curves was ventricular end-diastole. The images were digitally stored and analyzed off-line (QLAB). This analysis was performed using a semiautomatically traced ROI along the RA endocardial border. If necessary, the ROI was adjusted manually. Normative values of RAS were determined by the reference values from the latest multicenter study (WASE Normal Values Study International) that was addressed by EACVI/ASE consensus report on RA [6, 11].

To test the intraobserver reproducibility of RAS, measurements were repeated two weeks apart in 20 randomly selected patients from the study group. To test the interobserver reproducibility, the same 20 patients were measured by a second researcher, blinded to the prior measurements. Inter-observer and intra-observer variabilities in each parameter studied were evaluated with intraclass correlation coefficient (ICC). Inter-observer ICCs of RA reservoir (RAS_r), conduit (RAS_{cd}), and contractile (RAS_{ct}) strains were 0.974, 0.877, and 0.910, respectively. Intra-observer ICCs of RAS_r, RAS_{cd}, and RAS_{ct} were 0.981, 0.983, and 0.945 respectively.

TAPSE was acquired by using the apical 4-chamber view, the M-mode cursor was placed through the junction of the tricuspid valve plane and RV free wall. TAPSE was determined by the difference in the displacement of the RV base during systole and diastole. The notch on the TAPSE was visually assessed and accepted as the hump on the descending arm of the curve.

Statistical analyses

The numerical variables were investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov–Smirnov/Shapiro–Wilk's test) to determine whether they were normally distributed. Descriptive analyses were presented using mean (standard deviations) for normally distributed variables and medians and interquartile ranges (IQR) for non-normally distributed variables. Categorical variables were compared using the χ^2 test which was used to compare the existence of a notch in the descending arm of the TAPSE curve and preserved RAS_{ct}. Comparisons between subgroups were performed by using the Student-t test for unpaired data as a parametric test for normally distributed variables and Mann-Whitney U as a non-parametric test for non-normally distributed or ordinal variables. The variables affecting each RAS parameter were investigated using Pearson correlation. For the multivariable analysis, the possible factors identified with univariable analysis were further entered into the logistic regression analysis to assess which parameters were independent determinants of notch formation existence in TAPSE curve. Area under the receiver operating characteristic (ROC) curve (AUC) was calculated to evaluate the ability of RAS_{ct} to estimate the notch formation in the TAPSE curve. When a significant cut-off value was observed, the sensitivity, specificity, positive, and negative predictive values were presented. A P-value < 0.05 was considered significant for all the data examined. All statistical analyses were performed using the SPSS software Version 22.0 (IBM Corporation, Armonk, NY, US). The study was approved by the Regional Ethics Committees and Institutional Review Boards.

RESULTS

Study population and baseline characteristics

Table 1 summarizes the demographic, clinical, and echocardiographic data. The mean (SD) age of the patients was 47 (11.6) years, and most of the patients were male (75.8%). It was observed that 71.7% (n = 172) of patients had the notch formation in the TAPSE curve and 70.4% (n = 169) of patients had a normal value of RAS_{ct}. The vast majority of these patients who had a TAPSE with a notch formation also had preserved RAS_{ct} (n = 162, 95.9%; P <0.001).

Patients who had a TAPSE with a notch formation demonstrated a higher RAS_{r}, RAS_{cd}, and RAS_{ct} herewith RVGLS, RV free wall GLS, TAPSE, and RV S'. We have noticed that patients who had a TAPSE without notch formation had higher heart rates (Table 1). Tachycardia was observed with 35 patients (14.6%) during examination, and we have found a significant relation was found between having tachycardia and the absence of a notch formation (Table 1). The amount of the tachycardia existence among the patients who had a TAPSE with a notch formation (n = 169) has found 5.9% (n = 10) while 35.2% (n = 25) among the patients who had a TAPSE without a notch formation (n = 71; P <0.001). Age, gender, and the size of right heart chambers did not significantly differ between the two groups. The estimated systolic pulmonary artery pressure (sPAP) was significantly higher among the patients without a notch formation.

Univariable logistic regression analysis revealed a significant relationship between the notch formation at the TAPSE curve and RAS_{r}, RAS_{cd} and RAS_{ct} parameters and also RVGLS, RV free wall strain, sPAP, RV S',and TAPSE (Table 2). In the multivariable analysis, the RAS_{ct} (odds ratio [OR], 1.45; 95% confidence interval [CI], 1.13–1.77; P = 0.020), RVGLS (OR, 1.22; 95% CI, 1.09–1.35; P = 0.030), and RV free wall strain (OR, 1.20; 95% CI, 1.13–1.27; P = 0.026) remained significant with the notch formation.

We investigated the correlations between 3 different strain phases of the RA with other echocardiographic values to shed some light on the interaction between these parameters. The results revealed that all 3 phases had a significant correlation with each other besides this significant relation persevered with the RV S', TAPSE, RVGLS, and RV free wall strain (Table 3). Attention was drawn to the fact that the most affected phase by each RV S', TAPSE, RVGLS, and RV free wall strain, was the reservoir phase, followed by the conduit and finally contractile phase. The results showed that there was a strong correlation between the RAS_{r} and RAS_{cd}, while a highly good correlation was seen between the RAS_{r} and RAS_{ct}, and a modest correlation was observed between the RAS_{cd} and RAS_{ct} strain. There was a moderate correlation between the RAS_{r} and RAS_{cd} phases with RV S', TAPSE, RVGLS, and RV free wall strain while there was a low correlation between the RAS_{ct} and the RVGLS, and RV free wall strain.

After the recognition of the relation between the existence of the notch formation and the RAS_{ct}, the RAS_{ct} was evaluated to determine a cut-off value as an independent predictor of notch formation by receiver operator characteristic (ROC) analysis, a RAS_{ct} of −19% was found the most accurate predictor value for a notch formation (Supplementary material, *Figure S1*). The ROC area was 0.897 (95% CI, 0.844–0.951; $P < 0.001$). The sensitivity was calculated as 80% while the specificity was 87.3%. Positive and negative predictive values were reported in 75.7%, and 69.1%, respectively.

DISCUSSION

To the best of our knowledge, this is the first study that has investigated the relation between the TAPSE curve and the speckle-tracking–derived RA strain measurements in all 3 phases especially with the booster phase- the RAS_{ct}.

Our findings can be summarized as follows: (1) the TAPSE curve configuration has a relation with the RAS parameters; (2) both the TAPSE and RAS have similar courses when the RAS_{ct} remains preserved; (3) especially the descending arm of the TAPSE curve holds a clue with respect to the RAS_{ct}; (4) The TAPSE has a notch on the descending arm of its curve if the RAS_{ct} is above −19%.

It is well-known that strain is a dimensionless metric of myocardial function, the deformation of the myocardium and is calculated as the percentage of systolic shortening [8, 12]. It is well-known that atrial and ventricular functions are interrelated. When we compare the strain analyses of atrium to ventricle, atrial strain is thought to be more difficult and time consuming because of the far-field location of the atrium, the thin atrial walls, the presence of the appendage and the veins that drains into the atriums, and the need for more focused atrial views [6, 8]. It has been proven that the RAS is a cutting-edge technique with great potential in different clinical scenarios and a reliable tool to study RA performance, but it is also methodologically complex and difficult to interpretation. RA dysfunction by strain assessments could be demonstrated in several disorders including PH [13, 14], coronary artery disease [15], HF [16], atrial fibrillation or in top-level athletes [17]. RAS, especially $RAS_{r,}$ plays a role as a prognostic indicator for pre-capillary PH [13], besides RA and RV strains detect subclinical changes in RV function in pre-capillary PH as well 10. In patients with stable coronary artery disease, RAS as a marker for atrial wall deformation, occurs early in coronary artery disease even before any changes in atrial volumes or dimensions [15]. Also, RA function, as assessed by strain imaging, correlates with right heart hemodynamics in patients with HFrEF [18]. This imaging tool serves as an invaluable ally for guiding diagnosis, prognosis, and management in HF [19]. There is accumulating evidence that right atrial imaging has a wide range of potential clinical applications. One of the challenges to widespread clinical application of these techniques have been the lack of both standardization of the parameters to be measured and specific software packages to use to obtain such measurements.

On the other hand, the TAPSE is the most commonly used echocardiographic tool for evaluation of the RV function. Its popularity comes from its ease of application, being less dependent on optimal image quality than other measurements, its high reproducibility, and good correlation with the RV stroke volume [20]. As a result of our observations, we have noticed that some patients have a notch on the descending arm in response to late diastole phase where we expected the atrial contraction contribution while others had a smooth form of the descending arm. Therefore, at the crossroad between RAS analyses and the TAPSE, we have investigated the utility of TAPSE configuration for estimation of the RAS_{ct} in daily routine. There is a lack of data about the configuration differences and determinants of the TAPSE curve thus far. At the end of the recording all of the RA and RV strain parameters as well as the TAPSE in the same examination along with electrocardiography monitoring, the analyses showed that the majority of the study population (71.7%) demonstrated this notch formation. RAS and TAPSE curves showed similar shapes throughout the cardiac cycle while RV strain showed similar yet inverted shapes (Figure 1). RAS_{ct} was lower in the patients without notching in the TAPSE, even after taking into consideration of the lower TAPSE, RV function and enlarged RV sizes. We assume that the decline of the TAPSE curve especially the terminal part of this descendance corresponding to the late diastole where the p wave occurs, plays a role as an indicator of RAS_{ct}. It was demonstrated that this hump at the descending arm disappears when the atrial contribution diminishes, and RAS_{ct} drops below −19% (Figure 3). We suggest that this ease applicable imaging tool TAPSE serves as an invaluable guide to estimate the RAS_{ct} under favor of its configuration.

Strain analyses of atrium serves as a narrator of the 3 different phases of the atrial functions during cardiac cycle. First positive deflection of the strain curve represents the reservoir phase. It occurs when the RV contracts and the RA fills against a closed tricuspid valve. As might be expected, this metric is influenced by long axis ventricular contraction (higher RVGLS, RV free wall strain brings higher TAPSE values, and accordingly, higher RAS_r values), RA compliance, and RA volumes [21-23]. Our results proved that the RAS_r showed higher correlation with the RVGLS, RV free wall strain, and TAPSE than RAS_{cd} and RAS_{ct}

parameters. The study of Barbier et al. [24] underlined that the longitudinal ventricular function is a key determinant of atrial reservoir function. All RAS values were higher for the patients who had a notch formation in the TAPSE curve and each 3 of them had tended to be low with tachycardia. This can be explained by the negative impact of tachycardia on atrial functions due to the shorter filling time and consequently, inadequate suction of the ventricles. Some studies have claimed that there is a correlation between the heart rate and aggravation in atrial contraction, while other studies have not supported this notion [25, 26]. General opinion about the effect of the tachycardia on diastolic filling is that tachycardia will shorten the E wave deceleration time and fuse the E and A waves, and the mitral A wave will be higher in velocity because of the shortened diastolic filling time [27]. Thus, it is expected to observe a reduction with RAS_r and RAS_{cd}, while an increase with the RAS_{ct}. however, a large-scale meta-analysis of RAS showed that tachycardia did not have the effect of increasing contractile reserve [28]. In our study we have found a strong relation between the absence of the notch formation in the TAPSE and tachycardia (Table 1, 2).

On the other hand, when the literature was searched for the studies about RAS analyses, we observed that most of the previous studies investigated healthy subjects for normal reference ranges of RAS parameters and the differences between ages, geography, and gender [20, 29–31]. First, Padeletti et al. [29] reported that RAS_r was found at a rate of 49% (13) for 84 healthy individuals in 2012 [29]. Then in 2013, Peluso et al. [30] expanded the strain investigation with volumetric research and reported strain values in normal ranges among 200 healthy volunteers for 3 different strain values. They have reported that the RAS_r was found at a rate of 44% (10), while for RAS_{cd} it was 27% (9), and for RAS_{ct} it was –17% (4). Afterwards in 2018 Brand et al. [31] investigated strain values with 123 women without known cardiovascular disease or risk factors. Ultimately, Soulat-Dufour et al. [11] conducted the most large-scaled multi-center study with 2008 healthy adults. Both Brand et al. and Soulat-Dufour et al. indicated the differences according to the gender. Soulat-Dufour et al. reported that the RAS_r was found at a rate of 45.8% (13), the RAS_{cd} was at –18.4 % (7.5), and the RAS_{ct} was at –27.6% (9.7). We have found approximately similar strain values with previous studies as follows; RAS_r was 39.5 % (13.6), RAS_{cd} was –18.2% (6.3), and RAS_{ct} was –21.3% (6.7). The correlation between the RAS_r and RAS_{cd}, RAS_{ct} was highly strong, while a modest relation has been observed between the RAS_{cd} and RAS_{ct} in the current study. In a study that Vijiiac et al. [32] investigated the RA phasic functions in left-sided heart failure, they have demonstrated that RAS_r, RAS_{cd} and RAS_{ct} are all impaired in left-sided heart failure. They also found similar correlations as we found between

RAS and RVGLS. We have found that RAS_r showed a negative correlation with RVGLS (r= -0.48) while they have also demonstrated negative correlation (r = –0.53) as well. The same is consistent with the correlation between RAS_{ct} with RVGLS. We have found a positive correlation between RAS_{ct} and RVGLS (r = 0.36) in parallel with their correlation (r = 0.35). Nevertheless, the interaction between RAS_{ct} and other echocardiographic parameters, such as the RV S', TAPSE, RVGLS, and RV free wall strain was less than the interaction between reservoir and conduit phases. On the other hand, RAS_{ct} emerged as the predictor of the notch formation in TAPSE curve along with RVGLS and RV free wall strain. Thus, we accept that RAS_{ct} has the power to represent the TAPSE curve configuration irrespective of the impact of other echocardiographic parameters.

CONCLUSION

The changes in the TAPSE curve configuration represents the changes in the atrial contractile phase. The TAPSE curve has two different configurations, which are a notched and a smooth form. This difference corresponds to late diastole, which represents the atrial contractile phase. The descending arm of the TAPSE curve indicates the $RAS_{ct,}$ as to whether it is preserved or not. The notch formation persists if the RAS_{ct} is above –19%. Thus, an easier, more applicable, and more effortless tool the TAPSE can be accept as an indicator of atrial contractile phase. We suggest that the TAPSE curve configuration can be used to estimate the RAS_{ct} practically in daily routine.

Supplementary material

Supplementary material is available at https://journals.viamedica.pl/kardiologia_polska

Article information

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Table 1. Demographic, clinical characteristics, and echocardiographic data of patients

Demographic parameters	All (n = 240)	TAPSE with notch formation (n = 169)	TAPSE without notch formation (n = 71)	*P*-value
Age, years, mean (SD)	47.4 (11.6)	47.9 (11.5)	46 (11.7)	0.25
Gender, females, n (%)	58 (24.2)	17 (23.9)	41 (24.3)	0.95
BMI, kg/m² mean (SD)	26.3 (3.8)	26.2 (4)	26.4 (3.3)	0.77
Heart rate, beats/min, mean (SD)	80 (17)	76 (15)	90 (17)	<0.001
Tachycardia, n (%)	35 (14.6)	10 (5.9)	25 (35.2)	<0.001
Bundle branch block, n (%)	62 (25.8)	47 (19.5)	15 (6.3)	0.28

Co-morbidities, n (%)				
Coronary artery disease	57 (23.7)	20 (8.3)	37 (15.4)	0.05
Diabetes	50 (20.8)	23 (9.6)	27 (11.2)	0.09
Hypertension	81 (33.7)	36 (15)	45 (18.7)	0.06
Chronic renal failure	31 (12.9)	11 (4.6)	20 (8.3)	0.05
Echocardiographic parameters				
Left ventricular end-diastolic diameter, cm, mean (SD)	48.5 (6.9)	48.2 (6.4)	48.6 (6.5)	0.31
Left ventricular end-systolic diameter, cm, mean (SD)	20.4 (4.6)	20.1 (4.3)	20.5 (4.4)	0.26
Left ventricular Ejection fraction, %, median (IQR)	55 (40 – 65)	49.9 (40–60)	58 (45–65)	0.24
Estimated systolic pulmonary artery pressure, mmHg, mean (SD)	29.9 (7.4)	23.9 (8.9)	38.1 (9.9)	<0.001
Tricuspid annular plane systolic excursion, mm, mean (SD)	20.4 (4.9)	21.3 (4.8)	18.3 (4.6)	<0.001
Right ventricular systolic doppler velocity, cm/sec, mean (SD)	10.9 (3.2)	11.2 (3)	10.1 (3.4)	0.01
Right ventricle basal diameter, cm, mean (SD)	38.5 (6.1)	38.3 (6.1)	39 (6)	0.42
Right atrial area, cm^2, mean (SD)	16.7 (5.1)	16.7 (5.3)	16.8 (5.4)	0.8
Right ventricle global longitudinal strain, %, mean (SD)	−19.8 (5.2)	−21.3 (4.4)	−16.2 (5.1)	<0.001
Right ventricle free wall strain, %, mean (SD)	−21.7 (6.1)	−23.6 (4.6)	−17.9 (5.3)	<0.001
RA Reservoir strain, %, mean (SD)	39.5 (13.6)	44.6 (11.7)	27.2 (8.9)	<0.001
RA Conduit strain, %, mean (SD)	−18.2 (6.3)	−20.8 (10.2)	−11.7 (7.3)	<0.001
RA Contractile strain, %, mean (SD)	−21.3 (6.7)	−23.6 (5.9)	−15.6 (4.8)	<0.001
Tricuspid inflow E velocity, cm/sec,	0.51 (0.31–0.71)	0.52	0.5 (0.31–	0.49

median (IQR)		(0.32–0.72)	0.69)	
Tricuspid inflow A velocity, cm/sec, mean (SD)	0.74 (0.3)	0.75 (0.3)	0.72 (0.4)	0.59
Tricuspid inflow E/A ratio, mean (SD)	1.15 (0.6)	1.13 (0.6)	1.18 (0.6)	0.62

Abbreviations: BMI, body mass index; RA, right atrium; TAPSE, tricuspid annular plane systolic excursion

Table 2. Univariable logistic regression analysis of predictors for the notching in the descending arm of the TAPSE curve

Variables	**Odds ratio (95% CI)**	***P*-value**
RA reservoir strain, %	1.16 (1.12–1.20)	<0.001
RA conduit strain, %	1.11 (1.08–1.14)	<0.001
RA contractile strain, %	1.66 (1.42–1.80)	<0.001
EF, %	1.01 (0.98–1.04)	0.338
RVGLS, %	1.52 (1.26–1.78)	0.001
RV free wall strain, %	1.48 (1.26–1.60)	0.001
sPAP, mm Hg	0.98 (0.97–0.99)	0.026
Right ventricle basal diameter, mm	0.98 (0.93–1.02)	0.424
Right atrial area	0.99 (0.94–1.05)	0.081
RV S’	1.11 (1.01 - 1.22)	0.020
TAPSE	1.13 (1.06–1.20)	<0.001
Heart rate	0.97 (0.94–0.99)	0.037

Abbreviations: EF, ejection fraction; RA, right atrium; RV, right ventricle; RVGLS, right ventricular global longitudinal strain; RV S’, systolic excursion velocity; sPAP, estimated systolic pulmonary artery pressure; TAPSE, tricuspid annular plane systolic excursion

Table 3. The relation between right atrial strain values and other echocardiographic parameters

Variables	**RV S'**		**TAPSE**		**RVGLS**		**RVFWS**	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
RA-reservoir strain, %	0.570	<0.001	0.653	<0.001	-0.483	<0.001	-0.505	<0.001
RA-conduit strain, %	–0.530	<0.001	-0.591	<0.001	0.397	<0.001	0.427	<0.001
RA-contractile, %	–0.475	<0.001	-0.511	<0.001	0.369	<0.001	0.364	<0.001

Abbreviations: RA, right atrium; RVFWS, right ventricular free wall strain; RVGLS, right ventricular global longitudinal strain; RV S', systolic excursion velocity; TAPSE, tricuspid annular plane systolic excursion

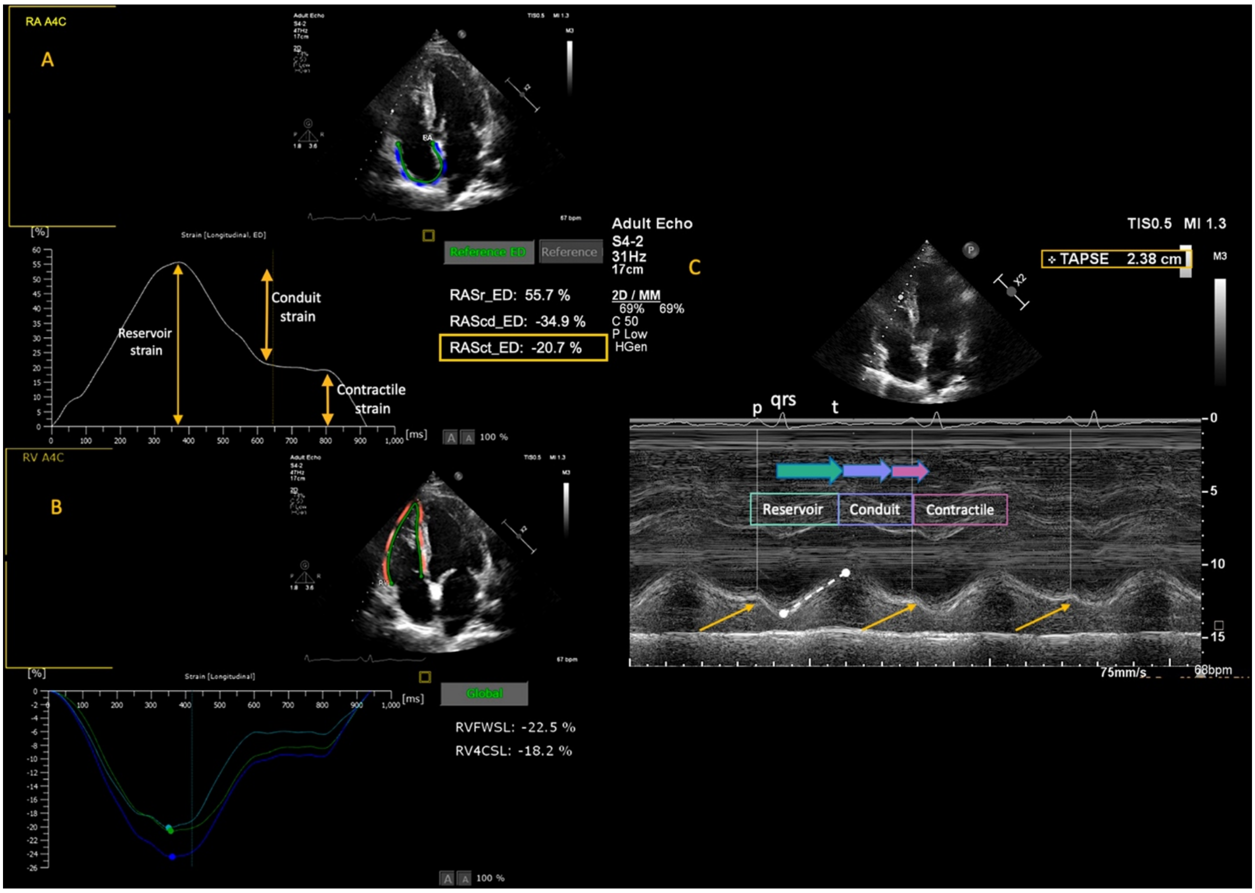

Figure 1. The demonstration of the similarity between atrial strain curve and TAPSE configuration and the notch formation existence on the TAPSE curve while right atrial contractile strain preserved. **A.** Right atrial strain curve. **B.** Right ventricular strain curves. **C.** TAPSE analyses and the notch formation on descending arm

Abbreviations: RASr_ED, end-diastolic right atrial reservoir strain; RAScd_ED, end-diastolic right atrial conduit strain; RASct_ED, end-diastolic right atrial contractile strain; RVFWS, right ventricular free wall strain; RVGLS, right ventricular global longitudinal strain; TAPSE, tricuspid annular plane systolic excursion

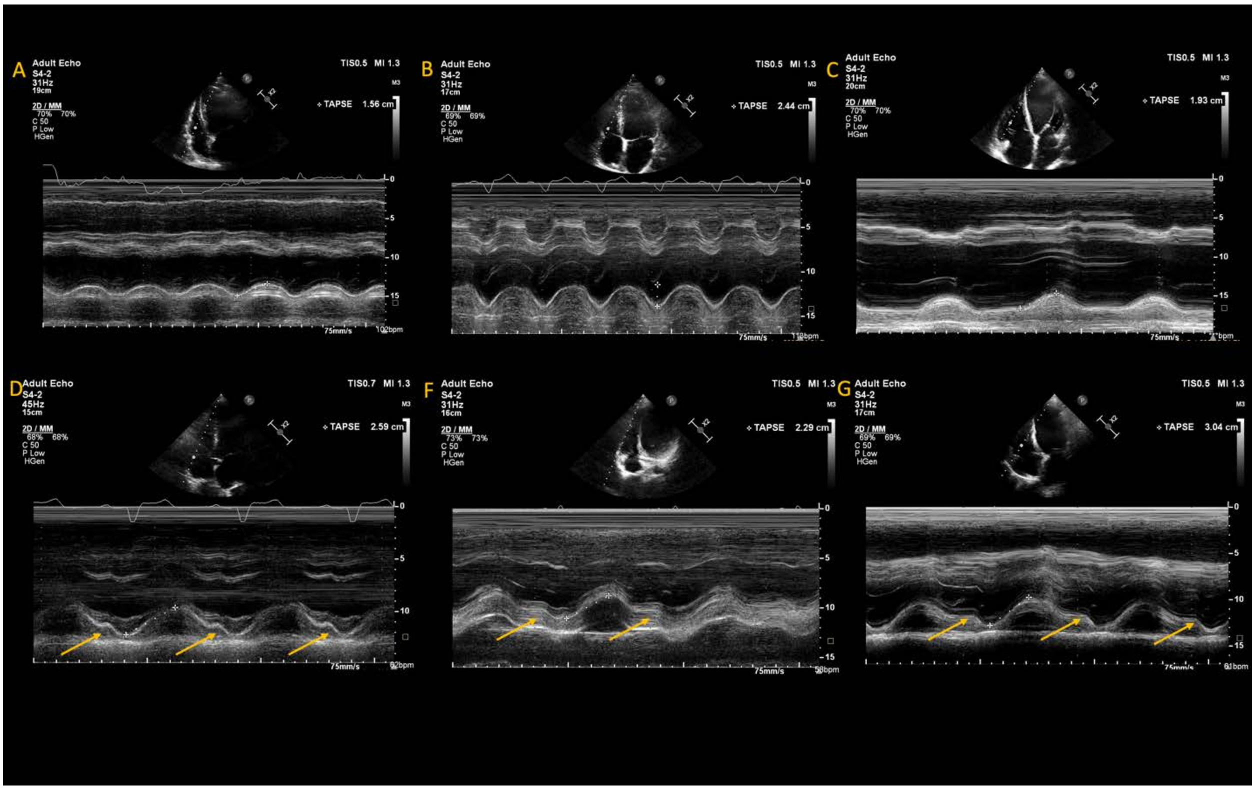

Figure 2. A, B, and C demonstrated TAPSE curves without notch formation while **D, F,** and **G** demonstrated notch formation at the late diastole simultaneously with the p wave. **A.** Right atrial strain curve. **B.** Right ventricular strain curves. **C.** TAPSE analyses and the notch formation on descending arm

Abbreviations: TAPSE, tricuspid annular plane systolic excursion

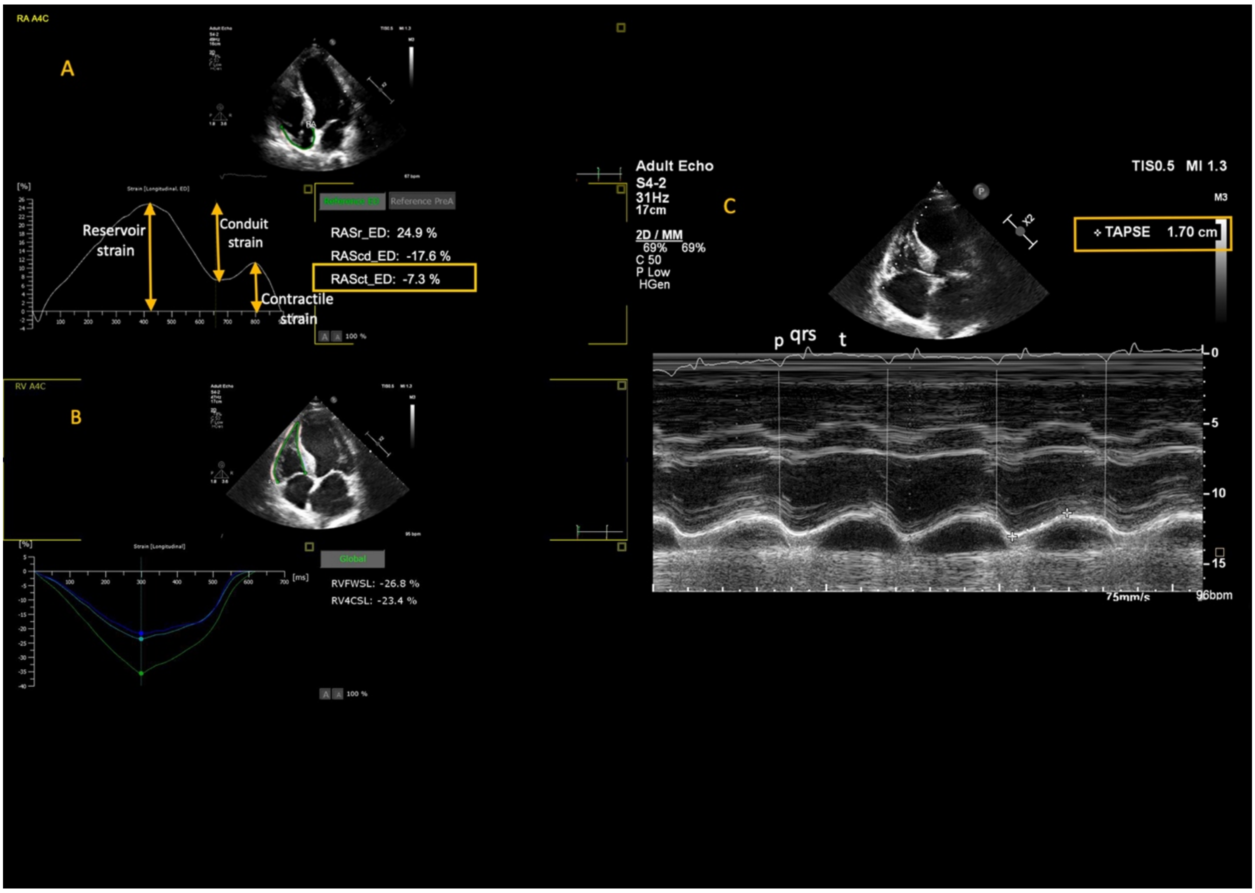

Figure 3. Demonstration of lower contractile strain indicates TAPSE curve without notch formation. **A.** Right atrial strain curve. **B.** Right ventricular strain curves. **C.** TAPSE analyses and a TAPSE curve without notch formation on descending arm.

Abbreviations: RASr_ED, end-diastolic right atrial reservoir strain; RAScd_ED, end-diastolic right atrial conduit strain; RASct_ED, end-diastolic right atrial contractile strain; RVFWS, right ventricular free wall strain; RVGLS, right ventricular global longitudinal strain; TAPSE, tricuspid annular plane systolic excursion