PHILIPS

Ultrasound

White paper

Bringing 3D ultrasound into practice for cardiac quantification

Philips Dynamic HeartModel[A.I.]

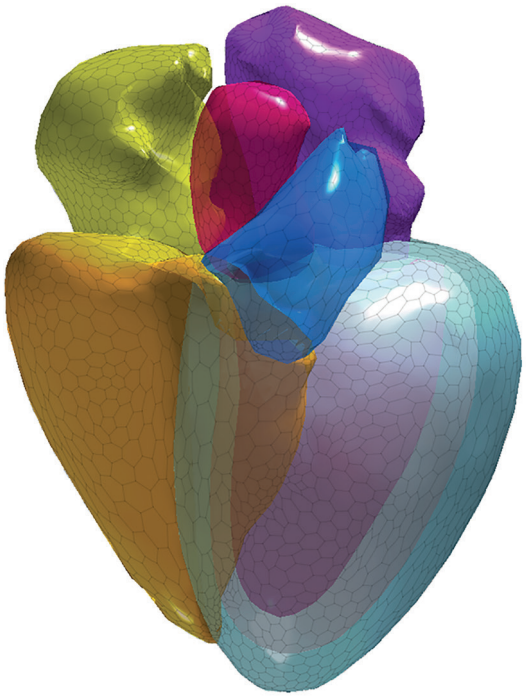
Cardiac function can be assessed in several ways, using a number of imaging modalities. Ultrasound provides cost-effective, robust capabilities to assess quickly moving structures of the heart without ionizing radiation exposure.

Typically the biplane method of disks summation (modified Simpson's rule), based on two dimensional (2D) echocardiographic (echo) images, has been used to make measurements such as left ventricle (LV) or left atrium (LA) volume and then used these measurements in the calculation of ejection fraction, stroke volume and cardiac output.

The limitations of the biplane method are that the apex is frequently foreshortened, and shape distortions not visualized in the apical two- and four-chamber planes are not included in the volume estimation.

To mitigate these limitations, measuring chamber volumes from 3D echo has been proposed, but the time and expertise needed to acquire a 3D image and perform 3D measurements has proven to be a barrier to wide-scale clinical acceptance.

To address these barriers, Philips has created the Dynamic HeartModel[A.I.], which is an efficient and robust method for cardiac function assessment.



Cardiac model used in the Dynamic HeartModel[A.I.] application includes LV epicardium, LV endocardium (blood-tissue and compacted myocardial borders), LA, RV endocardium, RV epicardium, RA, and attaching arterial and venous structures.

Image acquisition

Accurate 3D quantitation begins with acquiring a high-quality 3D volume. Dynamic HeartModel[A.I.] uses Anatomical Intelligence to find the heart in a 3D volume acquired from the standard apical four-chamber window, with the LV and LA centered along the volume axis. While Dynamic HeartModel[A.I.] will perform effectively in images that slightly deviate from this imaging window, large deviations should be avoided, as Dynamic HeartModel[A.I.] was not designed to function optimally under these circumstances.

The field of view of the 3D volume should be made wide enough and deep enough to include the entire LV and LA, but not too much wider or deeper, so the frame rate is not reduced more than necessary. An adequate frame rate is necessary to accurately construct the volume waveform. Dynamic HeartModel[A.I.] was designed and validated on images where at least 14 of the 17 ASE segments were visible (**Figure 1**). Images with fewer than 14 visible segments should be avoided for use in the Dynamic HeartModel[A.I.] application and for measurement of LV volumes, as the accuracy of the volume could be significantly reduced with such a large percentage of the chamber wall not clearly visible.

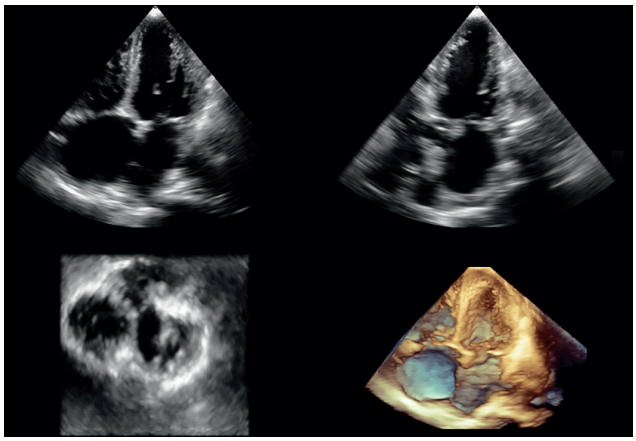


Figure 1 Example of a properly acquired 3D volume of the LV and LA acquired from a standard apical four-chamber window. The width and depth of the field of view do not far exceed the LV and LA, the chambers are centered in the volume, and at least 14 of the 17 ASE segments are visible.

Algorithm

Segmentation

The Dynamic HeartModel[A.I.] application is a model-based segmentation algorithm that has information as to the general structural layout of the heart, how the heart location varies within an image, the ways in which the heart shape varies, and the ways in which the heart is imaged using ultrasound. This prior information was incorporated into the model through extensive training using approximately 1,000 echo images from a wide variety of heart shapes and sizes, and with varying image quality. This exhaustive training enables the Dynamic HeartModel[A.I.] application to adapt the model to those hearts typically seen in a clinical scenario. The Dynamic HeartModel[A.I.] application, however, is not designed to adapt to large structural changes, such as those that might be seen in congenital defects.

Given the very large variety of heart shapes, there may be situations where the segmentation hasn't completely captured the anatomy to the user's satisfaction. For those situations, a flexible editing interface is provided to allow the user to make corrections to the displayed contours.

The model-based segmentation algorithm utilized in the Dynamic HeartModel[A.I.] application can best be described as a sequence of pattern fitting at finer and finer spatial scales, as summarized in **Figure 2**.

Knowledge-based identification

1. **Heart localization:** at the coarsest scale, the general pattern of the entire heart coinciding with the shape of the model is detected in the image, and the model similar to that shown in **Figure 2** is then positioned, oriented and scaled within the volume at the detected location.

2. **Chamber alignment:** proceeding to a finer spatial scale, the position, orientation and scale of each chamber in the model (LV, LA, RV and RA) is determined and the chambers then are transformed such that each structure better aligns to the locations as seen in the image.

Patient-specific adaptation

3. **Regional alignment:** at the finest spatial scale, small localized regions within each structure are detected, and the borders of the model moved to best align with the image.

4. **Regional alignment (blood-pool border):** as the innermost endocardial border, or blood-tissue border, exhibits a wider variation in shape as compared to the other borders, this border is initialized only after Step 3 and allowed more flexibility as compared to the other layers when locally adapting this border to best align with the image.

It is important to note that throughout the pattern-fitting process, while the model is adjusted to align with the image, the integrity of the model is also maintained such that the final adapted model can be considered a compromise between the patterns detected in the image and the prior knowledge imposed by the model.

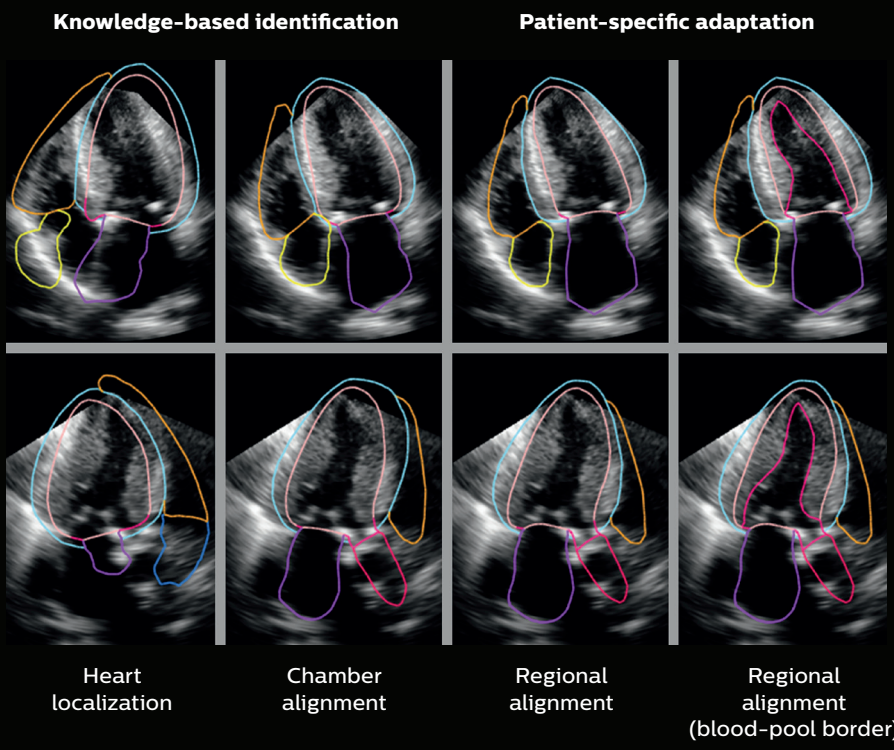


Figure 2
Summary of the model-based segmentation algorithm designed for the Dynamic HeartModel[A.I.] application.

Knowledge-based identification is used to first position and orient a model of the heart in the volume, and patient-specific adaptation is used to gradually transform the model at progressively finer spatial scales to the heart as seen in the image.

Phase detection

The segmentation is performed on two frames in the cardiac cycle. One frame is the frame at the R-wave and the second frame is the frame located at the estimated time at end-systole. The time of end-systole is estimated using a formula based on the R-R interval. After the dynamic tracking of the contour has been performed, the frame with the largest volume will be denoted as the EDV frame, and the frame with the smallest volume will be denoted as the ESV frame.

Border positioning

In clinical practice, the LV endocardial border is subjectively defined, and is often located by different clinicians at different positions within the myocardial tissue.

To handle this variation among users, Philips designed Dynamic HeartModel[A.I.] to detect two well-defined borders. These borders are the inner and outer extents of the myocardial tissue – one at the blood-tissue interface and the other at the interface of the compacted myocardium.

In segmenting the inner and outer extents of the myocardial tissue (represented by the green and red borders, respectively, in **Figure 3**), an intermediate location can be more robustly defined by a user in choosing a relative location for a single endocardial border that matches their judgment on the location of the actual contour.

The LA is a much thinner wall structure than the LV; as such, only a single boundary is detected for the LA.

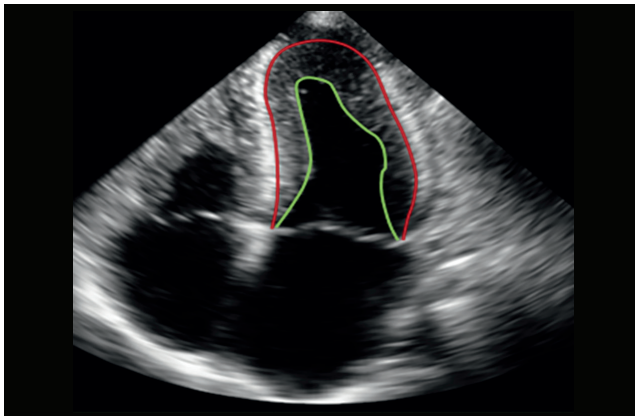


Figure 3 Dual endocardial border locations at the blood tissue (green) and compacted myocardium (red) interfaces. These borders are segmented automatically by the Dynamic HeartModel[A.I.] application and used along with user input to generate a single, consistently located endocardial border for volume measurement.

Tracking

The results of segmentation are the initial borders on the frames at the R-wave and the estimated time of end-systole. The user can provide corrections for the border positioning on these frames using the editing function. Starting from the border on the R-wave frame, 3D speckle tracking is used to track the border throughout the cardiac cycle. Tracking of the border is constrained so on the frame at the estimated time of end-systole the tracked border exactly matches the user-edited border.

As noted earlier, after the dynamic tracking of the border has been performed, the frame with the largest volume will be denoted as the EDV frame and the frame with the smallest volume will be denoted as the ESV frame (**Figure 4**).

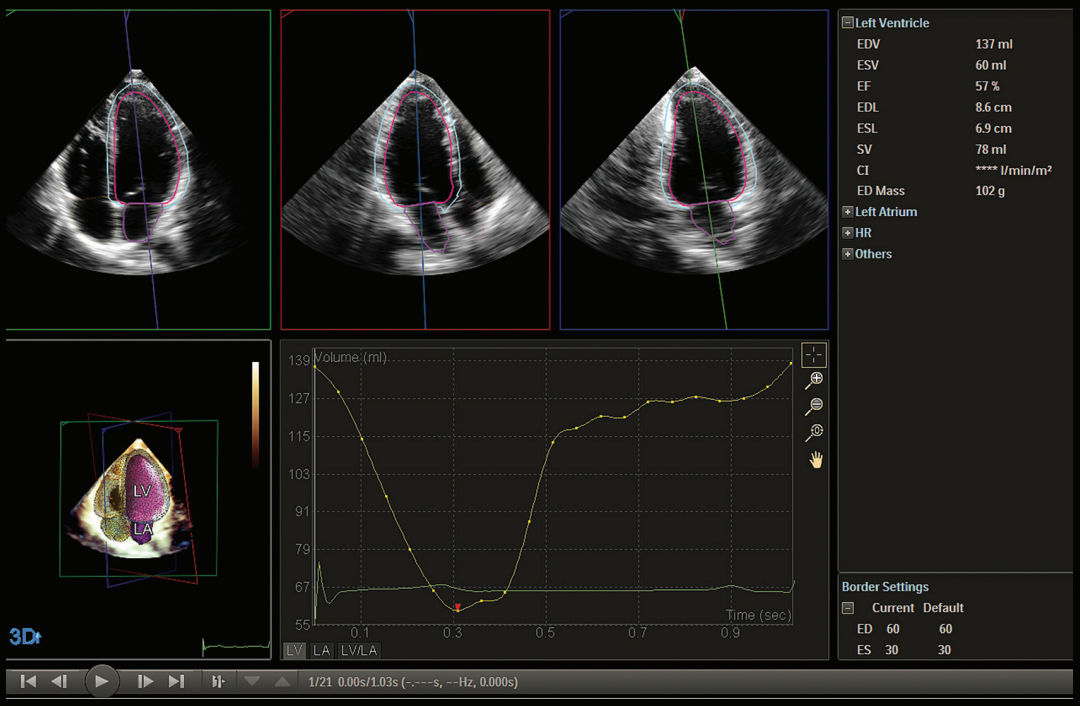


Figure 4
Dynamic HeartModel[A.I.] application five-up display showing the dynamic contours on the automatically aligned AP4, AP3 and AP2 views along with the volume waveform.

Tuning and editing

As previously described, the two LV borders are detected by the Dynamic HeartModel[A.I.] segmentation algorithm. The inner border is where the LV cavity meets the myocardium. The outer border is where the trabeculated myocardium meets the compacted myocardium. The user specifies where, relative to these two borders, the final single endocardial border should be placed. This relative location is controlled in the user-interface via graphical sliders – one for ED and one for ES. The default relative location (i.e., default slider values) can be specified by the user, and may vary due to preference by an institution or user as to where border should be placed.[2] The ability to be tuned to meet the individual preference of users allows the Dynamic HeartModel[A.I.] to generate fully automated or minimally edited results, despite widely varying tracing practices that exist in the clinical community.

While the borders generated by the fully automated Dynamic HeartModel[A.I.] application will suffice in a large percentage of the cases, there will be times when editing will be necessary or desired. In those situations, the user has two editing options available: global or regional. For the LV, the global edit consists of adjusting the ED or ES slider value, or relative location of the single LV endocardial border relative to the inner and outer borders that were automatically detected by the algorithm. For the LA, the user can globally move the border by clicking on the border between the control points and moving the entire border. For both the LV and LA, regional editing involves the user adjusting the border on a more localized basis via control points placed along the contour. The regional editing allows the user to use the Dynamic HeartModel[A.I.] application even on hearts exhibiting a unique or irregular shape.

The visualization and editing interface designed in the Dynamic HeartModel[A.I.] automatically displays the standard AP2, AP3, and AP4 views to the user. This saves a great deal of time as compared to other methods that require time-consuming manual orientation to display these views. With Dynamic HeartModel[A.I.], these views are automatically adjusted to the LV or LA at the press of a button so the chamber of interest is not foreshortened. In doing so, ultrasound users are not required to have significant experience in navigating around 3D ultrasound volumes to align the views to the standard views typically acquired in a routine ultrasound exam (**Figure 5**).

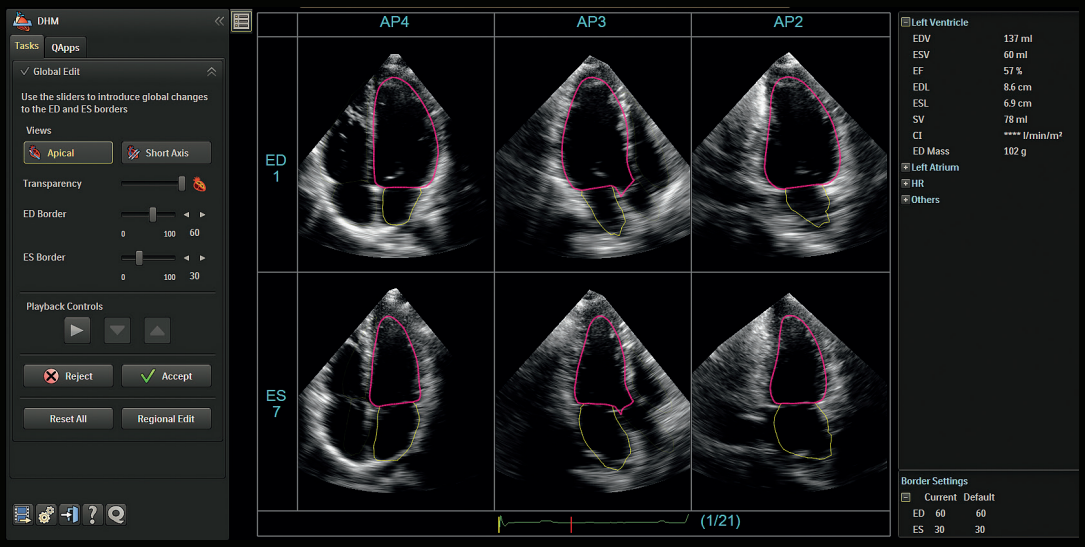


Figure 5
Six-up display showing the automatically aligned AP4, AP3 and AP2 views for the ED (top) and ES (bottom) frames.

Users can quickly adjust the location of the borders relative to the internally segmented inner and outer endocardial border using the sliders on the left of the screen.

Cardiac mass

The robust measurement of cardiac mass would be of significant clinical value. In ultrasound imaging, cardiac mass has typically been estimated using either 2D measurements or M-mode measurements. With measurements of this type there have significant geometric assumptions that can lead to errors. Measuring cardiac mass in 3D uses no geometric assumptions. To measure cardiac mass, Dynamic HeartModel[A.I.] adds an epicardial layer to the LV displays, as shown in **Figure 6**.

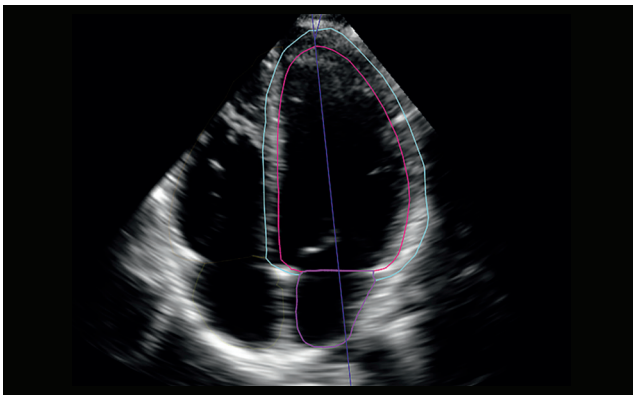


Figure 6 Epicardial border (blue) and endocardial border (red). The cardiac mass is measured as the volume of tissue between these borders.

Validation

The performance of Dynamic HeartModel[A.I.] for the purposes of quantifying the LV at ED and ES, and for quantifying the LA at left ventricular end-systole, has been assessed on several hundred images.

In the assessments, both the inner and outer LV endocardial borders and the LA border as generated by the fully automated Dynamic HeartModel[A.I.] application were compared to manual segmentations performed by several clinical experts.

The analyzed images were distributed fairly evenly as far as their geographic origin (Asia, Europe and North America), heart size, pathology, heart shape and image quality.

The Dynamic HeartModel[A.I.] application has also been studied at several centers globally. The results demonstrate that the application is robust and accurate at adapting to a wide variety of heart sizes and shapes in images with widely varying image quality.

In addition to the volume values at ED and ES, the border tracking over the cardiac cycle has been evaluated by numerous clinical experts with regard to how the tracked border follows the motion of the myocardium.

Multi-beat analysis

Cardiac function naturally varies beat to beat due to numerous physiologic factors. As such, the analysis of a single beat may not accurately reflect the “average” function. Dynamic HeartModel[A.I.] provides the ability to measure up to five beats and average the results of the analysis.

In a sequence of five beats, there may be beats that the user wishes not to analyze if they are judged to not be representative of average behavior. One common situation where this can occur is in a patient with rhythm irregularities. Dynamic HeartModel[A.I.] allows the user to select the beats to be analyzed. The User Interface to control the multi-beat selections is shown in **Figure 7**.

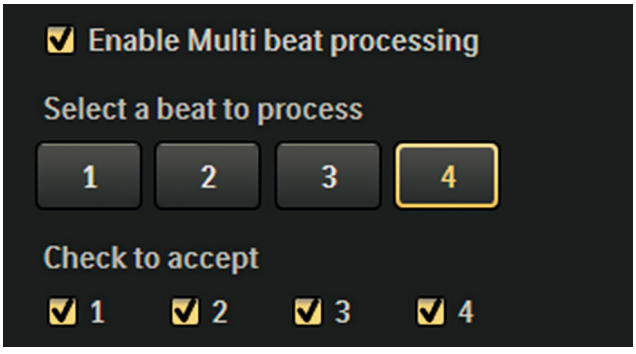


Figure 7 Task Guidance area showing the multi-beat processing controls.

Simultaneous analysis of LV and LA volumes

One of the major advantages of using 3D volumes for analysis of cardiac function is the ability to accurately measure the volume of the LV and the volume of the LA on the same cardiac cycle. This is not possible in most cases with 2D images because the major axis of the LV differs from the major axis of the LA. Thus the proper 2D view for measuring the LV is different than the proper 2D view for measuring the LA. Since in 3D the entire heart is scanned, the volumes of both the LV and LA can be measured in one acquisition. Dynamic HeartModel[A.I.] automatically measures both the LV and LA volume and allows the volume waveforms for both to be displayed on the same graph (**Figure 8**). This may be useful for appreciating the interaction between LA and LV performance.

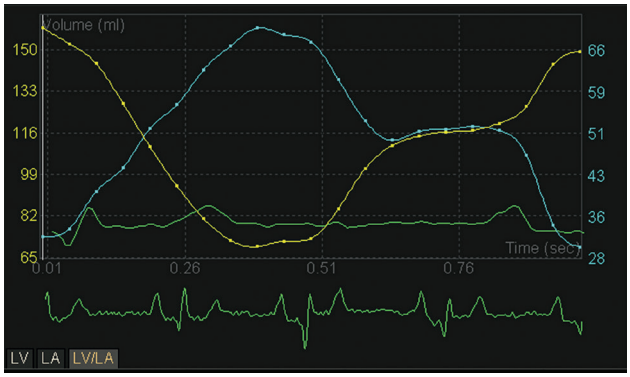


Figure 8 Simultaneous display of LV and LA volume waveforms.

Conclusion

Philips Dynamic HeartModel[A.I.] is a fully automated, model-based method for LV and LA measurement designed to address the variability inherent in current clinical practice. The automated border detection, 3D speckle tracking, sophisticated segmentation algorithm, intuitive workflow and user interface, and quick and easy visualization and editing make the Dynamic HeartModel[A.I.] an outstanding tool that enables the confident use of 3D echo in routine clinical practice on a wide range of patients.

References

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