REVIEW

Three-dimensional echocardiography in congenital heart disease

Échographie tridimensionnelle dans les cardiopathies congénitales

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Summary Three-dimensional (3D) echocardiography has improved dramatically due to technical advances in probe design and computer processing. Congenital heart disease demands a detailed understanding of the spatial relationships of cardiac structures to plan treatment, making 3D echocardiography highly attractive. Novel projections of cardiac structures can be achieved that are impossible by two-dimensional methods, and high frequency probes are now available to allow better 3D imaging in small children. The introduction of a 3D transoesophageal echo probe has extended the applications to real-time guidance of catheter procedures. All of these developments mean that 3D echocardiography is now an accepted complementary imaging technique to conventional cross-sectional echocardiography in congenital heart disease. In addition to morphology, 3D echocardiography can analyse ventricular volumes and function with fewer geometric assumptions than cross-sectional techniques. Analysis of myocardial motion, including 3D tracking of wall motion, is an emerging technique that may become important, particularly in long-term follow-up of operated congenital heart disease. Normal ranges of ventricular volumes and synchrony remain to be established in children. Further improvements in image processing, including automation of analyses and tailoring of software to ventricles of abnormal shape, may move such techniques from a research setting into more mainstream clinical practice.

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Résumé L'échographie tridimensionnelle (3D) a progressé de façon très importante, du fait de progrès techniques tant dans les sondes que dans le traitement informatique du signal. L'exploration d'une cardiopathie congénitale exige une compréhension approfondie des relations spatiales des structures cardiaques, faisant de cette approche échographique une technique particulièrement intéressante dans ce contexte. Les nouveaux plans d'exploration des structures cardiaques peuvent être obtenus, jusque-là inacceptables en échographie bidimensionnelle conventionnelle et des sondes de haute fréquence, actuellement disponibles permettent une évaluation échographique tridimensionnelle chez le petit enfant. L'apport des sondes transoesophagiennes 3D a permis d'étendre les applications de cette approche lors des procédures interventionnelles. Tous ces développements ont permis à l'échographie tridimensionnelle d'atteindre la maturité, et cette approche est maintenant considérée comme une technique d'imagerie complémentaire à l'évaluation conventionnelle 2D dans les cardiopathies congénitales. Outre, l'exploration morphologique, l'échographie 3D permet d'analyser et d'évaluer les volumes ventriculaires, la fonction ventriculaire, sans qu'il soit nécessaire de considérer les hypothèses géométriques qu'imposait la méthode conventionnelle. L'analyse de la cinématique segmentaire, y compris l'évaluation 3D automatique de celle-ci, est une technique émergente dont la place est croissante, en particulier dans le suivi au long cours des cardiopathies congénitales opérées. La définition des valeurs normales des volumes ventriculaires demande cependant à être confirmée chez l'enfant. Des améliorations dans le traitement de l'image, incluant leur caractère automatique, ainsi que le développement de logiciels d'évaluation de la géométrie ventriculaire devraient permettre à cette méthode d'exploration de passer naturellement du stade de la recherche aux applications cliniques en pratique quotidienne.

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Background

Advances in ultrasound probe technologies, image processing and computing power now mean that three-dimensional (3D) echocardiography is technically feasible with spatial and temporal resolution that was previously unachievable. Treatment of congenital heart defects, whether by surgical or interventional means, demands an understanding of the cardiac lesion to plan the optimal approach. 3D echocardiography has the potential to display normal and abnormal cardiac morphology as a true reflection of the actual anatomy rather than depicting user-defined cross-sectional images. The application of 3D echocardiographic techniques extends beyond cardiac morphology and is being used increasingly to evaluate cardiac function in terms of ventricular volumes, ejection fraction and estimation of ventricular dyssynchrony. The aim of this review is to describe 3D echocardiographic techniques that are currently available and how these are being applied to congenital heart disease.

3D echocardiographic techniques

In the past, 3D echocardiographic images were produced by reconstruction of multiple consecutive cross-sectional images into a 3D echocardiographic dataset. The 3D images that resulted thus represented a ‘virtual’ cardiac cycle and images were not truly real-time. A variety of acquisition techniques were described including the use of rotational transthoracic [1–3] or transoesophageal echocardiography probes [4,5]. Although composite 3D images of congenital heart defects were produced, these often had artefacts related to patient movement or due to the reconstruction technique itself (Fig. 1). Importantly, the 3D images produced represented a cardiac cycle that had never truly existed but was a virtual reconstruction from many sequential cardiac cycles acquired by two-dimensional (2D) echocardiography. The acquisition of such data was time consuming, due to the need to wait for the ultrasound probe to rotate through a large angle (typically 180 degrees) in 2–3
degree increments. Post-processing was also relatively slow and was performed offline, which limited the clinical applicability, and certainly made live guidance of procedures impossible. This approach has been superseded by the development of ‘matrix’ ultrasound probes [6,7]. Matrix probes have a number of arrays of ultrasound crystals arranged in parallel on top of each other, which transmit and receive the ultrasound signal. The amount of echocardiographic information generated is vastly greater than conventional 2D systems. Some of the post-processing takes place in the probe itself, to reduce the thickness of cables required to attach the probe to the ultrasound system. This has meant that 3D probes have had to be larger than 2D probes, but the very latest generations of 3D ultrasound probes have become much smaller, with a size and footprint similar to 2D probes. Conventional modalities such as 2D, M-mode, colour flow and Doppler functionality have been incorporated into most 3D probes.

In an analogous manner to 2D echocardiography, 3D images of the heart can be visualized ‘live’ within a user-defined area. Alternatively, a ‘full volume’ dataset, incorporating a larger breadth and depth of view may be acquired, usually over several consecutive cardiac cycles. The larger volume dataset requires post-processing either on the ultrasound system or offline. Some 3D ultrasound systems will now allow acquisition of a ‘full volume’ of data within a single cardiac cycle but with lower image resolution. 3D colour flow Doppler is also feasible on the current generation of 3D echocardiographic equipment but usually with a limited field of view and at a lower frame rate. The range of 3D ultrasound probes has increased to include a paediatric matrix probe (with high frequency and small footprint) [8] to permit optimal imaging of smaller infants and children. 3D transoesophageal echocardiography (TOE) has been made possible by the incorporation of a matrix transducer into the TOE probe. The currently available 3D TOE probe, due to its size, is only suitable for patients with a body weight greater than 25–30kg, which precludes its use in younger children. 3D TOE can facilitate the guidance of catheter procedures in real-time [9,10] as well as the evaluation of surgical repair. For the intraoperative assessment of patients too small for the 3D TOE probe, the alternative of 3D epicardial echocardiographic imaging remains an option [11].

Potential advantages of the 3D echocardiographic approach

Using 2D echocardiography, in either standard or user-defined planes, the image and its subsequent projection are defined at the time of acquisition. In contrast, the 3D dataset can be cut in an infinite number of planes at any time after acquisition. Furthermore the images can be displayed either as series of multiplanar reformatted images (MPR) or as rendered 3D views. The MPR technique permits the operator to view any cross-sectional cut plane and to move sequentially through the dataset. Rendered 3D views can be produced from planes selected by the operator and have the advantage of showing a depth of field. This allows visualization of the spatial relationship of near-field structures to far-field structures within a single projection. The ability to alter the plane of interrogation without limitation, means that some projections, for example en face views of atrioventricular valves or septal structures, can be produced. Such views cannot be achieved using conventional 2D techniques. Once such 3D projections have been produced, our own preference is to rotate the final images into a consistent anatomical orientation so that structures that are superior anatomically are projected uppermost on the image.

Limitations of 3D techniques

There are several technical limitations to 3D echocardiographic techniques. Currently, the spatial and temporal resolution of 3D echocardiographic images is inferior to cross-sectional techniques. Although there is often a facility to optimize frame rate, the resulting 3D frame rates are typically 25–40 frames per second. This is a particular problem in the early newborn period where heart rates are much higher, at 120–160 beats per minute. Thus, high heart rates coupled with the small size and fast movement of cardiac structures are a particular challenge in early infancy. The limitation of frame rate is important not only with respect to cardiac morphology but also with regard to cardiac function, where precise estimation of end-diastole and end-systole is important to derive indices such as ejection fraction and dyssynchrony index. 3D echocardiography should therefore be regarded as complementary to, not substituting for, 2D echocardiography. If a 3D volume of echocardiographic data is acquired over several cardiac cycles, the timing of acquisition is linked to the QRS complex on the electrocardiogram. Significant arrhythmia or patient movement can then create ‘stitch’ artefacts between different segments of the full 3D echocardiographic volume.

Patient selection for 3D echocardiography

Despite the technical advances in 3D echocardiography, the basic principles of ultrasound, relating to probe frequency, ultrasound penetration and axial versus lateral resolution, still apply. Thus, for optimal imaging, good acoustic windows are important. Intracardiac structures such as atrioventricular valves will be relatively easy to visualize whereas acoustically inaccessible structures such as intrapulmonary vessels will not be imaged well regardless of the ultrasound technique used. The introduction of a transoesophageal ultrasound probe has overcome some of the problems of acoustic windows, particularly in older and larger patients. The use of a paediatric matrix probe with a small footprint has also helped to improve image quality in younger children. Patient movement can be a significant problem, particularly in children, necessitating the use of sedation for full volume acquisition. For patients who are mechanically ventilated, a brief suspension of ventilation can optimize image quality by removing respiratory motion.
Figure 2. A. Transthoracic 3D echocardiographic image of the left atrioventricular valve in a patient with an atrioventricular septal defect. The valve is viewed en face from the ventricular aspect in an anatomical fashion so that superior structures are viewed uppermost on the image. B. Left atrioventricular valve viewed from the atrial aspect. Optimal anatomical orientation is obtained by rotation of the 3D dataset and cropping away intervening atrial structures. C. Transoesophageal 3D echocardiographic image of the anatomy of the atrioventricular septal defect viewed from the right atrial aspect. The atrial component of the defect has atrial margins marked by the arrow heads (>). The ventricular margin is marked by asterisks (*). The 3D technique permits this projection of the defect, which cannot be achieved by cross-sectional echocardiography. D. Transoesophageal 3D echocardiographic image of the atrioventricular septal defect viewed from the left atrial aspect. The atrial component of the defect has atrial margins marked by the arrow heads (>). The ventricular margin is marked by asterisks (*). The 3D technique shows clearly the underlying morphology. The relationship of the left ventricular outflow tract to the defect is shown particularly clearly. E. Atrioventricular septal defect following surgical repair. This is a transthoracic 3D image with the left atrioventricular valve viewed from the ventricular aspect. The sutured “cleft” (*) between the superior bridging leaflet and the inferior bridging leaflet can be clearly visualized as well as the triangular shaped mural leaflet. The ventricular septum is indicted by the arrow heads (>). Ant: anterior; AoV: aortic valve; CS: coronary sinus; FO: foramen ovale; IBL: inferior bridging leaflet; Inf: inferior; L: left; LAVV: left atrioventricular valve; LV: left ventricle; PA: pulmonary artery; Post: posterior; R: right; RAVV: right atrioventricular valve; RV: right ventricle; SBL: superior bridging leaflet; Sup: superior; SVC: superior vena cava.
Suitable cardiac lesions for 3D echocardiography

Patients with congenital heart disease are ideal candidates for imaging using 3D echocardiography. Many surgical and catheter interventions are undertaken in younger children in whom sonographic windows are excellent. Given the range of different congenital heart lesions, and the necessity to understand spatial relationships to plan therapy, congenital heart disease has become a major application of 3D echocardiography. Prominent among the cardiac lesions studied are abnormalities of the atrioventricular valves, atrial septal defects, ventricular septal defects and more complex abnormalities of the cardiac connections. These will be reviewed to demonstrate some of the novel advantages of 3D echocardiography. Guidance of catheter intervention for structural lesions will also be addressed.

The atrioventricular valves

In children, repair of atrioventricular valves is far preferable to replacement because this avoids the need for anticoagulation and obviates the need for replacement of mechanical valves simply to accommodate patient growth. For successful repair to be achieved, an understanding of valve morphology and mechanism of valvular closure is essential to plan repair. The 3D echocardiographic technique provides a depth of field that cannot be achieved using cross-sectional techniques and novel projections of anatomy of the valve can be produced, including en face views of the valves. When atrioventricular valves are shown en face, they can either be projected as if being viewed from the ventricle or alternatively as if being viewed from the atrium, which has been termed the ‘surgical’ view. As an example, atrioventricular septal defects can be assessed comprehensively including valve leaflets and the size of the atrial and ventricular components of the defect (Fig. 2). Such comprehensive evaluation involves not only en face visualization of the atrioventricular valves themselves but also en face projections of the atrial and ventricular septums [12]. Use of multiplanar reformatted images, rendered 3D views and colour flow Doppler can provide comprehensive imaging of the lesion, including valve morphology, chordal apparatus, closure mechanism and identification of areas of valvular regurgitation [13–17]. More subtle aspects of the anatomy of the atrioventricular septal defect such as the angle of the valvular leaflets to the crux of the heart have also been investigated with respect to longer-term valve function [14].

Ebstein’s anomaly of the tricuspid valve can be evaluated in detail using 3D echocardiography [18–20]. This can demonstrate features such as the abnormal rotation of the axis of the tricuspid valve and also the anatomy of the chordal attachments particularly their extension into the right ventricular outflow tract (Figs. 3A, B).

Atrial septal defects

The anatomy of atrial septal defects has assumed greater importance since the advent of catheter closure for such defects [21–24] (Fig. 4). Both transthoracic [21,22,25] and transoesophageal 3D techniques [24–26] have been employed with success in the evaluation of the size, location and rims of such defects, either to select patients for transcatheter occlusion or to guide the procedure itself. The 3D echocardiographic characteristics of different types of atrial septal defect have been described [12]. Currently, 3D echocardiography is used mainly as a complementary technique to conventional cross-sectional echocardiography in context of atrial septal occlusion [27]. When planning atrial septal occlusion, our practice is to acquire a full volume dataset, which is then cropped in both multiplanar and
rendered modes to define and measure the size, location, shape and adjacent rims of the defect (Fig. 4A). However, for guidance of interventions, the preferred 3D modality is selection of a limited area of interest, which can be seen ‘live’, i.e. in real-time. This 3D projection can be rotated to view different aspects of the atrial septum. The depth of field of 3D echocardiography is particularly helpful because it can view more of the length of catheters, which hitherto may have crossed the 2D imaging plane. During device occlusion of fenestrated atrial septal defects, for example, the wire or catheter path across the atrial septum can be visualized to ensure that a catheter is crossing through the major defect rather than a smaller fenestration (Figs. 4B C). The deployment of the occlusion device in the left atrium (Fig. 4D), apposition of the device to the atrial septum and release of the right atrial disc can all be visualized in real-time. Following deployment of the occlusion device, 3D echocardiography may assist in the assessment of whether the device is impinging on adjacent cardiac structures and that the devices have been fully deployed and conform to the atrial septum [9,23,24,27–31]. In guiding such procedures, it is our normal practice to rotate the echocardiographic image to an ‘anatomical’ orientation so that if there is an upwards movement of a device or catheter, the image projections on fluoroscopy and echocardiography are concordant [12,27].

Ventricular septal defects

Many of the advantages of 3D echocardiographic assessment of atrial septal defects can also be applied to ventricular septal defects. The size, number, shape and precise location of the ventricular septal defect can be visualized either as a guide to surgical planning or to guide catheter intervention for defects thought suitable for catheter closure [32–34] (Figs. 5A, B, C). The ability of 3D echocardiography to assess the complex shape of some ventricular septal defects [35] makes it an ideal technique to monitor closure of ventricular septal defects [36]. Catheter position is readily assessed using a 3D echocardiographic approach in a similar way to device occlusion of atrial septal defects (Fig. 5B). By appropriate image projection, the interrelationship of the occlusion device, catheter delivery system and the ventricular septal defect can be visualized (Fig. 5C).
3D echocardiography in congenital heart disease.

Complex lesions

With more complex congenital cardiac lesions, the advantages of a 3D echocardiographic approach become even more evident. Novel views of intracardiac relations, not obtainable by cross-sectional techniques can now be projected and may assist in surgical planning [37]. Double outlet right ventricle, for example, includes a diverse range of morphologies. The relationship of the great arteries, the position of the ventricular septal defect and its location with respect to atrioventricular and semilunar valves all present challenges in planning surgical management. The surgical approach must be tailored to the individual anatomy and might include an arterial switch operation, baffling of the left ventricular outflow to the ascending aorta or a single ventricle repair for cases where the heart cannot be septated. Standard cross-sectional echocardiography includes sweeps of cardiac structures in short and long axis to determine the relative position of cardiac structures. 3D echocardiography can produce non-standard, hitherto unobtainable views and with added depth to potentially include all of the components of the planned surgical repair (Figs. 6).

Assessment of ventricular volumes, ejection fraction and dyssynchrony

Three-dimensional echocardiographic techniques are increasingly used for the estimation of ventricular volumes, ejection fraction, regional wall motion and synchrony. 3D techniques make fewer geometric assumptions about ventricular shape than M-mode or cross-sectional echocardiographic methods. The 3D echocardiographic technique involves manual or automated tracing of endocardial borders throughout the cardiac cycle. This allows calculation of end-diastolic volume, end-systolic volume and ejection fraction. Importantly, the 3D techniques assess motion of the endocardium and not myocardial deformation.

The left ventricle

Assessment of left ventricular volume by 3D echocardiography has become relatively automated, which has reduced the time necessary to process acquired volumes. Typically, the operator defines four to five reference points, including the cardiac apex and mitral valve hinge points. The software traces the endocardial contour in three dimensions.
Figure 6. 3D echocardiography of DORV. DORV is a lesion for which an understanding of the precise morphology is essential to plan surgical intervention. This can be achieved by interrogation of the volumetric dataset using multiplanar reformatted images and rendered 3D images. A. Multiplanar reformatted images from a patient with DORV. This technique permits interrogation of the echocardiographic dataset in any user-defined planes. It is particularly helpful to “step through” the anatomy in complex morphologies. B. Rendered 3D echocardiogram projected form the ventricular aspect. This projection demonstrates the anatomy of a patient with DORV visualized from the ventricular apex. The relationship of the left ventricle, ventricular septum (arrow heads, <) and the great arteries is depicted in a single projection. To assist orientation, the image is rotated to bring the diaphragmatic surface of the heart (marked by *) into its true anatomical position. C. Projection of DORV visualized from the right ventricle. In this projection, the free wall of the right atrium, and the right ventricle, have been cropped away. The anatomy is viewed from the right ventricular aspect to demonstrate the relationship of the tricuspid valve, the ventricular septal defect and the great arteries. This may assist in selection of the optimal mode of repair. For reference, the inferior, diaphragmatic surface of the heart is marked by asterisks (*). D. Cropped view from the ventricular apex of the heart in DORV. This projection has been cropped close to the base of the heart to demonstrate the relationship between the mitral valve, tricuspid valve, VSD, aorta and pulmonary artery. In this example, the arrow shows that a route from the left ventricle to the aorta exists without impinging on the tricuspid valve or pulmonary valve. This patient had full repair by baffling from the left ventricle to the aorta through the VSD. Ao: aorta; AoV: aortic valve; DORV: double outlet right ventricle; Inf: inferior; L: left; LV: left ventricle; MV: mitral valve; PA: pulmonary artery; R: right; RV: right ventricle; Sup: superior; TV: tricuspid valve; VSD: ventricular septal defect; <: ventricular septum.

through the cardiac cycle so that a 3D model defined by the endocardial border is produced. The analysis of left ventricular function can extend to segmental analysis using the established 17-segment model of the heart (Figs. 7 A, B). A position statement of the American Society of Echocardiography has been published [38] as well as other comprehensive reviews of the technique [39]. With regard to the timing of endocardial motion in the different segments of the left ventricle, the dispersion of time taken to reach the minimum systolic volume can be used to measure intraventricular dyssynchrony [40,41].

Most of the published data is from adults, but data correlating paediatric or adolescent left ventricular volumetric data with ventriculography [42], nuclear [43] or magnetic resonance [44-46] techniques has shown the technique to be robust. The most recent reports use matrix ultrasound probes [42,45,47] and have addressed not only comparison with other modalities but differences between 3D echocardiographic ultrasound systems and software analyses [45,47]. Although such comparative data are helpful there is currently no large study that has reported normal ranges of left ventricular volumes in a population large enough to produce centiles across a large range of body size from small infants through to adulthood.

Data on synchrony of the left ventricle in adolescents has been published demonstrating a high degree of synchrony (systolic dyssynchrony index < 2%) [48], more synchronous than reported in adults [41]. Such normal data are important given the recognized association between left ventricular dysfunction and dyssynchrony, even in the paediatric age range [49].
Figure 7. A. 3D echocardiography of the left ventricle. A. The 3D outline of the right ventricle is shown in the upper right portion of the image. The colour-coded segments are demonstrated. In the lower section, the volume subtended by each of the cardiac segments throughout the cardiac cycle is illustrated. The time at which each segment reaches minimum volume is shown by the red triangles. The top left shows the systolic dysynchrony index using 16, 12 or 6 cardiac segments. B. This figure shows the 17 segments of the left ventricle in a standardized “bull’s eye” format. The upper part of the figure shows the timing of each segment to reach minimum systolic volume and the lower part represents the excursion of each segment. Thus, the technique facilitates recognition of segments that are abnormal with respect to timing, amount and direction of endocardial motion. This example is from a normal child showing normal synchronous findings.

The right ventricle

A comprehensive overview of the right ventricle in congenital heart disease is beyond the scope of this paper but has been published elsewhere [50]. 3D echocardiographic analysis of the right ventricle differs significantly from the left ventricle. The right ventricle wraps around the left ventricle, with a relatively convex free wall and, normally, a relatively concave contour facing the ventricular septum. Conventionally, the right ventricle is regarded as having an inlet, apical muscular and outflow components without a straight axis, in contrast to the left ventricle. Thus, the more complex shape of the right ventricle compared to the left ventricle hampers geometric modelling. Furthermore, there is no universally accepted segmentation model of the right ventricle to permit regional wall motion analysis. On a practical level, the relatively anterior position of the right ventricle makes it less acoustically accessible than the left ventricle and it can be difficult to incorporate the entirety of the right ventricle into a single 3D echocardiographic volume. This is particularly difficult in postoperative patients such those with operated tetralogy of Fallot in whom the right ventricle is dilated, particularly the right ventricular outflow tract. A recent consensus document relating to adult practice [51] has suggested that a disc summation method is used to estimate right ventricular volume and ejection fraction. Use of the disc summation method is time consuming; software has been developed to try to make this process more automated [52]. Using this approach, models of the right ventricle can be produced that permit calculation of end-diastolic volume, end-systolic volume and ejection fraction (Fig. 8).

In patients with congenital heart disease, rotational 3D echocardiographic transducers have been used to estimate right ventricular volume in comparison studies against angiography [53] or magnetic resonance imaging [54]. Validation studies using 3D matrix probes have suggested that 3D echocardiography can accurately reflect right ventricular volume when compared with phantoms [55] or compared with magnetic resonance imaging [52,56]. The volumes obtained by echocardiography tend to be less than those obtained by magnetic resonance imaging but with closer agreement in terms of ejection fraction. A limiting factor remains the relatively high proportion of patients in whom acoustic windows remain inadequate [56]. A study of smaller children with complex shaped ventricles and single ventricle physiology [57] has demonstrated good correlation between 3D echocardiography and magnetic resonance imaging but has also observed lower ventricular volumes and ejection fraction.

Figure 8. Three-dimensional echocardiographic assessment of the right ventricle. Planimetry of the contours of the right ventricle in a multiplanar reformatted view permits generation of a 3D representation of the right ventricle. This computes the right ventricular end-diastolic volume, end-systolic volume and ejection fraction. The grey regions on the model represent the tricuspid valve and pulmonary valve. PA: pulmonary artery; TV: tricuspid valve.
fraction with the echocardiographic technique compared to magnetic resonance imaging.

3D echocardiographic assessment of myocardial motion

Speckle tracking techniques work by the ultrasound system identifying unique patterns of pixels in the myocardial wall that can be tracked throughout the cardiac cycle on standard cross-sectional images [58]. Strain, strain-rate, rotation and twist can be calculated by the technique [58] and can be applied to congenital heart disease, for example patients following repair of tetralogy of Fallot [59]. 2D speckle tracking is limited to those speckles that remain in plane through the cardiac cycle and does not take account of through-plane motion of the heart [60,61]. Recent advances mean that speckles can now be tracked within a 3D echocardiographic dataset, which has the potential to overcome through-plane movement. This approach has been validated against other reference techniques [62–64] and has potential advantages in congenital heart disease where fibre orientation and pattern of movement of the myocardium is abnormal [65]. At present, 3D speckle tracking remains a research rather than a clinical technique but tracking of the myocardium in patients with congenital heart disease does appears feasible (Fig. 9).

Conclusions

In congenital heart disease, the dominant application of 3D echocardiographic techniques has been as a complementary technique to cross-sectional echocardiography to enhance morphological information. Probe developments mean that resolution has been improved particularly for smaller patients. The introduction of a 3D transoesophageal echocardiography probe has had a major impact on the guidance of catheter intervention. Volumetric and functional applications remain challenging in patients with congenital heart disease due to inconsistent ventricular shape. Further work is required in this area to produce normal ranges according to body size. Technical advances, including better software to account for abnormal ventricular morphology, 3D wall tracking and automation of analyses may help to bring such techniques into routine clinical practice.

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