Accuracy with Sparse Data Using Artificial Intelligence

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Abstract

Despite technological advances to ultrasound, it still faces challenges in delineating the complete contour of the internal surface of the heart when compared to cardiac MRI (cMRI) scanning. Arguably, suboptimal images are typical of echocardiography. Hence, Artificial Intelligence (AI) and big data have been utilized to address the issue of only having sparse data or the use of parts of the medical images which do show the heart walls, to extrapolate an accurate measurement or parameter. The end goal is to gain useful clinical data and further extend the benefits of ultrasound, which is found to be a relatively inexpensive modality that is portable, requires less training and provides a better patient experience. Clearly, using AI could be invaluable in the delivery of cardiac care.

The VMS+ is a cardiac imaging assessment tool that augments the ultrasound and uses an AI algorithm known as KBR. The AI has been proven to be consistently accurate when faced with sparse data. This AI technology is based on thousands of cMRI scans with a varied array of pathologies (big data). By taking a subset of data points that can be confidently delineated, as opposed to needing to indicate every point on the surface of the 3D volume, an accurate volume can still be measured. VMS+ can calculate the shape and size of cardiac chambers comparable to those derived from cMRI.

Introduction

The advent of Artificial Intelligence and big data has brought more efficient ways of determining diagnostic measurements of the heart. Using AI and big data, it is now possible to use a small sample of the total possible data points to extrapolate an accurate measurement or parameter. This capability is especially significant for various medical modalities that do not provide a clear, concise image of the organ. This can occur due to a variety of factors, one of which is the unique anatomical differences of a patient's organ. This is especially true in the case of cardiac imaging.

Ultrasound is used as a method of acquiring diagnostic information for the heart such as function and blood flow through the heart chambers. Ultrasound has seen dramatic improvements over the last few years but still faces challenges in delineating the complete contour of the internal surface of the heart, in comparison to cardiac MRI (cMRI) scanning.

For this reason, two-dimensional echocardiography (2DE), is not reliable in the estimation of chamber size and function, especially for the right ventricle (RV). It has inherent inaccuracies and correlates poorly with the gold standard MRI data. Due to its complex shape, geometric assumptions cannot be made about the size and shape of the RV from one or two views (which is the traditional way of measuring the left ventricle (LV), which consequently has a much simpler conical shape).

Furthermore, the traditional methods of chamber quantification require the delineation of the entire internal surface of the heart in each view and frequently this is impossible to obtain on a single view; especially if the heart chamber is very dilated which is frequently the indication to perform the assessment in the first place. Attempts to trace the heart border when the images are poor quality leads to significant inaccuracies. This is found to be more pronounced in larger or unusually shaped or positioned right ventricles, such as in patients with congenital heart disease (CHD). In order to address this issue, ultrasound manufacturers have heavily invested in 4D real time echocardiography (4DRTE) to try and visualize the entire internal surface of the heart chambers and give comparable visual, qualitative, and quantitative representation to cMRI.

Unfortunately, 4DRTE echo has its own inherent limitations. It has intrinsically lower spatial and temporal resolution compared to 2DE, usually requires the patient to stay still and hold their breath for several seconds, and can be extremely challenging to find an echocardiographic window which can provide optimal image quality in the axial, lateral and elevation planes simultaneously especially if the heart is enlarged (it is not infrequent to find a heart chamber so dilated that it exceeds the maximum size of the echocardiographic scan zone).

This can frequently lead to a poor-quality echo image suffering from dropout (parts of the heart not being seen) and in some cases, due to the position of the heart and the intersecting ultrasound beam, it is not possible to capture the entire chamber in one image. This occurs most often when imaging the right ventricle. When an incomplete image occurs, we can still use the parts of the image which do show the heart walls - this data referred to as partial or "sparse" data.

Cardiac MRI imaging is not constrained by the limitations of echocardiography in delineating the complete contour of the walls of the heart chambers, making it the gold standard for measuring chamber size. However, a complete cardiac MRI study is highly dependent of gating the heart cycle (as the heart fills and empties) with the image to ensure sufficient data is captured at a specific instance of the heart cycle.

Consequently, on cMRI, where every point on the heart border is easily distinguished, making automatic edge detection and thresholding algorithms technically feasible. Typically edge detection on an MRI image represents hundreds, if not thousands of points that outline the boundary that attribute to the accuracy and reproducibility of cMRI.

VMS+ enables reliable measurement of volumes and ejection fractions from the sparse data obtained from echocardiographic images, with sufficiently high feasibility and accuracy in patients with a variety of different heart anomalies; which are then used in clinical decision making. The VMS+ technology has been shown to produce chamber volumes and ejection fractions (EFs) that are comparable to those derived from the gold standard cMRI to be clinically useful. This technology uses existing ultrasound machines and enhances its capability. The VMS+ overcomes the inherent drawbacks of conventional 2D software and 3D software in that it only needs to define anatomic landmarks (i.e. sparse data), which are identified and verified on multiple 2D slices from standard 2D echo or extracted from the 4DRTE full volume. This approach reduces the impact of poor image quality, reduced spatial or temporal resolution, or incomplete depiction of the chamber of interest, giving the accuracy of MRI measurements with the convenience and easy availability of echocardiography.

VMS+ Knowledge-Based Reconstruction Algorithm With Sparse Data

AI and big data have been utilized to address the issue of having sparse data. By taking a subset of predefined anatomical points that can be confidently delineated, as opposed to needing to indicate every point on the surface of the 3D volume, an accurate volume can still be measured.

The user indicates the position of 20-30 predefined anatomical points on the ultrasound images where those structures can be clearly seen. The position of each data point is registered in 3D space (either by tracking the position of the echo probe between multiple image acquisitions, or by analyzing a 4DRTE volume). This represents a fraction of the total points that potentially make up the entire anatomical boundary, depending on the ultrasound view in question.

The VMS+ uses an algorithm that was generated from many thousands of cMRI scans – utilizing the power of big data – to calculate the shape and size of the cardiac chamber using the anatomical points indicated, to provide accurate measurements comparable to those derived from cMRI. Unlike learned AI which improves as it receives more information, the VMS+ uses an algorithm based on Knowledge Based Reconstruction (KBR) technology that has been proven to be consistently accurate regardless of how much data is input. This KBR technology is based on thousands of cMRI scans with a varied array of pathologies.

With accuracy in imaging established, the benefits of echo can be utilized and provide the clinician with more accurate, reproducible and consistent data to guide in the diagnosis and treatment of the patient. Imaging with an echo machine, in comparison with cMRI, has significant benefits in terms of cost, convenience, and operator skill. The cost per scan is drastically cheaper than that of a cMRI scan. The training to learn how to operate an echo machine can be completed within days which allows more staff to be certified to conduct the scan. Information can be obtained/combined with a patient's regular cardiac visit and Echo scans can also be completed in minutes, which provides far more availability for patients to be scanned. This allows measurements to be performed frequently, which gives one access to serial longitudinal assessment of cardiac function and early warning about any developing changes.

A case in point is illustrated by the images below that show the typical standard views established for a cardiac echo exam. In each view a set of anatomical landmarks are easily identified, irrespective of the quality of the images. The yellow borders on each view illustrate the calculated internal heart border based on the points identified on the ultrasound images and is comprised of relatively little data. In this case only 4 or 5 points can be identified in this image. By identifying 4 to 8 points on all the specific views, this small number of points are collectively used to feed the Ventripoint AI engine.

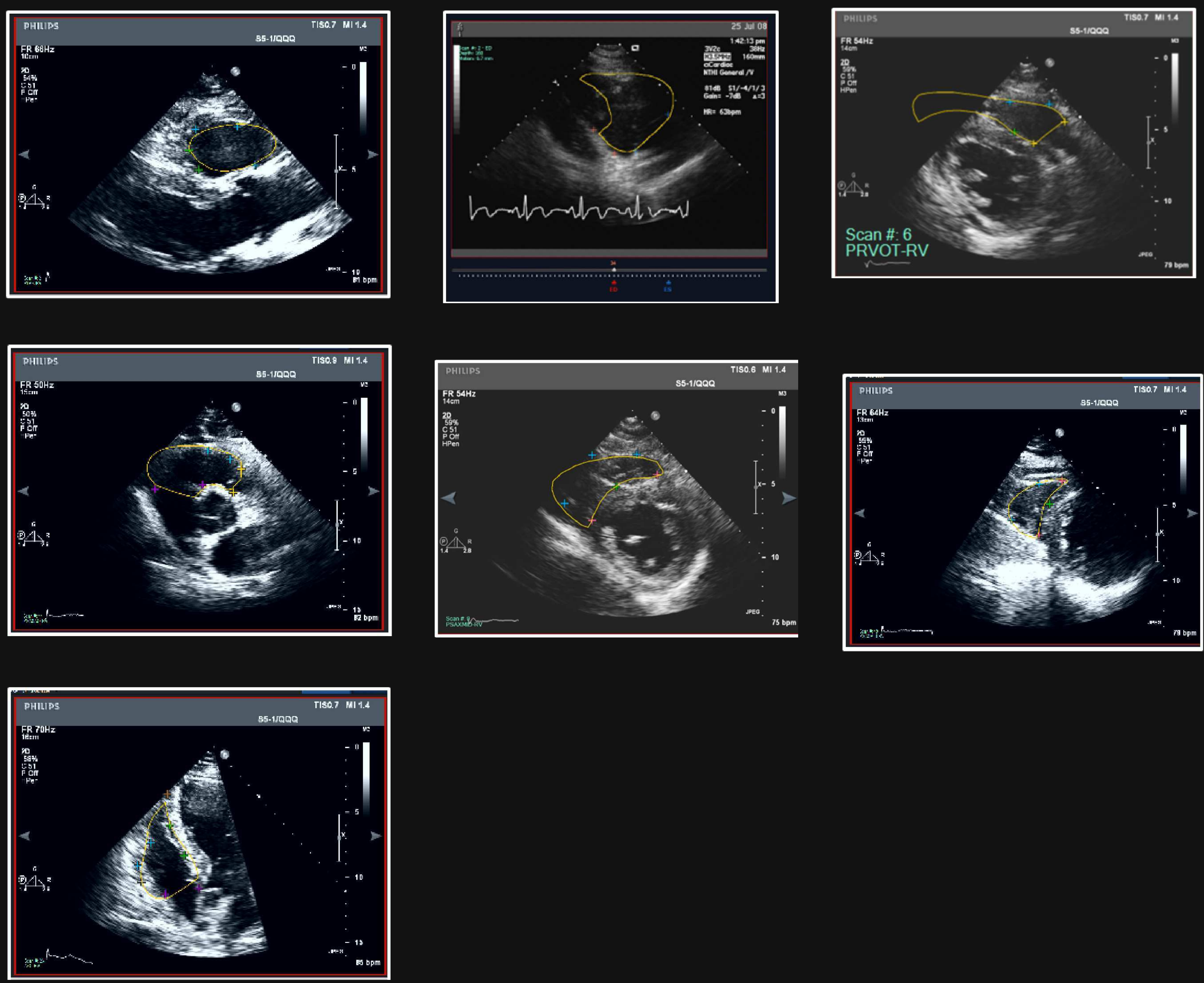


Figure 1: Views showing few anatomical landmarks identified. Parasternal Long Axis with two RV septal points and three endocardial points (A), Right Ventricular Inflow Tract with two RV annulus points and three endocardial wall points (B), Right Ventricular Outflow Tract with two pulmonary annulus points, one RV Septal point, and one RV endocardial point (C), Parasternal Short Axis with two TV annulus points, two pulmonary annulus points, one Conal Septal point, and two endocardial points (D), Parasternal Short Axis Mid RV with one septal point, two RV septal edge points, and two endocardial points (E), Parasternal Short Axis Distal RV with one Septal point, two RV Septal edge points, and two endocardial points (F), Apical 4 Chamber-RV with two TV annulus points, one basal bulge point, two endocardial points, two septal points, and one apical point (G).

CASE EXAMPLES

The following cases demonstrate the accuracy of the VMS+ system. These are three different cases. Each patient was scanned by a different sonographer, and, as is often the case in the real world when assessing the RV, the quality of the images are not ideal. In each case a limited number of data points (sparse data) are needed on each standard echo image to create a 3D model of the right ventricle and associated cMRI values. These same patients who received an echo also went through a cMRI for comparison of results. The VMS+ system provides output values that are within +/- 10% of cMRI values and is proven with the results that are shown in these provided cases.

CASE #1

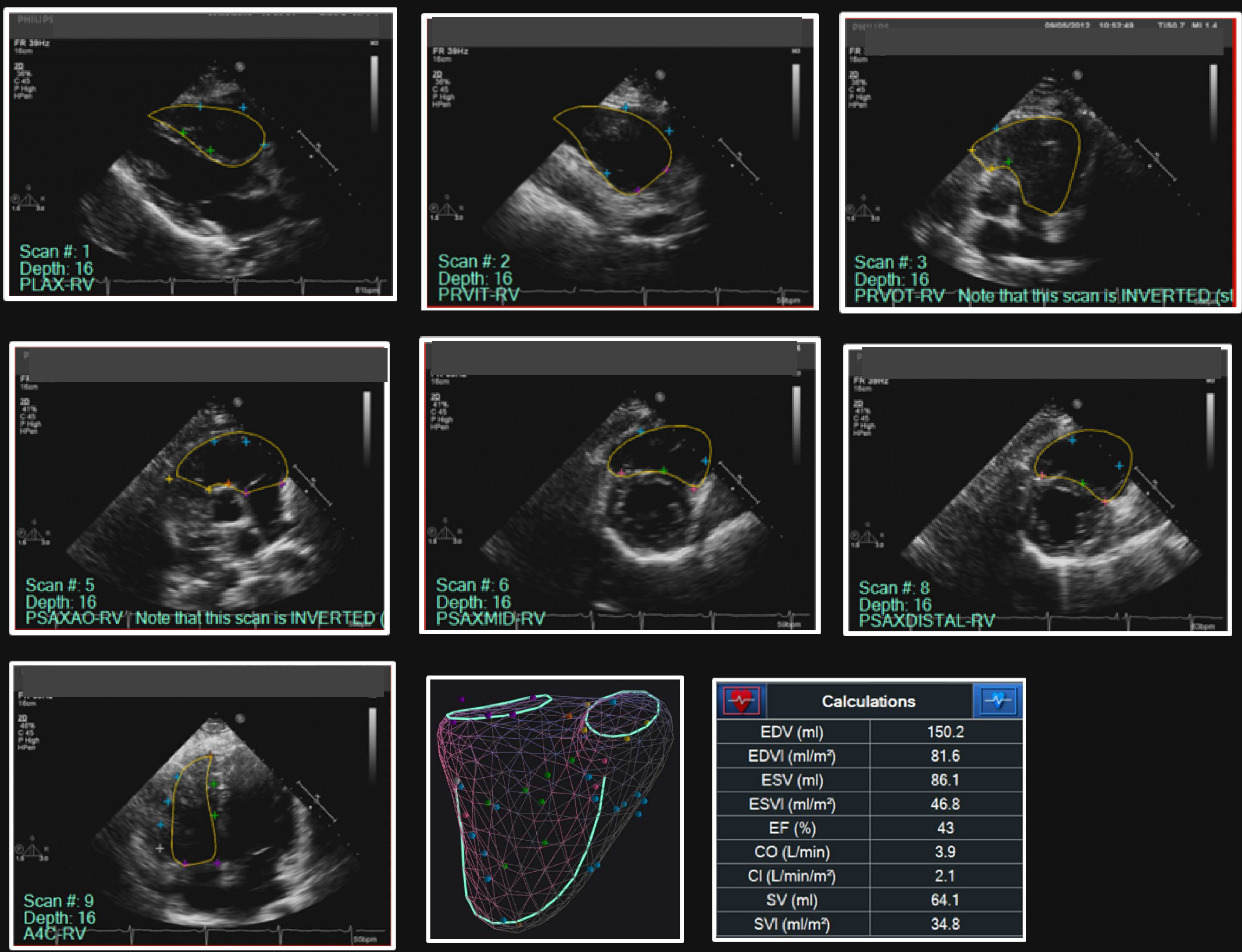
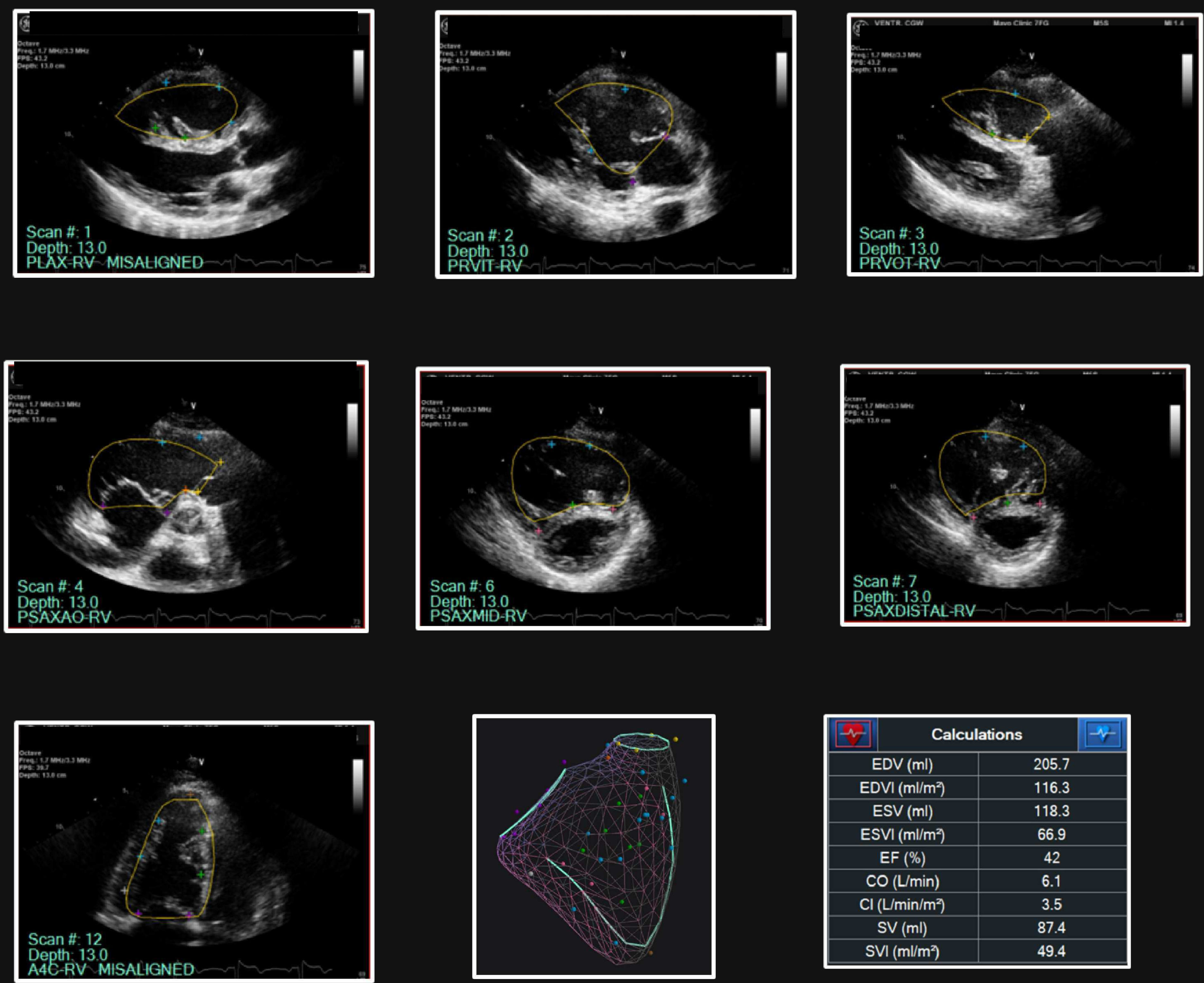


Figure 2: Patient Case 1 with views , 3D model, and calculations for Right Ventricle. (A) RV Parasternal Long Axis, (B) Parasternal Right Ventricular Inflow Tract, (C) Parasternal Right Ventricular Outflow Tract, (D) Parasternal Short Axis Aortic Outflow, (E) Parasternal Short Axis Mid , (F) Parasternal Short Axis Distal, (G) Apical 4 Chamber, (H) 3D Model of ED RV, (I) Calculations for ED and ES.

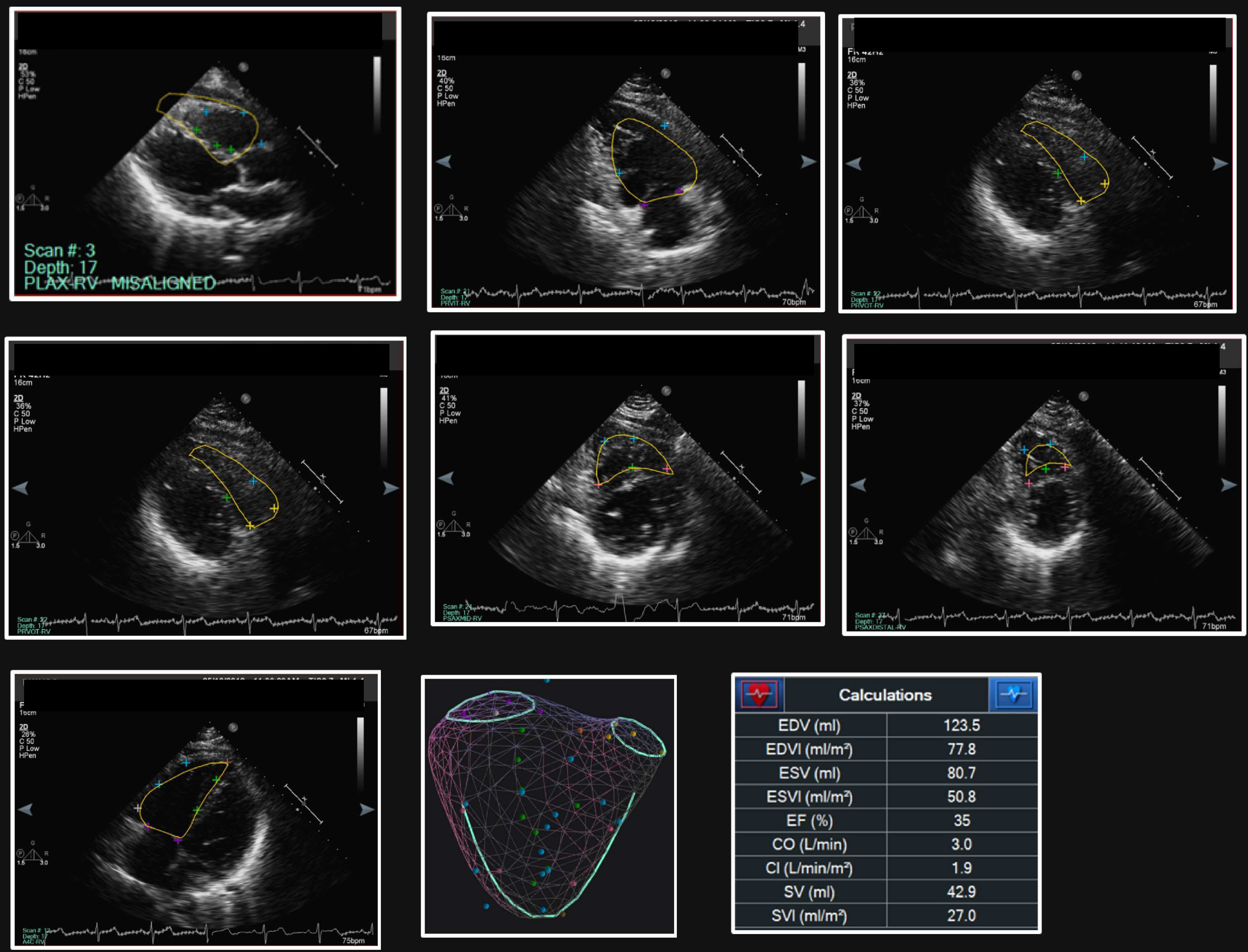
CASE #2



Calculations	
EDV (ml)	205.7
EDVI (ml/m²)	116.3
ESV (ml)	118.3
ESVI (ml/m²)	66.9
EF (%)	42
CO (L/min)	6.1
CI (L/min/m²)	3.5
SV (ml)	87.4
SVI (ml/m²)	49.4

Figure 3: Patient Case 2 with views , 3D model, and calculations for Right Ventricle. (A) RV Parasternal Long Axis, (B) Parasternal Right Ventricular Inflow Tract, (C) Parasternal Right Ventricular Outflow Tract, (D) Parasternal Short Axis Aortic Outflow, (E) Parasternal Short Axis Mid , (F) Parasternal Short Axis Distal, (G) Apical 4 Chamber, (H) 3D Model of ED RV, (I) Calculations for ED and ES.

CASE #3



Calculations	
EDV (ml)	123.5
EDVI (ml/m²)	77.8
ESV (ml)	80.7
ESVI (ml/m²)	50.8
EF (%)	35
CO (L/min)	3.0
CI (L/min/m²)	1.9
SV (ml)	42.9
SVI (ml/m²)	27.0

Figure 4: Patient Case 3 with views , 3D model, and calculations for Right Ventricle. (A) RV Parasternal Long Axis, (B) Parasternal Right Ventricular Inflow Tract, (C) Parasternal Right Ventricular Outflow Tract, (D) Parasternal Short Axis Aortic Outflow, (E) Parasternal Short Axis Mid , (F) Parasternal Short Axis Distal, (G) Apical 4 Chamber, (H) 3D Model of ED RV, (I) Calculations for ED and ES.

Conclusion

Using sparse data typical of echocardiographic images, allows for accurate determination of the volumes and associated measurements such as ejection fraction with a relatively inexpensive modality that is portable with low running costs. Clinical studies have shown the efficacy and reliability of using this sparse data approach to further extend the benefits of ultrasound. Cardiac disease is still the leading cause of death in the Western world, with accurate monitoring of cardiac function and response to treatment being invaluable in the management of these diseases.

The yellow tracing on each view illustrates the entire cardiac borders the VMS+ has created from relatively little data. In each specific view only 4-8 points need to be identified, with this very small subset of points allowing the Ventripoint AI algorithm to accurately determine the size, shape and function of the heart chambers. Comparatively, edge detection on an MRI image represents hundreds, if not thousands of points that outline the boundary that attribute to the great accuracy of cardiac MRI. With MRI every point on the surface is easily distinguished therefore making algorithms like edge detection and thresholding easily achievable. The VMS+ algorithm is based on using sparse data which removes the need for MRI quality images to create MRI quality results.

The VMS+ identifies necessary key cardiac landmarks on suboptimal quality echo images and uses that sparse data to determine accurate volumes and associated measurements such as ejection fraction with a relatively inexpensive modality that is portable with low running costs.

Learn more about the VMS+: **www.ventripoint.com**

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