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The third ultrasound dimension in anaesthesia and intensive care

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The use of perioperative echocardiography is well established in cardiac and non-cardiac practice.1 2 It is indicated for monitoring patients at risk of haemodynamic complications, and also in rescue situations when there may be cardiovascular instability.3 4 There have been advances in transoesophageal transducer technology, specifically the matrix array transducer, which has enabled the acquisition of three-dimensional (3D) images in real time. Standardization of the diagnostic use of 3D echocardiography has been recommended by officials on both sides of the Atlantic.5 6 Increasingly complex perioperative applications of 3D echocardiography are also becoming established for cardiac surgery and in the catheter laboratory. There is now a growing expectation that anaesthetists should be able to obtain accurate clinical measurements to guide decisions in these situations.7 This editorial explores the additional 3D data that could be potentially valuable, over and above standard two-dimensional (2D) ultrasound images.

In current practice, we are required to provide measurements of length, area, and volume of a cardiac structure. Using 2D imaging by a standard phased array transducer, it is possible to obtain cross-sectional images so that the length and area of a structure are measurable in the specific planes, obtained at the time of ultrasound scanning. Often, several 2D images are required.7 Volumetric estimations have to be calculated from geometric assumptions originating from measurements of length and area. Since the development and miniaturization of the matrix array transducer, a pyramidal data set of a cardiac structure may be obtained from the...
transoesophageal position. In contrast with 2D images of specific planes, this volumetric data set may be viewed so that one cross-sectional plane may be analysed simultaneously in relation to another. This multiplanar reconstruction also enables length, area, and volume to be measured. Using current software, three cross-sectional images of a structure are displayed simultaneously and optimized so that the measurement of interest may be made as accurately as possible. One advantage of these additional data relates to the transoesophageal assessment of left ventricular (LV) function. Previously, we have explained that volumetric data are underestimated by 2D images owing to the inability to view the maximum length of the LV in a specific cross-sectional plane. This foreshortening of the LV is obviated when there is a pyramidal data set obtained by 3D echocardiography. Recently, it has been shown that LV volume measured by 3D echocardiography in the intraoperative period is greater than that obtained by 2D echocardiography. In the overall quantification of LV function, these accurate 3D data supplement those obtained by established methods such as Doppler, tissue Doppler, and speckle tracking.

Using the same method of simultaneous display of cross-sectional images, measurements of any length in the aortic root may be made. In anaesthesia and intensive care, the main measurement is that of the diameter of the LV outflow tract which is used for the calculation of cardiac output from the equation:

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\text{Cardiac output} = \frac{\pi}{4} \times \text{diameter}^2 \times \text{velocity time integral} \times \text{heart rate}
\]

Since the long axis of the LV outflow tract can be optimally displayed, possible underestimations or overestimations are minimized, avoiding errors which would be squared in the equation. Furthermore, in the catheter laboratory, multiplanar display of the aortic root enables the distance between the aortic annulus and the left coronary ostium to be measured, so that the most appropriate size and type of transcatheter aortic valve may be implanted in the correct position.

Moreover, it can now be appreciated that structures such as the left ventricular outflow tract and aortic annulus may be oval-shaped rather than absolutely circular. The importance of this anatomical information is that calculations of an area such as that of the aortic annulus from the formula of a circle \([\text{Area} = (\pi \times \text{diameter}^2 / 4)]\) may be inaccurate. In this method, there is an incorrect geometric assumption which is magnified since the diameter is squared. Any inaccuracy may affect sizing of the appropriate aortic valve not only during open surgery but particularly during transcatheter aortic valve implantation. In the latter situation, complications such as severe paraprosthetic aortic regurgitation or patient-prosthetic mismatch may occur.

Measurements of area extend to the quantification of severity of valvular stenosis. Planimetry of the mitral valve area from a traditional 2D image is likely to provide an overestimated measurement. Since the stenotic leaflets form a funnel-shaped structure, there may be excessive angulation and foreshortening in a 2D image, leading to an underestimation of severity of mitral stenosis. However, from a 3D data set, the mitral valve may be viewed in simultaneous cross-sectional planes, allowing planimetry of the borders of the open leaflets (Fig. 1) at the appropriate level. Similarly, the area of the aortic valve may be obtained by multiplanar analysis and planimetry, giving values which have been shown to differ from traditional measurements obtained during application of the continuity equation.

Other than measurements of volume, length, and area, we use this multiplanar analysis of the 3D data set during valve repair. Before aortic valve repair, it is possible to identify, confirm, and quantify malcoaptation between adjacent cusps and hence the mechanism of aortic valve dysfunction. In contrast, using 2D echocardiography, there can be some uncertainty regarding which two cusps of an aortic valve with three cusps are seen in the long-axis view. Their position depends on the position of the probe and the planar angle used during the time of 2D image acquisition.

The same problem occurs during anaesthesia for mitral valve repair when several 2D cross-sectional images at different levels are required to identify the location and mechanism of pathological changes. Fortunately, from a 3D pyramidal data set, simultaneous analysis in multiple planes may be obtained. This process allows a cross-sectional plane of assessment to

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**Fig 1** Multiplanar views of the stenotic mitral valve displayed after acquisition of a 3D data set. The multiplanes are optimized, so that the mitral valve area may be measured by planimetry. LA, left atrium. (a) Image showing the funnel-shaped mitral valve (yellow arrow) in one plane. (b) Image showing the mitral valve (yellow arrow) in another plane. (c) Image showing the mitral valve en face. This view is required for measurement of mitral valve area by planimetry (red arrow). (d) Image showing the three planes of the 3D data set relative to each other.
move across the anterior and posterior leaflets so that the precise location and mechanism of relatively complex malcoaptation of the leaflets, such as commissural prolapse, may be detected. The consequence of the malcoaptation, that is to say, the regurgitant jet, may also be localized accurately in a 3D image and so assist the surgeon to make the most appropriate repair. Furthermore, there may be improved accuracy of quantification of mitral regurgitation. In 2D imaging, we measure the width of the vena contracta and make hemispherical assumptions to calculate its area. However, using 3D colour imaging, it is possible to visualize the volumetric variability of the jet, to avoid such a geometric assumption and thus to reduce measurement error.

In addition to adult practice, 3D echocardiography has revolutionized the clinical assessment and subsequent management of congenital heart defects. For instance, during device closure of interatrial and ventricular septal defects, 3D imaging facilitates improved appreciation of cardiac morphology and guidance of a cardiac catheter through an orifice. Furthermore, after multiplanar reconstruction of the 3D pyramidal data set, the septal defect may be displayed en face showing its area and shape. In this way, appropriate measurements of length may be made before selection and deployment of a closure device. Unfortunately, during 2D imaging, several cross-sectional images have to be obtained to guide the catheter and to find the longest length in an attempt to avoid an underestimated measurement.

Despite these strengths, in particular quantification of LV volume, 3D echocardiography has weaknesses, particularly in relation to ultrasound resolution and expertise required. Although elevational spatial resolution is obtained, there are problems with axial and lateral resolution since some structures of interest within a pyramidal data set are not perpendicular to the direction of the ultrasound beam. In 2D echocardiography, a structure is best viewed when it is perpendicular to the direction of the ultrasound beam and thus as clear as possible. In addition, present 3D transducers acquire images of much lower temporal resolution than those from the 2D modality. To minimize this reduction, the user may have to compromise on axial and lateral resolution by reducing the number of scan lines per frame (called line density), to reduce the size of image, and to acquire ECG-gated subvolumes of a structure which are stitched together. In the intraoperative period, the main implications for the anaesthetist are that the acquisition of large volumes such as the LV and images with 3D colour Doppler, have to be acquired over a few cardiac cycles, provided the patient has a regular rhythm and is not in atrial fibrillation. There has to be communication with the theatre team to avoid the use of diathermy, and respiration has to be held. After temporary acquisition, the ventilator has to be restarted and the image has to be checked for the absence of stitch artifacts before permanent storage for further analysis. In addition to stitch artifacts, some anatomical structures may appear thinner, thicker, or larger than they should be, leading to dropout, blooming, and blurring artifacts, respectively.

Other than issues with resolution, much expertise is required to process the pyramidal data set. In addition to the use of multiplanar reconstruction analysis for specific measurements, the pyramidal data set has to be cropped so that the structures within it may be viewed, with appropriate gain, brightness, and contrast. Despite recent modifications to facilitate cropping, expertise is needed since the structure of interest will have to be rotated to display the features in an appropriate anatomical position. Furthermore, despite its semi-automated features, volumetric analysis of the LV is still operator-dependent and hence subject to some inaccuracy. In a time-dependent environment such as the operating theatre or in the presence of haemodynamic instability, analysis of a 3D data set may not always be practical unless there is additional anaesthetic assistance.

In conclusion, the use of echocardiography has gone from strength to strength since its introduction into the perioperative arena over 20 yr ago. There are courses and accreditation processes for quality assurance not only for its use in the operating theatre but also for intensive care practice. In the next 5 yr, we envisage that the use of 3D ultrasound imaging will be increasingly routine and may extend to other areas of anaesthetic practice. This process will be facilitated by dissemination of expertise, automation from developments in software, and enhanced transducer technology. In this way, we will be able to meet increasing expectations and improve outcomes in the perioperative period.

Declaration of interest

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Pre-procedure ultrasound for central venous cannulation: a peep into reality

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Nothing in the world is more dangerous than sincere ignorance and conscientious stupidity

—Martin Luther King Jr

Today, we are caught in the middle of an indefinably difficult situation with regard to the technique of central venous cannulation (CVC). In spite of being a routine procedure commonly performed by healthcare professionals, it continues to be marred by complications such as cannulation failure, arterial puncture, haematoma, and pneumothorax. The proponents of the age-old landmark technique have been repeatedly accosted by compelling evidence towards high rate of complications.1 2 On the other hand, the propagators of real-time two-dimensional (2D) ultrasound (US)-guided CVC are often

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