Caas User Manual

Caas MR Solutions 5.2.1

IntelliSpace Portal

Caas
MR solutions

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User Manual Caas MR Solutions 5.2.1
 This document provides guidance and advices with regards to the proper use of Caas MR Solutions. Pie Medical Imaging B.V. cannot guarantee the proper functioning of the device when the device is used otherwise.

This User Manual applies to Caas MR Solutions 5.2.1, including subsequent maintenance releases (e.g. X.X.1, X.X.2).

Information in this document and all products it describes are subject to change without notice. Nothing contained within this document can be taken as an offer, warranty, promise or any kind of contractual condition.

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Manufactured in 2021.

CE 0123

Caution: US Federal law restricts this device to sale by or on the order of a physician.

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1 Introduction

This manual will guide you through all the functionalities that Caas MR Solutions has to offer.

1.1 Welcome to Caas MR Solutions

Caas MR Solutions is aimed at analyzing the performance of the heart. It is a software application for post-processing analyses needed in Cardiac MRI. The function of the heart can be assessed based on cine MR images, allowing understanding of contraction of the left and right ventricle. Blood flow can be assessed based on phase contrast MR images and corresponding magnitude MR images, for 2D Flow as well as 4D Flow. Caas MR Solutions allows the understanding of hemodynamics by visualization of blood flow using streamlines, pathlines, and vector fields. Additionally, blood flow can be analyzed by retrospective reformatting of flow planes.

1.1.1 Clinical benefits

Quantitative analysis of CMR images using Caas MR Solutions comes with a higher accuracy and reproducibility when compared to visual assessment alone.

Workflow	Benefit	Clinical parameter
Strain	Better assessment (accuracy and reproducibility) of cardiovascular dimensions compared to visual assessment alone.	Dimension of cardiovascular structure, calculation of strain parameters
2D Flow 4D Artery 4D Heart	Better assessment (accuracy and reproducibility) of cardiovascular dimensions and flow compared to visual assessment alone.	Dimension of cardiovascular structure, quantification of blood flow velocity and directions, wall shear stress, pressure drop

1.2 Disclaimer

1.3 Important safety information

When ⓘ is in front of the text in this user manual, it means that this is essential information for proper use of the software.

Serious incidents occurring from use from the software need to be reported to Pie Medical Imaging and your competent authority.

There are no contra-indications for using the software.

The software is a stand-alone medical device and has no effect use of other medical devices or combination of these medical devices.

The instructions provided in this document describe the use of the device according to its intended use. If used otherwise or for other purposes, Pie Medical Imaging B.V. cannot guarantee the reliability of the results.

1.4 Regulatory information

Country	Authorized Representative
Australia	Sponsor: Emergo Australia 201 Sussex Street, Level 20, Tower II Darling Park, Sydney, NSW 2000, Australia Tel: + 61 (0) 2 9006 1662
India	Importer: Morulaa HealthTech Pvt Ltd Plot no: 38, First Floor, Rajeshwari Street, Santosh Nagar, Kandanchavadi, Chennai 600096, Inida License number: PieMe-NLD/I/MD/001166

1.5 Intended Purpose and Indications for Use

1.5.1 Intended Purpose

Standalone diagnostic bioimaging software is intended to measure and visualize cardiovascular structures.

1.5.2 Indications for use:

Standalone software for medical image analysis intended for advanced visualization and quantitative analysis for diagnostic and/or for assistance during treatment in the field of cardiology or radiology by means of segmentation of cardiovascular structures and enabling the analysis of blood flow in the heart and large vessels based on multi-slice, multi-phase and velocity encoded MR images as well as measurement and reporting tools by providing the following functionality:

- Segmentation of cardiovascular structures and calculation of quantitative results
- Support signal intensity analysis for the myocardium
- Quantification of MR parametric maps (such as T1, T2, T2* relaxation)
- Visualization and quantification of blood flow velocity and directions

When the results provided by CAAS MR Solutions are used in a clinical setting to support diagnoses, the results are explicitly not to be regarded as the sole, irrefutable basis for clinical decision making.

1.5.3 Patient target groups

CAAS MR Solutions is to be used for patients with suspected vascular, valvular or ventricular disease who underwent a cardiac MRI scan.

1.5.4 Intended users

Caas MR Solutions is intended to be used by or under the supervision of a cardiologist or radiologist.

1.5.5 Instructions for use

- Correct data acquisition is of crucial importance for a correct analysis. Image artifacts can influence contour detection. Make sure acquisitions are made by experts in cardiac MR and are performed according to the guidelines[1–3]
- Record MR images using multiple body coils and preprocess the image data using a surface coil intensity correction algorithm. Optimal homogeneity of the MR images is important for the segmentation results. Magnetic field inhomogeneity corrections results[1,3] in optimal MR images, which is important for the segmentation and analysis results.
- Every MRI vendor applies specific scan protocols and DICOM data storage structures for the acquisition and storage of the MR 4D Flow data. This leads to variations in the DICOM

structure and the possibility that acquired MR 4D Flow images cannot be imported into the Caas 4D Flow application.

- The accuracy of post-processed 4D flow data analysis results are dependent on multiple parameters that are strongly influenced by the 4D Flow image acquisition.

Image acquisition for Strain Analysis:

- Acquire images with a Steady State Free Precession sequence.
- Acquire Steady State Free Precession images before acquisitions that require contrast as the contrast in the myocardium could influence the segmentation.
- For Left Ventricle analysis acquire Short Axis, 2 Chamber and 4 Chamber Long Axis images. For Right Ventricle analysis acquire Short Axis images.

1.5.6 Restrictions and Limitations

There are no restrictions or limitations.

1.5.7 Side-effects

There are no known potential side effects when using this software as intended.

1.6 Training

Training for this product is available via Pie Medical Imaging. One or more of the following training options are available:

- In person training. Please contact Pie Medical Imaging.
- Training via web-ex. Please contact Pie Medical Imaging.
- E-learning via the PMI academy. Visit http://academy.piemedicalimaging.com/ to access the PMI academy.

1.7 Conformance standards

The following standards are applicable to Caas MR Solutions:

Reference and title of the harmonized standard
EN ISO 15223-1:2016 (corrected version 2017-03) Medical devices - Symbols to be used with medical device labels, labelling and information to be supplied - Part 1: General requirements
EN 1041:2008/ A1:2013 Information supplied by the manufacturer of medical devices
EN ISO 13485:2016 Medical devices - Quality management systems - Requirements for regulatory purposes
EN ISO 14155:2011 Clinical investigation of medical devices for human subjects - Good clinical practice
EN ISO 14971:2019 Medical devices - Application of risk management to medical devices
EN 62304:2006/A1:2015 Medical device software - software life cycle
EN 82304-1:2017 Health Software – Part 1: General requirements for product safety
EN 62366-1:2015 Medical devices - Application of usability engineering to medical devices
DICOM PS-3:2016 Digital Imaging and Communications in Medicine standard

For a copy of the DICOM Conformance Statement of Caas MR Solutions, contact pmi@pie.nl or visit our website: www.piemedicalimaging.com.

1.8 Labeling Symbols

Explanation of symbols included on Caas MR Solutions can be found in the table below.

Symbol	Description
 YYYY-MM-DD	Medical device manufacturer and date of manufacturing
	Consult the Instructions for Use
	Consult the Instructions for Use for important cautionary information
Rx Only	Caution: US Federal law restricts this device to sale by or on the order of a physician
MD	The 'MD' label is used to indicate the device is a medical device.
UDI	The 'UDI' label precedes the UDI in the labelling to indicate that the number that follows is a Unique Device Identification (UDI).

1.9 Measurement accuracy

Caas MR Solutions has been extensively validated internally by Pie Medical Imaging, as well as externally of which results are published in scientific literatures. Please refer to the website: www.piemedicalimaging.com.

The accuracy and precision for CAAS MR Solutions are determined and are reported as follows:

Workflow	**Measurement**	**Overall accuracy**
MRI Strain	Global strain	The calculation of myocardial strain in CAAS MR Solutions is based on the deformation of the ventricular myocardium for each phase related to the End Diastolic phase. The Cine MR image data, as a result of the acquisition process, is provided to the CAAS MR Solutions software as a DICOM file. The DICOM image data will be limited to a certain resolution, and therefore, the accuracy of the strain calculation will depend on the accuracy of the imaging process of the DICOM image data. For example, using a clinical image data which represents the left ventricle of a healthy person with a pixel resolution of 1,48mm/pixel and a temporal resolution of 29ms which simulates the deformation of the ventricular myocardium. The accuracy of the global strain (for radial, circumferential and longitudinal) for this example, is within 5.0% (absolute global strain difference).

Workflow	**Measurement**	**Overall accuracy**
MRI 2D/4D Flow	Velocity data	Measurements of ventricular parameters in CAAS MR Solutions are based on phase-contrast (PC) MR image data. The PC MR image data, as a result of the acquisition process, is provided to the CAAS MR Solutions software as a DICOM file. The DICOM image data will be limited to a certain resolution. Data visualization and segmentation gives the possibility to perform quantifications on subpixel level where each pixel of the DICOM data is divided into a set of sub pixels. Therefore, the accuracy of the measurements within MR will depend on the accuracy of the imaging process of the DICOM image data and the level of the subpixels used. The accuracy for area and flow will be dependent on the size and complexity of shape, in addition to the sub pixel matrix size. For example, using a computer simulated model of a vessel tube with a radius of 10mm and a mean velocity (presented as parabolic profile) of 50cm/s, the vessel tube is positioned perpendicular to the plane defined by x and y with a voxel size of 1mm and a subpixel level of 2, the accuracy for the following parameter is:
	Flow	*±5.0%*

1.10 Terms and abbreviations

Term / Abbreviation	Explanation of term / abbreviation
CAAS	Cardiovascular Angiographic Analysis System
MR	Magnetic Resonance
ED	End Diastole
ES	End Systole
SA	Short Axis
LA	Long Axis
LV	Left Ventricle
RV	Right Ventricle
2CH	Two Chamber View
4CH	Four Chamber View
DICOM	Digital Communications in Medicine
DE	Delayed Enhancement
AHA	American Heart Association
FWHM	Full Width Half Maximum
SIE	Segmental Infarct Extent
SEE	Segmental Edema Extent
ROI	Region of Interest
sdev	Standard Deviation
MVO	Micro-Vascular Obstruction
MPRI	Myocardial Perfusion Reserve Index
PC	Phase Contrast
WSS	Wall Shear Stress
Max/Min	Maximum/Minimum
CFD	Computational Fluid Dynamics
MOCO	motion correction
VENC	Velocity encoding
MPR	Multiplanar Reconstruction
MFP	Myocardial flow reserve
FPP	First Pass Perfusion
EF	Ejection Fraction
PCA	Phase contrast angiography
WSR	Wall Shear Rate

2 Platform features

NOTE*: Please note that certain features, such as the Close Button or File Open/Save options, described in this manual may not be available when installed on a Third-Party workstation.*
NOTE*: It is not guaranteed that all functionalities work correctly with a touchscreen user interface.*

2.1 Data import Caas MR Solutions

Click the **Browse Icon** and select **Import Folder** to import a study for analysis. For each study an examination tab will be opened. A maximum of 5 studies can be opened at once.

All images of a study will be presented within the Image Ribbon. The Image Ribbon can be hidden by using the **Hide Image Ribbon** button.

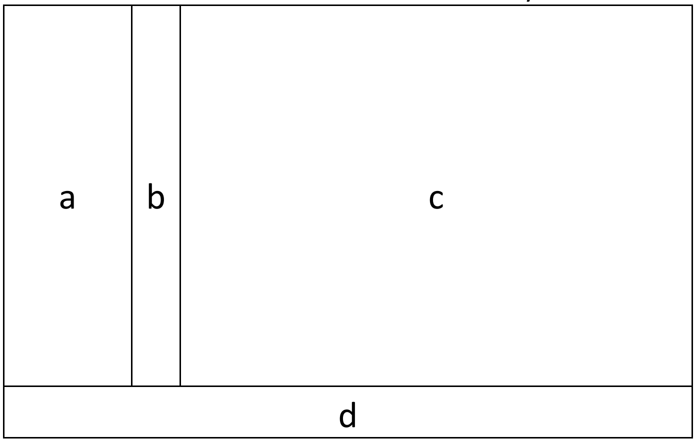
To open a previously saved examination, click the **Browse Icon** and then select **Open Examination.** Note that only examinations saved with CAAS MRV 4.1 or higher and CAAS MR 4D Flow 1.1 or higher can be opened.

Clicking the **Clone Button** on the examination tab to clone the examination in a second window. Cloning is only possible when at least two examinations are available and is only available in the module Strain.

The Image Ribbon contains series belonging to the current examination. Each image series is represented by a single thumbnail. Within each thumbnail the series description and number is shown at the top and the number of slices and phases at the bottom. The analysis modules are next to the image ribbon. At the bottom, a message bar is present which will lighten up if a message pops up or a action is performed (e.g. analysis saved).

2.2 General screen layout

Caas MR Solutions has a recurrent screen layout:



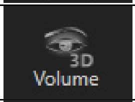
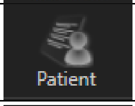
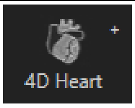
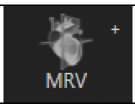
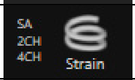
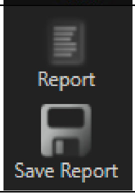
a	Image ribbon
b	Analysis modules
c	Workflow area
d	Messages

2.3 Analysis modules

Start an analysis or viewing session by:

- Selecting the image and clicking the module button or **+** next to the module-icon, or
- Drag and drop the image onto the module button.

It is possible to perform multiple analyses within a study. The active analyses are indicated with a number next to module-icon. A maximum of 3 analysis sessions can be created within an examination. The active images used in the analysis are indicated next to the module button. An examination can be closed by clicking the X located at the botton of the active analysis tab or the 'close examination-button.

	2D Viewer	Viewer for eyeballing all your MR series. Perform simple measurements and annotate on slices. Synced play/loop for a first assessment.
	3D Viewer	3D Viewer for MPR/MIP viewing. 3D Model with coronal, axial, and sagittal viewports.
	Patient information	View patient information details here and add missing information (e.g. weight, height)
	4D Flow Heart	Analysis module for blood flow quantification in the heart based on 3D phase-contrast images. [Intra-cardiac flow and valve tracking]
	4D Flow Artery	Analysis module for blood flow quantification in the heart based on 3D phase-contrast images. [WSS, 2D flow, Pressure difference]
	MR Ventricle Analysis	MR Ventricle analysis groups Strain assessment per patient/study.
	MR Strain	MR Strain allows for comprehensive assessment of diastolic myocardial function by means of myocardial strain.
	Reporting	All the work performed is automatically stored in the report when working with the modules in Caas MR Solutions, including patient information.

2.4 Settings

Click the **Tools Icon** to open the **Settings** menu. Screen layout, import and general export features can be configured. **Note:** this menu is only available to the local administrator.

2.5 Image set properties

To see or edit image properties right-click on the image thumbnail in the Image Ribbon. Selecting **Edit Imageset Properties** will show the image properties menu. Properties already present in the DICOM header cannot be changed.

Edits performed via the image set properties (e.g. heart rate) will influence the analysis if the edit is performed before an analysis is started. If edits are performed after an analysis is started **a warning is** shown and edits that are performed do not influence the analysis. Regarding 4D Heart and 4D Artery, editing heart rate in the Magnitude image set will influence the results, if heart rate is edited in one of the phase contrast images, the result is not changed.

Note that adjusting temporal resolution does not change the analysis.

Note that adjusting heart rate in Magnitude image set will influence the results on demand. If edits are performed after an analysis is started a warning is shown that the edits can influence the analysis.

2.6 Mouse control

General mouse behavior in Caas MR Solutions is explained below:

2D Viewer / Strain	
Zoom In/Out	mouse wheel scroll
Context Menu	right click
Adjust Contrast	right click + hold + drag left/right
Adjust Brightness	right click + hold + drag up/down
Pan	move near viewport border, when appears **right** click + hold + pan

3D viewer	
Zoom In/Out	Mouse wheel click + hold + move up/down
Context menu	right click
Adjust Contrast	right click + hold + drag left/right
Adjust Brightness	right click + hold + drag up/down
Pan	move near viewport border, when appears **left** click + hold + pan
4D Artery / 4D Heart	
Zoom In/Out	Mouse wheel scroll
Context menu	right click
Pan (3d view)	Mouse wheel hold + move
Pan (2d view)	move near viewport border, when appears **right** click + hold to pan

2.7 Shortcut Keys

Shortcut key	Action
Arrow keys	Navigate through slices (up down) and phases (left right)
Shift + mouse wheel	Navigate through phases (up down)
Alt + mouse wheel	Navigate through slices (left right)
Page Up	Next report page
Page Down	Previous report page
F1	Show help (same as menu item)
Spacebar	Play/Stop Looping
H	Hide overlays
Esc key	Exit any edit modes right away (Measurements or Annotation)
Additional for Analysis workflows	
Alt + C	Toggle Spline/Curve edit mode in Endo- and Epicard
Alt + E	Toggle edit mode between Endo- and Epicard
Alt + V	Toggle between LV and RV workflow
Del	Delete all contours from the active edit mode
Ctrl + Del	Delete all contours
Ctrl + Y	Redo a manually performed edit action
Ctrl + Z	Undo a manually performed edit action

3 General viewing and patient data

Caas MR Solutions provides two viewing modules. A 2D viewing module and a 3D viewing module.

3.1 2D viewer

In the 2D Viewing workflow up to 6 MR series can be viewed at a time.

<table>
<tr><td>a</td><td>b</td><td>c</td></tr>
<tr><td>d</td><td>e</td><td>f</td></tr>
<tr><td colspan="3">g</td></tr>
</table>

a-f	Viewport
d	Viewing toolbar

3.1.1 Viewports

Open an image series with one of the following options:

- Double click in the corresponding thumbnail in the Image Ribbon.
- Drag the corresponding thumbnail on the Viewing workflow button.
- Open Viewing workflow and drag the corresponding thumbnail in the desired viewport.

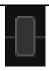
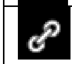
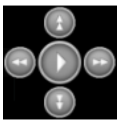
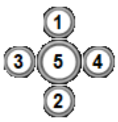
3.1.2 Viewing toolbar

Viewing toolbar has several options:

	Select the number of viewports, use the buttons at the bottom left of the viewport
	Clear all viewports (and measurements)
	Show/hide intersection lines
	Add Annotation text. **Double left mouse clicks** on the viewport where the annotation is needed. **Double click** on "Annotation" and text can be edited.
	Length Measurement. **Left click** to set the initial point and **left** click for each next measurement point. **Double click** to conclude the measurement.
	Angle Measurement: angle between two lines is depicted. **Click** to set the begin and endpoint of the line. Repeat for second line.
	Ratio Measurement: the length of two lines is compared. **Click** to set the begin and endpoint of the line. Repeat for second line.
	Move slider to adjust looping speed (frames per second)

3.1.3 Viewport controls

In each viewport, there are several controls. Hovering at a control will show a tooltip.
Navigation controls for a series are available on each viewport. The play button allows by default looping of images over consecutive phases. To allow looping over consecutive slices **press CTRL+left mouse click** on the button.

 and 	Slice and phase navigation. Move slider up/down or left/right, respectively. A marker will show as a reference on the slice/phase a measurement or annotation is performed.
	Show/hide active viewport intersection lines in other viewports
 and 	Link/unlink active viewport with other viewports
 and 	Maximize/minimize a viewport when viewing in 2, 4, or 6 viewport mode
 	1. Slice Navigation Up 2. Slice Navigation Down 3. Phase Navigation Left 4. Phase Navigation Right 5. Play/loop

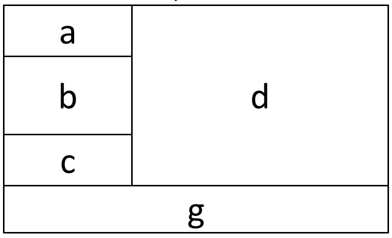
3.1.4 Context menu

By right-click in a viewport, a context menu will open. Several options are available:

Add Snapshot to Report	-
Delete all Measurements	-
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as...	Saves snapshot to a default location specified in the settings as *.dcm/ *.jpg/*.png file
Overlay	show/hide overlay of information and/or contours
Zoom in / Zoom out / Zoom 100%	Zoom controls
Contrast/Brightness	Opens window to edit contrast and/or brightness
Default Contrast/Brightness	-
Magnifying Glass	Opens a small magnifying window
Clear viewport	Deletes stack from current viewport

3.2 3D viewer

In the 3D Viewer workflow, several render modes are available.



a-d	Viewports
e	viewing toolbar

3.2.1 Viewports

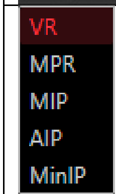
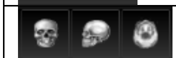
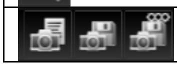
The 3D Viewer workflow consists 4 viewports in which series can be viewed: a main viewport and 3 viewports which show a sagittal, axial, and coronal view.

Series can be opened by:

1. Drag the corresponding thumbnail on the 3D Volume button.
2. Open Viewing workflow and drag the corresponding thumbnail in the desired viewport.

3.2.2 Viewing toolbar

Viewing toolbar has several options:

	Select the number of viewports, use the buttons at the bottom left of the viewport
	Select Render mode: - Virtual Rendering(VR); - MultiPlanar Reconstruction(MPR); - Maximum Intensity Projection (MIP); - Average Intensity Projection (AIP); and - Minimum Intensity Projection (MinIP).
	Phase selection (when >1 phase is available).
	Set main viewer to Coronal, Sagittal, or Axial view
	Slab mode, enables a slab in the Coronal, Sagittal, or Axial views.
	Sculpt mode: **Hold 'shift' + left mouse** to remove image data from the viewer.
	Add length measurement
	'Add snapshot to report', 'Save snapshot' to default location, and 'Save snapshot as…'

3.2.3 Context menu

Right-click in a viewport, a context menu will open.

Add Snapshot to Report	-
Delete all Measurements	-
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file

3.3 Patient Data

In the **Patient Data workflow** the patient information is presented. All information available in the DICOM header is imported in the patient data workflow.

If a data parameter is not available then it can be edited manually by the user. Patient information that can be edited (if missing) is outlined in red.

To anonymize patient data, click the button ‘Anonymize patient data’. ’Patient name’, ’ID’, and ’Accession number’ are set to ‘Anonymous’.

4 Strain workflow

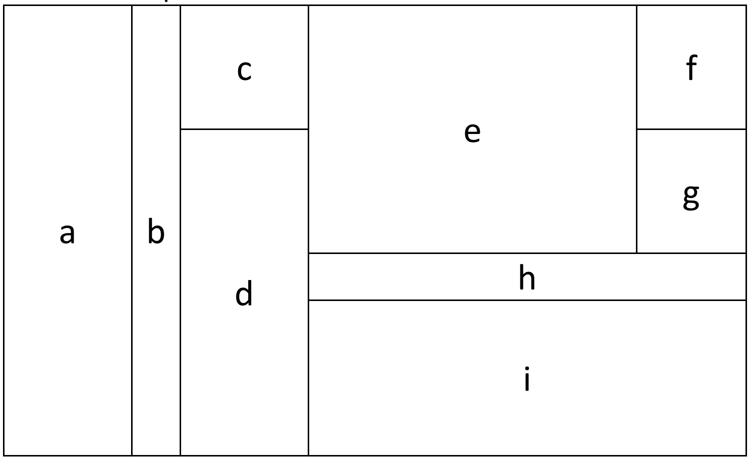
The Strain workflow is meant for comprehensive assessment of diastolic myocardial function by means of myocardial strain.

4.1 Mark Images

In this step, image data is selected for viewing and/or analysis.

4.1.1 Screen layout

At the start-up screen of the Strain workflow data needs to be selected.



a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	viewport
f	viewport
g	viewport
h	tabs
i	miscellaneous (selection by tabs)

4.1.2 Workflow

Drag and drop at least one Cine images to the viewports. Short Axis (SA) Cine for circumferential strain and radial strain and 4CH and/or 2CH Cine for longitudinal strain. The viewports have a label that indicate the stack.

In the workflow assistant, the checkbox ‘Automatically segment’ provides automatic contours for the selected stacks when **clicking** *‘Next’*. These contours are the input for displacement calculation.

4.2 Define & review

Caas MR Strain enables quantification of global strain parameters such as global longitudinal strain (GLS), global circumferential strain (GCS), and global radial strain (GRS). These parameters are based on the deformation of the myocardial wall. The workflow assistant describes the steps to be followed.

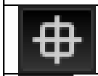
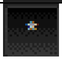
4.2.1 Screen layout

The screen layout is the same as in step *1. Mark Images*.

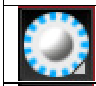
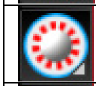
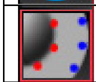
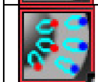
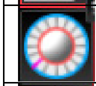
The available tabs(h) are:

- *Image overview*: shows a matrix of squares, with each square representing one image of the series. The different slices are presented along the vertical direction and the different phases along the horizontal direction When tracing is performed on the slice a red or blue dot is depicted in the right upper and/or lower corner of the matrix cell.
- *Image Thumbnails:* shows a thumbnail view of different phases related to the selected slice. The image currently displayed in the Main Viewport is indicated by a red outline.

In the workflow assistant the follow actions are available:

Icon	Description
	**'Set'**-button: **Set** the active cell in the *Image overview* as value
	**Sets** the active cell in the *Image overview* as value for all stacks
All	**Initiates** the segmentation of all stacks based on automatic segmentation
Only 2CH	**Initiates** the segmentation of the 2CH stack based on automatic segmentation
Only 4CH	**Initiates** the segmentation of the 4CH stack based on automatic segmentation
Only SA	**Initiates** the segmentation of the SA stack based on automatic segmentation
Process	**Initiates** tracing of the endo- and epicardium for displacement

In the main viewport a toolbar is available:

Icon		Description
	**Epicard**	Initiates the drawing or editing of an LV epicardial contour
	**Endocard**	Initiates the drawing or editing of an LV endocardial contour
	**Displacement points**	Enables viewing of epi- or endocard tracing or both, or no tracing to be overlayed
	**Show/hide displacement paths**	Shows/hides tracing paths
	**LRV Junction point**	Initiates the editing of the location of the LRV junction point and the visualization of (user) segments
	**Intersection lines**	Shows the intersection lines in the Short and Long Axis

4.2.2 Context Menu

The Context Menu for step 2. is the same for step 3. and can be opened by **right mouse click** in the viewport to enable the following actions:

Delete LV epicard	-
Delete LV endocard	-
Delete all	Deletes LV epicard and LV endocard
Add Snapshot to Report	Adds snapshot to report
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…	Saves snapshot to a to-be-specified location as *.dcm/*.jpeg/*.png file
Export Video	Exports a video of 1 heart cycle to a default location specified in the settings as *.dcm file
Export Video as…	Exports a video of 1 heart cycle a to-be-specified location in the settings as *.dcm file/*.wmv file
Overlay	Information > shows/hides stack information Contours > shows/hides contours
Zoom in/out/100%	Zoom controls
Contrast/brightness	Opens window to edit contrast and/or brightness (right mouse button hold)

Default Contrast/Brightness	-
Magnifying Glass	Opens a small magnifying window

Please note that the ‘save/export as…’ depends on Administrator settings and may not be available

4.2.3 Workflow

For circumferential strain and radial strain at least the short axis stack is needed. For longitudinal strain the long axis stacks are needed. The contour input for all selected stacks is provided when the option ‘Automatically segment’ has been selected.

4.2.3.1 Segmentation

Automatic segmentation can be performed for each stack separately.

1. **Select** the stack of interest in viewport e (see screen layout in the beginning of this chapter)
2. **Select** *End Diastolic* and *Systolic* Phase by navigating to the specified phase and use the button to indicate the LV ED or LV ES phase for the loaded stacks.
3. **Click** on *‘All’*, *‘Only 2CH’*, *‘Only 4CH’*, or *‘Only SA’* to initiate automatic segmentation.
4. **Check** if *Apex* and *Base* are correct. **Edit** by selecting the correct apical or basal slice in the *ED* and *ES* phase and **click** .
5. Important note: **Review** the segmentation as it is input for the tracing for all phases. Edit when necessary.

!	Check if LV Apex and Base definitions are correct in the Image Overview Matrix. Apex and Base are indicated by the letter A and B, respectively. Apex and Base can be modified in the Apex/Base control in the Workflow Assistant.

6. **Click** *Process* to initiate the tracing of de epicardial and endocardial phases.
7. **Check** the tracing results.

4.2.3.2 Manual segmentation

The SA stack is needed for circumferential and radial strain. The 2CH and 4CH stacks are needed for longitudinal strain.

1. **Select** a stack.
2. **Select** *End Diastolic* and *Systolic* Phase by navigating to the specified phase and **click** for *LV ED* or *LV ES*.
3. **Define** contours for all the LV ED phases of interest.
4. **Check** if *Apex* and *Base* are correct. **Edit** by selecting the correct apical or basal slice in the *ED* and *ES* phase and **click** *Set.*
5. **Click** *Process* to initiate the tracing of de epicardial and endocardial phases.
6. **Check** the tracing results.
7. **Click** *Next*

Define and edit contours

In **Spline** mode:

- **Define** points by **clicking** on the epi- or endocardial border in the image.
- **Add** more points by **left mouse Click**.
- **Edit** the points by **left mouse click** and **drag** them on the epi- or endocardial contour.
- **Delete** an existing point by double left mouse click

In **Curve** mode:

- **Click** and **hold** the **left mouse** on the epi- or endocardial border of the image
- **Drag** the mouse over the epi- or endocardial contour until you close the contour.

To draw a long axis contour:

- Draw two spline points on the valve to indicate the basal plane by **clicking left mouse** button.

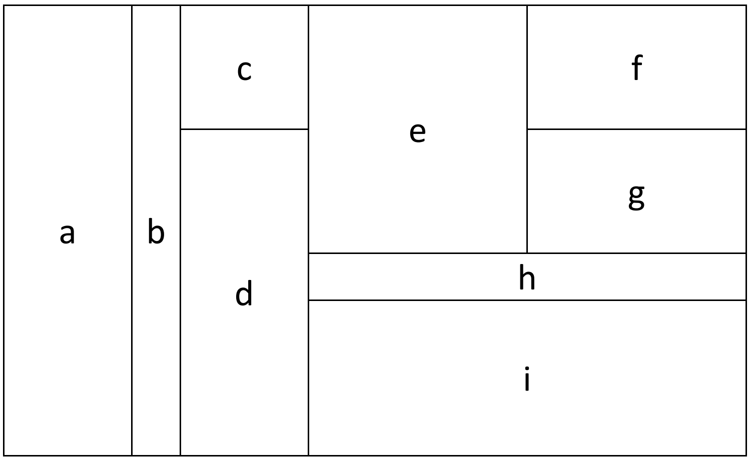
- Indicate the apical point by **clicking left mouse** and draw more points on the epi- or endocardial border to define the ventricle border.

!	Check if LV Apex and Base definitions are correct in the Image Overview Matrix. Apex and Base are indicated by the letter A and B, respectively. Apex and Base can be modified in the Apex/Base control in the Workflow Assistant.

4.3 Review results

In this step, visualisation and quantification of myocardial strain is provided based on the tracing performed in step *2. Define & Review.*

4.3.1 Screen layout

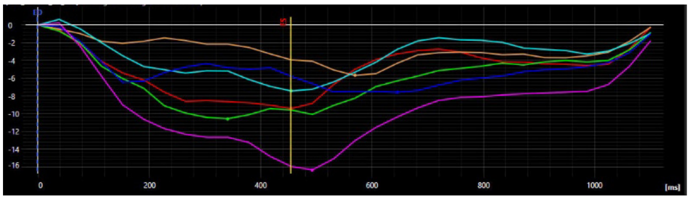
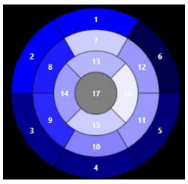


a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	viewport
f	viewport
g	viewport
h	tabs
i	miscellaneous (selection by tabs)

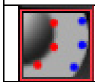
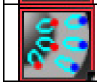
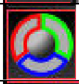
The *Results* (i) are default below the viewports. In contains numerical results, graph results, and a Bull's eye when applicable. In the workflow assisstant a selection can be made in the *Segments Mode* dropdown menu to view results:

- *Global*: shows the global strain values and graphs for the loaded Cine Stacks
- *User Segments*: shows the user segments strain values and graphs for the loaded Cine Stacks
  - *Segments*: **select** the number of segments
  - *Strain type*: **select** between *Radial, Circumferential, or Longitudinal Strain* (if available)
    - *Longitudinal stack*: when *Longitudinal Strain* is chosen, **select** 2CH or 4CH to be input for the strain values and graphs. No Bull's eye is shown in this case.
  - *Show in Bull's Eye*: **select** the outcome value to be shown in the Bull's eye
- *AHA-17 Segments Model*: shows the strain values and graphs for the loaded Cine Stacks
  - *Slice selection*: **select** *All, Basal, Mid, or Apical* slices to be shown in the *Results* tab.
  - *Strain type*: **select** between *Radial, Circumferential, or Longitudinal Strain* (if available)
    - *Longitudinal stack*: when *Longitudinal Strain* is chosen, **select** 2CH or 4CH to be input for the strain values and graphs. **Note** that the results for segment 2, 5, 8, and 11 are missing.
  - *Show in Bull's Eye*: **select** the outcome value to be shown in the Bull's eye
    - *Time to Peak Strain*
    - *Peak strain*

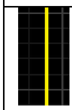
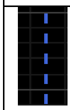
The visual lay-out for strain results is (in general) as follows:

User segments	Strain graph	Bulls eye (when available)
Segment 1 *Segment 2* *Segment n*		

In the main viewport a toolbar is available:

Icon		Description
	**Displacement points**	Enables viewing of epi- or endocard tracing or both, or no tracing to be overlayed
	**Show/hide displacement paths**	Shows/hides tracing paths
	**Segments**	Shows/hides tracing segments
	**Show/hide color maps**	Shows/hides color maps
	**Intersection lines**	Shows the intersection lines in the Short and Long Axis

In the *Results* tab, numerical values and graphs are depicted. Segment names are represented in the graph and Bull's eye, depending on the selection in the workflow assistant. **Hovering** over a graph or segment in the Bull's eye will highlight the corresponding segment and show the numerical value.

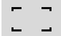
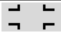
Icon	Description
	End systolic phase marker
	Active phase marker, synchronizes with the images in the viewports
	End diasystolic phase marker

4.3.2 Workflow

Depending on the result that is needed, select the corresponding *Segments Mode* and the dropdown menu's in the previous chapter.

5 4D Artery Workflow

The Artery workflow is meant for analysis of blood flow in cardiovascular vessels.
Several user actions are repetitive throughout the module:

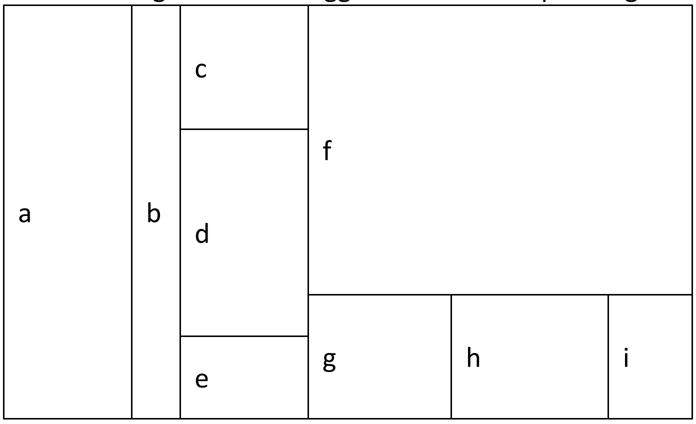
	Maximize viewport
	Minimize viewport
Show intersection lines	Shows intersection of image data
 or 	The numbers next to the module icon indicate: - to start '+' a new analysis within the same study - to change to either the '1'-, '2'-, '3'-analysis within the same examination
< Back	Go back to previous step in workflow
Next >	Proceed to next step in workflow
Close Analysis	Exits the current analysis of this study and prompts a save message

5.1 Mark Images

In this step, image data is selected for viewing and/or analysis.

5.1.1 Screen layout

Four viewports are present in the start-up screen of the Artery workflow. Anatomical data and phase contrast images can be dragged to the corresponding viewport.



a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f	viewport
g	viewport
h	viewport
i	viewport

In 'Settings', the following menus can be opened:

- *Velocity Direction*, to apply **manual marking** and **inversions**
- *Velocity Correction*, to apply **aliasing correction**, **window of interest** (magnitude image will be windowed with a Gaussian filter. This suppresses high signal intensities on the edges of the acquisition volume) , and **offset correction** (**None**; **Static tissue**: corrects offset based on static tissue estimates (linear))[11]
- *View Settings,* to change brightness and contrast

To indicate flow directions, white arrows are present in the directional viewports (figure 1-g, 1-h, 1-i):

- positive x-direction points from Left to Right, or vice versa depending on the flow direction
- positive y-direction points from Top to Bottom, or vice versa
- positive z-direction points inside the screen, or vice versa.

The z-direction is represented by a 'white circle with a cross' representing flow going into the monitor or a 'white circle with a black dot' representing flow coming out of the monitor.

5.1.2 Workflow

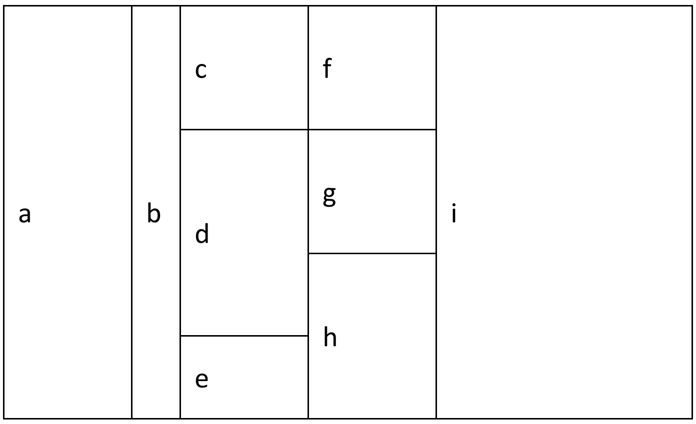
Drag and drop the magnitude and three directional phase contrast images from the Image Ribbon (figure 1-a) in the Magnitude and X, Y, Z directional PC viewports. When all necessary data is present in the DICOM headers the software automatically recognizes the magnitude and corresponding phase contrast images. A green check icon or a red cross appears to provide feedback.
Due to post-processing of DICOM data it may occur that information in the DICOM headers is lost. In this case **manual marking** found under the *velocity directions* in the 'Settings' can be used to load the images in the viewports.

(!)	Note: When Manual marking is used to load the images and an image is dragged into the incorrect viewport, or inversions are needed to process the data, the software will try to calculate the correct directions and inversions. A warning message will appear with "The velocity directions seem to be incorrect. If you want to correct them automatically, press Auto XYZ". By clicking *Auto XYZ*, the user can choose to correct the velocity directions automatically according to the suggested direction information calculated by the software.
(!)	If the warning message does not appear the setting for the loaded images are considered to be correct according to the calculation done by the software. Always check if the inversions are correct, even if the inversions are set automatically by the software. Incorrect inversion settings can be recognized by a distorted/unexpected flow pattern in the streamlines.

5.2 View

In this step, image data can be viewed in Multiplanar Reconstruction (MPR) view with overlays.

5.2.1 Screen layout



a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f	viewport
g	viewport
h	viewport
i	viewport

In viewport f, g, and h intersection lines are visible. The colors below the viewport name represents the intersection line in the other two viewports. In the MPR viewport, a crosshair represents the pivot point of all views.

5.2.2 Context Menu

The Context Menu can be opened by **right mouse click** in the MPR viewport (i) to enable the following actions:

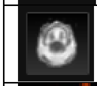
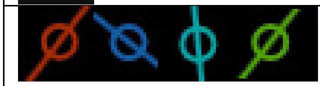
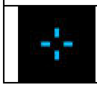
Add Snapshot to Report	Adds snapshot to report
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…	Saves snapshot to a to-be-specified location as *.dcm/*.jpeg/*.png file
Send to Image ribbon	Sends the current MPR cine as an enhance MR dicom to the image ribbon (e.g. to be used for valve tracking).
Export Video	Exports a video of 1 heart cycle to a default location specified in the settings as *.dcm file
Export Video as…	Exports a video of 1 heart cycle a to-be-specified location in the settings

	as *.dcm file/*.wmv file
Reset all viewports	Resets to default view.

Please note that the 'save/export as…' depends on Administrator settings and may not be available

5.2.3 Workflow

In the workflow assistant icons **reset** to a default view. Use **left mouse button** to navigate the MPR viewport. **Drag** the intersection lines up/down, left/right, or rotate the intersection lines. In the workflow assistant and viewports the following icons are present:

Icon	Description
	Reset all orthogonal viewports
	Reset MPR viewport to coronal viewport
	Reset MPR viewport to sagittal viewport
	Reset MPR viewport to axial viewport
	Rotate the intersection lines: Red axial Blue sagittal Cyan MPR Green axial
	Crosshair representing pivot point. Double click to move position of crosshair.

In the dropdown menu *Image data*, three choices are available for a MPR view based on the image data: *Magnitude*, *Phase static volume*, and *Static volume*.
In the dropdown menu *Overlay*, three velocity overlays are available: *speed*, *in-plane speed*, and *through-plane speed*. By default, no overlay is displayed.

- It is possible to apply a *Maximum Intensity Projection* (MIP) to the overlay. The thickness of the slab used for the MIP can be adjusted.
- The *Magnitude scaled* option allows the user to scale the velocity image data to reduce noise in the resulting overlays.
- The MIP intersection lines can be hidden by unchecking the checkbox *Show intersection lines*.

To continue the workflow, **click** *Next* in the workflow assistant to proceed to the next workflow step *3. Set centerline Input* for a 3D Mesh model. Or **click** on *4. Analyze Artery* in the *Workflow step* (3 in figure 2) to forward to *Free Plane* analysis.

5.2.3.1 Send to Image ribbon

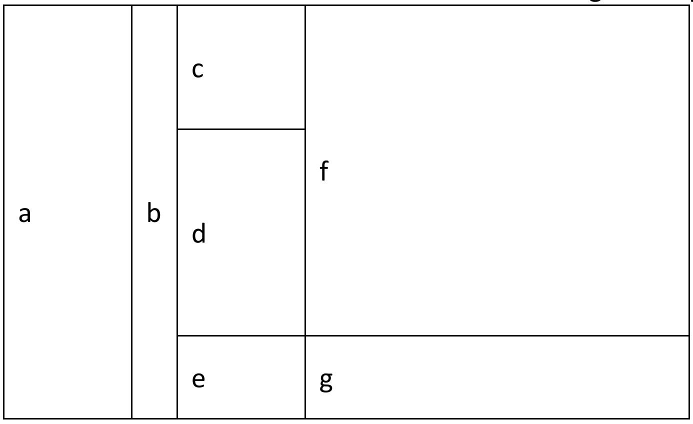
The context menu in the MPR view (i) provides the option '*Send to image ribbon'.* This enables the user to recreate a cine image, e.g. to be used for valve tracking.

5.3 Set Centerline input

Visualization and calculation is based on a 3D mesh model and planes are positioned in the vessel of interest along the centerline of the segmented vessel tree. This step is necessary when a 3d Mesh model is needed for Wall Shear Stress. It also provides automatic contours based on the mesh model in step 4 'Analyze Artery'.
This step can be skipped by **clicking** *Next* in step *3. Set centerline input* or by **clicking** on *4. Analyze Artery* in the *Workflow step* (3 in figure 2) to forward to *Free Plane* analysis.

5.3.1 Screen layout

In the 3D volume viewport (6 in figure 3) an anatomical representation of the 4D phase contrast data is shown. This so called **Static Volume** is an average of all phases of the 4D data.



a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f	3D volume viewport
g	Velocity profile graph

Below the **Static Volume**, for each added point, a graph (figure 3-g) representing the velocity profile at the point's location is shown (highlighted when hovering over a graph or point). From these graphs, the average maximum blood flow phase over time of all the points is determined and presented as the default phase to be segmented.[12,29]
It is however possible to select any of the other phases as default segmentation phase by **dragging** the red marker to the phase of choice:

	Active Segmentation phase. This is the default phase selected by the software to create a 3D mesh model
	Segmentation phase slider, to select a different phase then indicated by the software

!	When the (new) segmentation phase is not the active segmentation (green dashed line), then all available segmentations will be deleted.

In 'Settings', the *3D Visualization Settings* can be opened to change *Total opacity*, *Opacity range* and *color transfer (LUT)*. The latter can be used to change linear translation of pixel values to change brightness of the data. When applied it can improve input of centerline points.

5.3.2 Context menu

The Context Menu can be opened by **right mouse click** in the 3D volume viewport (figure 3-f) to enable the following actions:

Add Snapshot to Report	Adds snapshot to report
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…	Saves snapshot to a to-be-specified location as *.dcm/*.jpeg/*.png file
Remove point	(When right mouse click on a point) removes point

Please note that the 'save/export as…' depends on Administrator settings and may not be available

5.3.3 Workflow

Two modes are available to provide input for the centerline:

- <u>Automatic</u>: **Define** the *Main centerline* by **placing** the start point, and end point (annotated with an M) of the centerline with a **left mouse click** in the vessel of interest. Changing a points location is possible to **drag** the point to a new location. The software snaps to a location where velocity data is present.

- Manual: **Define** the *Main centerline* by **placing** the start point, and add points by **left mouse click** along the vessel of interest. The last provided input will be annotated as an end point of the centerline (annotated with an M). Changing a points location is possible to **drag** the point to a new location. The software snaps to a location where velocity data is high.

> Manual mode can be helpful in data with a lot of noise; in data with a large differences in velocities; and in tortuous vasculature.

5.3.4 Side branches

In the 'Automatic mode', branches can be added to the main centerline after the main centerline is set with a **left mouse click** at the end of the branches. Deleting a node can be perfomed by right mouse click on a node and select '*Remove point*'.
In the 'Manual mode' , branches can be added to the main centerline after the main centerline is set. **Right-click** on a node and choose '*add branch*' from the context menu to set a side-branch that branches off from that point. Deleting a node can be perfomed by **right mouse click** on a node and select '*Remove point*'.
Click '*Next*' and the software will automatically search for a path through the centerline points. The software will automatically place the centerline through the middle of the vessel and automatically detects the vessel surface mesh for the selected phase. In the next step the 3D Mesh model can be edited.

> (!) Note that the points for defining the centerline should be placed in the correct order, according to expected blood flow direction.

5.4 Analyze Artery

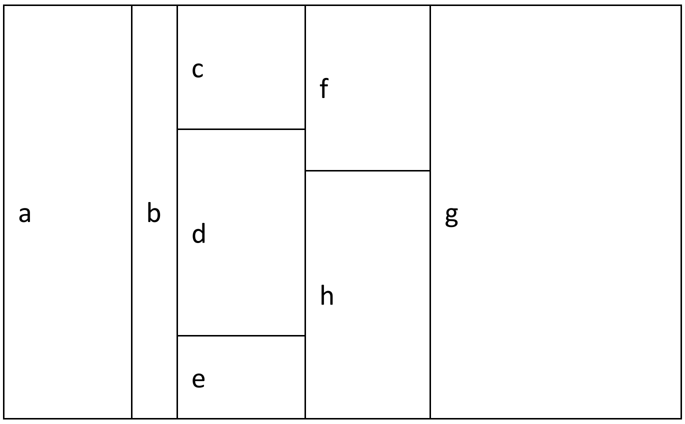
In this step, the software provides the functionality to visualize or quantify blood flow using cross-sectional analysis planes (hereafter called, **emitter planes**).

5.4.1 Edit vessel model

When step *3. Set centerline input* is performed, the '*Edit Vessel model*' step will appear before step *4. Analyze Artery*.
In '*Edit Vessel model*' the user is provided with the 3D Mesh model of the selected cardiac phase and needs to accept the model before the user can continue to the '*Analyze Artery*' step. If no centerline input was given, the 'Edit Vessel model' step is automatically skipped.

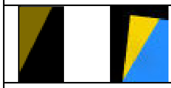
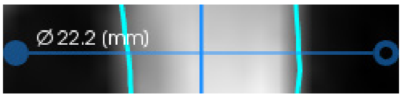
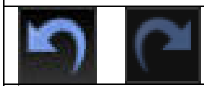
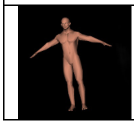
5.4.1.1 Screen layout

The 3D Mesh model can be edited in the cross-sectional viewport and the longitudinal viewport.



a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f	Cross-sectional viewport
g	Longitudinal viewport
h	3D model viewport

The longitudinal viewport shows a stretched MPR of the centerline. The changes are visible in the 3D model viewport. Several icons are explained:

Icon	Description
	Tabs to switch the *cross-sectional* and *longitudinal viewport* to Static (phase contrast) or Magnitude image data
	Orientation marker: it correlates *the cross-sectional plane* with the plane in the *3D volume*
	The blue line with the closed and open circles on the end correspond with the cross-sectional and longitudinal viewport. It also shows an estimation of the segmented lumen diameter of the current view in the longitudinal view.
	Undo and redo action buttons
	Hovering over the *cross-sectional viewport* the pixel intensity of the underlying image will be shown
	Avatar to show 3D Volume orientation related to the body position

5.4.1.2 Context menu

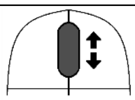
The Context Menu can be opened by **right mouse click** in the cross-sectional viewport, longitudinal viewport, and 3D Model viewport (figure 5) to enable the following actions:

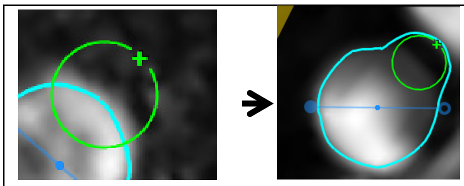
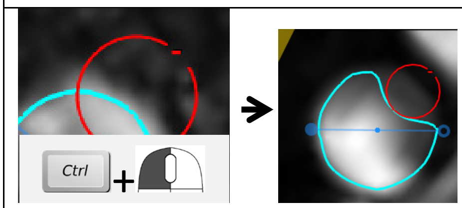
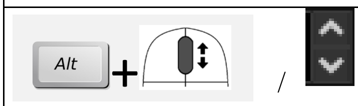
All viewports	
Add Snapshot to Report	Adds snapshot to report
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…	Saves snapshot to a to-be-specified location as *.dcm/*.jpeg/*.png file
Cross sectional viewport only	
Show Coordinate System	A coordinate system is shown and can be changed to set an anatomical reference point
Hide Coordinate System	Hides the coordinate system
Longitudinal viewport only	
Set current rotation as axle angle	Sets current view parallel to x-axis in coordinate system depicted in the cross-sectional viewport.

Please note that the 'save/export as…' depends on Administrator settings and may not be available

5.4.1.3 Workflow

In the workflow assisstant the plane size of the cross-sectional viewport can be increased or decreased by **dragging** the slider left or right.
Edits of the 3D Mesh model can influence the orientation of the plane, **click** *Update Centerline* to fit a new centerline. The checkbox *Model transparency* enables transparency of the 3D Mesh model.
To edit the 3D mesh model of the selected phase in the longitudinal or the cross-sectional viewport use the following actions:

Icon	**Description**
	Scrolling in the *cross-sectional viewport*, the plane moves up and down over the centerline in the 3D volume. Scrolling in the *longitudinal viewport* the vessel contour will rotate around its centerline.

	Adjust the mesh by adding a spherical volume with a left mouse click. This can be performed in the cross-sectional and longitudinal viewport. All adjustments in the 2D views are added in the 3D volume. On screen a green tool with a '+'-sign will appear
	Adjust the mesh by deleting a spherical volume by holding the CONTROL button + left mouse click. This can be performed in the cross-sectional and longitudinal view. On screen a red tool with a '-'-sign will appear.
	Adjust the radius of the editing tool by pressing the alt-button and simultaneously scrolling the mouse wheel up and down or use the arrows above the cross-sectional view.

To continue the workflow, **Click** *Accept* to accept all corrections, update the vessel centerline, and continue to the *'Analyze Artery'* step. During editing the contours, the centerline can be updated **clicking** *Update Centerline*.

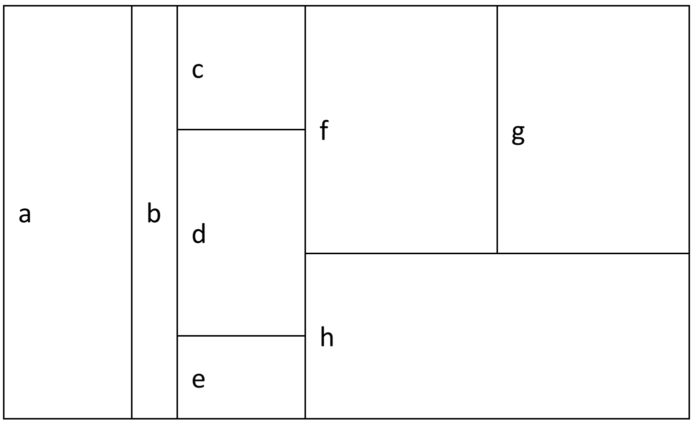
The 3D Mesh model of the selected cardiac phase will provide initial contours for the 2D reformatted planes in step *4. Analyze Artery*.
Note: The 3D Mesh model is input for the Wall shear Stress algorithm among which is a model fit of velocity profiles near the vessel wall. Depending on the voxel size, the precision of the segmentation does not need to be pixel accurate. The vessel wall is calculated according to similar methods described in literature.[30,31]

5.4.2 Screen layout

In the workflow assisstant (figure 5-d) the plane size of the cross-sectional viewport can be increased or decreased by **dragging** the slider left or right.

Note that changing plane size updates the contour and previous edits will be lost.

Vessel model edits can be performed based on the current cardiac phase, which is selected with the phase slider below the *3D viewport* and the *cross-sectional viewport*. A detailed description of *Vessel model* is available below:



a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f	3D viewport
g	Cross-sectional viewport
h	Graph and results area

In the 3D viewport (figure 5-f) the static volume is presented and overlays can be applied. The *Overlays (3D)* are available in the workflow assistant.

Overlay (3D)	Description
Streamlines	Visualize flow for every cine frame of the heart cycle. Streamlines are instantaneous tangents to the velocity vector calculated individually for every cine frame of the heart cycle emitted from *'emitter planes'* at

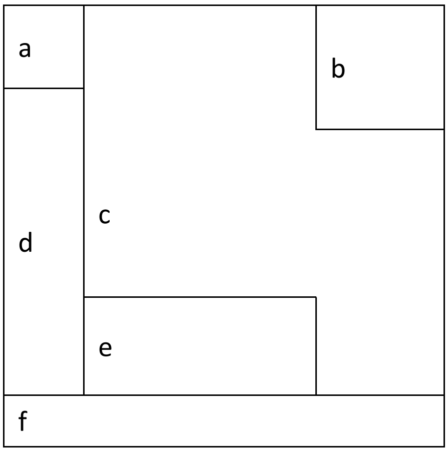
	specified locations.
- Backward streamlines	Visualize flow for every cine frame of the heart cycle entering an *emitter plane*
- Spacing	Adjust spacing of streamlines/pathlines/vectors. The space between – and number of – the emitted streamlines/pathlines/vectors can be increased or decreased
- Terminal Speed [cm/s]	Velocity cut-off value. Below the selected value streamlines are not shown
Pathlines	Visualize flow over the heart cycle, it is a line followed by an imaginary particle over time.
- Time range for the analysis [ms]	Adjust time range of pathlines. By adjusting the time range sliders it is possible to show pathlines within a sub-time range of one heart cycle
- Trace length [ms]	Adjust the length of the pathlines emitted from the emitter plane
Vector fields	Visualize velocity vector of the *emitter plane*
- Vector scale [(cm/s)/mm]	Adjust the value of the vector scale
Wall stress*	Visualize the Wall shear stress against the vessel wall
- Model transparency	Enables transparency of the Wall shear stress overlay
- View 3D volume	Shows the the 3D volume
- Blood Viscosity [mPa s]	Adjust blood viscosity, µ
- Wall stress type	WSS can be shown and exported in four ways. Total Shear stress, Circumferential shear stress (parallel to emitter plane), Axial shear stress (perpendicular to emitter plane), and Normal shear stress
- Vector scale	Adjust the size of the vector scale (ranging from 10-20-50-100-200-500-1000)
Pressure difference*	Visualize and calculate the pressure difference between a reference and an obstruction plane
- Blood density [kg/m^3]	Adjust blood ρ density
- Segment length [mm]	Distance between the reference and obstruction plane
Export	When available an export icon is visible to export results of the corresponding overlay. An extension file can be needed to enable export.

Overlays (3D) options and settings within the overlays.

ⓘ	Note that multiple parameters related to image acquisition influence accuracy of the WSS calculation, which could lead to an underestimation of WSS values. It is important that the 3D mesh model is carefully selected. The user should be aware of the phase that the 3D Mesh model is based on.

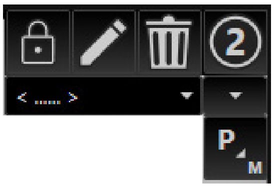
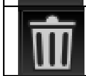
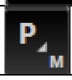
5.4.2.1 3D and cross-sectional viewport

The 3D viewport shows the 3D model, adjustments to the visualization can be controlled in the settings (figure 5 - 3). Information regarding spatial resolution and velocity encoding is available in the upper left corner. The color bar represents the values of the overlay chosen in *Overlays (3D).* The red arrow with the number next to it, can be dragged up/down to change the value and the overlay color.



a	Orientation marker
b	Toolbar
c	3D model or cross-sectional view
d	Color bar
e	Avatar (3D viewport) or Velocity point picker (cross-sectional viewport)
f	Phase slider

The yellow *Orientation marker* (figure 7 - a) in the *3D Viewport* correlates with the marker in the *cross-sectional plane* and vice versa. The toolbar has several functions:

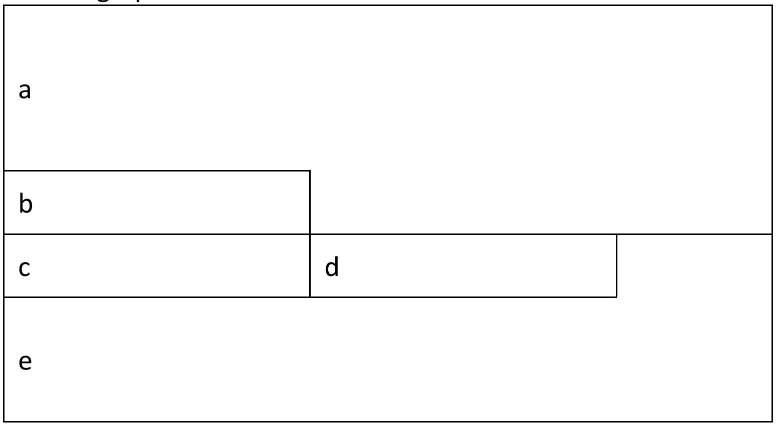
Toolbar	Icon	Description
	 and 	Detach and Attach plane to centerline Only available when ‘Set Centerline input’ was performed
		Enter ‘Free plane’ mode
		Remove plane (alternative: double click on plane)
	 A  B	A Open/close tool tray for corresponding plane B Unfold menu to select different plane
		Provide the plane with a name or reference
		Switch the 2D viewport to Phase or Magnitude image data

The phase control slider is located below the 3D volume viewport.

	a) Navigate to the beginning of the pathlines animation b) Navigate to the previous step of the pathlines animation c) Play or pause the pathlines animation d) Navigate to the next step of the pathlines animation e) Navigate to the ending of the pathlines animation
	A – Phase Slider B – Vessel model marker. Available 3D Mesh vessel model, non-active C – Vessel model marker. Available 3D Mesh vessel model, active
	Number of phases and time of the phase/total time of heart cycle Not available in Pathlines
	Represents the temporal phase of the heart cycle Only available in Pathlines
	Loop speed of pathlines animation can be increased or decreased Only available in Pathlines

5.4.2.2 Graph and results area

Several graphs and results are available.



a	Graph
b	Graph selection
c	Result tab 1
d	Result tab 2
e	Numerical results

The available graph types are:

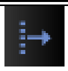
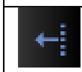
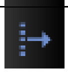
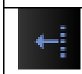
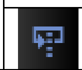
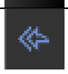
Graph results	Description
Flow (ml/s)	Blood flow for the current plane over all phases
Max velocity (cm/s)	Maximum velocity for the current plane over all phases
Min velocity (cm/s)	Minimum velocity for the current plane over all phases
Mean velocity (cm/s)	Mean velocity for the current plane over all phases
Velocity sDev (cm/s)	Standard deviation (variation) of blood flow velocity for the current plane over all phases
Contour Area (mm^2)	Area of the contour for the current plane over all phases

The available numerical results are:

Numerical results	Description
Cardiac output (l/min)	The blood volume that is pumped by the heart per minute. This is calculated by multiplying the pumped blood volume by the heart rate.
Forward flow (ml)	The amount of flow through the plane in forward direction in the given time interval (from start phase to end phase)
Backward flow (ml)	The amount of flow through the plane in backward direction in the given time interval (from start phase to end phase)
Net Forward Flow (ml)	The total amount of flow through the plane in the given time interval (forward flow - backward flow)
Regurgitation fraction	The ratio between the amount of backward flow and forward flow
Flow Displacement	The distance between the geometric center of the lumen and the center of area with the most flow, which is normalized for the lumen diameter (calculated in the peak systolic phase)[21,32]

5.4.3 Context menu

The Context Menu can be opened by **right mouse click** in *3D viewport*, *Cross-sectional viewport*, and the *Graph and results area* (figure 5) to enable the following actions:

All viewports		
Add Snapshot to Report		Adds snapshot to report
Save Snapshot		Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…		Saves snapshot to a to-be-specified location as *.dcm/*.jpeg/*.png file
3D viewport only		
Overlays > Planes		Hide/show emitter planes
Export video		Saves video of current view to a default location specified in the settings as *.dcm
Export video as…		Saves video of current view to a to-be-specified location as *.dcm/*.wmv
Attach all planes to centerline		Attaches all free planes to the centerline. Only available when step *3. Set Centerline input* is performed
Add plane		Adds plane
Remove plane		Removes plane
Cross sectional viewport only		
Copy		Copies current contour to all phases towards the right of current phase
		Copies current contour to all phases towards the left of current phase
		Copies current contour to all phases
Propagate		Propagates current contour to all phases towards the right of current phase
		Propagates current contour to all phases towards the left of current phase
		Propagates current contour to all phases
Reset all		Resets contours to default based on 3D mesh model. Only available when step *3. Set Centerline input* is performed
Overlay	No overlay	No overlay
	Velocity overlay	Velocity overlay with color bar

	Flow displacement	Ratio defined as the distance between the center of the lumen and the center of velocity of the flow, which is normalized to the lumen diameter

Please note that the 'save/export as…' depends on Administrator settings and may not be available

5.4.4 Workflow

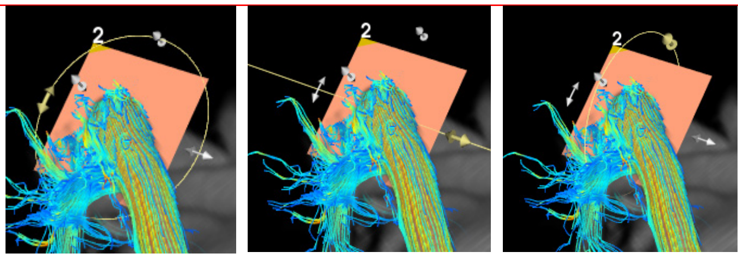
Caas provides the functionality to analyze blood flow in 2D by retrospective reformatting of *emitter planes* in a 3D volume. Streamlines, pathlines and vector fields all originate from an *emitter plane*.

- *Emitter planes* can be **added or deleted** throughout the *4. Analyze artery* workflow by **double clicking** within the lumen of the 3D volumes. Up to 10 planes can be added.
- **Holding** '*ctrl-button + mouse click*' will a place plane anywhere within the 3D Volume. This will neglect a present centerline.

Contours based on the 3D mesh model of the selected phase are provided when step *3. Set centerline input* is performed.

- When this step is skipped, contours can be defined in the cross-sectional viewport. For reference, this is called *Free plane* mode.
- In *Free plane* mode, contours on the reformatted 2D flow viewport are not automatically determined. Manual contouring is needed by at least indicate two spline points.

When 'Free Plane' is activated, three arcs and three lines will appear when hovering over the corresponding arrow. Dragging the arrows will allow to manipulate the plane in the specific direction.



Depending on the contours, graphs and results are presented below the *3D viewport* and the *cross-sectional viewport*.

5.4.5 Define contour

Select the plane of interest in the cross-sectional viewport by **left mouse click** on the plane or in the toolbar**.**

!	Check if the initial contour shown in the cross-sectional viewport represent true vessel lumen

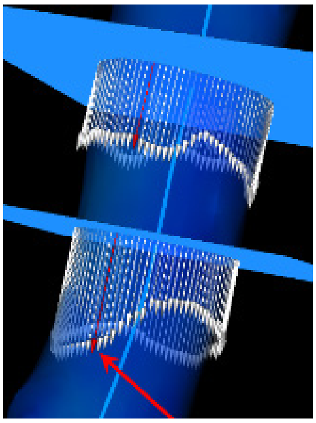
Contour adjustments can be performed:

1. **Add** spline points — **double left mouse click** in the cross-sectional view
2. **Delete** spline points — **double click left mouse button** on the spline point
3. Relocate spline points — drag and drop by holding the left mouse button
4. **Propagate** or **Copy** — See context menu chapter above.

5.4.5.1 Wall shear Stress

Caas MR 4D Flow provides the functionality to visualize Wall Shear Stress (WSS) in a 3D segmented model of the vessel of interest.

5.4.5.2 Wall shear Stress Method



Wall shear inside blood vessels arises from the blood flow that shears against the vessel wall. Only the blood flow parallel to the vessel wall contributes to the shear against the wall. Wall shear can be quantified by means of the *wall shear rate* (WSR). The wall shear rate is given by the gradient of the velocity profile of the parallel blood flow at the vessel wall.[33] For further information, see the references.[30,31,33,34]
For each emitter plane, 90 resampled WSS vectors are shown along the vessel in the 3D viewport. A red vector is used as an anatomical reference point (see *Show coordinate system*).

5.4.5.3 Workflow

By default, the phase selected in workflow step *3. Set Centerline input* is segmented.

- It is possible to segment every phase of the cycle. The visualized Wall shear Stress is dependent on the velocity data belonging to the current phase selected by the slider and the wall position belonging to the active 3D vessel model (which can selected by double clicking any available *Vessel model marker*).

To add, copy, propagate, edit, or delete or a 3D Mesh Vessel model, the workflow assistant provides five buttons:

Add	Add a 3D Mesh vessel model of the current phase indicated by the slider
Copy	Copy the active 3D Mesh vessel model to the current phase selected by the slider
Propagate	Propagate the active 3D Mesh vessel model to fit the current phase selected by the slider
Edit	Edit the active 3D Mesh vessel model
Delete	Delete the active 3D Mesh vessel model

The results of the Wall Shear Stress are per phase, and per plane. If more 3D Mesh models are created, the results are per model, per phase, and per plane. All these results are exported in a comma separated file (*.csv). The exported results are:

- WSS [mPa]
- WSS - circumferential [mPa]
- WSS - axial [mPa]
- WSS – normal
- Segmental WSS (between 2 planes)

The data also can be used for further data processing in other software (e.g. matlab).

!	Note that multiple parameters related to image acquisition influence accuracy of the WSS calculation[34], which could lead to an underestimation of WSS values.
!	It is important that the 3D mesh model is carefully selected. The user should be aware of the phase that the 3D Mesh model is based on.

5.4.5.4 Pressure Difference

The software is able to calculate the pressure difference (ΔP) between a **reference** and an **obstruction** plane (placed at site of obstruction/stenosis). Pressure difference measurements can be performed to asses a stenosis. When a stenosis is present, a pressure drop is expected at the location of the stenosis (obstruction plane) compared to a healthy part of the vessel (reference plane).[36]
This calculation is based on the **modified Bernoulli** equation:

$$\Delta P = 0.5\rho(v_{reference}^2 - v_{obstruction}^2)$$

where ρ is the mass density of blood, $v_{reference}$ and $v_{obstruction}$ are the velocities in the reference plane and the obstruction plane, respectively.
To measure pressure difference:

1. Place the reference plane in a healthy part of the vessel where pressure is normal
2. Place the obstruction plane in the stenosis or location of interest

3. According to the equation described above a pressure difference is calculated in the obstruction plane

In the reference plane, the pressure is set to zero and the pressure difference towards the obstruction plane is visualized by streamlines with a colour ranging from blue to red.

5.4.5.5 Flow displacement

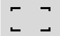
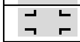
Flow displacement is defined as the distance between the center of the lumen and the ‘‘center of velocity’’ of the flow, which is normalized to the lumen diameter. This method is described in more detail, see the references.[21,22]

Flow displacement is calculated only for the Peak Systolic phase. The Peak Systolic phase is determined for each emitter plane and determined by using the temporal location at the peak within the 2D Flow graph. The Peak Systolic phase is indicated as a marker on the phase slider. Numerical results and Flow graph results of every plane can be saved in a CSV file by **clicking** on the *CSV save* button.

	Important note: The Peak Systolic phase used for flow displacement can differ from the Peak Systolic phase used in WSS analysis.
	Heart rate is determined by the recorded scan and cannot be adjusted.

6 4D Heart Workflow

The Heart workflow is meant for analysis of intra-cardiac blood flow.
Several user actions are repetitive throughout the module:

	Maximize viewport
	Minimize viewport
Show inter section lines	Shows intersection of image data
 or 	The numbers next to the module icon indicate: - to start '+' a new analysis within the same study - to change to either the '1'-, '2'-, '3'-analysis within the same examination
< Back	Go back to previous step in workflow
Next >	Proceed to next step in workflow
Close Analysis	Exits the current analysis of this study and prompts a save message

6.1 Mark Images

In this step, image data is selected for viewing and/or analysis.

6.1.1 Screen layout

Eight viewports are available for anatomical reference images to be used with valve tracking. At least one 2D cine image dataset should be loaded. Four viewports are present in the start-up screen of the Artery workflow.

<table>
<tr><td rowspan="3">a</td><td rowspan="3">b</td><td>c</td><td>f</td><td>g</td><td>h</td><td>i</td></tr>
<tr><td>d</td><td>j</td><td>k</td><td>l</td><td>m</td></tr>
<tr><td>e</td><td>n</td><td>o</td><td>p</td><td>q</td></tr>
</table>

a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f-m	Anatomical viewport
n-q	Phase contrast viewport

Note that the viewport arrangement can vary

In 'Settings', the following menus can be opened:

- *Velocity Direction*, to apply **manual marking** and **inversions**
- *Velocity Correction*, to apply **aliasing correction**, **window of interest** (magnitude image will be windowed with a Gaussian filter. This suppresses high signal intensities on the edges of the acquisition volume) , and **offset correction** (**None**; **Static tissue**: corrects offset based on static tissue estimates (linear))[11]
- *View Settings,* to change brightness and contrast

To indicate flow directions, white arrows are present in the directional viewports:

- positive x-direction points from Left to Right, or vice versa depending on the flow direction
- positive y-direction points from Top to Bottom, or vice versa
- positive z-direction points inside the screen, or vice versa.

The z-direction is represented by a 'white circle with a cross' representing flow going into the monitor or a 'white circle with a black dot' representing flow coming out of the monitor.

6.1.2 Workflow

1. **Drag and drop** 2D cine images to the corresponding valve viewports. For correct visualization and assessment of flow through each valve, the 2D cine images should match the valve type.

Tricuspid Valve	Pulmonary Valve	Mitral Valve	Aortic Valve

Right 2CH	RVOT Sagittal	Left 2CH	LVOT Sagittal
4CH	RVOT Coronal	4CH	LVOT Coronal

RVOT = Right Ventricular Outflow Tract; CH = Chamber view; LVOT = Left Ventricular Outflow Tract

In the workflow assistant, the box *Show intersection lines* can be (un)checked to show how the 2D cine images intersect

2. **Drag and drop** the magnitude and three directional phase contrast images from the Image Ribbon in the *Magnitude* and *X, Y, Z directional phase contrast* viewports. A green check icon or a red cross appears to provide feedback.

Due to post-processing of DICOM data it may occur that information in the DICOM headers is lost. In this case **manual marking** found under the *velocity directions* in the 'Settings' can be used to load the images in the viewports.

ⓘ	Note that the user is responsible for checking that the image data matches the valve type. The software does not perform a check if image data matches valve type. See the table below for an example of which cine data can be used for each valve.
ⓘ	Note: When Manual marking is used to load the images and an image is dragged into the incorrect viewport, or inversions are needed to process the data, the software will try to calculate the correct directions and inversions. A warning message will appear with "The velocity directions seem to be incorrect. If you want to correct them automatically, press Auto XYZ". By clicking *Auto XYZ*, the user can choose to correct the velocity directions automatically according to the suggested direction information calculated by the software.
ⓘ	If the warning message does not appear the setting for the loaded images are considered to be correct according to the calculation done by the software. Always check if the inversions are correct, even if the inversions are set automatically by the software. Incorrect inversion settings can be recognized by a distorted/unexpected flow pattern in the streamlines.

6.2 Track Valves

The complex motion of cardiac valves and surrounding structures significantly changes the appearance of the region of interest during the cardiac cycle. MR 4D flow data usually has limited spatial and temporal resolution. Caas MR 4D flow uses the input of 2D cine MR sequences to track the movement of cardiac valves.

6.2.1 Screen layout

Depending on if 1 or 2 Cine image stacks are loaded in step *1. Mark Images*, 1 or 2 viewports are available for valve tracking.

To select a valve (figure 10-e), **click** on the valve tabs to track the valve.

<table>
<tr><td rowspan="3">a</td><td rowspan="3">b</td><td>c</td><td colspan="2">e
f | g</td></tr>
<tr><td rowspan="2">d</td><td>f</td><td>g</td></tr>
<tr><td>h</td><td>i</td></tr>
</table>

a	Image ribbon
b	Modules
c	Workflow steps
d	Workflow steps
e	Valve tabs
f	Viewport
g	Viewport
h	Displacement graph
i	Displacement graph

After tracking is performed, displacement graphs are shown below the viewport. The graph represents the displacement of the anatomical plane (in mm). A red phase slider in the graphs indicates the current phase. Blue and red graph points indicate default tracking point or an edited tracking point, respectively.

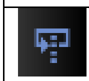
In the workflow assistant, a color-coded overlay showing the velocity values mapped on the image data is available in the dropdown menu *Overlay*:

Speed	3D Velocity overlay
In-plane speed	Velocity overlay parallel to the image data
Through-plane speed	Velocity overlay perpendicular to the image data
Through-Valve plane speed	3D velocity component perpendicular to the valve plane. *Only available when tracking is performed.*

- The color bar range can be adapted by **dragging** the red arrows up/down.
- The *MIP mode* includes speed values from a larger region (slab) of the volume in the overlay. When enabled (checkbox), the slab is indicated with dotted purple lines in both viewports and can be adapted in the workflow assistant by changing the [F/B] (front and back thickness).
- The *Magnitude scaled* option allows the user to scale the velocity image data to reduce noise in the resulting overlays (this leads to an overlay with lower intensities outside the blood pool, but also lower overall intensities).

6.2.2 Context Menu

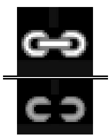
The Context Menu can be opened by **right mouse click** in viewport to enable the following actions:

 Track right	Based on the landmark correction, re-tracking of the landmark points is performed going forward in time starting from the current corrected phase (until the end of the phase range)
 Track left	Based on the landmark correction, re-tracking of the landmark points is performed going backwards in time starting from the current corrected phase (until the end of the phase range)
 Track all	Based on the current landmark correction, re-tracking of the landmark points is performed for all phases
Correct Misalignment	Explained below
Alternative Plane	Explained below
Add Snapshot to Report	Adds snapshot to report
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…	Saves snapshot to a to-be-specified location as *.dcm/*.jpeg/*.png file

Please note that the 'save/export as…' depends on Administrator settings and may not be available

6.2.2.1 Correct Misalignment

There could be a mismatch between the image data of 2D Cine and 4D phase contrast. To correct this, the overlay can be shifted in X-Y direction in order to correct the spatial misalignment.



When *Correct Misalignment* is enabled in the context menu, the overlay can be **dragged** to the correct position. The user can move each cine plane independently relative to the 4D Flow data using the link- and unlink-button between the two viewports or moving both cine planes together.

To **reset** the applied correction, in the *Correct Misalignment* mode below the viewports *Reset*-buttons are visible and will reset the alignment to default.

6.2.2.2 Alternative Plane

When the 4D flow velocity data shows artifacts around the valve plane due to the turbulent nature of the regurgitant jet at this position (e.g. in an eccentric regurgitant jet), it is possible to position the another flow analysis plane at a different position than the anatomical tracked valve plane for certain time phases.

The *Alternative Plane* enables placing a non-anatomical (valve) plane for any time phase, perpendicular to the local flow at a position of interest.

6.2.3 Workflow

6.2.3.1 Verify misalignment

In the Workflow assistant:

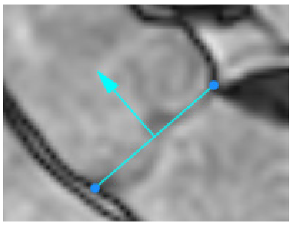
- **open** the *Overlay* dropdown and **enable** the *Speed* overlay to verify the presence of misalignment between the 4D flow and cine images.
- If misalignment is observed, **right mouse click** to open the *Context menu* in a viewport and **click** on *Correct Misalignment.*
- Manually **drag** the 4D image correctly on top of the cine images. The presence of misalignment should be validated in all cine views of all valves.
- When the misalignment is removed, **right mouse click** to open the *Context menu* and **click** on *Correct Misalignment* to disable *Correct Misalignment*.

Misalignment between the 4D flow and cine images could easily be observed by perpendicular intersected vessels. During this process disable the *MIP* function to prevent confusion.

6.2.3.2 Track Valves

Initiate the semi-automatic valve tracking by:

- In a cine image set select a phase on which the valve is visible.
- Place two landmarks at the edge of valve on the annulus with **left mouse button**.
  Based on these two points the software will automatically place landmark points at all phases and track the valve over time.
    - User tip: use zooming, click on the border of the myocardium and the valve, use initiation phase where valve is most clearly visible.



When applicable, **repeat** this for the second image set. A reference point will be visible in the second cine images set, based on the landmark points in the first image set.

- Verify if tracking over time is correct. If not, the position of the landmarks can be adjusted by **dragging** a landmark point to a new location. An edited phase is visible in the valve displacement graph by a red dot.
- **Open** the *Context Menu* and **redo** tracking based on a correction. Repeat this procedure if the result is not satisfying with a new phase.

Tracking must be performed and verified for both views per valve separately. If automated tracking fails over some phases, manually adjust the position for these phases.

Important note: The landmark points will be input for the valve contours in step 3 '*Analyze Heart*'. If two 2D cine image sets are loaded, this will result in 4 spline points as input for a valve contour. If one 2D cine image set is loaded, this will lead to 2 spline points as input for a valve contour.
Important note: ensure the tracking is evaluated and corrected if necessary.
Important note: ensure the temporal resolution of the valvular cine data is equal or higher than the temporal resolution of the MR 4D flow data.

6.2.3.3 Track Valves – Alternative plane

Regurgitation could results in an eccentric jet through the valve. To reliable measure the regurgitated flow, it is possible to place a plane at a different position than the anatomical valve plane for specific time phases. This plane is positioned proximally toward the valve in the core of the visualized regurgitant jet (the highest backwards velocity).
Instructions:

- **Open** the *Context Menu* and **select** *Regurgitation plane*. The interface will automatically switch to the *Through-Valve Plane Speed* overlay on the CINE images.
  The mouse-icon is substituted with a crosshair.
- Position a regurgitation plane proximally toward the valve in the core of the regurgitant jet (the highest backwards velocity) by **click left mouse button**. The software will look for the maximum flow velocity in the z-direction and creates a plane perpendicular to the flow direction.
  This results in purple plane lines in both viewports. The *Through-Valve Plane Speed* overlay is adjusted according to placed regurgitated plane.
- **Verify** if the regurgitation plane is correctly positioned perpendicular to the flow direction. If needed, manually improve the plane orientation by manually adjusting the landmark points. A purple mark will appear on the phase slider below the viewport to indicated whether a regurgitant plane is present in that specific phase.

Repeat the steps above for each phase in which an alternative plane is needed.

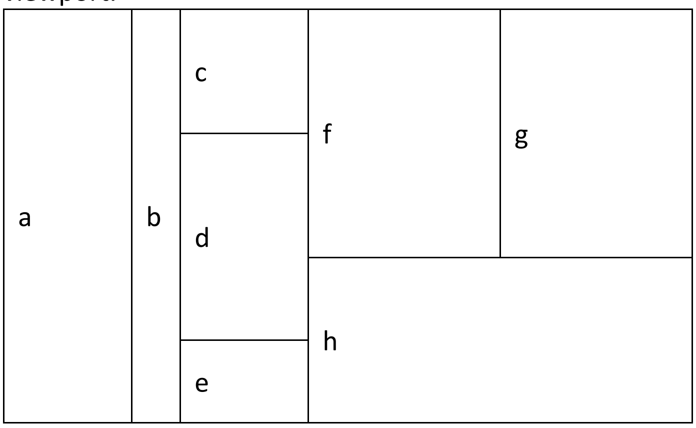
Note: An (eccentric) regurgitant jet is not always exactly positioned at the level of the cine images. Therefore, it is recommended to check the presence of regurgitation with the MIP function enabled and disabled.
Note: Due to incoherent flow at the stenotic lesion, phase dispersion can occur which results in signal loss and incorrect velocity assessment of the regurgitant jet at the location of the valve lesion itself. Distal to the lesion, the phase signal will reappear. Measurement of regurgitant flow should be performed here (usually 0.5-1.5 cm distal to the regurgitant orifice). If this occurs, these phases need to be analyzed by using the regurgitation plane.

6.3 Analyze Heart

In the Analyze Heart step 3D visualization of blood flow can be performed via a 3D representation of blood flow velocity by streamlines.

6.3.1 Screen Layout

A phase static volume is shown in the 3D viewport with the contours of the valves tracked in step *2. Track Valves*. In the cross-sectional viewport the valve is shown which can be selected above the 3D viewport.

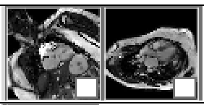
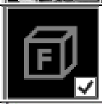


a	Image ribbon
b	modules
c	workflow steps
d	workflow assistant
e	settings
f	3D viewport
g	Cross-sectional viewport
h	Graph and results area

In the workflow assisstant:

- the plane size of the cross-sectional viewport can be increased or decreased by **dragging** the slider left or right.

Note that changing plane size updates the contour and previous edits will be lost.

	Enable reference Cine image(s) by **(un)checking** the box. The cine images are used for valve tracking in step 2.
	The static volume model is represented as a cube and is switched on/off by **(un)checking** the checkbox.
	The valves can be shown or hidden by **clicking** their corresponding buttons. Each valve plane has a reference color in the 3D Volume viewport: Tricuspid Valve (TV=green), Pulmonary Valve (PV=blue), Mitral Valve (MV=orange), and Aortic Valve(AV=yellow

- Overlays (3D) can be selected: None or Streamlines.
- Streamlines settings can be adjusted:
  - **Spacing**: the space between the streamlines emitted from the emitter plane can be increased or decreased
  - **Terminal speed**: Velocity cut-off value, below the selected value streamlines are not shown
- General settings:
  - '*Valve motion correction'* can be enabled or disabled. It corrects the through plane blood velocities measured in the anatomical valve plane using the through plane motion of the tracked valves.
  - *'Apply to alt. planes'* can be enabled or disabled. It corrects the through plane blood velocities measured in the alternative planes using the through plane motion of the tracked valves.
  - *'Use Alternative planes'* can be enabled or disabled. It uses the alternative plane for analysis results when an alternative plane is present.

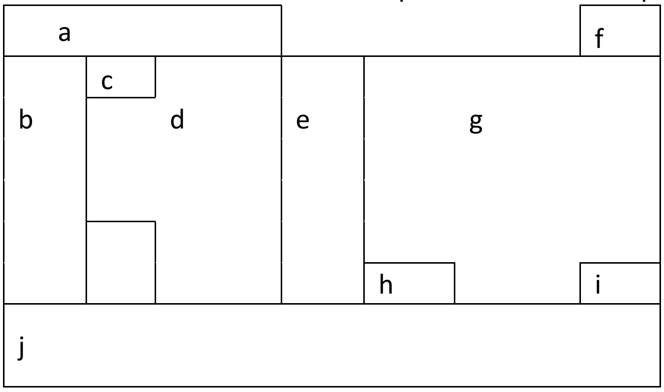
Velocity flow data is affected by the motion of the heart which results in an offset that influences the correctness of the calculated flow quantification results. This motion is a result of the systole and diastolic cycle and needs to be corrected to find the most accurate ventricular blood flow results.[37] The offset that can be found in velocity flow data relates well to the movement of the heart at the location of the fitted measurement plane. Several articles describe the necessity and procedure of correcting for heart motion in 4D velocity flow data measured at a measurement plane located at the heart valve.[11,33,37]

Important note: ensure the tracking is evaluated and corrected if necessary

Important note: ensure the temporal resolution of the valvular cine data is equal or higher than the temporal resolution of the MR 4D flow data.

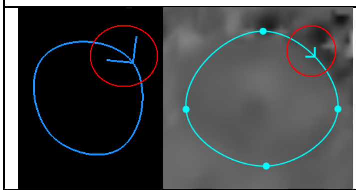
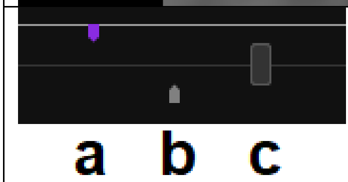
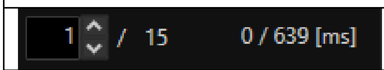
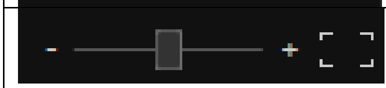
6.3.1.1 3D and cross-sectional viewport

See below a more detailed description of the 3D viewport and the cross-sectional viewport.



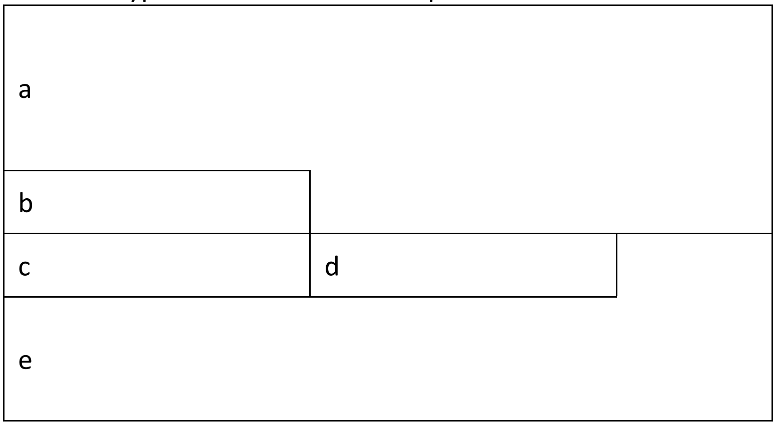
a	Valve tabs
b	Color bars
c	Voxel size and Velocity encoding
d	3D Model
e	Color bars 2D Viewport
f	Phase or Magnitude
g	Cross-sectional viewport
h	Min/Max velocity in contour
i	Point picker velocity
j	Phase slider

Select a valve by **clicking** on one of the *Valve tabs*. The selected valve will be depicted in the *Cross-sectional viewport*. Information regarding spatial resolution and velocity encoding is available in the upper left corner (c). The color bar represents the values of the overlay chosen in *Overlays (3D).* The red arrow with the number next to it, can be dragged up/down to change the value and the overlay color. A checkbox to apply *Contour movements for all phases* is situated below the cross-sectional viewport. It moves the contour similar for all phases.

Icon	Description
	Tabs to switch the *cross-sectional* and *longitudinal viewport* to Phase contrast or Magnitude image data
	Orientation marker: it correlates *the cross-sectional plane* with the plane in the *3D volume*
	a) Purple marker indicates a alternative plane is available b) Gray marker indicates a contour is edited on the anatomical valve plane c) Phase slider
	Number of phases and time of the phase/total time of heart cycle
	Valve plane shift: It shifts the anatomical valve plane over its normal vector. Situated below the cross-sectional viewport. The distance of the displacement is shown on the slider as well as the default location of the valve plane.

6.3.1.2 Graph and results area

Several graphs and results are available. The 2D flow results are shown in the graph and in the table below the 3D Volume and the cross-sectional viewport. Moving the cursor over the graph will show the valve type and the result at the place of the cursor. Other results are shown in the tables below



a	Graph
b	Graph selection
c	Result tab 1
d	Result tab 2
e	Numerical results

The available graph types are:

Graph results	Description
Flow (ml/s)	Blood flow for the current plane over all phases
Max velocity (cm/s)	Maximum velocity for the current plane over all phases
Min velocity (cm/s)	Minimum velocity for the current plane over all phases
Mean velocity (cm/s)	Mean velocity for the current plane over all phases
Velocity sDev (cm/s)	Standard deviation (variation) of blood flow velocity for the current plane over all phases
Contour Area (mm^2)	Area of the contour for the current plane over all phases
Valve motion [cm/s]	

The available numerical results are:

Numerical results	Description
Cardiac output (l/min)	The blood volume that is pumped by the heart per minute. This is calculated by multiplying the pumped blood volume by the heart rate.
Forward flow (ml)	The amount of flow through the plane in forward direction in the given time interval (from start phase to end phase)
Backward flow (ml)	The amount of flow through the plane in backward direction in the given time interval (from start phase to end phase)
Net Forward flow (ml)	The total amount of flow through the plane in the given time interval (forward flow - backward flow)
Regurgitation fraction	The ratio between the amount of backward flow and forward flow
Flow Displacement	The distance between the geometric center of the lumen and the center of area with the most flow, which is normalized for the lumen diameter (calculated in the peak systolic phase).[21,32]

6.3.2 Context Menu

The Context Menu can be opened by **right mouse click** in *Cross-sectional viewport* and the *Graph and results area* to enable the following actions:

All viewports	
Add Snapshot to Report	Adds snapshot to report
Save Snapshot	Saves snapshot to a default location specified in the settings as *.dcm file
Save Snapshot as…	Saves snapshot to a to-be-specified location as

		.dcm/.jpeg/*.png file
Cross sectional viewport only		
Copy		Copies current contour to all phases towards the right of current phase
		Copies current contour to all phases towards the left of current phase
		Copies current contour to all phases
Reset all		Resets contours to default based on 3D mesh model. Only available when step *3. Set Centerline input* is performed
Overlay	No overlay	No overlay
	Image overlay	Velocity overlay with color bar
	Valve area overlay	Velocity overlay with color bar for the contoured area only
	Flow displacement	Ratio defined as the distance between the center of the lumen and the center of velocity of the flow, which is normalized to the lumen diameter

Please note that the 'save/export as…' depends on Administrator settings and may not be available

Recommendation: based on your preference to improve the observers' velocity interpretation the velocity *image overlay* or *valve area overlay* can be enabled. By adjusting the color bar range, the image overlay is adjusted accordingly to the velocity. By repeatedly selecting the same color bar range (e.g. -50 up to +50), subjects scanned with different VENC setting still can be analyzed with a comparable color scale.

6.3.3 Workflow

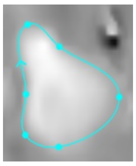
For each valve, velocity mapping must be performed by contour delineation. The initial contour that is provided, corresponds with the four landmarks from the valve tracking as spline points. Contour needs to be defined in each phase, but can be copied forward/backward in time between phases in the *Context Menu*:

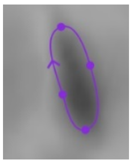
1. **Select** the valve for which image data and contours will be shown in the cross-sectional viewport
2. **Enable** Valve motion correction (default on)
3. **Adjust** the contour on the area of flow for each phase accordingly to the forward or backward velocity.
    a. When Regurgitation planes are present, **adjust** the (purple) contours on the backward velocity.
    b. When valve is closed and no regurgitation (backward flow) velocity is present, the area of the contour should be small, to reduce the effect of noise on the forward and backward flow.

Important note: If the contour is not reduced in size the forward and backward flow may be overestimated and this may result in more variation in forward flow between valves

Recommendation: Start checking contours in the phase with highest flow (+ or -), followed by a phase with no flow. Then use *Copy Right/Left* (whatever is applicable) in the context menu to reduce editing contours.

6.3.3.1 Define contours





Contour adjustments can be performed:

1. **Add** spline points — **double left mouse click** in the cross-sectional view
2. **Delete** spline points — **double click left mouse button** on the spline point
3. Relocate spline points — drag and drop by holding the left mouse button
4. **Copy Right/Left/All** — See context menu chapter above.
5. **Move** valve contour **button** — **move** the cursor in the proximity of the valve contour and an icon will appear. **Click and hold left mouse** and **drag**
6. Plane shift normal — **move** the valve plane along the valve planes' vector and inverse' normal vector

6.3.3.2 Diastolic Assessment

In a tab next to the 2D Flow results, '**Diastolic Assessment'** can be performed. The early (E) and late (A for atrial) filling of the ventricle are determined by automatically placing the E- and A-peak in the **'mean velocity'** graph.

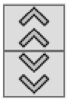
This is shown with markers, these markers can be overruled by dragging the markers to a different graph position.

The e' is determined based on the **'valve motion'** graph.

Numerical results	Description
E/A	Ratio between peak blood flow in Early and Atrial filling phases
E/e'	Ratio between Early filling phase peak blood velocity and peak annular velocity
E velocity [cm/s]	Peak average velocity of blood flow during Early filling
A velocity [cm/s	Peak average velocity of blood flow during Atrial filling
Averaged e'[cm/s]	Peak average annular velocity during Early filling

7 Report

The report contains multiple pages with all analysis result of one patient.



Navigate through the pages with the arrows or using the mouse wheel.

The first page contains patient information. Other pages depend on the performed analysis and are recognizable by the Module name. Analysis results can be included or excluded by the checkboxes.

Note that the bull’s eyes in the report depend on the option chosen for depicting the temporal results (i.e. user segments or AHA model)

When snapshots are made and added to the report an extra report page is created where the snapshots are depicted.

8 Save Report and Examination

8.1 Save Report

The analysis report can be saved by clicking in the **Save Report** Tab or in the **Browse Icon** and then **Save Report.** By default the report is saved on the **Default export path** defined in the **Settings**.

By **Save Report as...** the user can specify the location. Admin rights are needed to change this setting.

8.2 Export Examination

An Examination can be saved by clicking in the **Browse Icon** and selecting **Save Examination as …** . By clicking **Save Examination** the examination is saved in the Default location.

See the Installation Manual for more information

9 Settings

9.1 Examination heading

Choose the Examination Heading which will be represented in the examination tabs and on the top of the screen.

9.2 Thumbnail sorting

The thumbnails in the thumbnail ribbon can be sorted based on acquisition time, file size, or series number.

9.3 Thumbnail representation

Choose to depict large thumbnails or compact thumbnails

9.4 Screen layout

Screen layout is automatically set by default or can be set to landscape or portrait representation. By default, the thumbnail ribbon is represented on the left in a landscape representation of the screen.
Several user settings can be adjusted:

- Smooth pixels of an MRI image when zooming
- Auto-collapse image ribbon
- Zoom Setting
- Monitor selection in case of multiple screens
- Color theme (light and default (dark))

9.5 Import

By default, the software will stack slices of one series based on the series UID. Because Siemens uses different series UID numbers for slices belonging to one stack, the function **Automatically merge Siemens stacks** will take other unique DICOM features to stack slices to belonging to one stack. The function **Automatically merge stacks** will merge stacks based on the same features as the **Automatically merge Siemens stacks**, however does this vendor independently.

When duplicate slices are present within one acquisition the option "**automatically use the newest slice when handling duplicate slices"** will build the stack including the slice containing the latest acquisition time.

9.6 Export

In the export tab default options can be changed.

The video export animation speed can be changed here as well as if an exported video should open automatically after export.

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