4D Auto LAQ
(Left Atrial Quantification)

Introduction

There has been an increased interest in quantification of the left atrium (LA) for various types of diseases; e.g. heart failure, heart valve diseases, atrial fibrillation, and so on.

Parameters describing LA volumes, ejection fraction as well as deformation/strain have been studied for this purpose. The joint EACVI and ASE standardization committee recently issued a recommendation for deformation imaging of the LA, based upon 2D speckle tracking[1] (Ref. European Heart Journal - Cardiovascular Imaging (2018) 0, 1–10). The GEHC 4D Auto LAQ feature uses 3D data and provides volumes and emptying fraction in addition to the strain parameters recommended by EACVI and ASE.

3D quantification is generally more accurate than 2D, in the sense that fewer assumptions are made with respect to shape. Likewise, acquisition issues like foreshortening may also be reduced with 3D.

4D Auto LAQ is currently available on Vivid™ E95, on EchoPAC™ Software Only and on the EchoPAC Plug-in from version 203. Data sets acquired with transthoracic 4D probes are supported.

Method

To measure the LA cavity volume during the cardiac cycle, a semi-automated segmentation algorithm is used. The algorithm is initialized with one landmark which is placed at the Mitral Valve (MV) center at the annulus level.

The segmentation algorithm computes the deformation of the 3D model by solving a state estimation problem using an extended Kalman filter (https://en.wikipedia.org/wiki/Kalman_filter) which combines LA geometry, a motion model and edge detection algorithms.

The strain calculation is based on the change of length of different lines along each anatomical direction. To calculate longitudinal strain, eight longitudinal lines (Figure 1), each connecting two opposite LA basal points, are sampled from an automatically constructed triangular mesh. The circumferential strain calculation uses seven circumferential lines (Figure 2) that are equidistantly distributed between the LA base and the LA apex. Strain is then calculated for each frame time as $s(t) = (L(t) - L(tref))/L(tref) \times 100\%$, where $L(t)$ is the line length at time t and tref is set as the time of the LV ED. Global strain is calculated for each direction as the average strain of the respective directional lines.

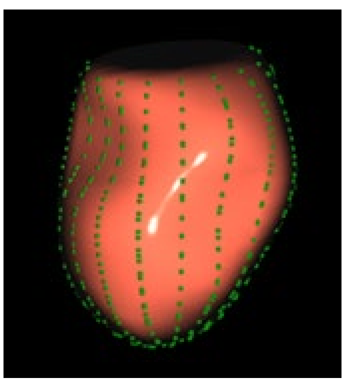

Figure 1: Points used to determine longitudinal lines for longitudinal strain calculation.

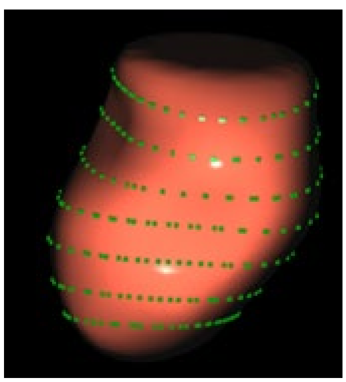

Figure 2: Points used to determine circumferential lines for circumferential strain calculation.

4D Auto LAQ workflow description

This fully integrated tool requires a 4D full volume data set acquired with a transthoracic 4D probe. Care must be taken during acquisition to ensure that the complete LA is included, and that the volume rate exceeds 12 volumes per second for adequate temporal assessment and volume/EF/Strain calculation.

The workflow is divided into stages accessible both through the touch panel (scanner only) as well as on the main screen. When entering the tool, the first step is to adjust 2D gain and zoom if needed. These controls are also available throughout the remaining stages to always ensure optimal image quality. Then, at the **Set Landmark** stage (see Figure 3), adjust the Frame control until the mitral valve is closed. If required, one can quickly adjust the landmark position by dragging it so that it's placed at the center of the mitral valve at the annulus level. Also, adjust the image position and angle such that the vertical line intersects the MV center as well as the apex of the LA. Use the pictograms in the upper right corner of each quadrant for guidance.

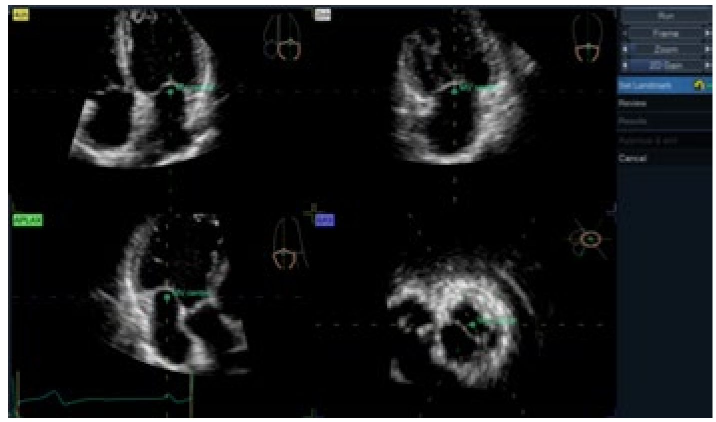

Figure 3: Set Landmark stage

The next stage is the **Review** stage (see Figure 4). At this point in time the system will run segmentation for the whole volume data set to locate the endocardial borders for the LA. If necessary, the contours can easily be edited by the operator through an intuitive and flexible user interface. If needed, exclude the pulmonary veins and the LA Appendage. The editing offers undo/redo capabilities, easy access to the ES, ED and preA frames, as well as, the ability to change these in the event systems' default tracings are not correct. It also offers an editing tool (pen size). One can at any time go back and forth between the various stages as one observes the results and sees a potential need for editing and adjustment.

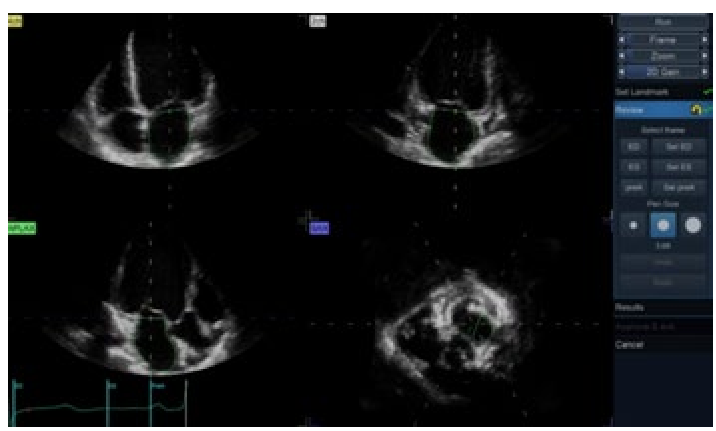

Figure 4: Review stage

The **Results** stage provides an overview of the various parameters that have been calculated:

Volumes and EF:

- LA Vmin = Minimum atrial volume
- LA Vmax = Maximum atrial volume
- LA VpreA = Volume at onset of atrial contraction
- LA EV = Ejection Volume (LA Vmax – LA Vmin)
- LA EF = Ejection fraction (LA EV / LA Vmax)

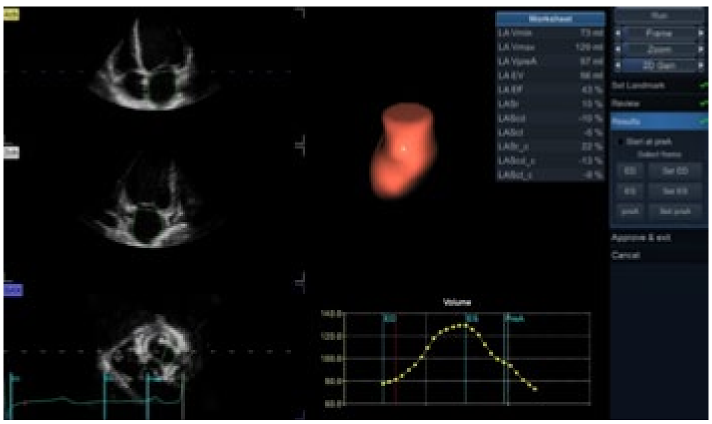

Figure 5: Results Volume Curve

Strain:

Three longitudinal and three circumferential strain values are derived. The EACVI/ASE consensus document does not recommend use of segmental strain due to the thin walls which make it difficult to achieve reliable results.

Longitudinal LA Strain is calculated as a change in the average longitudinal length (for the whole LA) from one mitral annulus to the other along the LA endocardial border. (See method description mentioned previously).

Circumferential strain is calculated as change in the average circumferential length (for the whole) LA along the endocardial border. (See method description mentioned previously).

- LAS**r** = longitudinal strain during **reservoir** phase, measured as the difference of the strain value at mitral valve opening (ES) minus ventricular end-diastole (ED) (positive value). The reservoir phase encompasses the time of left ventricular isovolumic contraction, ejection, and isovolumic relaxation.
- LAS**cd** = longitudinal strain during **conduit** phase, measured as the difference of the strain value at the onset of atrial contraction (PreA) minus mitral valve opening (ES) (negative value). In patients with atrial fibrillation, LAScd has the same value as LASr, but with a negative sign.
- LAS**ct** = longitudinal strain during **contraction** phase, measured only in patients in sinus rhythm as the difference of the strain value at ventricular end-diastole (ED) minus onset of atrial contraction (PreA) (negative value).
- LAS**r**_c = circumferential strain during **reservoir** phase, measured as the difference of the strain value at mitral valve opening (ES) minus ventricular end-diastole (ED) (positive value).
- LAS**cd**_c = circumferential strain during **conduit** phase, measured as the difference of the strain value at the onset of atrial contraction (PreA) minus mitral valve opening (ES) (negative value). In patients with atrial fibrillation, LAScd has the same value as LASr, but with a negative sign.
- LAS**ct**_c = circumferential strain during **contraction** phase, measured only in patients in sinus rhythm as the difference of the strain value at ventricular end-diastole (ED) minus onset of atrial contraction (PreA) (negative value).

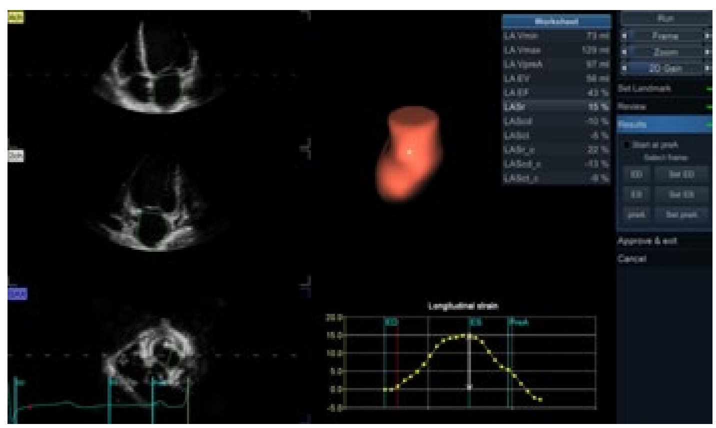

Figure 6: Results Strain Curves

Validation:

LA volume measurements (both fully automatic and with additional user input such as adjusting alignment and mesh edits) were validated by comparing with results from the "Triplane volume" tool. The tool is available on the GE 4D ultrasound scanners (Vivid E95 v201 and v202) ref. Figure 7. Manual triplane volume measurements were done at the frames corresponding with minimum LA volume (in most cases ED frame), maximum LA volume (in most cases ES frame) and at the preA frames. Then, these results were compared to the ones obtained from the 4D Auto LVQ tool. Ref. Table 1.

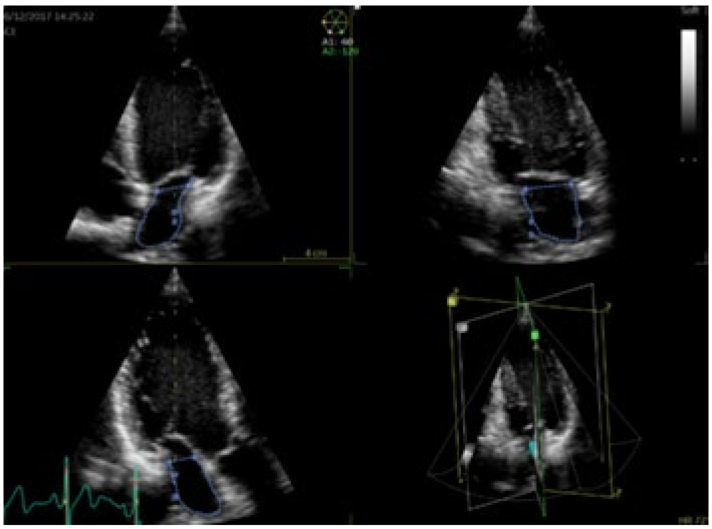

Figure 7: Example LA segmentation done in "Tri plane volume" tool.

Table 1: Volume validation

Volume Parameter	Range	Max error	Min error	Average error	Range with editing	Max Error with editing	Min error with editing	Average error with editing
LA Vmin[ml]	7:74	5.0	1.0	2.4 +/- 1.4	6:80	4.0	0.0	1.6 +/- 1.2
LA Vmax[ml]	19:130	9.0	1.0	3.6 +/- 2.4	19:131	5.0	1.0	3.0 +/- 1.5
LA VpreA[ml]	12:97	11.0	0.0	3.1 +/- 3.6	11:98	5.0	0.0	1.7 +/- 1.8

To validate strain, the results from 4D Auto LAQ were compared to manual caliper measurements from the FlexiSlice tool. Slices from FlexiSlice were identically aligned with those from the 4D Auto LAQ tool. Four manual caliper length measurements in each anatomical direction were done at each frame of interest (ED, ES, preA). Figure 9 shows an example from the alignment/measurement from an internally developed 4D Auto LAQ "validation" screen, while Figure 8 shows the FlexiSlice method. The latter method was regarded as the gold standard reference. For validation results, see Table 2.

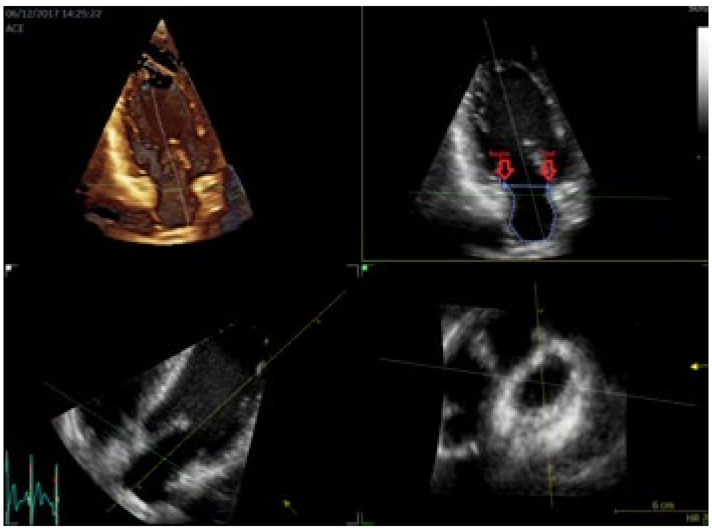

Figure 8: Example of FlexiSlice view used to measure LA longitudinal length.

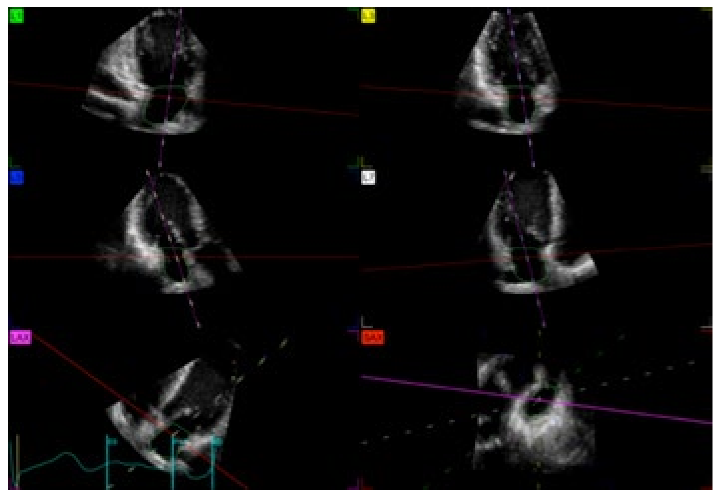

Figure 9: Reference alignment screen shot from the tool.

Table 2: Strain calculation reference planes used for validation.

Strain Parameter	Range	Max error	Min error	Average error	Range with editing	Max Error with editing	Min error with editing	Average error with editing
LASr [%]	5:37	4.6	0.7	3.1 +/- 1.5	5:31	3.7	0.7	1.7 +/- 0.9
LAScd [%]	-21:5	4.1	0.5	2.3 +/- 1.5	-18:-4	2.3	0.5	1.4 +/- 0.7
LASct [%]	-16:0	3.0	0.2	0.9 +/- 0.9	-15:0	2.4	0.2	1.0 +/- 0.6
LASr_c [%]	5:47	4.9	0.0	1.6 +/- 1.6	4:50	2.4	0.1	1.0 +/- 0.6
LAScd_c [%]	-23:-5	2.4	0.3	1.0 +/- 0.7	-25:-6	3.9	1.1	2.1 +/- 1.0
LASct_c [%]	-24:3	2.6	1.2	1.9 +/- 0.6	-25:2	3.5	0.4	1.6 +/- 1.0

Imagination at work

[1] http://asecho.org/wordpress/wp-content/uploads/2016/02/2015_ChamberQuantificationREV.pdf
http://asecho.org/wordpress/wp-content/uploads/2017/04/Lang_Guidelines-for-Chamber-Quantification.pdf

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