RESEARCH

Feasibility of proximal right coronary artery imaging by 2D and 3D echocardiography in comparison to coronary angiography

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Abstract

The present study was carried out to test the feasibility of proximal right coronary artery (RCA) imaging and to detect proximal RCA narrowing and occlusion by 2D and 3D transthoracic echocardiography in comparison to coronary angiography (CA). Standardised 2D and 3D echocardiography were performed prior to CA in 97 patients with sinus rhythm. The following parameters were determined: the longest longitudinal detectable RCA segment, the minimum and maximum width of the RCA, the area and number of detectable narrowing $>50\%$ of the proximal RCA and the correlation between the echocardiographic and angiographic findings. The visualisation of the proximal RCA and the detection of coronary artery narrowing in the proximal RCA are generally possible. Differences in width and area were not statistically significant between 2D and 3D echocardiography, but showed significant differences between echocardiography and CA. For the detection of proximal RCA narrowing, higher sensitivity and specificity values were obtained by 2D than by 3D echocardiography. However, in patients with sufficient image quality 3D echocardiography permits a more detailed visualisation of the anatomical proportions and an en-face view into the RCA ostium. The visualisation of the proximal RCA is feasible and narrowing can be detected by 2D and 3D echocardiography if image quality is sufficient. CA is the gold standard for the detection of coronary artery stenoses. However, the potential of this new approach is clinically important because crucial findings of the proximal RCA can be presumably detected non-invasively prior to CA.

Key Words
► coronary arteries
► right coronary artery
► three-dimensional echocardiography
► transthoracic echocardiography

Introduction

Echocardiography is the most important and most commonly used noninvasive imaging modality in patients with coronary artery disease. However, suspected stenoses of the coronary arteries are routinely detected owing to ischemia-induced wall motion abnormalities at rest and during stress. In addition, determination of coronary flow reserve (CFR) by pulsed-wave Doppler comparing coronary flow signals at rest and during vasodilator stress can be used for the detection of suspected coronary stenoses (1, 2).

The direct visualisation of the morphology of coronary arteries is usually performed by coronary angiography (CA). Although CA represents the diagnostic and therapeutic gold standard for coronary artery imaging in patients with coronary artery disease, specific parts of

native coronary artery branches can also be visualised directly by transthoracic echocardiography. Furthermore, specific vessel parts can be visualised by colour-coded flow signals using 2D and 3D colour-coded Doppler echocardiography (3).

However, the morphological visualisation of specific parts of the coronary artery tree by 2D transthoracic echocardiography is not common in the clinical scenario. The distal part of the left anterior descending (LAD) coronary artery can be detected well by conventional 2D colour-coded Doppler echocardiography in almost all cases. This is due to the fact that the LAD is located in the anterior interventricular sulcus, which is relatively close to the chest wall (4, 5, 6). The detection of other parts of the coronary artery tree is feasible in 50–100% of the cases (7, 8, 9). Specific parts of the right coronary artery (RCA) are detectable in 50–75% of the patients (10, 11).

In case of RCA stenosis >50% the proximal regions are affected more frequently (12, 13). The present study was carried out to test the feasibility of imaging the RCA and to detect proximal RCA stenoses by direct visualisation of the coronary morphology in this region using 2D and 3D transthoracic echocardiography. The echocardiographic results were compared to findings observed by CA representing the gold standard for detection of coronary artery stenoses.

Methods

In the present prospective single-centre study 97 patients (69 males, 28 females; mean age 66 ± 14) were enrolled within 1 year. All subjects provided informed consent after full explanation of the purpose and nature of all procedures and all investigations were approved by the Local Ethical Committee. Only patients with sinus rhythm and sufficient image quality were included. Patients with arrhythmias and verified pre-existing wall motion abnormalities were excluded. Owing to limited image quality in echocardiography, two patients were excluded from the analysis. All patients had an elective indication for CA. All patients were investigated by one physician with a high degree of expertise in echocardiography.

A standardised transthoracic echocardiography was performed prior to the intervention in all patients in left lateral decubitus position (14). Parts of the RCA could be visualised in standardised 2D parasternal views. An improved acquisition of the proximal RCA can be realised by isolated rotations of the transducer starting from the standardised parasternal long axis view (Fig. 1). Additional non-standardised oblique views were acquired to
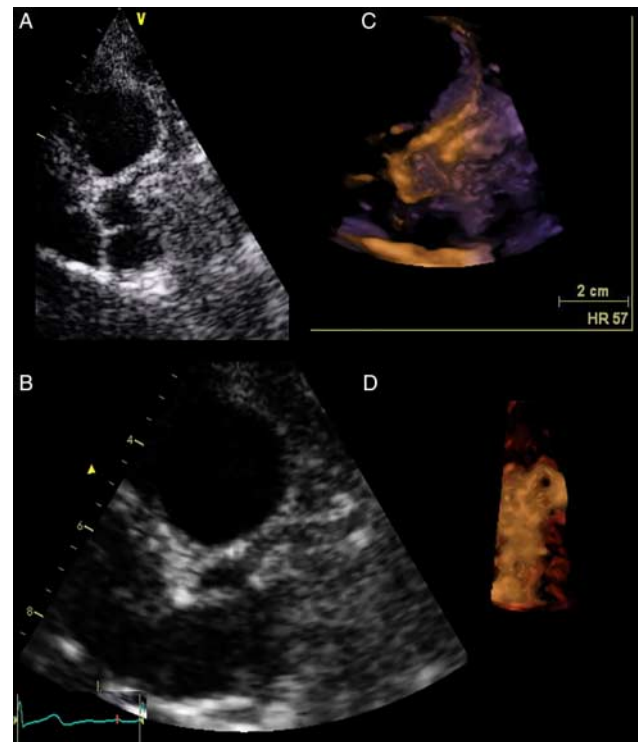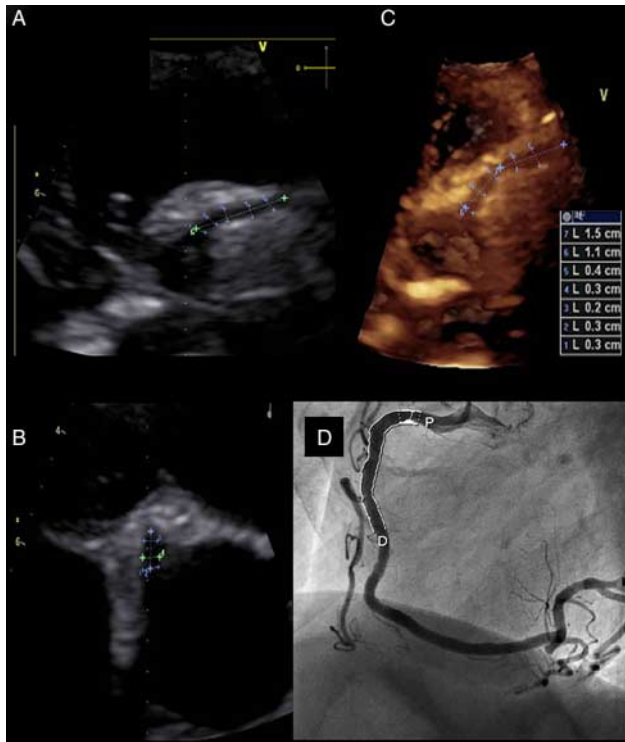

Figure 1
Visualisation of the proximal RCA in a patient without coronary artery stenosis in the parasternal long axis view using 2D (A), 2D-zoom (B) and 3D (C) echocardiography. Furthermore, a 3D 'en-face'-view of the RCA ostium is shown (D).

complement the documentation for visualisation of longer vessel courses and better detection of RCA narrowing (Fig. 2). The parts that could be visualised by 2D echocardiography were subsequently visualised by 3D echocardiography. The use of 3D echocardiography requires a biplane preview. For this reason, it was always acquired after the 2D approach. The biplane preview also permits an optimised 3D acquisition of the proximal RCA and gives a better overview of the anatomical proportions. The analysis of the proximal vessel was also performed by post-processing using the flexi-slice feature.

All data sets were acquired with ultrasound systems of one vendor (Vivid 7 or a Vivid E9, GE Healthcare, Solingen, Germany). 2D echocardiography was performed using a M4S-probe (Vivid 7) or M5S-probe (Vivid E9). 3D4D echocardiography was performed using a 3V-probe (Vivid 7) or 4V-probe (Vivid E9).

CA was performed by a mono- or biplane X-ray system (Philips, Allura Xper FD10/10, FD20, Hamburg, Germany). In all patients the femoral approach was used. Stenoses of the RCA are divided in proximal, medial and distal stenoses due to the localisation of the stenosis (15).

Figure 2
Visualisation of the proximal RCA in a patient with proximal RCA narrowing in the parasternal 2D long axis view (A), parasternal 2D short axis view (B) and with 3D echocardiography (C). Furthermore, the complete course of the RCA obtained by coronary angiography is shown (D).

The left anterior oblique view was used to evaluate the proximal part, the right anterior oblique view to evaluate the medial part and the posterior anterior view to evaluate the distal part of the RCA and the ramus interventricularis posterior.

All measurements were performed offline after post-processing with the algorithm of the EchoPac Software version 112 (GE Healthcare Vingmed Ultrasound AS, Horten, Norway) and the Xcelera main window Q-Analysis Software (Philips, version R3.2L1 SP2 3.2.1.712-2011, Amsterdam, The Netherlands). In all data sets the longest longitudinal course, the minimum and maximum width and the number of detectable stenoses of the proximal RCA were determined. Based on the widths, the minimum and maximum areas were determined by using the formular of the area of disk. Differences in vessel width between 50 and 75% of the maximum area in non-calcified RCA by CA were not defined as stenosis, but the narrowing was measured and the results were included into the cohorts according to the calculated lumen reduction. The narrowing of the vessels was classified into three groups, with narrowing of <50,

≥ 50 and $\geq 75\%$ based on differences in percentage area change obtained by CA, 2D and 3D echocardiography. Occlusions of the proximal RCA were considered separately. For comparison between CA and echocardiography, only the proximal visible RCA by echocardiography was considered. Stenoses of distal parts of the RCA were not taken into account for the morphological comparison of the angiographic and echocardiographic data of the proximal RCA. Metric measurements, e.g. the maximum longitudinal course of the RCA or the determination of the width, were calibrated referring to the corresponding method. All echocardiographic measurements were done prior to the evaluation of the results obtained by CA.

Statistical analysis

The paired Student's t-test was used to compare values of the vessel length, width and area of 2D and 3D echocardiography and CA. A deviation of 1 mm was accepted. P values <0.05 were considered statistically significant. All analyses were performed using the SPSS Software version 20.0. In addition, sensitivities and specificities were determined by the use of two-by-two contingency tables.

Results

Although the complete course of the RCA cannot be visualised by 2D and 3D transthoracic echocardiography, the proximal part of the RCA could be visualised in every patient who was enrolled in the study. In six of 97 patients, a proximal occlusion of the RCA was detected by CA. Each of these occlusions was also detected by 2D and 3D echocardiography.

Depending on the image quality, the length, width and area of the proximal RCA segment could be well determined in 89 of 91 patients (98%) using 2D and 3D

Table 1 The number of patients (n) and the maximum and average length of the RCA referring to the different methods are shown. For comparison, only the proximal visible RCA by echocardiography was considered.

Method	n	Maximum length (mm)	Average length (mm)	P (2D vs 3D)
2D	89	35	18.59 ± 5.39	
3D	89	30	18.72 ± 6.12	>0.05
Coronary angiography	89	Complete course	Complete course	

RCA, right coronary artery.

Table 2 The number of patients (*n*) and the minimum, maximum and average width of the proximal RCA referring to the different methods are shown.

Method	n	Minimum diameter (mm)			P vs CA	Maximum diameter (mm)			P vs CA
		Minimum	Maximum	Average		Minimum	Maximum	Average	
2D	89	1	6	**2.98±1.10**	<0.05	1	7	**3.95±1.14**	<0.05
3D	89	1	5	**3.08±1.03**	<0.05	1	7	**4.15±1.16**	<0.05
CA	89	0.65	3.71	**2.47±0.60**		1.91	5.53	**3.63±0.70**	

P values of <0.05 were considered statistically different. RCA, right coronary artery; CA, coronary angiography.

echocardiography. Thus, for length, width and area measurements of the proximal RCA performed by 2D and 3D echocardiography, 89 patients were considered. The maximum length of the proximal RCA was determined by 2D echocardiography. However, the highest average length was determined by 3D echocardiography. Differences in length were not statistically different between 2D and 3D echocardiography (Table 1).

The minimum, maximum and average widths and areas of the proximal RCA did show significant differences between echocardiographic and angiographic measurements. Obviously, the width could be measured more precisely to two decimal places by CA, leading to minor overestimation in echocardiography. Differences between 2D and 3D echocardiography were not statistically different (Tables 2 and 3).

The number and distribution of the detected stenoses using the different imaging modalities are shown in Table 4. In comparison to CA, an increased narrowing of the RCA and an increase of the degrees of the detected stenoses was obtained by 2D and 3D echocardiography. In addition, in five patients, medial or distal stenoses >50% of the RCA were detected by CA.

In Tables 5 and 6, two-by-two contingency tables for the determination of sensitivity and specificity are shown. Higher values for sensitivity (77% vs 70%) and specificity (64% vs 58%) for the detection of proximal RCA stenosis were observed by 2D echocardiography.

Discussion

Specific parts of the coronary artery tree can be directly visualised by conventional transthoracic echocardiography (16). To our knowledge, this is the first prospective study showing that coronary artery stenoses can be detected by modern 2D and 3D echocardiography at least in the proximal region of a coronary vessel. The main findings of this study are as follows:

i) the visualisation of the proximal course of the RCA and the detection of narrowing in this proximal region is feasible with 2D and 3D transthoracic echocardiography.

ii) The detection of proximal RCA occlusion was possible in all cases that were observed by CA.

iii) The visualisation of the proximal RCA region can be improved by advanced post-processing, leading to an improved visualisation and differentiation of the proximal RCA region. However, the spatial resolution of 3D echocardiography seems to be insufficient in comparison to 2D echocardiography in obtaining better results for the objective detection of vessel narrowing.

iv) However, in patients with sufficient image quality, 3D echocardiography permits an en-face view into the right coronary ostium and an improved visualisation of the anatomical proportions of the proximal RCA region.

Table 3 The number of patients (*n*) and the minimum, maximum and average areas of the proximal RCA referring to the different methods are shown.

Method	n	Minimum area (mm²)			P vs CA	Maximum area (mm²)			P vs CA
		Minimum	Maximum	Average		Minimum	Maximum	Average	
2D	89	0.8	28.3	**7.89±5.85**	<0.05	0.8	38.5	**13.28±7.56**	<0.05
3D	89	0.8	19.6	**8.27±5.45**	<0.05	3.1	38.5	**14.56±7.78**	<0.05
CA	89	0.34	15.84	**6.30±2.62**		2.85	24.05	**10.72±3.98**	

P values of <0.05 were considered statistically different. RCA, right coronary artery; CA, coronary angiography.

Table 4 The number and distribution of the detected RCA stenoses using the different imaging modalities are shown. In ten patients, medial or distal stenosis of the RCA could also be observed by CA, which could not directly be detected by echocardiography.

Degree and distribution of RCA stenoses or narrowing	CA	2D	3D
Stenosis (%)			
<50%	76/89 (85%)	52/83 (58%)	48/83 (54%)
≥50–<75	13/89 (15%)	34/83 (38%)	37/83 (42%)
≥75	0/89 (0%)	3/83 (3%)	4/83 (4%)
Complete stenosis	6	6	6
Proximal	89/89 (13≥50%)	89/89 (37≥50%)	89/89 (41≥50%)
Medial	9/89 (4≥50%)	–	–
Distal	1/89 (1≥50%)	–	–
n	89	89	89

RCA, right coronary artery; CA, coronary angiography.

In current literature the visualisation of coronary arteries with echocardiography is often described with the help of indirect approaches using colour-coded flow signals obtained by colour-coded Doppler echocardiography or by functional tests for stress-induced wall motion abnormalities. In addition, functional testing of flow limitation of the LAD was often described by the determination of CFR of the LAD (1, 2, 3). The proximal RCA is normally not suitable for CFR determination due to inappropriate Doppler angulations of the flow phenomena. Thus, with respect to the visualisation of the proximal RCA from the parasternal approach, Doppler measurements are not suitable and not valid.

The present study focuses on direct visualisation of proximal parts of the RCA. The vessel widths and areas assessed by 2D and 3D transthoracic echocardiography did statistically differ from values obtained by CA. In some cases, the minimum widths were underestimated, owing to oblique views due to secants views of the proximal RCA. Inaccuracies due to secants views can be reduced by 3D echocardiography because this approach enables a more comprehensive post-processing of the acquired 3D data sets. Thus, the visualisation of specific parts of the coronary artery tree requires a high degree of standardisation and a high degree of expertise in the method to avoid secants views.

In comparison to CA, the minimum widths could not be determined with the highest accuracy in echocardiography, which leads to overestimation in echocardiography. In contrast to echocardiographic measurements, minimum widths can be assessed more precisely, or up to two decimal points, with CA.

3D echocardiography enables a new approach for the visualisation of specific parts of the proximal RCA and the detection of RCA stenoses in the proximal regions.

An en-face view permits a direct view into the ostium of the RCA (Fig. 2). Therefore, stenoses of the proximal RCA can be directly detected by 3D echocardiography. In addition, owing to an improved and more comprehensive visualisation of the anatomical proportions, the main vessel of the RCA can be differentiated more precisely from artefacts and smaller side branches of the RCA, which is more difficult in 2D echocardiography. However, currently 3D images can only be acquired with a lower spatial resolution in comparison to conventional 2D images. When calculating the area of vessel narrowing, the error is increased in comparison to the change of vessel width in smaller vessels due to the limited spatial resolution. Thus, in smaller vessels narrowing is rather overestimated by 2D and 3D echocardiography.

CA obviously represents the gold standard for detection of coronary artery stenoses in patients with coronary heart disease. The sensitivity and specificity for the detection of coronary artery stenoses in the proximal

Table 5 A two-by-two contingency table for the determination of sensitivity and specificity for the detection of RCA stenosis by 2D echocardiography is shown.

	CA		
2D area	Diseased (≥50%)	Healthy (<50%)	Total
2D echocardiography			
Positive test	True positive 10	False positive 27	37
Negative test	False negative 3	True negative 49	52
2D-sensitivity: 77% 2D-specificity: 64%	13	76	89

RCA, right coronary artery; CA, coronary angiography.

Table 6 A two-by-two contingency table for the determination of sensitivity and specificity for the detection of RCA stenosis by 3D echocardiography is shown.

2D area	CA		
	Diseased (≥50%)	Healthy (<50%)	Total
2D echocardiography Positive test	True positive 9	False positive 32	41
Negative test	False negative 4	True negative 44	48
2D-sensitivity: 70% 2D-specificity: 58%	13	76	89

RCA, right coronary artery; CA, coronary angiography.

RCA by 2D and 3D transthoracic echocardiography were in acceptable ranges. In general, lower specificities may ensue, owing to oblique secants views leading to underestimation of the vessel width. Lower sensitivities can be observed in case of limited image quality, non-optimised settings of the ultrasound machines and non-sufficient spatial resolution. The main problem in the detection of coronary artery stenoses by transthoracic echocardiography is the fact that only proximal stenoses can be detected. It is known in the literature that the whole course of the RCA could be reconstructed by 2D and 3D transesophageal echocardiography. However, this method is not yet established in clinical routine due to methodological difficulties and time-consuming post-processing (17). In this study, in 11% of the patients distal stenoses or narrowing of the RCA were also verified by CA. However, the visualisation of longer courses of the coronary arteries with even higher spatial resolutions due to further technical developments presumably will have an important impact on achieving higher specificities and sensitivities as well as more precise determinations of the vessel widths.

Conclusions

The visualisation of the proximal region of the RCA is feasible and narrowing in these regions can be detected by 2D and 3D transthoracic echocardiography if image quality is sufficient. CA, however, is the gold standard for the detection of coronary artery stenoses. The potential of this new approach is presumably clinically important because crucial findings of the proximal RCA can be detected noninvasively prior to the coronary intervention.

Limitations

The main limitation of the present study is the fact that only patients with a sufficient parasternal acoustic window were included. Obviously, the image quality has a crucial influence on the acquisition of the data sets and subsequently on the measurements. In addition, the acquisition of near real-time full-volume 3D data sets is influenced by the cooperation of the patient during breath holding to avoid stitching artefacts, which is limited in patients with arrhythmias.

A control group of healthy subjects could not be considered for the analysis because these patients would have had no clinical indication for CA, which is obviously an invasive and risky procedure associated with radiation exposure.

In the present study, only the feasibility of the direct visualisation of the proximal RCA and the detection of proximal RCA stenoses by echocardiography was tested. Distal stenoses of the coronary arteries could be detected directly only by CA.

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