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ORIGINAL PAPER

Right coronary artery motion analysis: a novel method to measure right ventricular systolic function by selective coronary angiography

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Abstract
Right ventricular systolic dysfunction is prognostic in various cardiovascular diseases. Right ventricular systolic function is not commonly assessed in the catheterization laboratory. Therefore, we developed a novel, reproducible method to measure right ventricular systolic function during selective coronary angiography. We analyzed the angiographic systolic translational motion and maximum speed of the right coronary artery (RCA) in 97 consecutive patients and compared it to the tricuspid annular plane systolic excursion (TAPSE) as measured by echocardiography. All measurements were performed by two independent operators on two occasions. Inter-observer variability and intra-observer variability were excellent for RCA motion distance and for RCA maximum speed. There was a significant correlation of the RCA motion distance and RCA maximum speed with the TAPSE measured by echocardiography (Pearson's correlation for RCA distance: $r = 0.59$, $p < 0.001$, $r^2 = 0.35$; for RCA speed: $r = 0.40$, $p < 0.001$, $r^2 = 0.16$). The area under the receiver operating curve for the RCA motion distance was 0.88 (95% CI 0.80–0.96) for discrimination of normal and abnormal right ventricular systolic function. A cut-off value less than 22.3 mm systolic RCA motion had a specificity of 93.3% and a sensitivity of 75.6% for identifying an abnormal right ventricular systolic function. Analysis of the RCA motion is a reproducible and reliable method to measure right ventricular systolic function during selective coronary angiography. It is a simple and useful tool to assess right ventricular function in the catheterization laboratory and may serve for risk assessment for right ventricular failure.
Clinical trial registration Data for this study was collected retrospectively from Swiss Transcatheter Aortic Valve Implantation Registry (NCT01368250). https://clinicaltrials.gov/show/NCT01368250.

Keywords Right ventricular systolic function · Selective coronary angiography · Tricuspid annular plane systolic excursion · Motion analysis · Transthoracic echocardiography

Introduction

Right ventricular (RV) systolic function is a prognostic factor in various cardiovascular entities such as pulmonary hypertension [1], valvular and congenital heart disease [2], as well as heart failure or stroke after myocardial infarction [3–5]. The most commonly used imaging modality to asses RV function is echocardiography, where measurement of the tricuspid annular plane systolic excursion (TAPSE) and the peak systolic tricuspid annular velocity have become a widely used method to estimate RV performance [6–8]. Furthermore, there is now compelling evidence in support of utilizing three-dimensional echocardiography and cardiac magnetic resonance imaging (CMR), for the assessment of RV function. However, despite their noticeable improvement in calculating end-systolic and end-diastolic volume, these modalities remain costly, time consuming and therefore mostly reserved for rare indications [9–11].

Unlike the common practice of assessing left ventricular systolic function during cardiac catheterization by left ventricular angiography, evaluating that of the right ventricle is not routinely performed. Therefore, we sought to develop a method to assess right ventricular systolic function during coronary angiography.

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We hypothesized that measurement of the systolic translational motion of the right coronary artery (RCA) may reproduce the TAPSE as measured by echocardiography. Hence, the angiographic movement of the RCA during systole could be used to evaluate RV systolic function. Indeed, other studies have shown a significant correlation between TAPSE by echocardiography and TAPSE measured by coronary computed tomography angiography (CCTA) [12] or CMR [13]. However, no study has so far investigated the angiographic motion of the RCA to establish a method for RV systolic function assessment by selective coronary angiography.

Methods

Data for this study was collected retrospectively from Swiss Transcatheter Aortic Valve Implantation Registry (NCT01368250). All patients were part of this nationwide, prospective, multicenter cohort study. They all provided written informed consent. This study was approved by the appropriate institutional review boards and was performed in accordance with 1964 Helsinki declaration and its later amendments. This registry was chosen because many included patients underwent transthoracic echocardiography and selective coronary angiography. We investigated 97 patients who underwent transthoracic echocardiography and selective coronary angiography between September 2009 and December 2015.

Inclusion criteria

- Selective coronary angiography and transthoracic echocardiography during patient evaluation for aortic valve replacement.
- Participation in the Swiss TAVI registry with written informed consent for data acquisition and analysis.
- Right dominant coronary artery system or left dominant system with the RCA course in the atrio-ventricular sulcus.
- Right anterior oblique projection in 30° angulation of a selective RCA angiogram.

Exclusion criteria

- Movement of table or respiratory movements precluding measurements in the same cardiac cycle.
- Left dominant system with the RCA taking a course along the right ventricular free wall.
- Proximal or ostial chronic total occlusion of the RCA

Proof of principle

To evaluate right ventricular systolic function, we analyzed the systolic translational motion of the RCA. To measure the motion, we used synedra view program (synedra information technologies gmbh, Innsbruck, Austria).

The angiographic motion of the RCA was measured in a thirty degree right anterior oblique view. RCA movement towards the apex was measured in millimeter at the midpoint between the RCA ostium and the crux cordis at 90 degrees, using the outer edge of the artery as a reference point. The frame rate was 15 frames per second to ascertain accurate measurements (Fig. 1).

Besides measuring the maximum RCA movement distance during systole, we also calculated the maximum speed of the RCA movement during systole by using frame rate and maximal displacement between two frames. We used a 15 frames per second rate to allow comparison between the calculated maximal velocities.

The motion distance and maximum speed of the midportion of the RCA during systole towards the apex was compared to the TAPSE by echocardiography. All measurements were performed by two independent operators on two occasions to assess intra-observer and inter-observer variability. Measurement of TAPSE by transthoracic echocardiography was performed using M-mode imaging through the tricuspid annulus in an apical four-chamber view as previously described [14].

Statistical analysis

RCA motion distance in coronary angiography was compared to TAPSE by Pearson's correlation. To assess

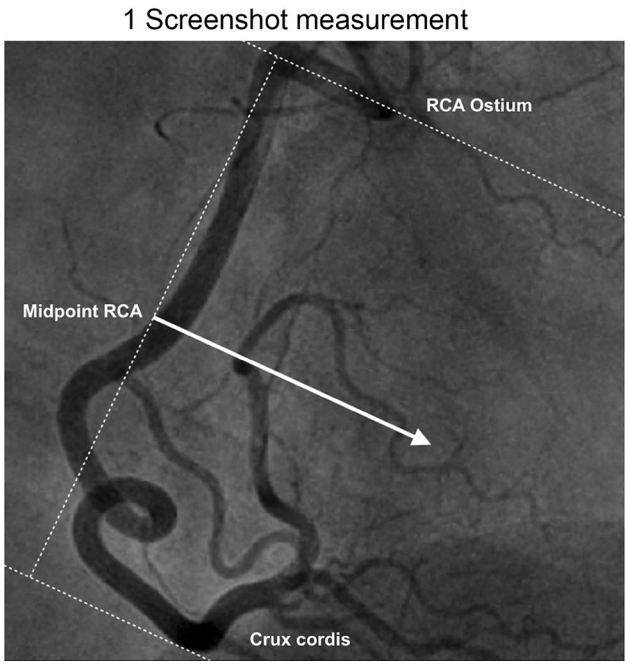

Fig. 1 Measurement of RCA motion

intra- and inter-observer variability Cronbach's Alpha and Bland–Altman analysis was used. Receiver operating characteristic curves (ROC curves) for RCA motion distance and maximum speed of RCA (highest sum of specificity and sensitivity) were drawn. In accordance with recent guidelines, we choose a TAPSE of more than 17 millimeter (mm) as a cut-off value for a normal RV systolic function [14, 15].

A two-tailed p value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS Statistics program (version 23, IBM software, Armonk, New York, United States).

Results

A total of 97 patients enrolled in the Swiss TAVI Registry who underwent a coronary angiography at our center, were included in the analysis. The mean age of the population was 82 ± 6.2 years, of which 44.4% (n = 43) were males.

Overall on angiography, the mid-portion of the RCA moved an average of 25.9 ± 9.9 mm (range 5.5 to 49.2 mm) with a maximum speed of 11.3 ± 4.7 cm per second during systole towards the apex. The TAPSE in echocardiography was 21.2 ± 4.5 mm (range 9 to 35 mm).

Intra- and inter-observer variability analysis

Operators A and B measured all 97 patients twice on two different days to obtain inter- and intra-observer variability. During repeat measurements, the operators were blinded towards the previous reported values.

During independent repeat measurements, the reliability of operator A (Cronbach's Alpha) was 94.7% (95% CI 92.1–96.5, $p < 0.001$) and 95.2% (95% CI 92.8–96.8, $p < 0.001$) and of operator B 98.1% (95% CI 97.2–98.7, $p < 0.001$) and 97.6% (95% CI 96.4–98.4, $p < 0.001$) for the RCA motion distance and RCA speed, respectively. Inter-observer variability was excellent for both measurements (Cronbach's Alpha for distance 97.6%, 95% CI 96.4–98.4, $p < 0.001$; for speed 96.4%, 95% CI 94.6–97.6, $p < 0.001$). The Bland–Altman analysis (Fig. 2) showed that the 95% limits of agreement between the two operators ranged from − 7.84 to 4.17.

Correlation of RCA motion distance and RCA maximum speed with TAPSE by echocardiography

There was a significant correlation of the RCA motion distance and RCA maximum speed with the TAPSE measured by echocardiography (Pearson's correlation for RCA distance: r = 0.59 (95% CI 0.424–0.753), $p < 0.001$, $r^2 = 0.35$; for RCA speed: r = 0.40 (95% CI 0.212–0.586), $p < 0.001$, $r^2 = 0.16$) (Fig. 3).

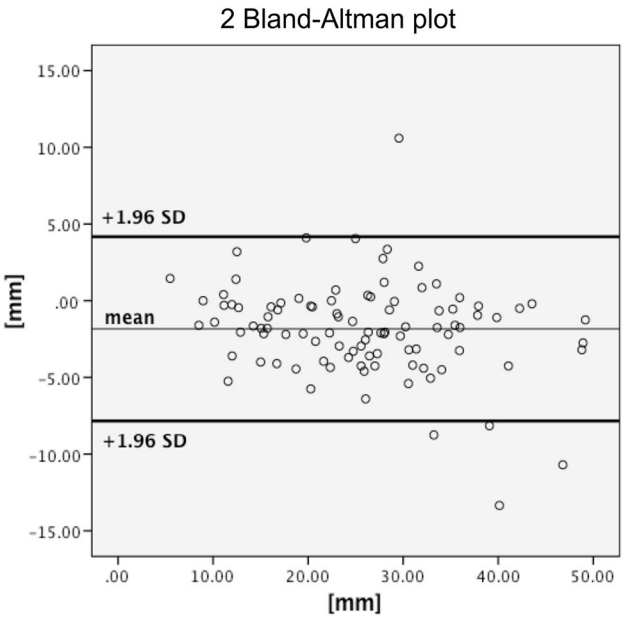

Fig. 2 Bland–Altman plot showing the scatter diagram of differences between operator A and B plotted against the mean RCA motion distance and the 95% limits of agreement

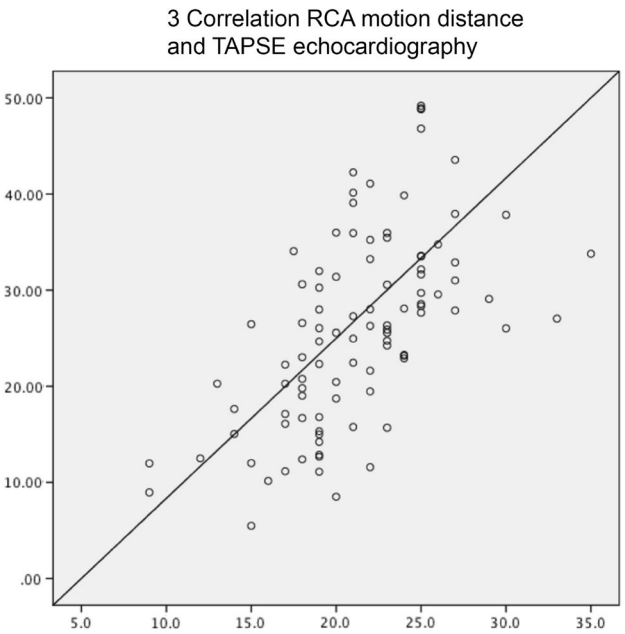

Fig. 3 Correlation of right coronary artery (RCA) motion distance and tricuspid annular plane systolic excursion (TAPSE)

Receiver operating curves for RCA motion distance and RCA maximum speed

In patients with a normal right ventricular systolic function measured by echocardiography the RCA motion distance was 27.8 ± 9.2 mm and the RCA maximum speed was

12.0 ± 4.4 cm per second. The area under the ROC curve for the RCA motion distance was 0.88 (95% CI 0.80–0.96) and for RCA maximum speed 0.81 (95% CI 0.67–0.94) for discrimination of normal and abnormal right ventricular systolic function (Fig. 4). The best cut-off value for RCA motion distance was 22.3 mm with a specificity of 93.3% and a sensitivity of 75.6%.

Discussion

The aim of this study was to develop a simple and reproducible method to measure RV systolic function during selective coronary angiography by analyzing the systolic translational motion of the RCA. Our study demonstrates that RV functional evaluation can be performed by measuring RCA motion distance during coronary angiography with good correlation to TAPSE by echocardiography.

We found a significant correlation of the RCA motion distance and RCA maximum speed with the TAPSE measured by echocardiography. This finding is concordant with previously published data regarding a significant correlation between TAPSE measured by echocardiography and TAPSE by CCTA [12] or CMR [13]. Furthermore, we showed an excellent inter- and intra-observer variability for RCA motion distance and RCA maximum speed during coronary angiography. Hence demonstrating accurate reproducibility of the studied measurements independent of the operator.

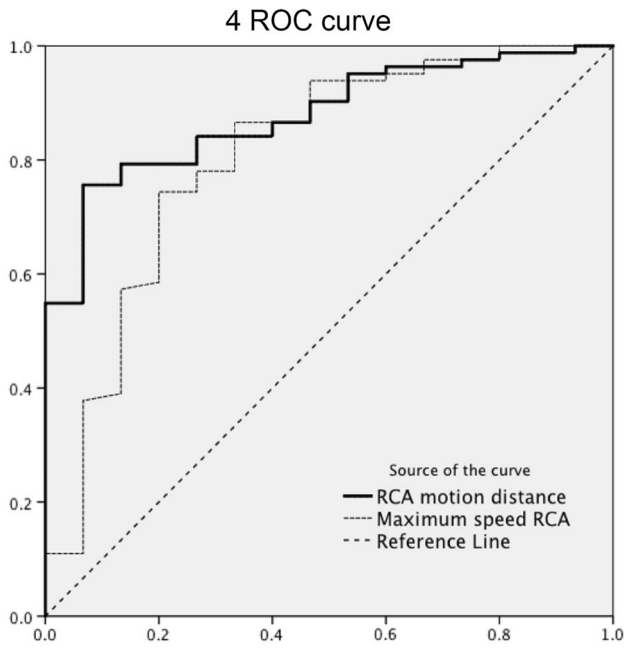

Fig. 4 Receiver operating characteristics (ROC) curve of RCA motion distance and maximum speed of RCA

Overall RCA motion distance and RCA maximum speed demonstrated good diagnostic performance. Analysis of ROC curves show that the area under the curve was greater for RCA motion distance than for RCA maximum speed. A cut-off value less than 22.3 mm systolic RCA motion had a specificity of 93.3% and a sensitivity of 75.6% for identifying an abnormal right ventricular systolic function. Other studies showed similar specificity and sensitivity of their CT [12] or CMR [13] based methods compared to TAPSE. Singh et al. [12], using a cut-off value < 16 mm for a normal TAPSE by echocardiography, found a specificity of 82% and sensitivity 93% for CT-TAPSE.

The presence of arrhythmia, especially atrial fibrillation may be of relevance using this method. However, for the use of TAPSE in echocardiography no specific recommendations are made by current guidelines [14]. Atrial fibrillation may lead to lower (echocardiographic) TAPSE measurements [16], which may also apply for our method.

To date, systolic function of the RV is a blind spot in the cardiac catheterization laboratory. While left ventricular systolic function is routinely assessed by ventriculography, the same method is not validated and rarely used for RV assessment. Echocardiography may not be available during or before coronary angiography, so many patients, who enter the cardiac catheterization laboratory, leave it without knowledge of RV performance. In this study, we introduce a simple and reproducible method to measure RV systolic function in the catheterization laboratory. Our method does not require additional radiation or contrast and no additional software. A 30° right anterior oblique view of the RCA is a routine projection in most centers performing selective coronary angiography. The method does not require sophisticated training and can be measured on most currently used angiography systems. Nevertheless, an automatic measurement would facilitate RCA motion analysis. Upon further validation and establishment of the method, dedicated software integrated into current angiography systems would reduce the time and extra effort of the measurement. Automatic detection of the RCA and RCA movement during the cardiac cycle similar to speckle tracking software meanwhile considered routine in echocardiography may proof adequate to execute the proposed algorithm.

Study limitations

Our study was conducted with a relatively small number of subjects and all patients had similar indications for coronary angiography (as part of the examination for aortic valve replacement). Additionally, due to the same enrollment bias, patients' mean age (82 ± 6.2 years) tended to be older than what is normally seen in the catheterization lab, hence contributing to a less wide range of TAPSE measurements. Furthermore, most of our examined patients were Caucasians.

Therefore, we were not able to evaluate ethnicity-based differences.

In contrast to CMR or three-dimensional echocardiography evaluation of RCA motion distance, coronary angiography remains a two-dimensional indirect method for evaluating RV function. Refinement of cut-off values for our method should be accomplished by analyzing large cohorts with diverse cardiac conditions, ethnicities and ages.

Conclusions

Conclusion and outlook

This study shows as a proof of principle, that analysis of RCA motion is a reproducible method to measure right ventricular systolic function during selective coronary angiography. With this simple and useful tool, right ventricular function can be assessed in the catheterization laboratory. The method needs to be further validated by analyzing larger cohorts with diverse cardiac conditions, ethnicities and ages. An automatic measurement of the RCA motion with integration into current angiography systems would further facilitate the analysis.

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Compliance with ethical standards

Conflict of interest There are no conflicts of interest.

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