

3D Auto RV — right ventricular quantification

Anke Sedlmeier, Senior Product Manager, TOMTEC

David Prater, MS, Clinical Scientist, Philips

Overview

There are several measurements for right ventricular (RV) function in 2D echocardiography, for example Fractional Area Change (FAC), Tricuspid Annular Plane Systolic Excursion (TAPSE) and Right Ventricular Index of Myocardial Performance (RIMP). The limitations of 2D measurements for RV assessment are well-known. Foreshortening and geometric assumptions make 2D not well suited for quantification.

The importance of RV function has been underestimated due to enormous attention given to the evaluation of the left heart, lack of familiarity with ultrasound techniques that can be used in imaging the right heart, and the complexity of the RV shape and anatomy (**Figure 1**).

These limitations can be overcome by using 3D. With the growing availability of 3D techniques such as magnetic resonance (MR) imaging and 3D echocardiography, assessment of shape and functional changes in the right ventricle becomes feasible. Three-dimensional modalities offer exceptional accuracy and reproducibility in the assessment of RV shape and function.

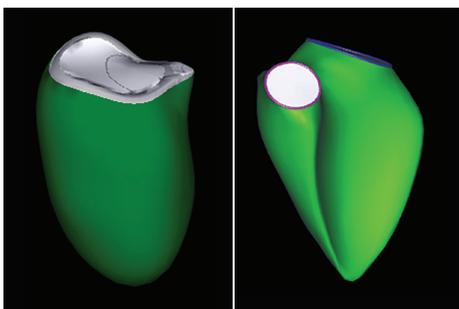


Figure 1
Compared to the left ventricle (left), the right ventricle shape (right) is much more complex.

Although MR has excellent intra- and inter-observer variability, it is expensive, not widely available, and cannot be performed in patients with special conditions such as metallic implanted devices, claustrophobia and irregular heart rhythm.

Three-dimensional echocardiography is available and well validated against the gold standard MR. The latest guideline recommends 3D echocardiography measurements of RV when knowledge of RV volumes may be clinically important.

TOMTEC has extensive experience in 3D RV measurements. 4D RV-FUNCTION has been part of the TOMTEC portfolio since 2006. Evolving from 4D RV FUNCTION, the 3D Auto RV enhanced workflow and performance is powered by machine learning artificial intelligence, making it feasible for routine clinical use. This on-cart availability and its automated workflow within the application accelerate the process of measuring RV values.

3D echo quantification on right ventricle

The 3D Auto RV application combines proven TOMTEC experience in RV analysis software with Philips machine learning artificial intelligence similar to HeartModel^{A.I.}. Auto-segmentation provides the initial image alignment and contour positioning. These operations significantly reduce, and in many cases eliminate, the manual image adjustments needed for RV analysis. The result is both faster analysis and improved reproducibility.

RV auto-segmentation

Auto-segmentation technology is based on a deformable model which consists of a boundary detector and multiple shape models of the RV. The boundary detector uses information from both image gradients and the distribution of the image grayscale values. The shape models consist of a mean shape and shape modes, with the shape modes accounting for the shape variations due to differences in anatomy and pathology. The auto-segmentation process begins with an initial boundary estimate used to select the best-fitting shape model. The final boundary is a balance between the initial boundary and the selected shape model. Both the boundary detection and the shape models utilize artificial intelligence and are trained using a large number of clinical images annotated by echocardiographic experts.

3D Auto RV maintains all the manual functionality of the TOMTEC 4D RV-FUNCTION software, including View Adjustment and Tracking Revision. Auto-segmentation does these two steps automatically but the user may still do them manually. This functionality provides the speed and robustness of automatic operation with the flexibility of manual adjustment.

3D Auto RV operation

The 3D Auto RV application is initiated via a touchpanel button labelled 3D Auto RV. The auto-segmentation process is executed and the user is shown the Tracking Revision workflow step (**Figure 2**). If the user is satisfied with the tracking, they can proceed directly to the Analysis workflow step where the dynamic 3D volume (Beutel) is shown along with the volume waveform and numerical results. For easy navigation, the work-step list is shown on the side of the View Adjustment and Tracking Revision workflow steps. A minimum of 10 volumes per second are required to ensure the quality of volume analysis.

The entry point for the standard TTE acquisition in automatic mode is the Tracking Revision workflow step. This screen shows the RV model and corresponding 2D contours over the complete heart cycle.

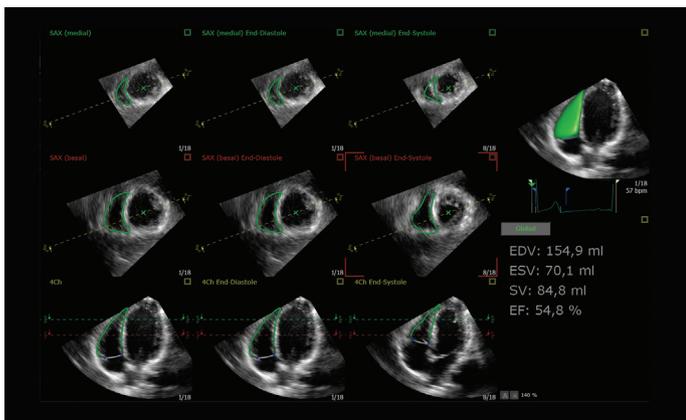
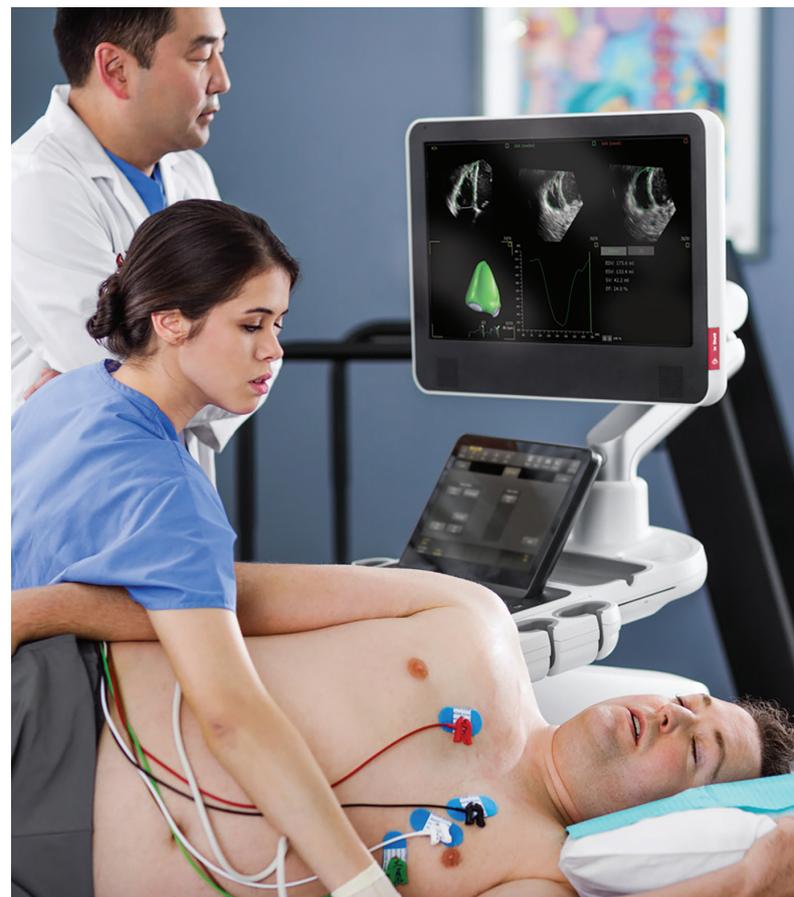


Figure 2 Tracking revision workflow step.

The model is tracked over the entire cardiac cycle using speckle tracking technology. The resulting dynamic surface model can optionally be adjusted by the user in end-diastole (ED) or end-systolic (ES). To edit, the user just drags the contour line in ED or ES. There are different pen sizes depending on the area the user wants to change. If more editing is needed, it is highly recommended to start editing in ED and re-track. If initial model fails completely, landmarks in the view adjustment state should be checked and adjusted.

When leaving the application out of Tracking Revision and activating the “Accept Measurements” checkbox, all global values are saved.



View adjustment

In the View Adjustment workflow step, the user can manually adjust the image landmarks (**Figure 3**). At end-diastole, the left and right ventricular long axes are set to define a basic coordinate system. Based on that, a RV-focused four-chamber view and a short-axis view are derived by the system. Also, the heart cycle to be analyzed can be changed in this state.

In the View Adjustment workflow step, the following general settings can be adjusted:

- Default acquisition window (TTE, subcostal)
- Automatic start in tracking revision (only available for TTE)
- Change default heart cycle
- Change default pause time (pause time in view adjustment to set landmarks)
- View orientation (apex up/down)
- Change default layout (in tracking revision)
- Result display size

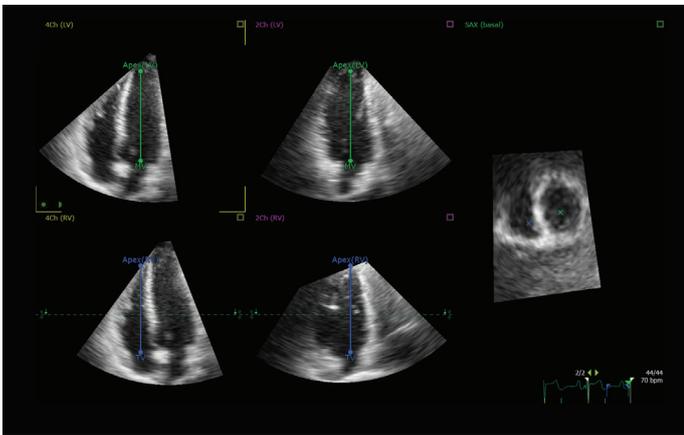


Figure 3 View Adjustment.

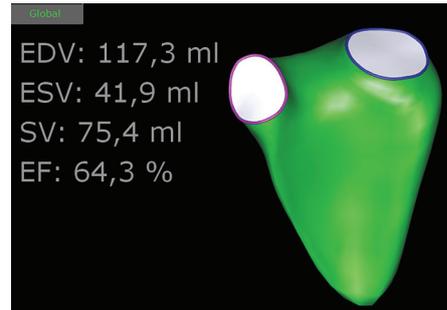


Figure 4 Model with global results.

Analysis

3D volumes over time are computed numerically from the dynamic surface model and used to calculate end-diastolic volume (EDV), EDVi*, end-systolic volume (ESV), ESVi*, ejection fraction (EF) and systolic volume (SV) (**Figure 4**). Additionally, the surface model is intersected with the RV-focused four-chamber view to derive standard 2D measurements (RVLS, TAPSE, FAC and distances) from the same geometry. ES and ED are identified as the frames with the lowest and largest ventricular volumes. The volume over time is also displayed in a volume-versus-time curve.

When leaving the application out of Analysis and activating the “Accept Measurements” checkbox, all global and 2D measurement results are saved.

*Indexed values are calculated if patient weight and height is available.

Validation

4D RV-FUNCTION is well validated with many papers.^{4,5,6}

EDV results from the auto-segmentation were compared to expert manual adjustment of the image alignment and contour position for 73 data sets. Shown in **Figure 5** is the correlation plot of the EDV for the auto-segmentation versus the manual adjustments for the 73 data sets.

The R-value is 0.79.

For 65% of the data sets, the EDV from the auto-segmentation were within 15% of the manual adjustments, and for 49% of the data sets the automatic results were within 10% of the manual results.

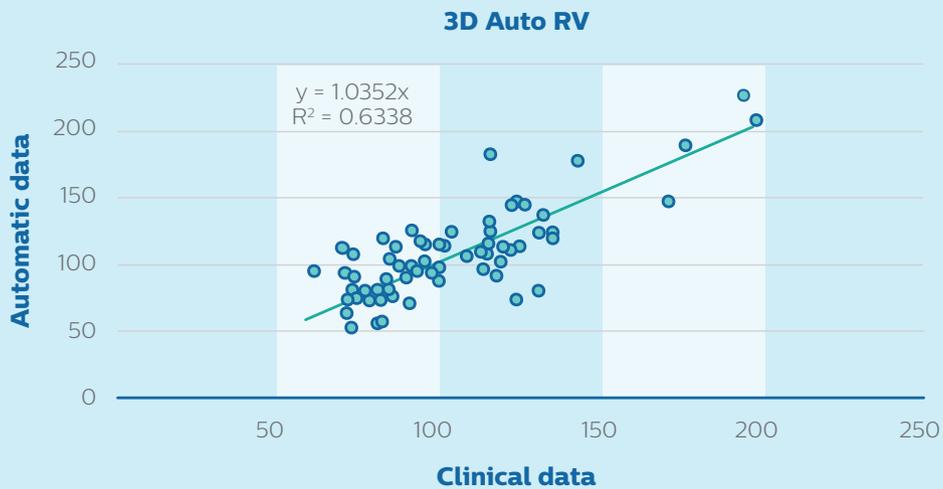


Figure 5 Correlation plot of EDV for auto-segmentation versus manual adjustments.

Frequently asked questions

Are the results the same on-cart as off-cart?

Yes, the application on- and off-cart is identical.

How is the RV longitudinal strain (LS) measured?

The RV LS is calculated from the four-chamber view which is derived from the 3D data set. The frame rate may not be optimal for strain calculation.

Is there a minimum volume rate required?

To ensure the quality of the results, we require a minimum volume rate of 10 volumes per second and a minimum of 10 volumes per heart cycle.

The ASE Recommendations for Cardiac Chamber Quantification by Echocardiography recommends a temporal resolution of more than 20–25 volumes per second.

What is the meaning of the color difference?

- To ensure a consistent shape, user interaction is confined to parts of the RV surface model.
- The user can identify editable regions by the light green intersection contours.
- Additionally, valve annulus geometry can be modified (purple: pulmonary valve, blue: tricuspid valve) (**Figure 6**).

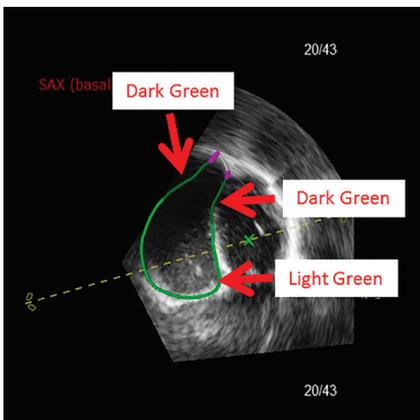


Figure 6 SAX view with pulmonary valve side-cutting.

What does the 'x' marker in the view adjustment indicate?

The cross in the SAX view shows where the Apex-MV and Apex-TV axes intersect the SAX. This view can be helpful in orienting the views.

How does the software define ED and ES time points; can they be edited?

ED and ES are defined as time points of largest (ED) and smallest (ES) volume. The time points are defined after tracking in the Tracking Revision workflow step. The blue flags of the electrocardiogram (ECG) are positioned accordingly.

They cannot be edited.

How does 3D Auto RV detect the borders? Does it use speckle tracking?

The boundary detection utilizes information from both image gradient and the distribution of the image grayscale values. The shape models consist of a mean shape and shape modes, with the shape modes accounting for shape variations due to differences in anatomy and pathology. The model is tracked over the entire cardiac cycle using speckle tracking technology.

What landmarks does it use for tracking?

No individual landmarks are used for tracking, but rather sections of the 3D model contour.

What is 3D Auto RV validated against?

Refer to validation section.

Are we including trabeculae or excluding them?

Trabeculae are included in the model volume of RV.

How does it work on dilated hearts?

Dilated hearts are validated in publications. The challenge with dilated hearts is to acquire images such that the free wall is in the field of view.

How does 3D Auto RV work on contrast images?

Due to the small amount of available data sets, there is no validation for contrast data available.

Are there any issues with lower EF's? Hypercontractility?

There are no known issues.



What's the recommendation if it doesn't track?

If the tracking fails but the orientation of the data set is correct, then in the tracking revision stage the contour in the ED frame should be edited and the “re-track” button used. ED will be re-tracked.

If the complete model orientation failed, e.g., Apex and MV are interchanged, go to the View Adjustment workflow step. Correct the landmark position of the Apex (LV), MV, Apex (RV) and TV and proceed with tracking revision.

Will it reject a volume? If so, what are the parameters in which it will reject?

A minimum of 10 volumes per heart cycle and 10 volumes per second is required.

If the results of 3D Auto RV vary when scanning the same patient, how can I explain that?

The algorithm is searching for contours in the acquired image. If the quality differs, the contours are different, e.g., the free wall can be seen completely on one data set but parts are missing on the second data set.

The algorithm needs to follow its trained knowledge where the contour of the free wall might be – this can result in different volume values.

Can I do a multi-beat acquisition and which beat will 3D Auto RV use?

3D Auto RV is always analyzing one heartbeat at a time. The heartbeat can be selected in View Adjustment workflow step. It is possible to pre-select any heartbeat (can be changed in the user setting).

References

- 1 Leary PJ, et al. Three-dimensional analysis of right ventricular shape and function in pulmonary hypertension. *Pulm Circ.* 2012 Jan-Mar;2(1):34–40. doi: 10.4103/2045-8932.94828.
- 2 Lang RM, Badano LP, et al. Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr.* 2015 Jan;28(1):1-39. doi: 10.1016/j.echo.2014.10.003 .
- 3 Messner AM, Taylor GQ. Algorithm 550, Solid Polyhedron Measures. *ACM Transactions on Mathematical Software.* 1980 Mar;6(1):121-130.
- 4 Muraru D, et al. New speckle-tracking algorithm for right ventricular volume analysis from three-dimensional echocardiographic data sets: validation with cardiac magnetic resonance and comparison with the previous analysis tool. *Eur Heart J Cardiovasc Imaging.* 2016 Nov;17(11):1279-1289.
- 5 Laser KT, Karabiyik A, Korperich H, Horst JP, Barth P, Kececioglu D, Burchert W, Dalla Pozza R, Herberg, U. Validation and Reference Values for Three-Dimensional Echocardiographic Right Ventricular Volumetry in Children: A Multicenter Study. *J Am Soc Echocardiogr.* 2018 Sep;31(9):1050-1063. doi: 10.1016/j.echo.2018.03 .010.
- 6 Medvedofsky D, et al. Novel Approach to Three-Dimensional Echocardiographic Quantification of Right Ventricular Volumes and Function from Focused Views. *J Am Soc Echocardiogr.* 2015 Oct;28(10):1222-31. doi: 10.1016/j.echo.2015.06. 013.

