Detailing the results of their practical research on animal echocardiography, the CABMM's **Katharyn J Mitchell** and **Colin C Schwarzwald** discuss standardising cardiac imaging

The heart in motion

Interpretation of ultrasound waves, created by the excitation of piezoelectric crystals, has been used as a diagnostic imaging modality since 1954. Initially, the first recordings were from the oscillations of a single point of interest over time, known as A-mode (amplitude) and later M-mode (motion) recordings. Over the following 60 years, there have been amazing advances in the ability to visualise in real time the structure and function of many vital organs using 2D B-mode (brightness) and Doppler modalities. In diagnostic imaging of the heart, the specialised use of ultrasonic waves has become known as echocardiography.

The images obtained using echocardiography can show the cross-sectional anatomy of the cardiac structures, the movement of the myocardium and the flow of blood throughout the cardiac cycle. Echocardiography is used to detect and characterise congenital and acquired cardiac diseases and allows both functional and structural assessment of the heart.

Echocardiography has become a safe, non-invasive, low cost, accessible diagnostic procedure and is routinely performed in cardiovascular evaluations every day. Historically, one and two-dimensional images have been interpreted and multiple imaging planes with complex measurement algorithms have been required to best assess cardiac function as a whole. More recently, inferences about both global and regional myocardial function have been made through the refinement of tissue Doppler imaging (TDI) and 'offline' 2D speckle tracking (2DST) analysis.

Over the past few years, technology has been advancing even faster. The newest echocardiography systems allow the capture of 3D images in real time, creating a 'virtual heart' and showing dynamically the effect of any changes in the structure or function of the heart. Generalised use of this technology will permit faster and more accurate assessment of cardiovascular disease.

Horse echocardiography

In veterinary medicine, the use of echocardiography for the diagnosis of cardiovascular diseases in horses was first reported in 1977. Since this time, echocardiography has become the essential diagnostic technique in equine cardiology. Horses can suffer from a range of cardiovascular diseases that can result in reduced performance, collapse or even sudden death. The detection of cardiac disease via echocardiography is becoming an important part of pre-purchase examinations and in the assessment of poor performance.

Today, access to specialised, portable echocardiographic systems allows veterinarians to rapidly diagnose equine heart disease across many parts of the world. However, it is important to understand the limitations of such imaging techniques. A survey conducted in 2014 of large animal medicine specialists working in equine cardiology showed that there is no general consensus amongst equine echocardiographers on what is considered a standard measurement technique for assessment of heart size and mechanical function. Experience further indicates that a similar lack of consensus also exists in small animal, and even human, cardiology in both clinical and research environments.

Our research group has primarily been working on standardising the use of imaging planes and measurement systems and has published on the reliability of echocardiography in normal horses. This will allow for increased collaboration between researchers in different geographical locations as the images obtained

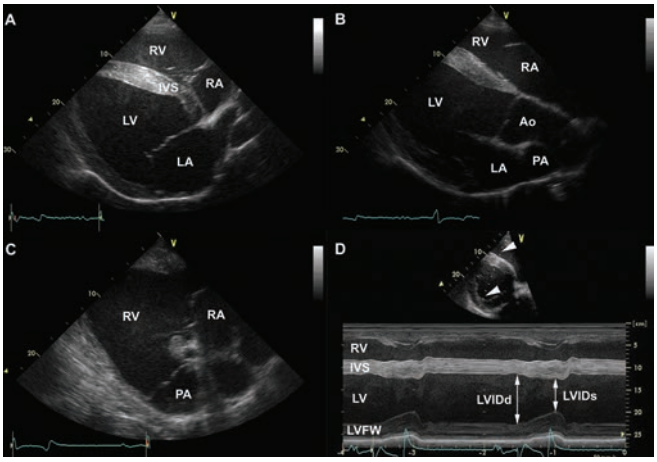

Fig. 1 Standardised views used in equine echocardiography

across echocardiographers should become more consistent.

Fig. 1 summarises the standard echocardiographic imaging planes routinely used in most mammal species. These views make up the basic framework for a standardised cardiac imaging examination to assess both structural and functional changes in horses (and other species) with cardiovascular disease. In the image, A shows a right parasternal long axis four-chamber view focused on the left atrium, whereas B indicates a right parasternal long axis left ventricular outflow tract view. C represents a right parasternal long axis right ventricular outflow tract view, whilst D symbolises a right parasternal short axis M-mode of both ventricles at the level of the chordae tendineae.

Additionally, our group has been pioneering the use of advanced imaging techniques such as tissue Doppler imaging and 2DST in horses by describing the relevant techniques and proving reliability of the methods.

Wall motion analysis

Tissue Doppler imaging allows the measurement of myocardial velocities during the cardiac cycle, particularly as the ventricle contracts during systole and relaxes during diastole. The images shown in Fig. 2 were obtained from a horse suffering from nutritional myopathy involving severe myocardial necrosis and inflammation. On initial presentation, abnormalities in diastolic function resulting in decreased ventricular relaxation were detected on TDI (Fig. 2A). After appropriate treatment, improvements in diastolic function were detected (Fig. 2B-C).

Fig. 2 shows a pulsed-wave tissue Doppler imaging (PW TDI) image of the left ventricular free wall recorded at the level of the chordae tendineae in a right parasternal short axis view of a horse with nutritional cardiomyopathy (A-C) and a normal horse (D). The abnormal ventricular relaxation pattern (i.e. inversion of the Em/Am ratio) confirms myocardial disease primarily affecting diastolic function. The horizontal scales of the spectral tracings indicate the time in seconds; the vertical scales indicate the velocity in centimetres per second. S1 represents peak radial wall motion velocity during isovolumic contraction; Sm, peak radial wall motion velocity during ejection; E1, peak radial wall motion velocity during isovolumic relaxation; Em, peak radial wall motion velocity during early diastole; and Am, peak radial wall motion velocity during late diastole.

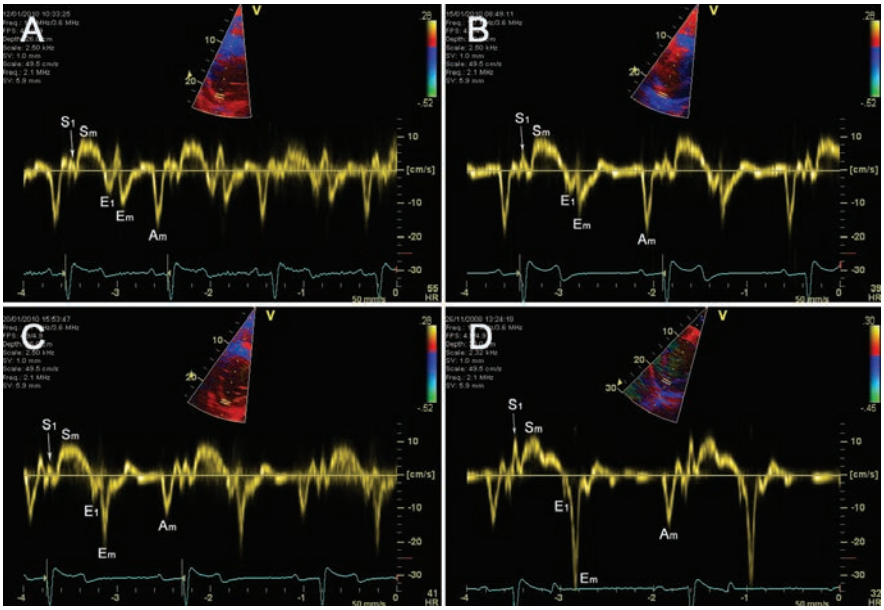

Fig. 2 A) PW TDI on day four; B) PW TDI on day seven; C) PW TDI on day 12; D) PW TDI of a healthy horse. Note the Em/Am inversion on days four and seven, indicating diastolic dysfunction and impaired ventricular relaxation

Offline 2DST analysis can be performed based on 2D B-mode images to quantify the percent deformation (strain), the rate of deformation (strain rate), and absolute motion (displacement, rotation) of the myocardial tissue during the cardiac cycle (Fig. 3). This provides additional information on both regional and global myocardial function. This

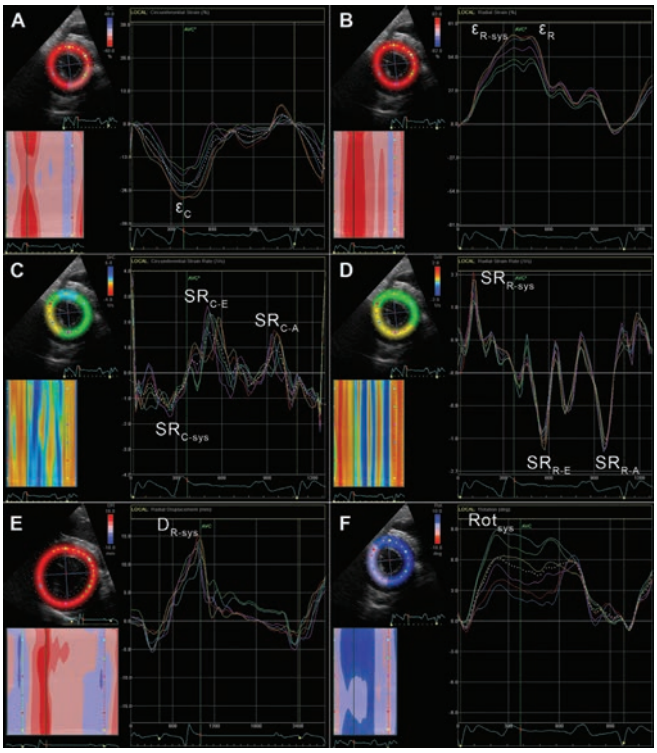

Fig. 3 Trace screens of the 2DST software displaying the following information: A) Circumferential strain (εc); B) Radial strain (εr); C) Circumferential strain rate (SRC) during systole (sys), early diastole (E) and late diastole (A); D) Radial strain rate (SRR) during systole, early diastole and late diastole; E) Radial displacement (DR); F) Rotation (Rot)

technique has been utilised to evaluate and quantify the effect of exercise on myocardial motion, hoping to detect subtle decreases in myocardial function in horses with poor performance.

The top left panel of Fig. 3 shows a 2D image with the segmented region of interest (ROI) and parametric colour coding at the time of aortic valve closure, whilst the bottom left image shows M-mode with parametric colour coding. The right image demonstrates a trace display for the selected variable – the colours of the traces correspond to the colours of the segmented ROI. The dotted line (where shown) indicates the instantaneous average of all segments at the respective time of the cardiac cycle. An ECG is plotted for timing purposes. The start and the end of the cycle (S waves) are marked on the ECG with yellow dots. The time of aortic valve closure is indicated by a green vertical line dividing the cycle into its systolic and diastolic components.

Fig. 4 The VisualSonics Vevo 2100 preclinical imaging platform at the Vetsuisse Faculty, University of Zürich, Switzerland

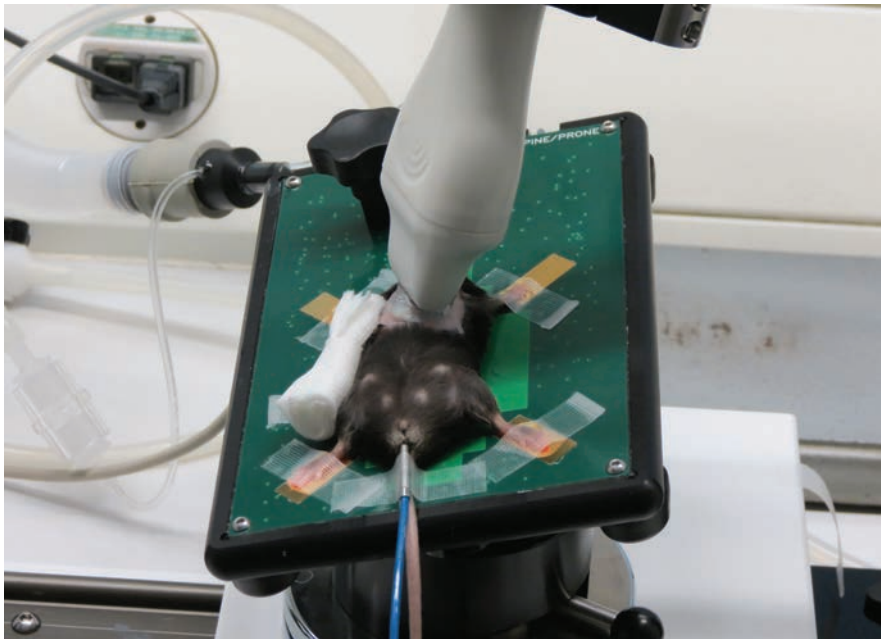

Fig. 5 An anaesthetised mouse is positioned for echocardiography using the VisualSonics Vevo 2100 preclinical imaging system

Preclinical echocardiography

Concurrently, the application of echocardiography in the preclinical research context has been evolving rapidly. The availability of rodent imaging platforms has revolutionised the research capacity of many scientific cardiovascular projects. The use of very high frequency transducers allows high quality image acquisition of many research species, including mice, rats and rabbits (Figs. 4 and 5). Advances in software technology have led to the quantitative assessment of global and regional myocardial function with tissue Doppler imaging and 2DST (Figs. 6 and 7). Furthermore, the use of photoacoustic imaging and contrast echocardiography allows the visualisation of microvascular tissue architecture and perfusion.

In Fig. 6, offline analysis using 2DST has been performed. The pictures depict radial strain (upper right) and longitudinal strain (lower right)

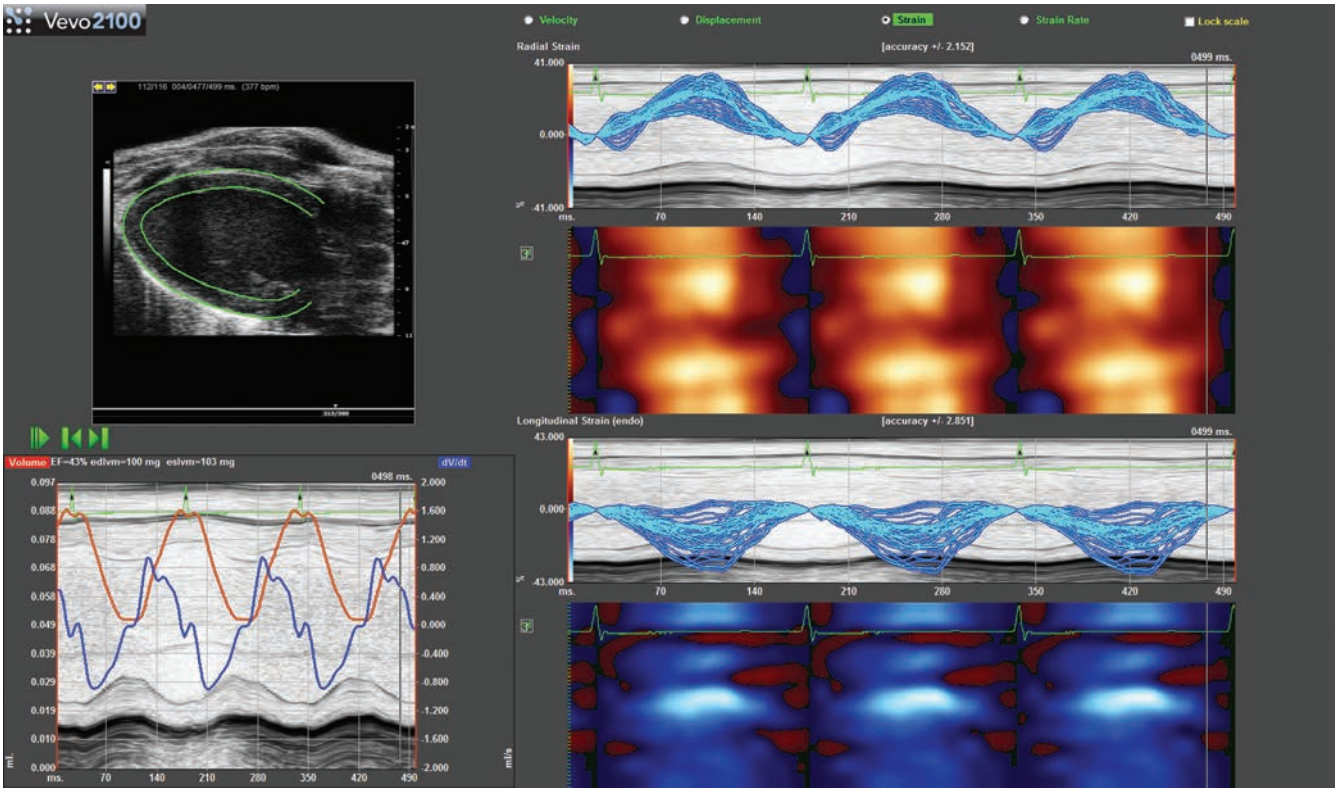

Fig. 6 2DST analysis in a left parasternal long axis view of the left ventricle of a mouse

in trace display and in M-mode with parametric colour coding during three cardiac cycles. The upper left shows a 2D B-mode image with region of interest, and the lower left an M-mode tracing of the left ventricle and estimated left ventricular volume (red line) and change of volume over time (blue line).

In Fig. 7, offline analysis using 2DST has been performed. The tracings are superimposed to a left ventricular M-mode recording and show the peak, time to peak and synchronicity for both radial (upper right) and circumferential (lower right) strain. The left panel provides numeric values on segmental peak strain and segmental synchronicity.

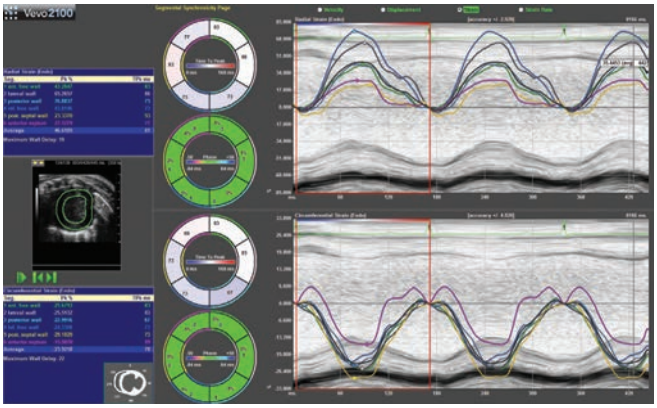

Fig. 7 2DST analysis in a left parasternal short axis view of the left ventricle of a mouse

Currently, our research lab offers rodent cardiovascular imaging using the VisualSonics Vevo 2100 imaging platform (Fig. 4 – currently without photoacoustic imaging capabilities). On-going projects utilise high frequency echocardiography to monitor global myocardial dysfunction in a diabetic mouse model, remodelling in hypoxia-induced pulmonary hypertension, the effects of acute myocardial infarction on regional myocardial dysfunction, and the function of pulmonic and aortic valves in a valve replacement model.

Every day we continue to utilise echocardiography to look inside the beating hearts of animals. The information we gather allows us to make informed recommendations about their future athletic potential, identify potential increased risk for collapse or sudden death, and instigate appropriate treatment options. The increasing integration of echocardiography in preclinical studies can provide real-time functional and structural data that will improve the translational application of research.

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