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Role of Imaging Modalities in the Quantitative Assessment of Atherosclerotic Plaques in the Thoracic Aorta

Aim	Comparative analysis of the height of atherosclerotic plaques (AP) in the descending thoracic aorta (TA) according to two-dimensional (2D) and three-dimensional (3D) transesophageal echocardiography (TEE), and contrast-enhanced multislice computed tomography (MSCT).
Material and methods	The TA was examined using 2D, 3D TEE and contrast-enhanced MSCT in 34 patients (20 men and 14 women aged 68 [62; 71] years). AP heights were compared using the Bland-Altman method and the Spearman correlation analysis. This was a blinded comparative study which assessed the AP morphometry using each of the radiation modalities without knowing the results of the method being compared.
Results	100 APs were examined in the descending TA. The mean height of all analyzed APs in the descending TA was 2.2 mm [2; 2.7] for 2D TEE, 3.1 mm [2.7; 3.55] for 3D TEE, and 3.05 mm [2.55; 3.55] for MSCT. The AP heights measured with 2D TEE was statistically significantly smaller than the heights of similar APs measured either with 3D TEE or MSCT. The mean difference (bias) was 0.88±0.34 mm between 2D and 3D TEE, and 0.83±0.41 mm between 2D TEE and MSCT. The correlation coefficients for the AP heights were r=0.87 (p<0.001) between 2D and 3D TEE and r=0.86 (p<0.001) between 2D TEE and MSCT. There were no differences in the height of similar APs between 3D TEE and MSCT.
Conclusion	The three-dimensional reconstruction of AP in the TA by TEE is more accurate for quantitative assessment of AP than a two-dimensional study.
Keywords	Two- and three-dimensional transesophageal echocardiography; multislice computed tomography; thoracic aorta; atherosclerosis; atherosclerotic plaques
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Introduction

The technical and imaging advantages of three-dimensional (3D) transesophageal echocardiography (TEE) in quantifying and assessing the geometry of atherosclerotic plaques in the thoracic aorta (TA) compared with two-dimensional (2D) examination allowed more accurate diagnosis of the ultrasound stage of TA atherosclerosis and complicated plaques [1]. Our previous findings [1] suggest that 3D TEE is more informative than 2D examination in assessing the height, signs of instability, and complex geometry of TA plaques, and that 3D modes should be used in the areas of interest of both verified plaques and localized or diffuse increases in intima-media thickness (IMT) >1 mm. Weissler-Snir et al. also demonstrated larger TA plaques on 3D TEE compared to 2D echocardiography [2]. At the same time, these studies are limited by the lack of a comparative analysis of the accuracy of 2D and 3D TEE in the quantitative assessment of TA plaques with the diagnostic efficacy of multislice computed tomography (MSCT) or magnetic resonance imaging (MRI), which in recent years have been positioned as the leading imaging techniques for aortic pathology, including atherosclerosis [1, 2].

Despite the use of ionizing radiation and iodinated contrast media, MSCT remains the most commonly used imaging modality in the clinic for the diagnosis and follow-up of patients with acute and chronic aortic diseases [3–5]. On the one hand, this is due to the wider availability of the technique and the possibility of using it in patients with severe cardiac and respiratory failure and pacemakers [5]. On the other hand, the undoubted advantages of MSCT are the short examination time, the high spatial and temporal resolution, and the much larger volume of data obtained with extensive post-processing, making it possible to measure the aorta at any level and build three-dimensional reconstructions [5]. In this regard, we chose

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MSCT as a reference technique for comparative assessment of TA plaque height in 2D and 3D TEE and the accuracy of these modes in diagnosing the ultrasound stage of TA atherosclerosis.

Objective

Perform comparative analysis of atherosclerotic plaque height in the descending thoracic aorta using two-dimensional and three-dimensional transesophageal echocardiography and contrast-enhanced multislice computed tomography.

Material and Methods

This study provides the necessary additional data to support the results that were presented in our previous paper [1]. Thirty-four patients (20 male and 14 female, mean age 68 [62; 71] years) referred for MSCT were examined. The main indications for MSCT in the patients examined were diagnosis of the degree of coronary artery stenosis, including assessment of graft and stent patency (n=5); thoracic aortic dilatation of various degrees (n=12); abdominal aortic aneurysm (n=1); aortic wall dissection (n=1); aortic valve stenosis prior to transcatheter aortic valve replacement (n=13). Clinical characteristics of patients are presented in Table 1.

The study was carried out following the Declaration of Helsinki and approved by the Committee on Biomedical Ethics. Written informed consent was obtained from all patients who agreed to participate in the study. Absolute contraindications to TEE and contrast enhanced MSCT, atrial fibrillation, frequent extrasystoles were exclusion criteria.

One day prior to MSCT, fasting 2D and 3D TEE was performed on an Epiq 7G ultrasound diagnostic system using an X8-2t matrix transesophageal transducer. Esophageal intubation was performed in the left lateral decubitus position after topical oropharyngeal mucosal anesthesia (10% lidocaine spray).

The ascending aorta, localizable arch regions, and the entire descending TA were visualized in 2D mode in longitudinal and transverse sections according to the standard protocol using X-Plane scanning [5]. The electrocardiogram (ECG) in the modified II lead was recorded synchronously. IMT was measured at a distance of 25–30 cm from the incisors on the transverse projection of the descending TA in at least three conditional segments and the mean value was calculated. IMT <1 mm with a clear and even contour was considered normal [5]. The 3D examination was performed in Live 3D, 3D Zoom, and Full Volume modes. A series of 2D and 3D videos were recorded on the device's hard drive and later processed offline in the QLab 15.0 workstation. The height of each plaque was measured in 2D and 3D modes. If local or diffuse IMT >1.0 mm was detected in 2D mode, 3D TEE was performed in the area of interest using a combination of Live 3D, 3D Zoom, and Full Volume modes.

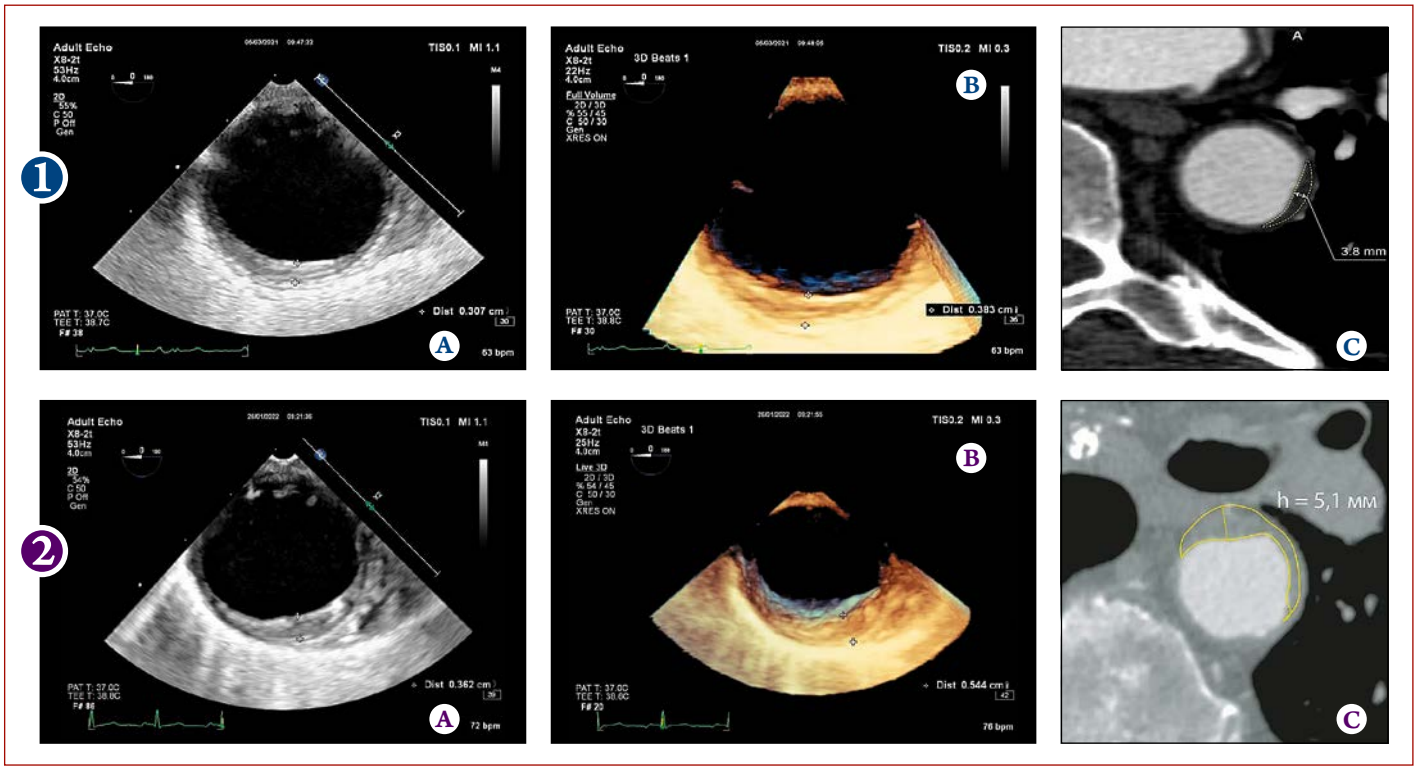
According to the 2015 guidelines of the American Society of Echocardiography (ASE) and the European Association for Cardiovascular Imaging (EACVI) [5], five stages of thoracic aortic atherosclerosis are distinguished: Stage 1 – IMT < 2 mm; Stage 2 – local or diffuse increase in IMT

Table 1. Clinical characteristics of the 34 patients examined

Parameter	Value	
	n	%
Male	20	58.8
Female	14	41.2
Mean age, years*	68 [62; 71]	
Connective tissue dysplasia	4	11.7
Coronary artery disease	24	70.6
Postinfarction cardiosclerosis	11	32.4
History of coronary artery stenting	12	35.3
History of coronary artery bypass grafting	7	20.6
Hypertension (BP > 140/90 mm Hg)	34	100
History of stroke or transient ischemic attack	2	5.8
Chronic kidney disease stage 3–5 (creatinine clearance < 60 mL/min/m^2)	2	5.8
Obesity (BMI ≥ 30 kg/m^2)	14	41.2
Diabetes mellitus type 2 or impaired glucose tolerance	11	32.4
Smoking	9	26.5
Dyslipidemia	33	97.1
Ascending aortic aneurysm without dissection (diameter ≥ 50 mm)	8	23.5
Borderline ascending aortic dilation (diameter 40–49 mm)	6	17.6
Abdominal aortic aneurysm (diameter ≥ 30 mm)	1	2.9
Degenerative aortic valve stenosis	16	47.1
Thoracic aortic atherosclerosis		
• Stage 1	2	5.8
• Stage 2	20	58.8
• Stage 3	9	26.5
• Stage 4	1	2.9
• Stage 5	2	5.8
Carotid stenosis < 50 %	7	20.6
Carotid stenosis ≥ 50 %	31	91.2
Femoral stenosis < 50 %	4	11.7
Femoral stenosis ≥ 50 %	23	67.6
Left ventricular ejection fraction, %*	65 [58; 69]	

* Data are presented as the medians and quartiles (Me [Q1; Q3]).
BP, blood pressure; BMI, body mass index.

Central Illustration. Examples of 2D and 3D TEE and MSCT evaluation of plaque height in the descending thoracic aorta



1A – 2D TEE, plaque height 3 mm; **1B** – 3D TEE, plaque height 3.8 mm; **1C** – MSCT, plaque height 3.8 mm.
2A – 2D TEE, plaque height 3.6 mm; **2B** – 3D TEE, plaque height 5.4 mm; **2C** – MSCT, plaque height 5.1 mm.

of 2–3 mm (small plaques); Stage 3 – plaques > 3–5 mm high without mobile or ulcerogenic components; Stage 4 – plaques > 5 mm high without mobile or ulcerogenic components; Stage 5 – plaques of any height with a mobile or ulcerogenic component.

The contrast-enhanced chest MSCT was performed on an empty stomach on a 64 slice Discovery NM/CT 570c hybrid CT scanner. Intravenous infusion of iodinated contrast agent (Ultravist 370 or Iomeron 400) was used for enhancement in a volume of 60–110 mL, depending on the patient's body weight. Intravenous contrast agent was injected at a rate of 4–5 mL/sec. The examination was recorded in retrospective mode synchronized with the ECG for subsequent reformatting of the images in 10 cardiac cycle phases. The parameters of the examination were as follows: tube voltage 120 kV, tube current 400–600 mA, tube rotating speed 0.3 s, pitch: 0.18–0.22 (depending on heart rate). Images were reconstructed using standard protocols. The slice thickness was 0.625 mm [5]. The resulting images were processed on Advantage Workstations 4.7 with subsequent measurement of all TA sections, creation of volumetric reconstructions, and estimation of plaque height.

The study was blinded and comparative, in which plaque morphometry was performed with each imaging modality used, without knowledge of the results of the method being compared.

Statistical processing of the findings was performed using Statistica 10.0 (StatSoft Inc., USA). The nature of distribution was determined using the Shapiro-Wilk test. Given the non-normal distribution of the sample, the data were presented as the medians and quartiles (Me [Q1; Q3]). Comparison of plaque height in the descending TA on 2D and 3D TEE and on MSCT was performed using the Bland – Altman method. In addition, the relationship between plaque height in the descending TA in 2D and 3D TEE and MSCT was evaluated by correlation analysis, which was performed by calculating Spearman's correlation coefficients.

Results

High-quality images of 100 plaques visualized and measured by 2D and 3D TEE and MSCT of the descending TA were selected for comparative analysis of plaque height.

The mean height of all analyzed plaques in the descending TA was 2.2 [2; 2.7] mm on 2D TEE, 3.1 [2.7; 3.55] mm on 3D TEE, and 3.05 [2.55; 3.55] mm on MSCT. Comparison of plaque height on 2D and 3D TEE and MSCT using the Blend-Altman method confirmed the hypothesized significant discrepancy in the data obtained (Figure 1). We found that plaque height on 2D TEE was statistically significantly lower than the height of the same plaques on 3D TEE and MSCT (Figure 1 and Central figure). This is confirmed by the significant bias and its standard deviation, which was 0.88 ± 0.34 mm between 2D TEE

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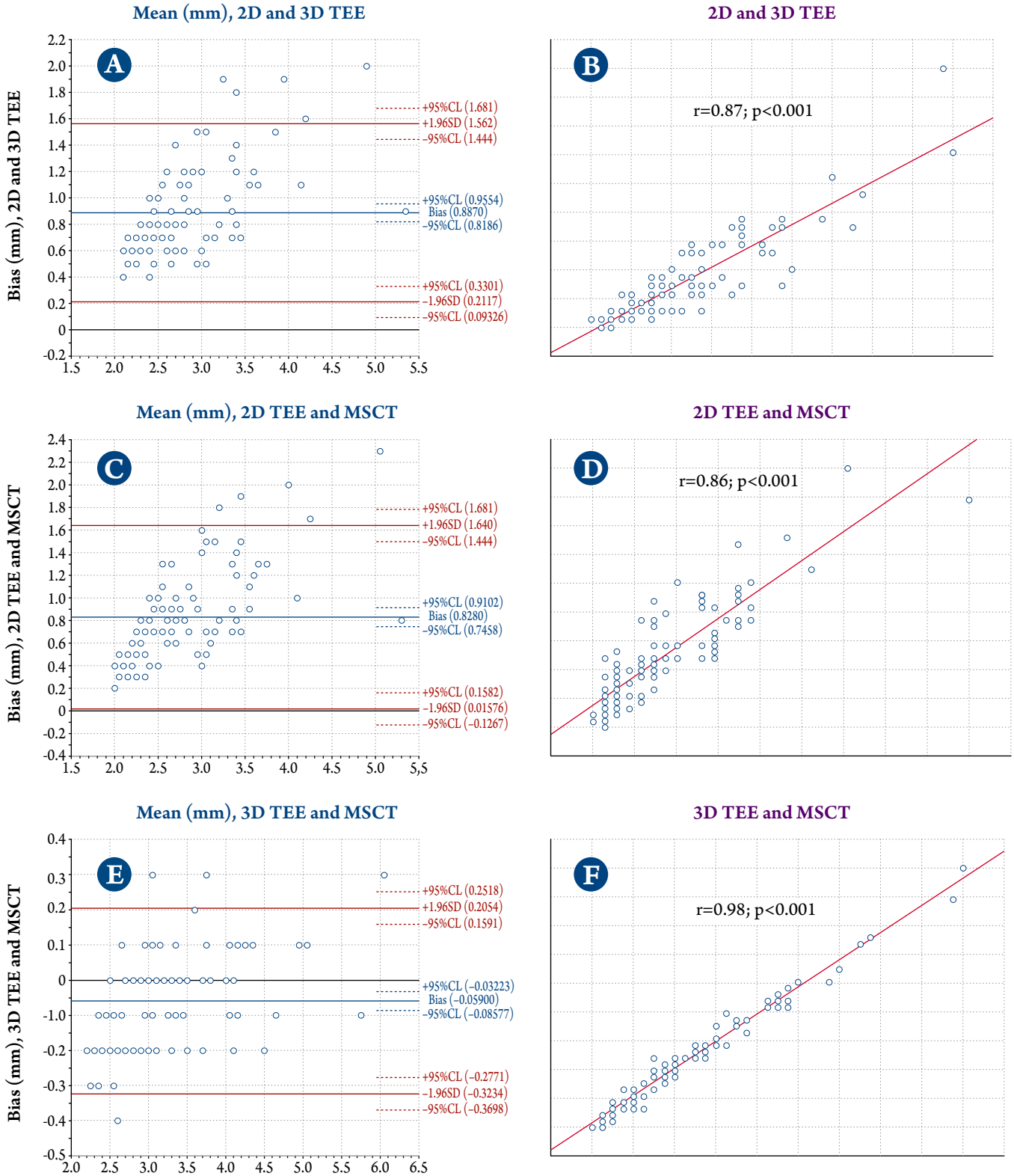
Figure 1. Comparative analysis of plaque height in the descending thoracic aorta in 2D and 3D modes of multiplanar TEE and MSCT by Bland-Altman method and Spearman's correlation analysis (n=100)



A–B: 2D and 3D TEE; **C–D**: 2D TEE and MSCT; **E–F**: 3D TEE and MSCT.

and 3D TEE and 0.83 ± 0.41 mm between 2D TEE and MSCT, despite high statistically significant correlation coefficients for plaque height both between 2D TEE and 3D TEE (r=0.87; p<0.001) and between 2D TEE and MSCT (r=0.86; p<0.001) (Figure 1). At the same time, there was no significant difference between the heights of the same plaques on 3D TEE and MSCT (Figure 1 и Central figure). This was evidenced by the statistically insignificant bias

tending toward zero and its standard deviation, which was –0.06 ± 0.13 mm between 3D TEE and MSCT (Figure 1).

This is supported by our finding of the highest statistically significant correlation coefficient for plaque height between 3D TEE and MSCT ($r = 0.98$; $p < 0.001$).

Discussion

The widespread introduction of 3D TEE into clinical practice has led to changes in diagnostic algorithms and methodological approaches for the evaluation of TA plaques. In our previous study [1], it was shown that 3D reconstruction of TA plaques has an objective advantage over the well-known limitations of 2D imaging, allowing visualization of plaques in stereo structure, from different viewing angles, over a longer length, with the possibility of rotation, which makes it possible to obtain completely different quantitative and structural characteristics of plaques, in contrast to 2D mode.

After analyzing the morphometry of 620 TA plaques according to 2D and 3D TEE data, we found that in contrast to the 2D mode, the plaques are visualized as larger structures in the 3D reconstruction due to greater height [1]. In addition, we have shown that 3D TEE provides more accurate diagnosis and quantification of complicated plaques, especially those with a mobile component [1]. This leads to the diagnosis of higher ultrasound stages of TA atherosclerosis in 3D mode than in 2D mode, which clarifies the clinical diagnosis and is important for dynamic follow-up and prognosis of such patients [1]. At the same time, the previous study was limited by the lack of a comparative analysis of the results of morphometric assessment of TA plaques using ultrasound techniques – 2D and 3D TEE – with data from contrast-enhanced tomography, particularly MSCT.

In this study, using contrast-enhanced chest MSCT as a reference technique, we demonstrated that 3D TEE more accurately reflects the height of TA plaques than 2D mode, which is an important prerequisite for accurate diagnosis of the ultrasound stage of TA atherosclerosis based on plaque height [5]. After performing a comparative analysis of the height of 100 plaques in the descending TA measured by 2D and 3D TEE and MSCT, we found using Bland-Altman analysis and Spearman's correlation analysis that 2D TEE was inferior to both 3D TEE and MSCT in the accuracy of plaque quantification. At the same time, the smallest bias between plaque height in 3D TEE and MSCT and the highest correlation coefficient between them indicate that 3D reconstruction in TEE most objectively reflects the quantitative characteristics of TA plaques. This was not surprising to us because multiplanar reconstruction of TA plaques on MSCT generally reflects the principle of 3D image stereostructure acquisition on TEE. In this context, we expected such a high and statistically significant correlation between plaque height on 3D TEE and MSCT.

The results of the comparative analysis of TA plaque height by known and novel ultrasound technologies and MSCT obtained in this study significantly complement our previous data [1] and are of great practical importance, because due to the wide introduction of 3D TEE into the diagnostic process in recent years, it should be reasonably recommended to perform 3D reconstruction of TA plaques during screening and follow-up examinations in order to more accurately diagnose the ultrasound stage of TA atherosclerosis.

Limitations

We excluded from the analysis single plaques located along the posterior wall of the descending TA that were partially visualized in 2D mode due to the limited sector size of an ultrasound slice. In some cases, large plaques with complex geometries could not be fully visualized in 3D mode due to the limited axial resolution of the ultrasound transducer array.

Conclusion

Three-dimensional reconstruction of atherosclerotic plaques in the thoracic aorta by transesophageal echocardiography is a more accurate tool than two-dimensional examination for quantifying atherosclerotic plaques and diagnosing the ultrasound stage of atherosclerotic changes in the thoracic aorta.

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