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Value of Transesophageal 3D Echocardiography as an Adjunct to Conventional 2D Imaging in Preoperative Evaluation of Cardiac Masses

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Background: This study sought to compare three-dimensional (3D) and two-dimensional (2D) transesophageal echocardiography (TEE) to assess intracardiac masses. It was hypothesized that 3D TEE would reveal incremental information for surgical and nonsurgical management. Methods: In 41 patients presenting with intracardiac masses (17 thrombi, 15 myxomas, 2 lymphomas, 2 caseous calcifications of the mitral valve and one each of hypernephroma, hepatocellular carcinoma, rhabdomyosarcoma, lipoma, and fibroelastoma), 2D and 3D TEE were performed, aiming to assess the surface characteristics of the lesions, their relationship to surrounding structures, and attachments. Diagnoses were made by histopathology (n = 28), by computed tomography (n = 8), or by magnetic resonance imaging (n = 5). Benefit was categorized as follows: (A) New information obtained through 3D TEE; (B) helpful unique views but no additional findings compared to 2D TEE; (C) results equivalent to 2D TEE; (D) 3D TEE missed 2D findings. Results: In 15 subjects (37%), 3D TEE revealed one or more items of additional information (category A) regarding type and site of attachment (n = 9, 22%), surface features (n = 6, 15%), and spatial relationship to surrounding structures (n = 8, 20%). In at least 18% of all intracardiac masses, 3D TEE can be expected to deliver supplementary information. In six patients, additional findings led to decisions deviating from those made on the basis of 2D TEE. In 11 subjects (27%), 3D echocardiographic findings were categorized as "B." Conclusions: Information revealed by 3D imaging facilitates therapeutic decision making and especially the choice of an optimal surgical access prior to removal of intracardiac masses. (ECHOCARDIOGRAPHY, Volume 25, July 2008)

three-dimensional echocardiography, transesophageal, echocardiography, cardiac masses

A heterogeneous group of cardiac diseases is associated with intracardiac masses. Early detection is important. Assessment of mobility, risk of embolism, and benign versus malignant character of the lesion requires sufficient information on morphologic features, the spatial relationship to surrounding structures, extension, surface characteristics as well as type and site of attachment.[1–4] This information is also of utmost importance for selecting an adequate surgical approach if resection is indicated.[5–7] The development of echocardiography, computed tomography (CT), and magnetic resonance imaging (MRI) has greatly improved preoperative diagnostics.[8–10] But however, specifically the area of cardiovascular imaging is undergoing an explosion of new technology, accompanied by ever increasing costs. Nevertheless, the diagnosis itself can almost always be established by transthoracic or transesophageal echocardiography (TEE).[11] Three-dimensional (3D) TEE is cost saving as well and was introduced to combine the advantages of echocardiography with those of CT and MRI, an approach allowing optimized

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morphological and functional analysis.[12] This study sought (1) to evaluate the sensitivity of 3D TEE in comparison to conventional TEE for heterogeneous intracardiac masses and (2) to test if 3D TEE leads to additional management decisions for medical and surgical management.

Materials and Methods

Patients

From 1996 to 2006, 41 patients (22 men, 19 women; mean age 58 ± 13 years) with intracardiac masses were prospectively studied. Patients underwent imaging as part of a search for a cardiac source of embolism (n = 34 [81%]), assessment of tumor spread (n = 5 [12%]), or workup of arrhythmias or angina pectoris (n = 3 [7%]). In 13 subjects (32%), a conservative management was chosen, whereas 28 individuals (68%) were scheduled for surgical therapy. In 29 patients (71%), the diagnosis was established by histopathologic examination. In the remaining 12 cases (29%), the diagnosis was made ex juvantibus, and/or by CT or MRI (Table I). In addition to a physical examination, all patients underwent the following tests: electrocardiogram, chest x-ray, transthoracic echocardiography, conventional TEE. The latter was subsequently compared to 3D image reconstruction.

TABLE I

Classification and Localization of Intracardiac Masses

Diagnosis	Localization	n
Myxoma	LA	14
	LV	1
Fibroelastoma	Aortic valve	1
Lipoma	LV	1
Thrombus	LV	2
	LA	11
	RA/SVC	2
	PFO	1
	Mitral valve	1
Rhabdomyosarcoma	LA/LAA	1
Lymphoma	RA/LA	1
	RA/RV	1
Hepatocellular carcinoma	RA/IVC	1
Hypernephroma	RA/IVC	1
Caseous calcification	Mitral annulus	2

LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle; IVC = inferior vena cava; SVC superior vena cava; LAA = left atrial appendage; PFO = patent foramen ovale.

Echocardiographic Examinations

TEE was performed with 5–7 MHz transesophageal probes and commercial ultrasonographic units (Sequoia C256, Acuson-Siemens Inc., Mountain View, CA, USA and Toshiba SSH 160A, SSA 270A, and SSA 380A Power Vision, Toshiba Inc. Tochigi, Japan). The masses were systematically imaged using distinct transgastric and transesophageal cross-sectional views, in order to identify all segments, to assure precise localization, and to assess the surface characteristics and the spatial relationship to surrounding native structures. After completion of two-dimensional (2D) TEE diagnostics, three 3D data sets were acquired in the rotational scanning mode with a 3D Windows NT work station (TomTec Imaging Systems Corp., Munich, Germany) connected to the ultrasonographic unit (n = 39). In the beginning of the study, parallel scanning with the "lobster tail" probe was used in two patients. The most appropriate data set was then selected for further analysis. For data acquisition, an integral stepper motor rotated the probe from 0° to 180° at 2° intervals or in case of parallel scanning, the stepper motor pulled the probe back in 2 mm steps with electrocardiographic and respiratory gating. Digitized data sets were stored for offline 3D image reconstruction. To facilitate spatial orientation, the following cut planes were used: (a) orthogonal four-chamber view, including the right ventricle and the aorta, (b) two-chamber view, including the left atrial appendage and the aorta, and (c) en face short-axis views from both atria, ventricles and from the ascending aorta if needed. In addition, serial longitudinal cuts were placed through the masses in order to depict the respective site of attachment. Opacity and threshold were adjusted to create suitable 3D images. In each patient, both examinations were analyzed by two experienced observers. The first observer was the person who had performed the examination, the second observer viewed the videotape of the TEE study and performed 3D image reconstruction from the stored data sets. Both observers met all requirements for documentation and maintenance of competency in TEE and for performing perioperative examinations at the advanced level.[13] Observers were mutually blinded to the surgical results.

Classification of Findings Yielded by 3D Imaging

All information obtained from 3D TEE was categorized according to the grading system proposed by Chan et al.[14]: (A) 3D echocardiography provides new findings not detected by 2D echocardiography; (B) 3D echocardiography provides helpful and unique anatomic perspectives but does not yield new findings; (C) 3D echocardiography provides diagnostic information equivalent to the data obtained by 2D imaging; (D) 3D missed findings detected by 2D echocardiography.

Statistical Analysis

Data are expressed as mean ± SD. For categorical variables, frequencies are shown. StatXact 4.0.1 for Windows (Cytel Statistical Software and Services, Cambridge, MA, USA) was used for analyzing the probability for 3D TEE yielding additional information and for calculating confidence intervals of 95%, assuming a multibinominal distribution. Sensitivity of 3D TEE and conventional TEE with respect to type and site of attachment, surface characteristics, and spatial relationship to surrounding structures was comparatively tested using McNemar's test. The effect of the type of mass on the results of either echocardiographic approach was calculated with the chi square test. The paired 2-tailed Student's *t*-test was used to analyze differences between the duration needed for 3D TEE compared with the time required for conventional TEE. Statistical significance was defined as $P < 0.05$. Data were analyzed with SPSS 11.5 for Windows (SPSS, Chicago, IL, USA).

Results

General Findings

Intracardiac masses occurred in all cardiac chambers. In 17 cases (41%), benign tumors and in 5 patients (13%), malignant tumors were found (Table I). Among all myxomas (n = 15; 68% of all tumors), histopathological analysis revealed 10 masses (45% of all tumors) to be of the papillary/gelatinous type and five (23% of all tumors) to be of the ovoid/solid type. In 17 individuals (41%), a thrombus was demonstrated; seven of these thrombi were surgically removed. In the remaining 10 patients (24%), thrombi disappeared after anticoagulant therapy. In two patients (5%), echocardiographic finding of a caseous calcification was supported by MRI and led to conservative therapy.

TABLE II

Confidential Intervals Regarding Category A–D Information

Category of 3D Information	Number of Patients n (%)	Confidential Interval
A	15 (37%)	18–54
B	11 (27%)	12–46
C	14 (34%)	19–57
D	1 (2%)	0–15

Level of confidence = 95%

Comparison of Echocardiographic Methods

In 15 patients (37%), 3D TEE yielded one or more findings consistent with category A, revealing additional information about attachment type and site (n = 9, 22%), surface characteristics (n = 6, 15%), and the spatial relationship to surrounding structures (n = 8, 20%). Sensitivity of 3D TEE regarding functional and morphological characteristics of cardiac masses was higher than the respective sensitivity of conventional TEE (97% vs. 63%; $P < 0.05$). According to calculated intervals of confidence (Table II), 3D TEE carries category A information in at least 18%, but not in more than 54% of patients with cardiac masses. Nevertheless, the frequency of category A information was not related to the type of mass ($P > 0.05$). In 11 subjects (27%), 3D echocardiographic findings were categorized as "B." In 14 individuals (34%), 3D TEE revealed category C information, but in the remaining case (2%) of a lipoma growing intramyocardially and epicardially, only category D information was obtainable.

In six cases (15%), category A information had a marked impact on the subsequent diagnostic strategy and therapy. In one patient (2%), the initially planned surgical approach was modified, in another (2%), a completely different approach was selected. In one of these two patients, two mobile masses were demonstrated in the left ventricular outflow tract (Fig. 1) adjacent to the aortic valve. For resection, these lesions were therefore accessible through the ascending aorta,[6] avoiding a ventriculotomy, while permitting gentle removal of both thrombi. In the other patient, a left atrial myxoma was found to be small and

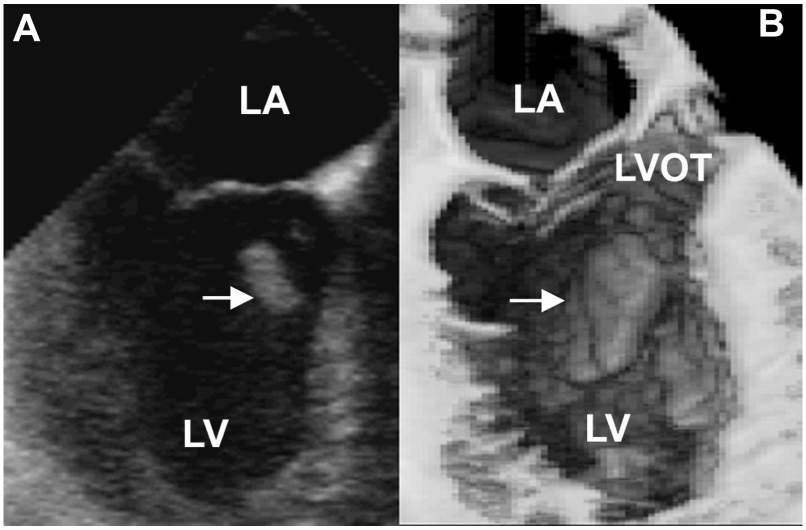

Figure 1. ***A.*** *Two-dimensional image demonstrates one small mass.* ***B.*** *Three-dimensional image reconstruction reveals that there are two masses and shows their spatial relationship to the left ventricular outflow tract. LA = left atrium; LV = left ventricle; LVOT = left ventricular outflow tract; →, masses.*

of the ovoid/solid type, making disintegration from traction unlikely (Fig. 2). The myxoma could therefore be removed through a right atriotomy and septotomy in the region of the fossa ovalis by minimal invasive port access approach, avoiding a thoracotomy. In another patient, in whom a thrombus was seen attached adjacent to the P2-segment of the mitral valve, additional valve reconstruction was planned and successfully carried out. In the fourth patient, who had presented with angina and who was found to have a fibroelastoma with typical attachment to the aortic valve, the mass was clearly observed to occlude the right coronary ostium intermittently. This phenomenon offered sufficient explanation for the patient's angina. In consequence, a risky coronary angiography prior to surgical excision was waived. In the fifth individual with concomitant diseases including chronic atrial fibrillation, a smooth mass suspected to be a thrombus was broadly attached to the interatrial septum. This led to a conservative strategy with long-term anticoagulation (Fig. 3). In the sixth subject with right atrial lymphoma, the decision for operative removal was supported by 3D TEE, which demonstrated a polypoid shape likely to become the source of emboli. Only 3D TEE depicted that the lymphoma was comprised of a bigger and a smaller mass (Fig. 4).

The time needed for 3D TEE (image acquisition and reconstruction) was longer than that required to complete TEE (15.2 ± 1.2 minutes [range 12.1 to 16.3] vs. 9.1 ± 1.4 minutes [range 7.1 to 11.2], $P < 0.05$). The additional time required for 3D TEE was 6.0 ± 1.4 minutes, only.

Discussion

Two pilot studies have evaluated 3D TEE in a small number of patients.[12,15] This is the first prospective investigation of the method's basic and advanced diagnostic capabilities in intracardiac masses. The results are in line with those of a previous study on real time 3D echocardiographic determination of lesion size.[16] The present results add significantly to the few previously reported data. Although intracardiac masses are morphologically and clinically heterogeneous, 3D echocardiography can display their shape, site of attachment, surface characteristics, and interference with surrounding structures with more continuity, integration, or perspective in a greater number of patients. Generally, a 3D image reconstruction contains not more information than the serial 2D images acquired to perform that reconstruction. However, the ability to perform standardized serial image acquisition within a very short time represents an important advantage compared to manual 2D scanning. Moreover, subsequent 3D image reconstruction is capable of combining much partial information from 2D images creating one image or loop. In comparison, it is much more difficult or even impossible to do that integration mentally. Independent of the etiology of the respective masses, more than one-third of patients with intracardiac lesions directly benefit from 3D TEE in that important additional findings can be demonstrated which are not depicted by conventional TEE. In the majority of cases, 3D images are helpful for the assessment of masses and provide additional results

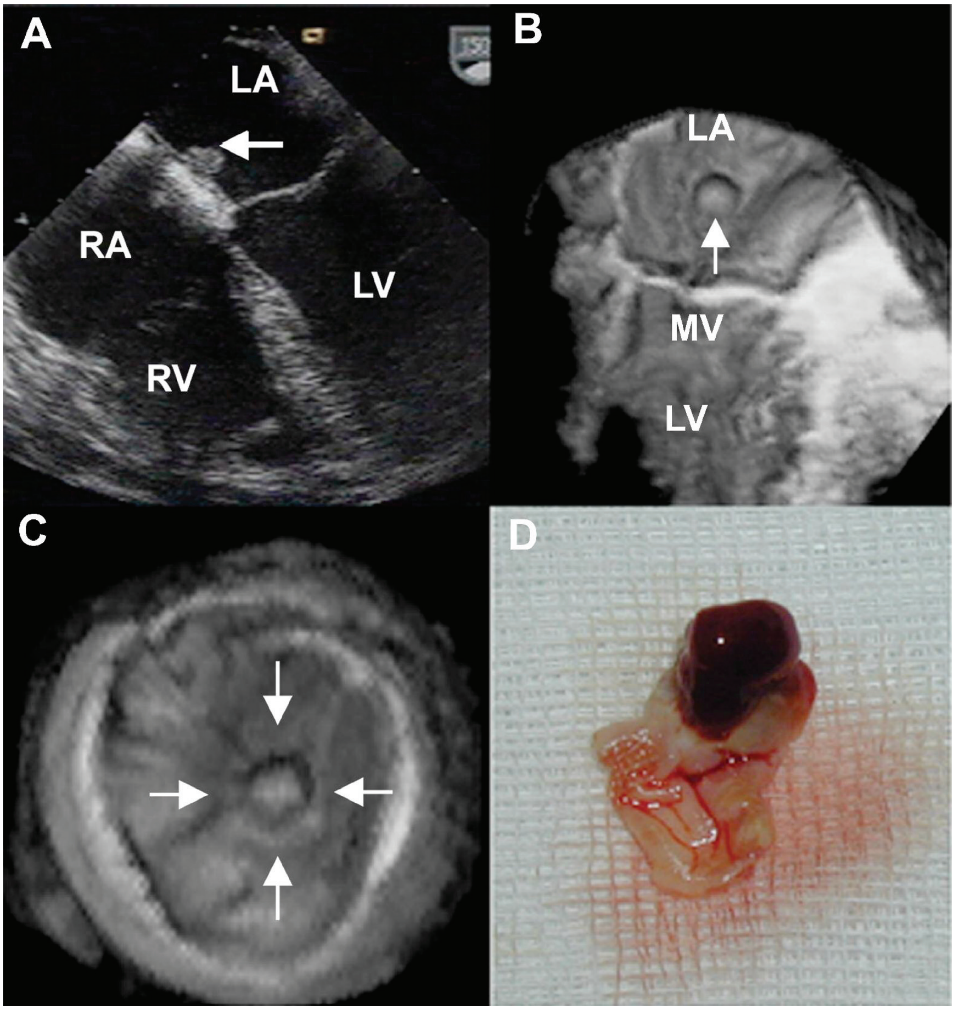

Figure 2. *Small left atrial myxoma of the ovoid/solid type visualized by two-dimensional (**A**) and three-dimensional (**B** and **C**) echocardiography. Spatial imaging permitted to plan tumor excision (**D**) as a minimal invasive procedure using a port access system. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle; →, small myxoma attached to the oval fossa.*

that impact the subsequent diagnostic or therapeutic approach. In almost all other patients, 3D TEE is at least capable of confirming the results of 2D TEE, thereby increasing the reliability of those findings. The only exception was seen in the case of an intramural tumor where an important limitation of the method became evident: 3D TEE provides only en face views of the endocardial surface, which does not permit visualization of completely intramural anomalies. Consequently, superiority of 3D TEE is limited to intracavitary cardiac masses. The method seems to be much less sensitive for intramural tumors or those tumors growing in part intramurally.

Although Gosvami et al. have demonstrated that 2D TEE information considering size, shape, attachment, mobility, prolapse into the ventricle, and surface characteristics of myxomas can generally be confirmed intraoperatively,[17] 3D TEE was shown to reveal supplementary or new information; data of primary significance for surgical and of secondary significance for conservative treatment. For example, myxomas can be classified as having a smooth surface (ovoid/solid type) and can therefore be differentiated from myxomas with an irregular surface (papillary/gelatinous type). The latter type is characterized by a higher rate of embolization due to its tendency to spontaneous

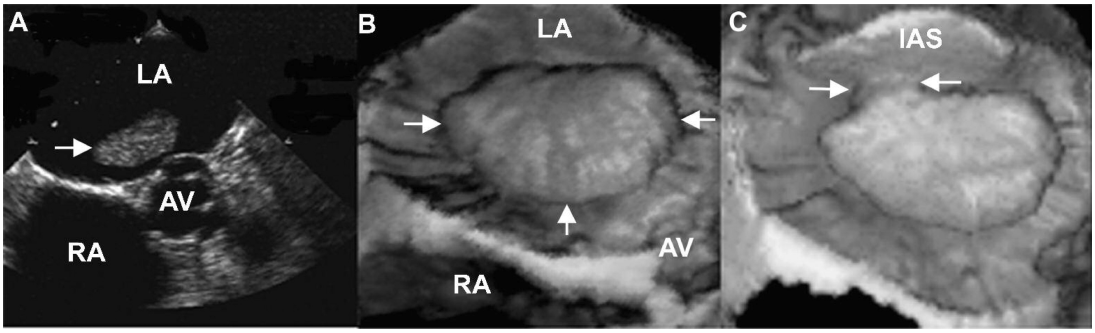

Figure 3. *Two-dimensional imaging (**A**) shows a different lesion size than three-dimensional image reconstruction (**B** and **C**). Only three-dimensional imaging depicts the smooth surface and the lesion's attachment to the interatrial septum. AV = aortic valve; IAS = interatrial septum; LA = left atrium; RA = right atrium.*

fragmentation and self-disintegration.[2] Since myxomas have been reported to embolize in 30–50%,[3] cerebral embolism must be considered an important threat. The fact that 3D TEE explicitly displays the surface characteristics of masses, consequently facilitating risk stratification in comparison to conventional cut plane echocardiographic analysis, is of considerable prognostic significance. The capabilities of 3D TEE stand out even more in the light of today's trend toward minimally invasive surgical excision. In comparison to conventional surgery, more detailed morphological information is required in order to optimally prepare minimal invasive surgery. In that respect, cardiac surgeons attach great value to detailed delineation of the spatial relationship between the surface of a mass and the surrounding native structures, in particular to any interference with the structures crucial to cardiac physiology. In particular circumstances, 3D TEE is even capable of explaining pathophysiological changes, for example, in the case of fibroelastoma occluding the right coronary artery.[18]

In contrast to MRI, which is being considered the gold standard for depicting cardiac masses,[19,20] 3D TEE is much less cost-intensive and can be employed at the bedside [21] as well as in the operation room.[22–24] Another advantage is the fact that any routine 2D TEE can be easily extended to a 3D TEE with little time spent, when there is suspicion for an intracardiac mass. On the other hand, MRI possesses distinct advantages over 3D echocardiography: its ability to predict the most probable tissue diagnosis in many cases.[25,26] To provide anatomical information beyond the heart is another important advantage of MRI and CT. As a future perspective, 3D TEE and MRI may be combined as fusion imaging. This may further

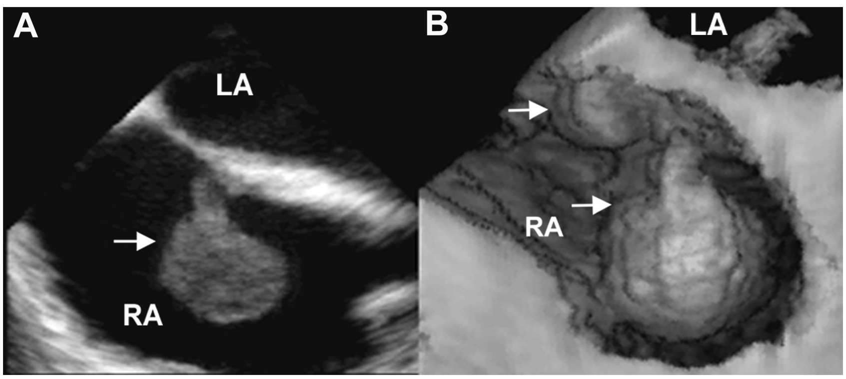

Figure 4. ***A.*** *Right atrial lymphoma visualized by two-dimensional imaging; and **B.** three-dimensional image reconstruction. The smaller part of the lymphoma was overlooked and the attachment site not adequately depicted by conventional echocardiography. Moreover, two-dimensional echocardiography is misleading, suggesting that the mass is attached to the oval fossa and may be a myxoma. LA = left atrium; RA = right atrium; →, lymphoma growing from the transition between right atrial roof and interatrial septum into the right atrium.*

facilitate follow-up examinations in general and especially intraoperative 3D imaging on the basis of preoperative MRI.[27] In that respect, live 3D TEE is prone to increase role of 3D echocardiography by using the experiences from conventional 3D TEE.[28,29]

Limitations

Several limitations must be acknowledged. First, this study is limited by the paucity of some tumors, which are therefore underrepresented, while much more frequently occurring intracardiac masses are overrepresented. Another limitation results from some cases of conservative treatment with anticoagulation and echocardiographic follow-up of lesions without histological validation, that is, undetermined etiology. Moreover, study limitations include also the difficulty and cost of assessing additional imaging information in a randomized fashion, in a truly blinded fashion where the information is not shared with the clinicians caring for the patients and in a systematic fashion where all imaging modalities are obtained on all patients. Finally, as was necessary given the relative low prevalence of cardiac tumors the time frame for the present study spanned over a decade. A period over which 2D and 3D TEE were further developed so that image acquisition, processing, and therefore also image quality changed slightly.

Clinical Implications / Conclusions

The clinical significance of 3D TEE as a diagnostic tool supplementing conventional 2D TEE for diagnosing intracardiac masses has been underestimated up to now. The former method is capable of providing distinct information on any relationship between mass and surrounding structures including hemodynamic interference. However, 3D image reconstruction is restricted to en face views so that intramurally growing masses are not or only in part visualized. In the majority of patients, information revealed by 3D imaging facilitates therapeutic decision making and the choice of an optimal surgical access prior to removal of intracardiac masses, what needs to be weighed against the very little additional time spent. With the ongoing development of minimal invasive surgery, 3D TEE—and especially live 3D TEE as it is introduced right now—may gain increasing importance for optimal spatial conceptualization prior to tissue-sparing and gentle excision of intracardiac masses. Information revealed by 3D imaging facilitates therapeutic decision making and especially the choice of an optimal surgical access prior to removal of intracardiac masses.

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