4D Auto MVQ
(Mitral Valve Quantification)

Federico Veronesi, Glenn Reidar Lie, Stein Inge Rabben
GE Healthcare

Introduction

As the number of mitral valve repairs is on the rise, so is the need for mitral valve quantification. Due to the complex anatomy and physiology of the mitral valve apparatus, 4D visualization and quantification is becoming increasingly important. The use of 4D imaging prior to, during and after these repairs is mandatory for certain procedures.

4D quantification tools for the mitral valve have existed for some time and are available from several vendors. These tools provide more objective and accurate measurements as compared to 2D quantification tools, where access to desired views may be more difficult.

The 4D Mitral Valve Quantification tools are usually automated to achieve quick access to the measurements of interest.

GE Healthcare has over the years introduced a series of quantification tools for 2D (e.g. 2D Strain, AFI and 2D Auto EF) as well as for 4D (4D Auto LVQ, 4D LV Mass, 4D Strain, 4D Auto AVQ). GE Healthcare has also licensed tools from TomTec.™ These tools, 4D RV Function and Mitral Valve Assessment, were implemented as plug-ins into our 4D ultrasound systems (Vivid™ E9, Vivid S70 with 4D and Vivid E95) as well as the EchoPAC™ work station. We have now implemented GE Healthcare's 4D Auto MVQ tool as a replacement for TomTec's Mitral Valve Assessment.* This tool is seamlessly integrated into the Vivid systems' workflow providing quick access to 4D raw data analysis.

Method

4D Auto MVQ is a quantification tool for rapid semi-automated detection of morphology of the mitral valve, including the annulus and the leaflets.

Segmentation of the MV during systole is performed using a multistep approach. First, from the user-identified landmarks the MV annulus is identified by means of template matching along an a-priori 3D saddle-shaped line.

Then, the MV leaflets are represented by a surface which during segmentation is deformed using image data together with the tracked annulus. The segmentation is represented as a state estimation problem and solved with an extended Kalman filter. From the detected surface, the MV coaptation line and possibly MV orifice is detected considering shape and thickness of anterior and posterior MV leaflets.

4D Auto MVQ workflow description

The fully integrated tool requires a 4D data set containing the mitral valve acquired with a TTE or a TEE probe, either in a full volume or zoomed acquisition. Care must be taken during acquisition to ensure that the complete valve, with the ring/annulus is included, and that the volume rate exceeds 12 volumes per second for adequate temporal assessment if dynamic systolic performance is of interest.

Speed of access to stored 4D images (from pressing the 4D Auto MVQ button on the touch panel until the 4D data is available for analysis) is twice as fast compared to its predecessor. The 4D rendering quality of the valve is similar to that of the original scanner acquisition throughout the entire quantification procedure.

The workflow is divided into stages (see Figure 1) accessible both through the touch panel as well as on the main screen. When entering the tool, the first step is to adjust 2D gain, 4D gain and zoom if needed. These controls are available throughout the remaining stages to always ensure optimal image quality. Then one can set/adjust the End Systolic (ES) and End Diastolic (ED) time events if needed. This is followed by an **Alignment** stage (see Figure 2) to ensure a standardized and expected view is obtained where the vertical axis crosses through the center of the MV, while the horizontal axis is parallel to the mitral valve.

Six **Landmark** points (see Figure 3) are then placed (two mitral annulus points, two anterior/posterior points, the coaptation point plus the aorta point). Using the above described method, the tool then generates a model for the leaflets and the annulus which can easily be edited by the operator through an intuitive and flexible user interface. The editing offers undo/redo capabilities, and one can at any time go back and forth between the various stages as one observes the results and the potential need for editing. Both systolic and full cycle loops can be played, though the tool only displays the model during systole.

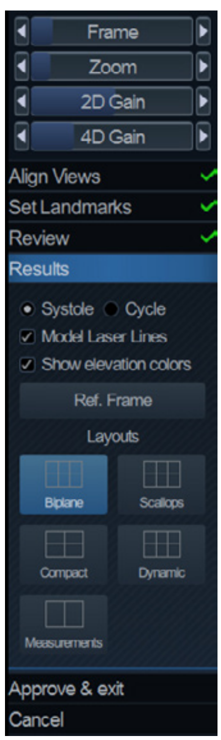

Figure 1. Stages

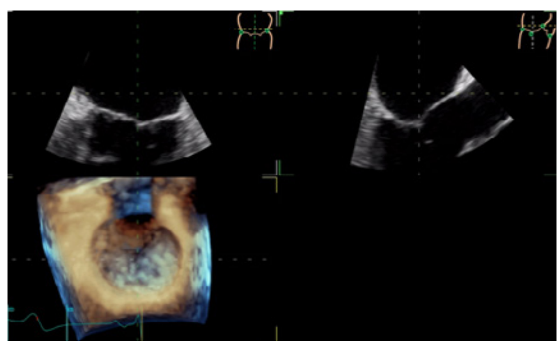

Figure 2. Alignment stage

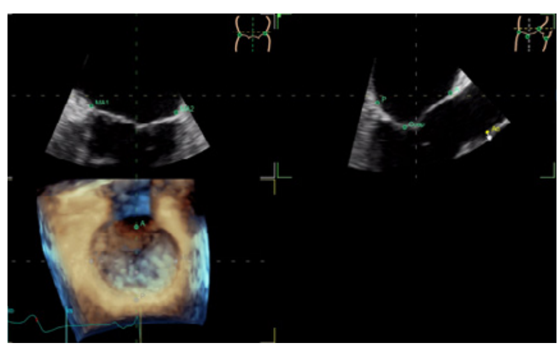

Figure 3. Landmark stage

The tool offers three layouts at the **Review** stage (Biplane, Scallops and Commissures) depending on assessment needs (See Figure 4). In the Review stage, the 3D model can be checked in all slices. To visualize the model in different slices, the user must rotate and translate the reference slices in 2D view (dotted lines) and observe the segmentation in the other interactive views. The 3D model is adjusted by clicking and dragging contours on 2D views when needed.

Five layouts are offered at the Results stage, see Figure 5 (Biplane, Scallops, Compact, Dynamic and Measurements). The Results layouts show all the Annulus and Leaflets parameters including three that were not supported in the predecessor tool (Inter-trigonal Distance, Anterior Leaflet Angle and Billowing Height).

The Laser Lines introduced on GE systems years ago can be offered as an overlay on to the model to ease orientation both in the Review and Results stages.

The ten most commonly requested and used measurements are transferred into the Worksheet for reporting when selecting the **Approve & Exit** button. Now, the tool also stores the complete setup and the results together with the exact screen view. When later recalling this particular image/loop and entering the 4D Auto MVQ tool, all prior alignments, landmarks, models and results are recalled for ease of continued analysis and review. This also serves as quality control.

Additionally, for documentation purposes at any time during use of the tool, image screen shots can be stored to the clipboard and be part of the study.

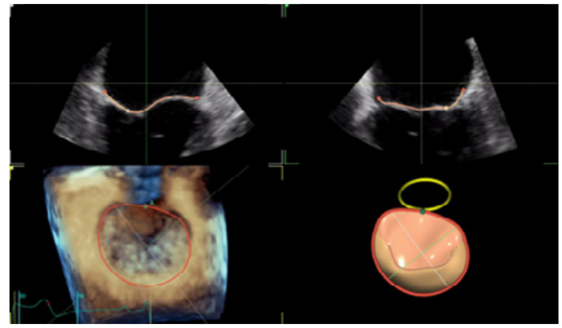

Figure 4. Review – Biplane

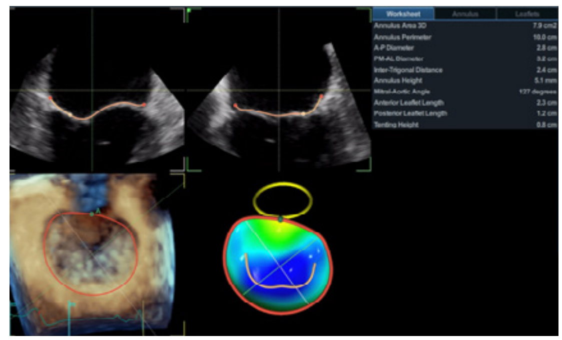

Figure 5. Results – Compact

Validation

The 4D Auto MVQ tool has been compared to the MV Assessment tool by TomTec on a set of 20 4D datasets including both normal subjects and patients affected by mitral valve disease. Results of the comparison are reported in table 1 as average ± standard deviation.

For further information regarding the validation, contact your local representative.

Limitations:

The measurements obtained from the two products compared in the validation span a clinically significant range. However, the number of subjects analyzed is limited and further studies on specific populations are needed to identify the clinical benefit of using advanced 3D tools to characterize the MV.

Both 4D Auto MVQ (and MV Assessment – TomTec) use an automated segmentation algorithm to initiate a 3D model from where the tool's measurements are calculated. There is an inherent risk that these automated segmentation algorithms may give inaccurate 3D models. That means that the tool results should not be approved without review and, if necessary, editing of the 3D model. If the tools are used without review and editing, the expected accuracy will be negatively affected.

Table 1. Comparison between 4D Auto MV and MVA Assessment tool by TomTec

	Measurement unit	Values MVQ	Values TomTec	TomTec - MVQ Difference
Annulus Perimeter	cm	13.7 ± 2.6	13.71 ± 2.64	0.01 ± 0.58*
Annulus Area 3D	cm^2	15.12 ± 5.57	14.51 ± 5.32	-0.61 ± 1.37*
AL-PM diameter	cm	4.44 ± 0.78	4.37 ± 0.82	-0.07 ± 0.25*
A-P diameter	cm	3.76 ± 0.78	3.86 ± 0.83	0.11 ± 0.34*
Annulus Height	mm	7.05 ± 2.59	7.46 ± 2.14	0.42 ± 1.58*
Mitral Annular Excursion	mm	6.58 ± 3.37	7.02 ± 3.22	0.44 ± 2.1*
Posterior Leaflet Angle	°	21.85 ± 17.72	23.76 ± 15.05	1.91 ± 6.85*
Mitral-Aortic Angle	°	127.7 ± 10.4	127.72 ± 14.12	0.08 ± 8.59*
Anterior Leaflet Area	cm^2	7.64 ± 2.42	7.77 ± 2.63	0.13 ± 1.0*
Posterior Leaflet Area	cm^2	8.48 ± 4.11	8.83 ± 4.12	0.36 ± 1.0*
Tenting Height	cm	0.62 ± 0.39	0.62 ± 0.29	0.0 ± 0.26*
Anterior Leaflet Length	cm	2.48 ± 0.53	2.46 ± 0.48	-0.02 ± 0.23*
Posterior Leaflet Length	cm	1.77 ± 0.68	1.87 ± 0.71	0.11 ± 0.24*

*Not significantly different (Two-tails paired Student's t-test with $P>0.05$)

Imagination at work

*Available on the Vivid E95 and Vivid S70N 4D Productivity Elevated release.

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