3D echocardiography

Current clinical applications
&
recent developments

Folkert Meijboom,

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Why 3D echo?

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- Poor spatial and temporal resolution compared with 2D

Why 3D echo?

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- To obtain spatial information in one data set
  - *Volumes*
    - LV
    - RV
    - atria
  - *complex anatomy –spatial relation of structures*
    - Mitral valve
    - Any other structure

Why 3D echo?

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- To obtain spatial information in one data set
  - *Volumes*
    - LV
    - RV
    - atria
  - *complex anatomy – spatial relation of structures*
    - Mitral valve
    - Any other structure
  - *To make cross-section impossible to make with 2D*
    - En-face view of valves, septums etc

Why 3D echo?

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- another echo-modality, to be used for its strong points
- Use 3D *on top of* 1D, 2D and Doppler modalities,
  - *not instead of*

3D echo in clinical practice

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- Current applications
  - *LV function*
  - *RV function*
  - *Morphology*
  - *3D TEE*
    - Morphology – MV
    - Guiding interventions
  - *3D & teaching*

LV function

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LV function

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- Echo is the work horse of cardiac imaging
- In virtually all echo`s LV function is assessed
  - *M-mode: FS*
  - *2D: EF - planimetry (Simpson)*
  - *3D: EF - volumetrics*

Reliability of M-mode and 2D bi-plane Simpson

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- Good representation of LV function
  - *Spherical shape of LV*
  - *Normal septal motion*
  - *In absence of regional wall motion abnormalities*

Paradoxical septal movement

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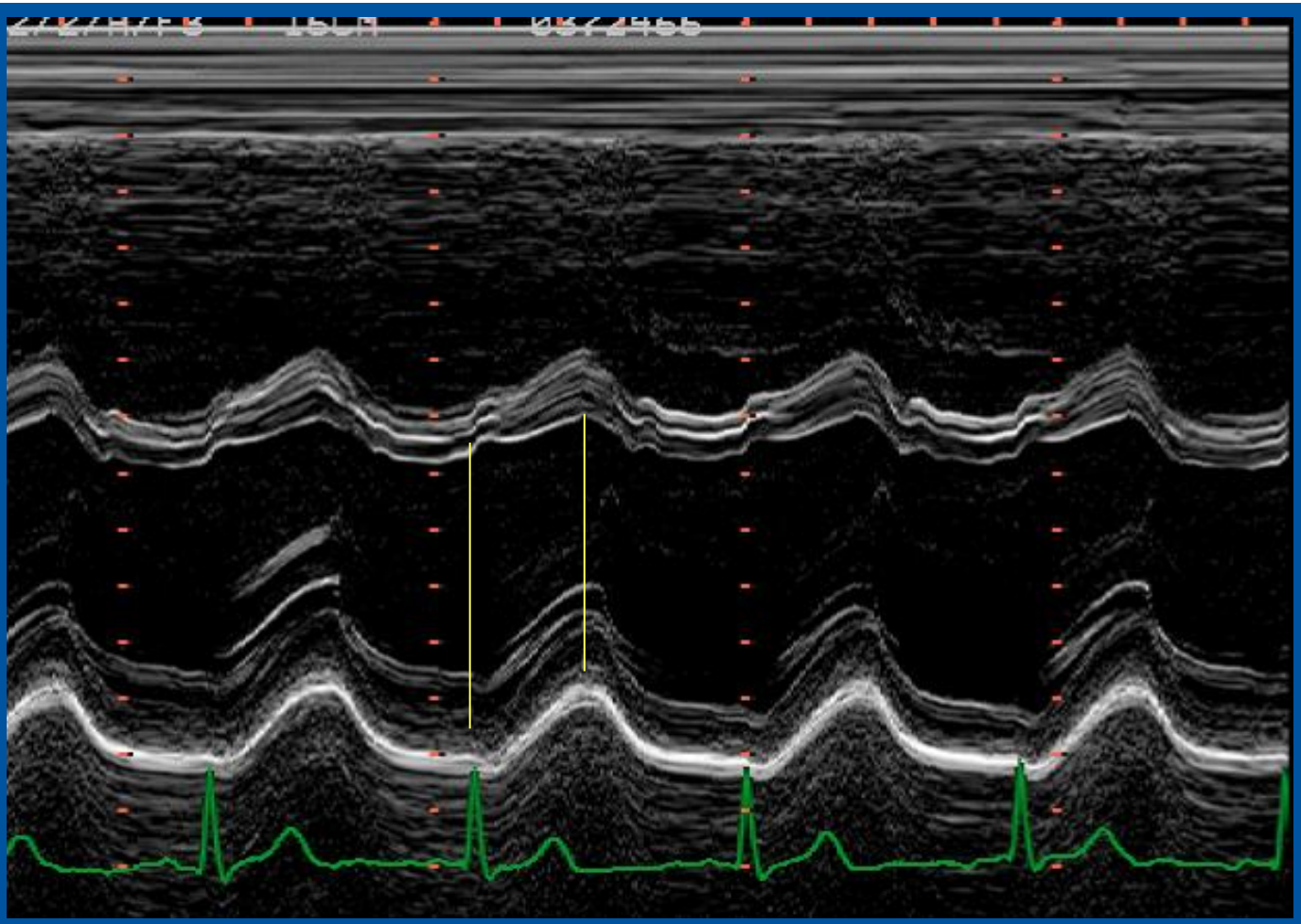

- FS 10% does not represent very poor LV function

Diastolic flattening of IVS = volume overload RV

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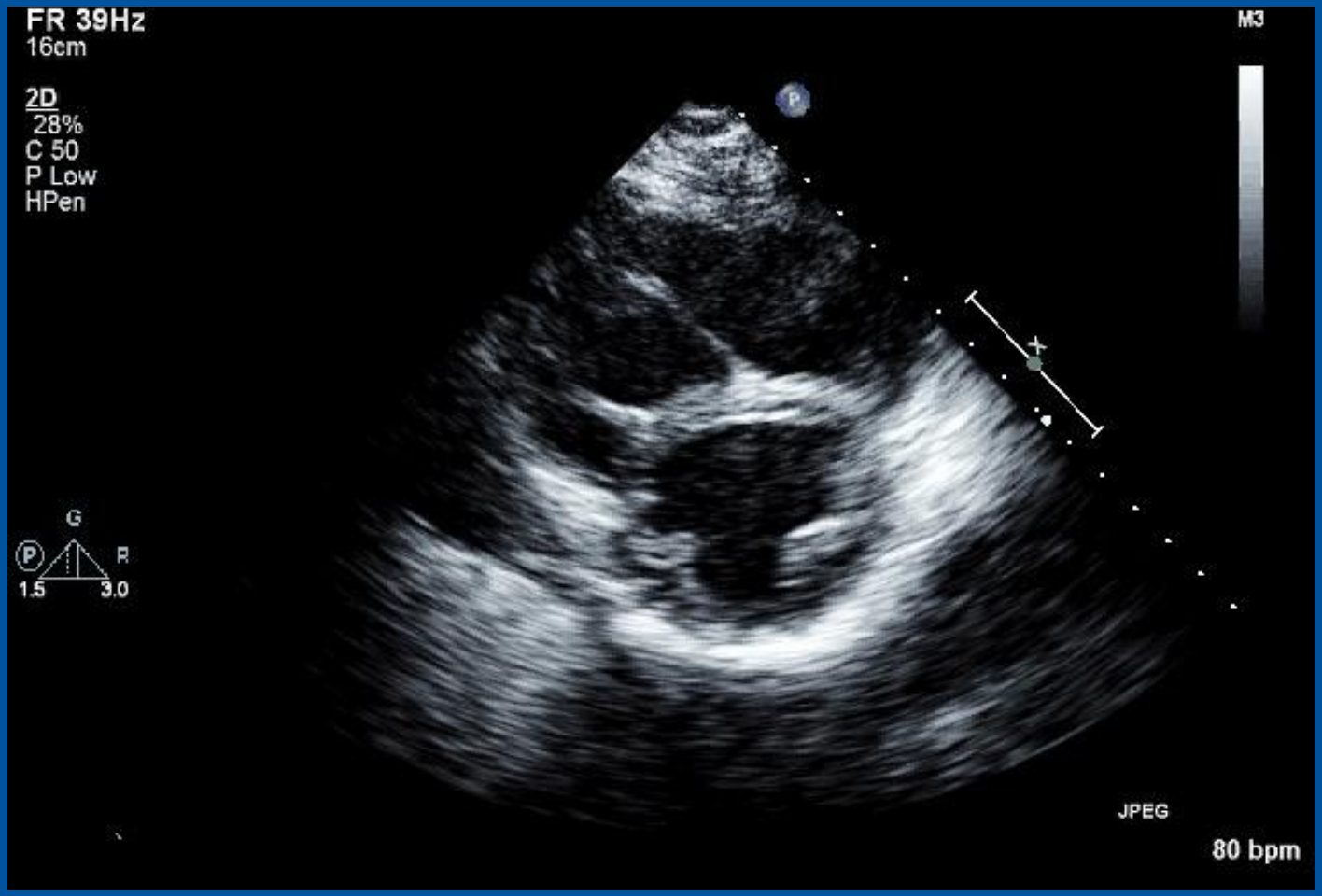

Systolic D-sign = pressure overload RV

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Reliability of M-mode and 2D planimetry

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Reliability of M-mode and 2D planimetry

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- Good representation of LV function
  - *Spherical shape of LV*
  - *Normal septal motion*
  - *In absence of regional wall motion abnormalities*

- Often ***not*** the case in patienst we are interested in
  - *Regional wall motion abnormalities after MI*
  - *RV pathology in CHD patients*

How good is echo in assessment of LV function?

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echo (M-Mode, 2D & 3D) – MRI -CT

(volume in ml, EF in %)

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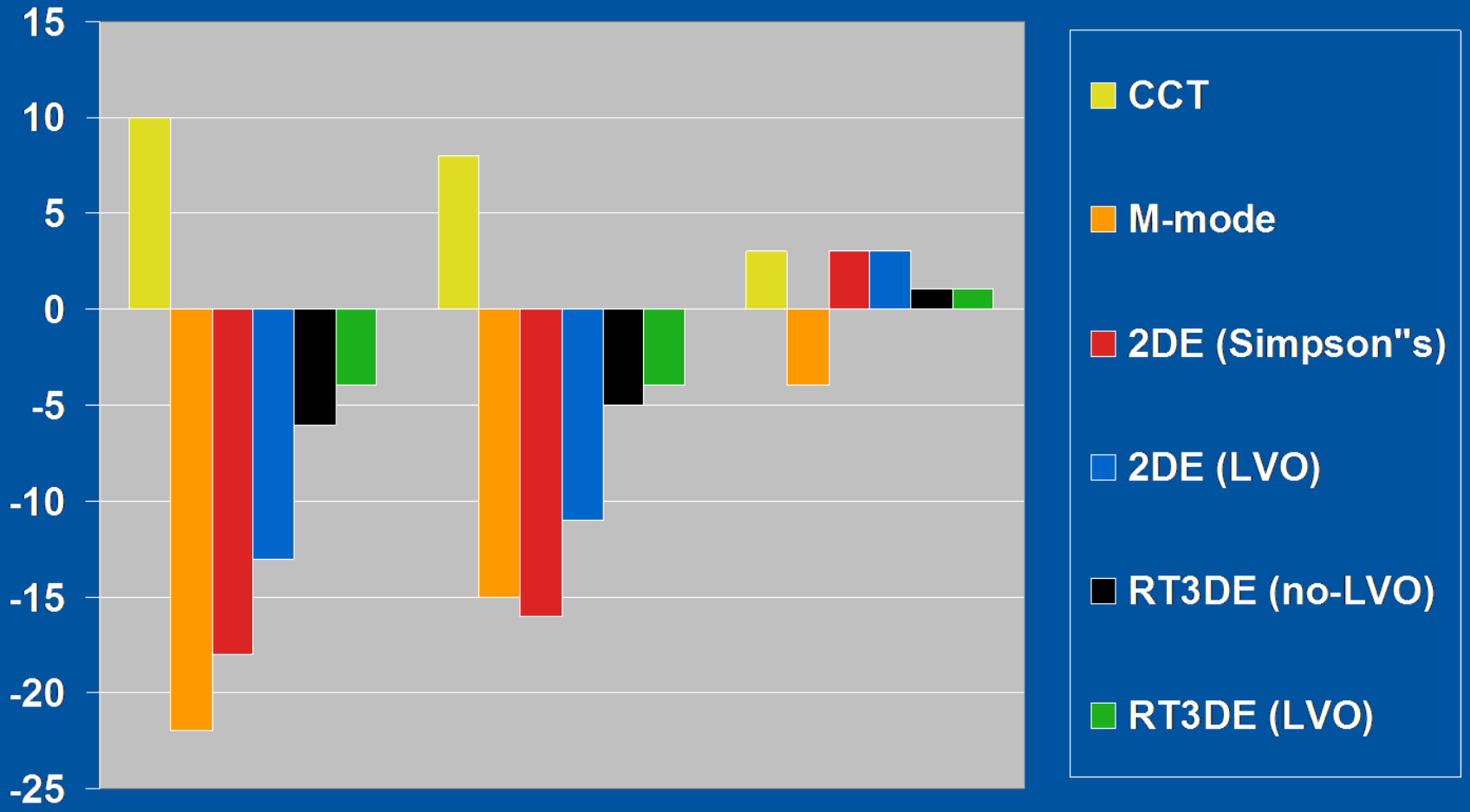
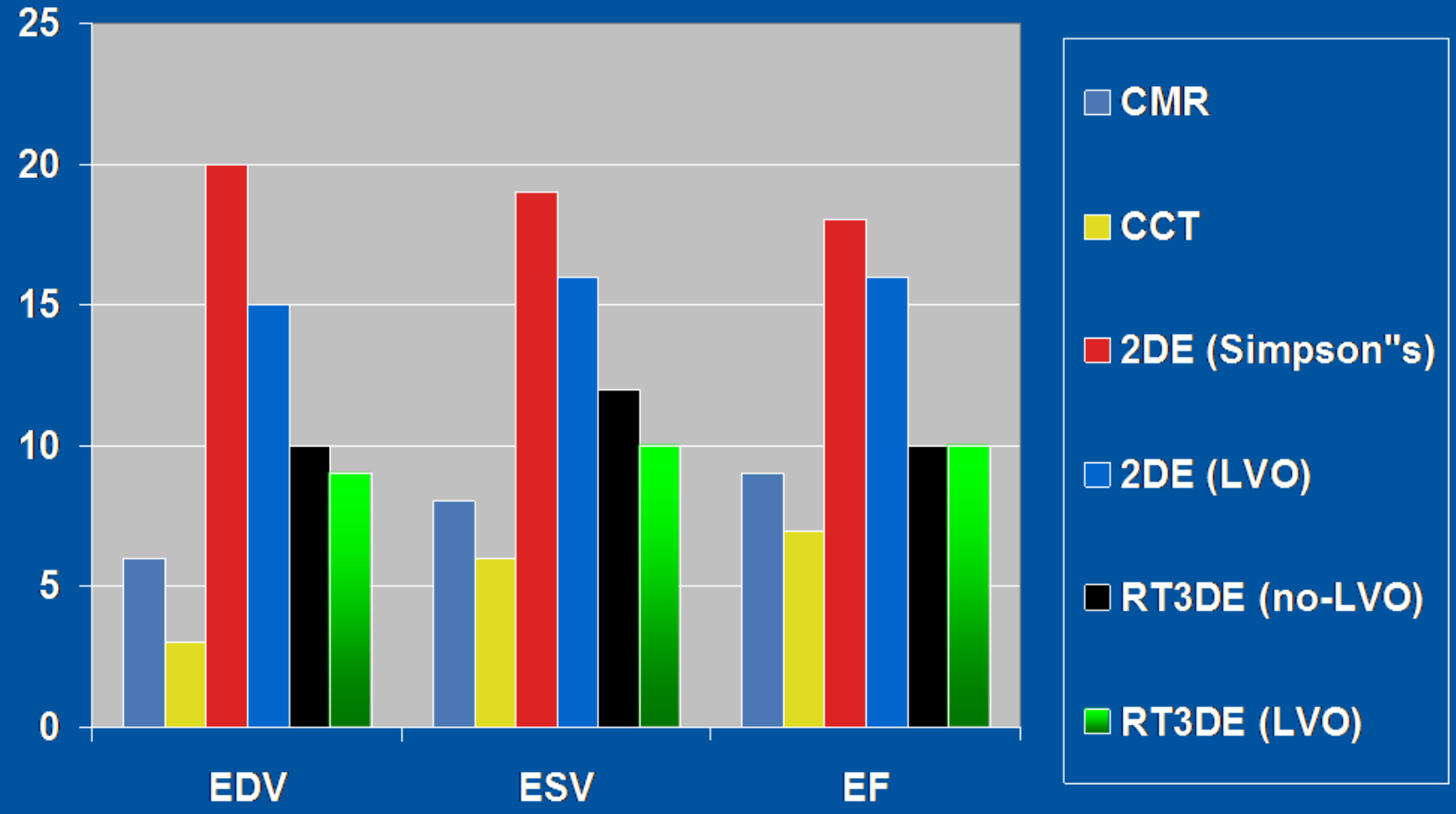


•Sugeng et al. Circulation. 2006. 114(7): p. 654-61.

Inter & intra-observer variability LVF



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RT 3D echo & LV function

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- RT 3D echo
  - *more reproducible (better correlation with MRI)*
  - *more robust (less intra & inter-observer variablity)*

  than M-mode and 2D

RT 3D echo & LV function

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- RT3D echo feasible in clinical practice?
  - *How is it done in clinical practice?*
  - *How much time does it take?*

RT3D echo & Global LV function

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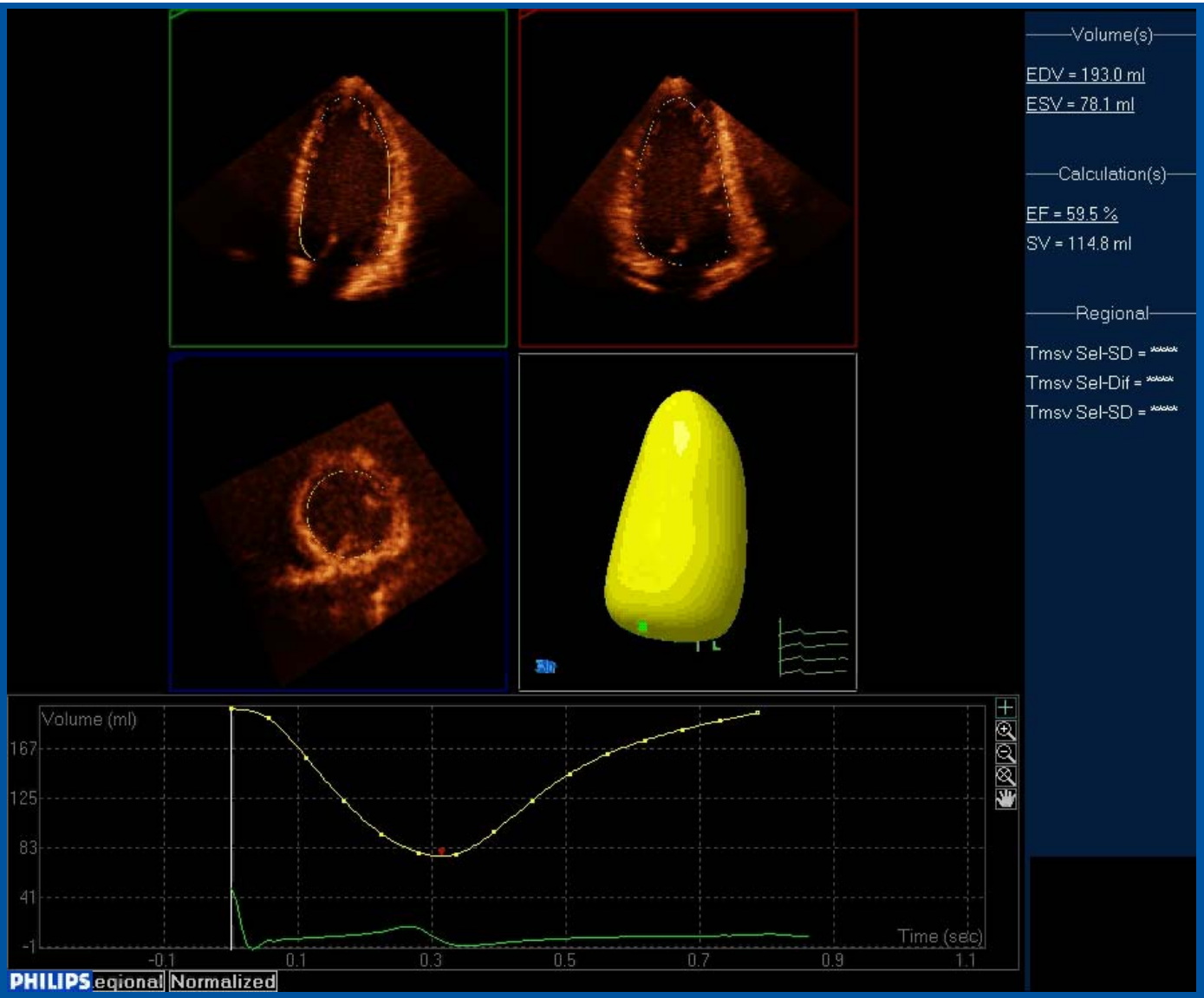

RT3D echo & LV function

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- Is it feasible in clinical practice?
- For which patients?

3D matrix transducer

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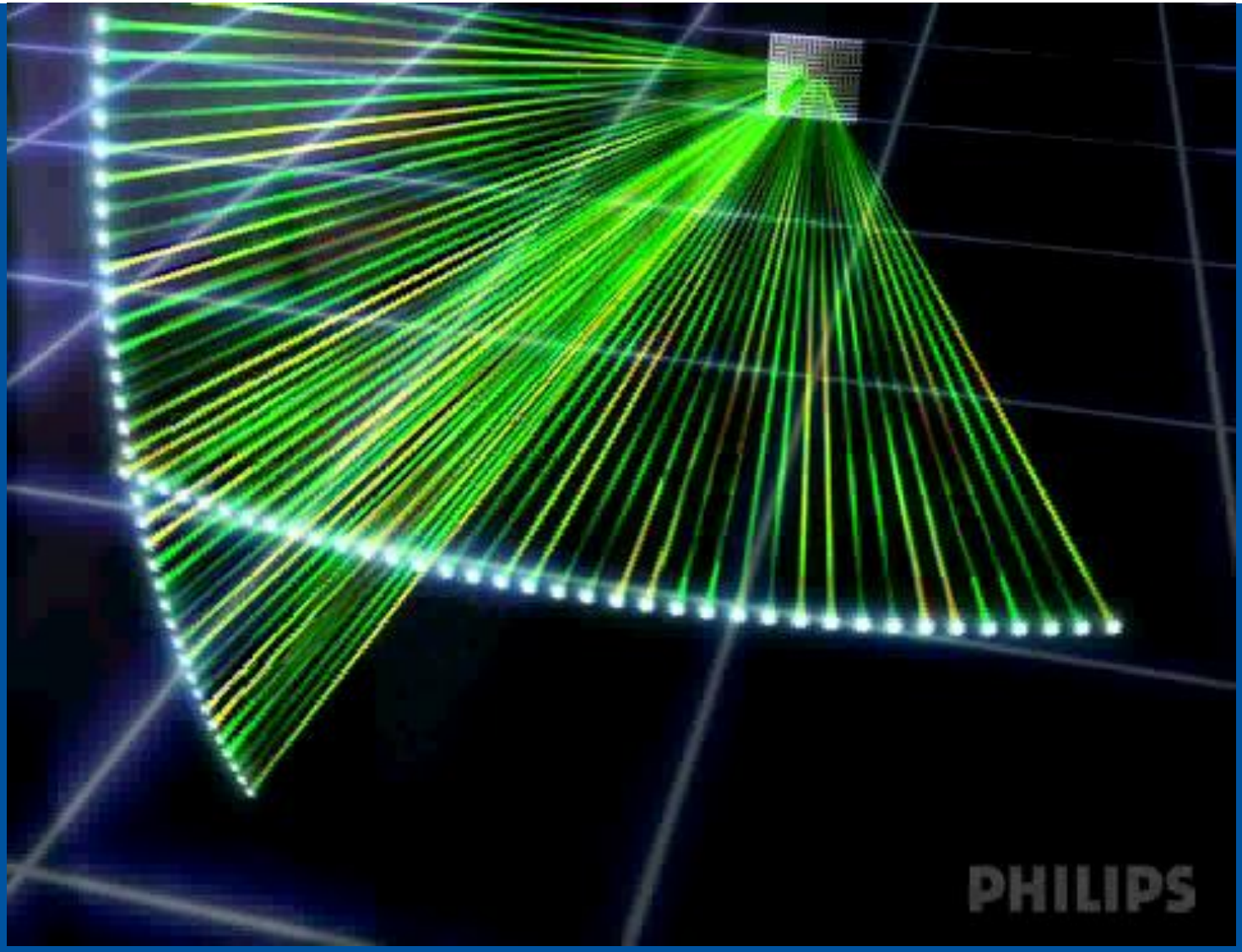

RT 3-D data acquisition

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Full matrix array transducer modules

1. **Real-time** 3D, no `breath hold`. narrow sector (60° x 30°)

2. **`zoom mode`** → enlargement of subsegment of 3D data pyramid (30° x 30° sector)

3. **Full volume** = 90° x 90° (110° x 110°) pyramide volume

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Off-line analysis necessary

Full volume acquisition

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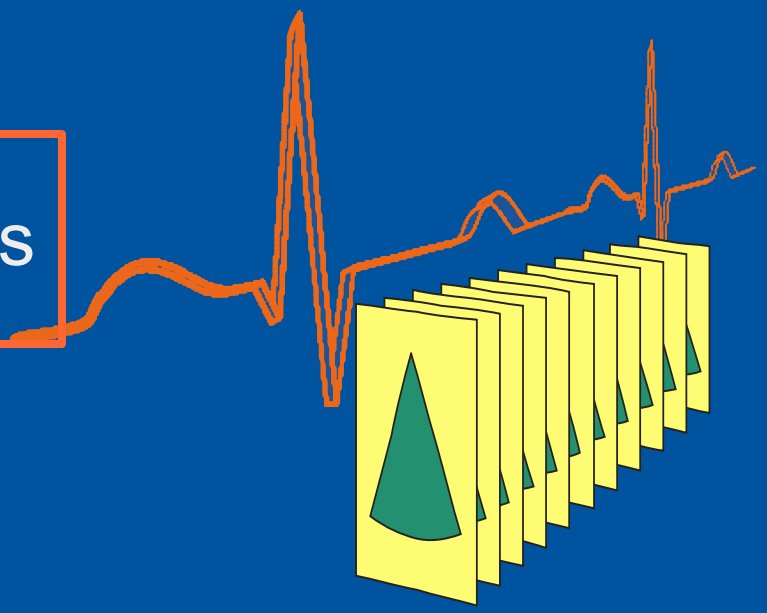
- 4-7 subsequent subvolumes combined to a 90° x 90° pyramid volume
- ECG triggerd on R wave
- `breath-hold`
- Aquisition time: 5- 8 secs
- No actual real time



Full-volume 3D data set from the apex

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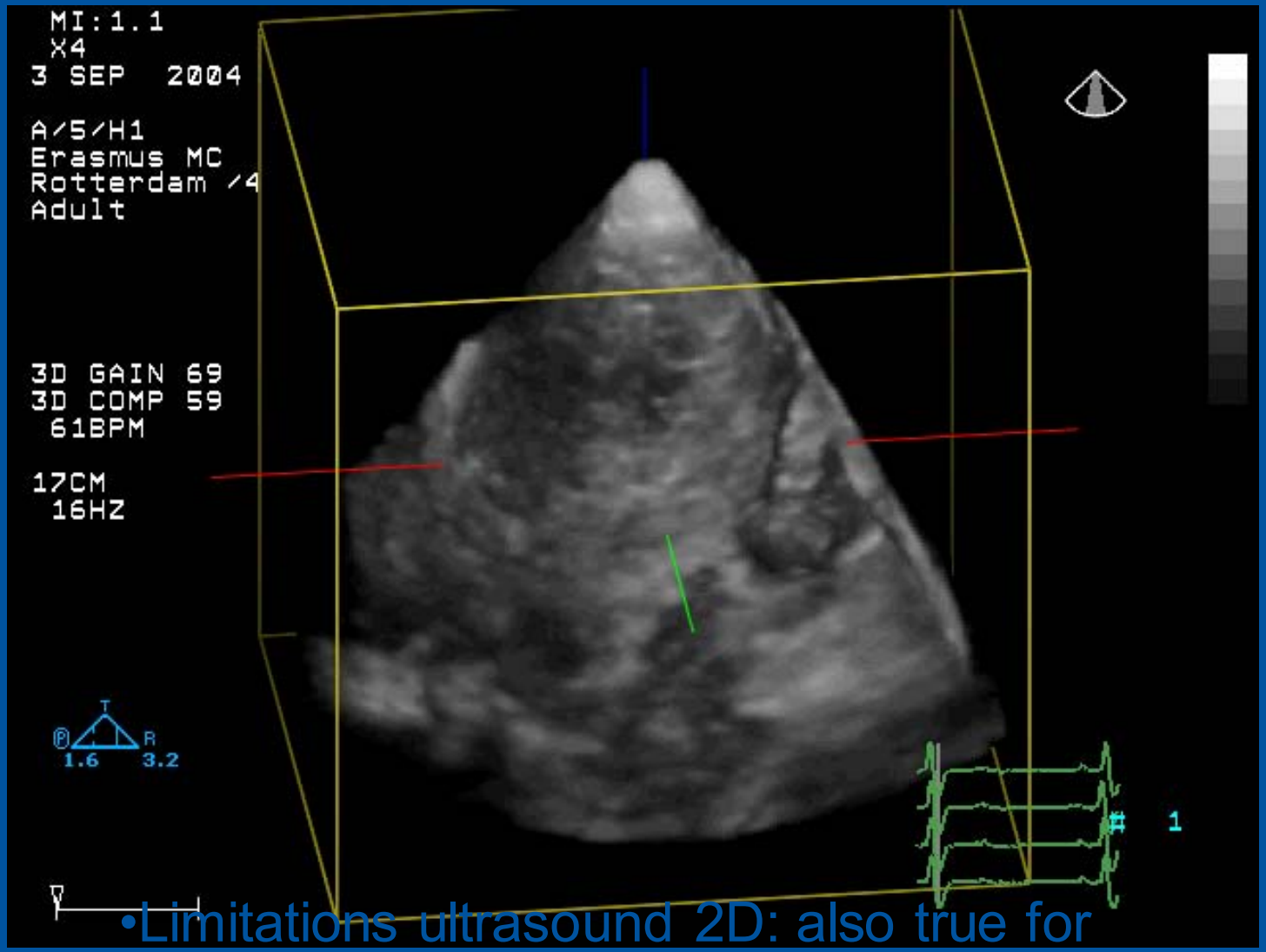

- Limitations ultrasound 2D: also true for

RT3D Analysis of LV volumes

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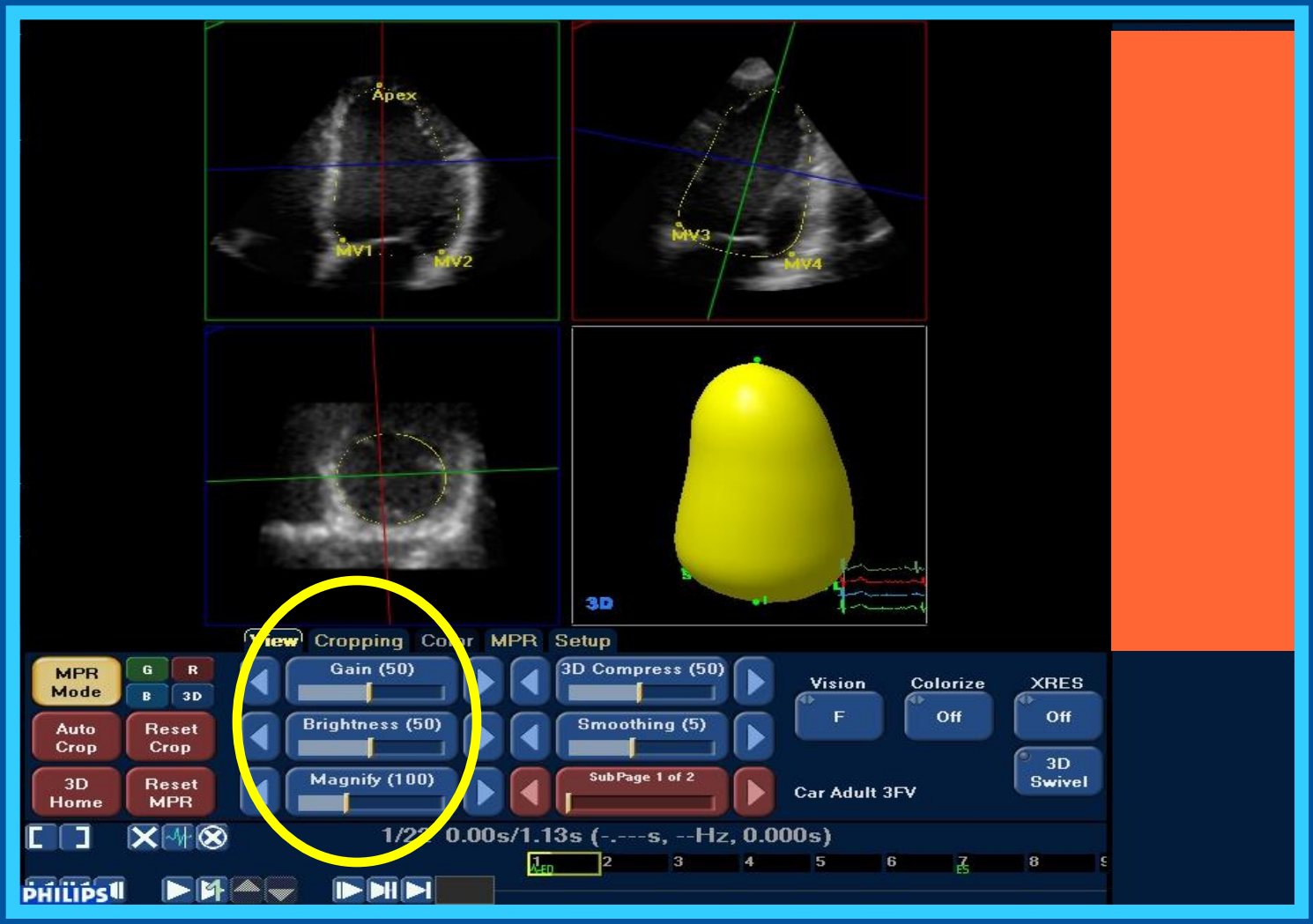

RT3D Analysis of LV volumes

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RT3D Analysis of LV volumes

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- Adjustment of orthogonal axis

RT3D Analysis of LV volumes

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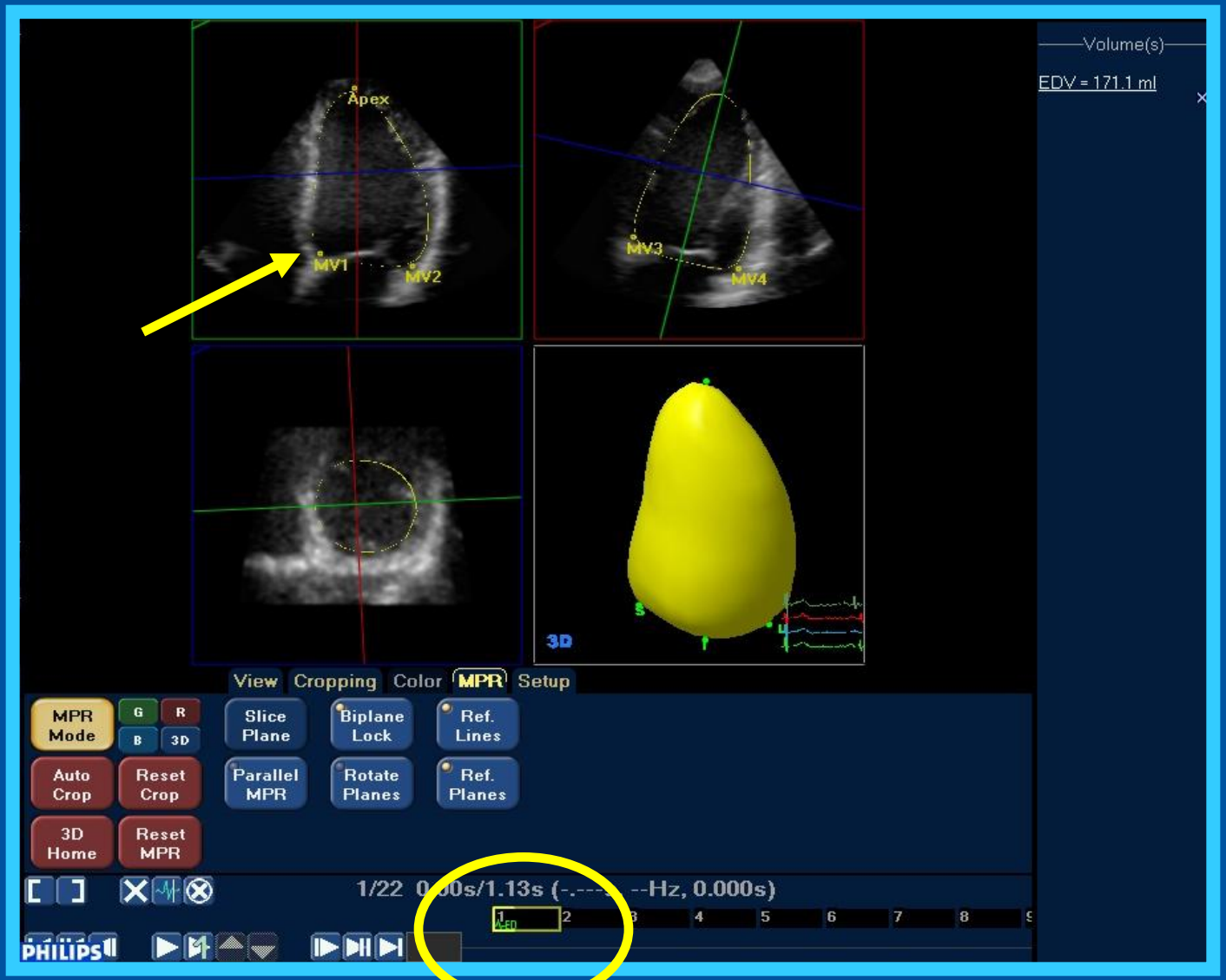

RT3D Analysis of LV volumes

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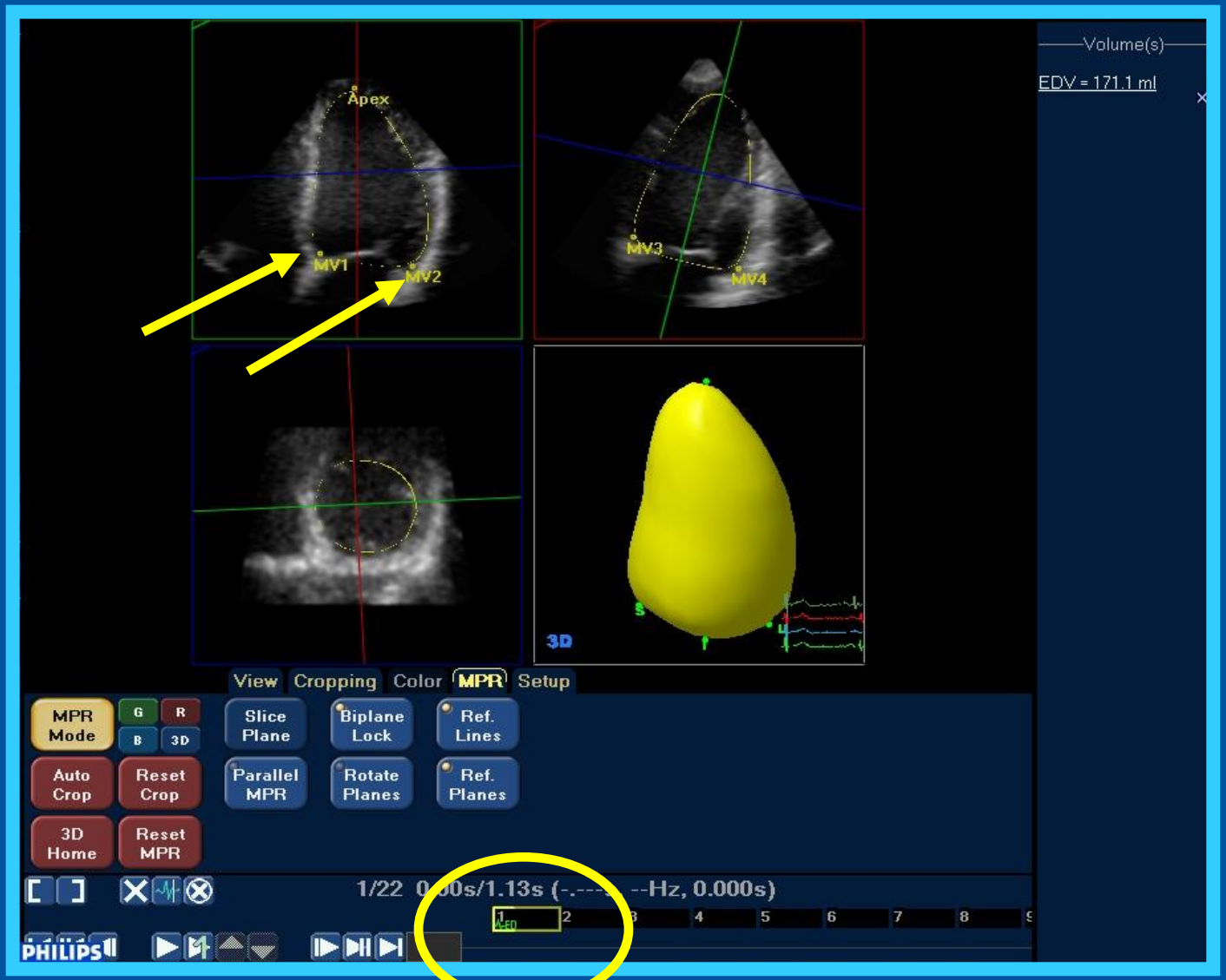

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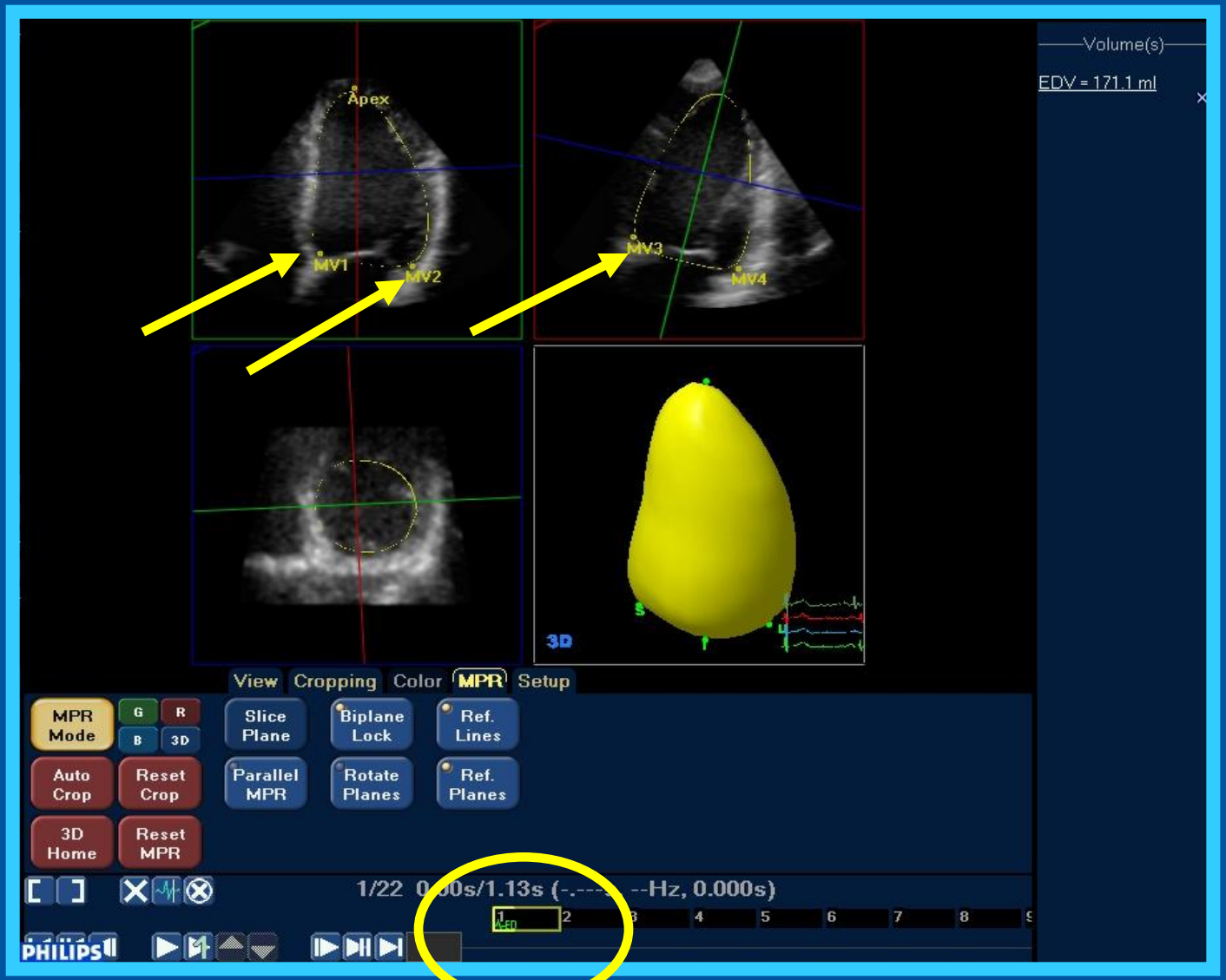

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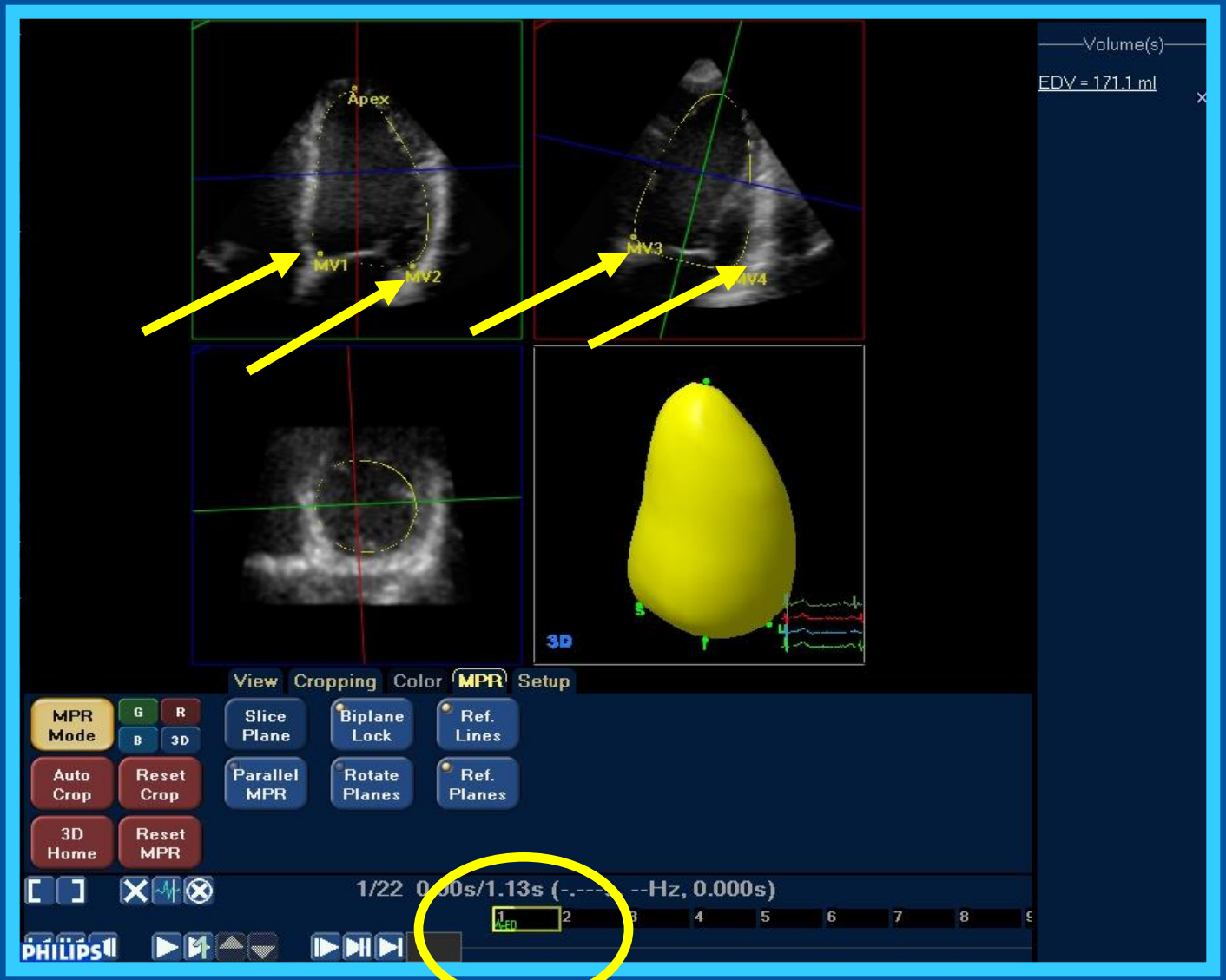

RT3D Analysis of LV volumes

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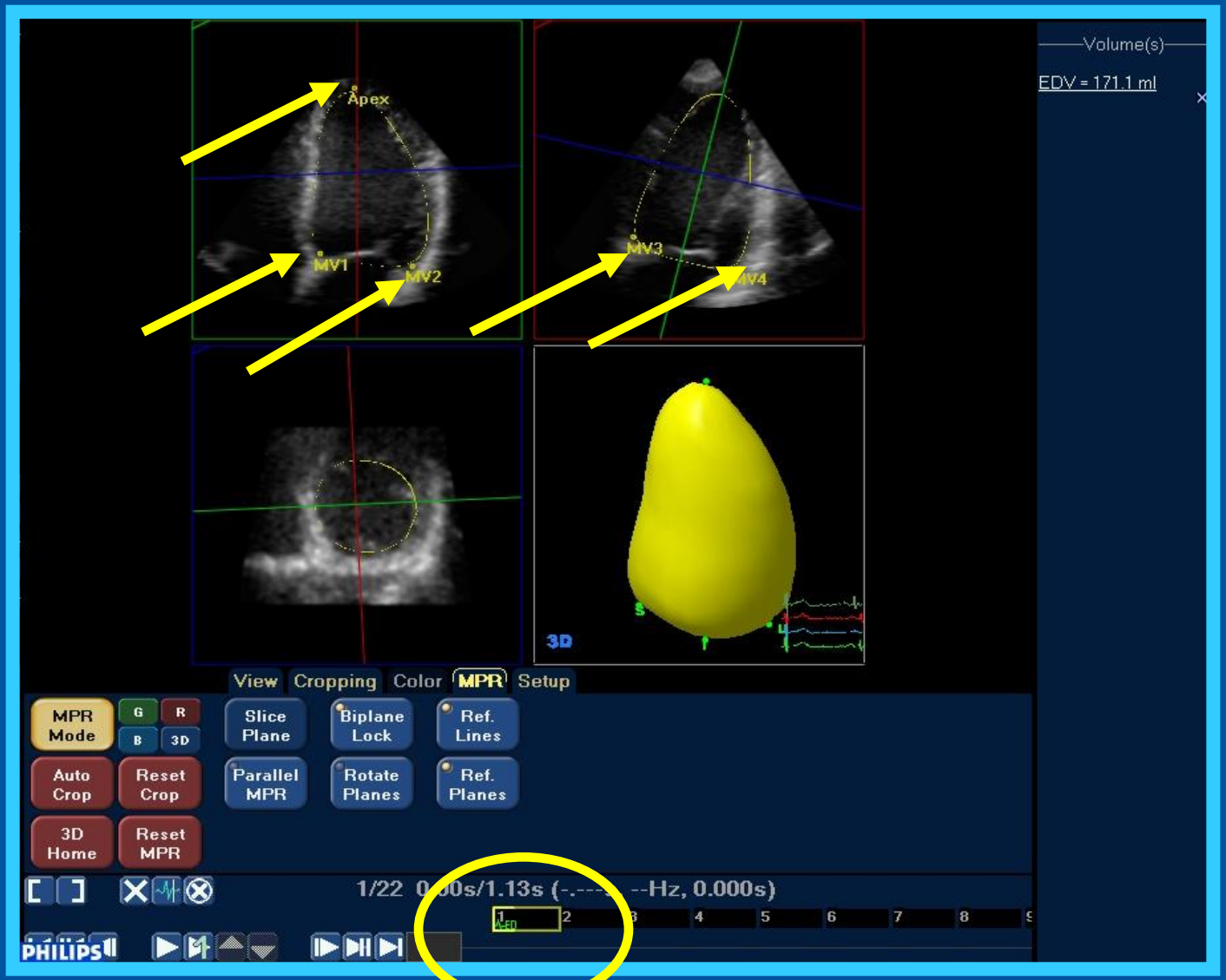

- These anatomical landmarks are well defined
  - *Straightforward*
  - *Easy to identify*

- The endocardial border detection is automated
  - *Based on algoritms*

→ *Little inter- and intra-observer variability*

RT3D Analysis of LV volumes

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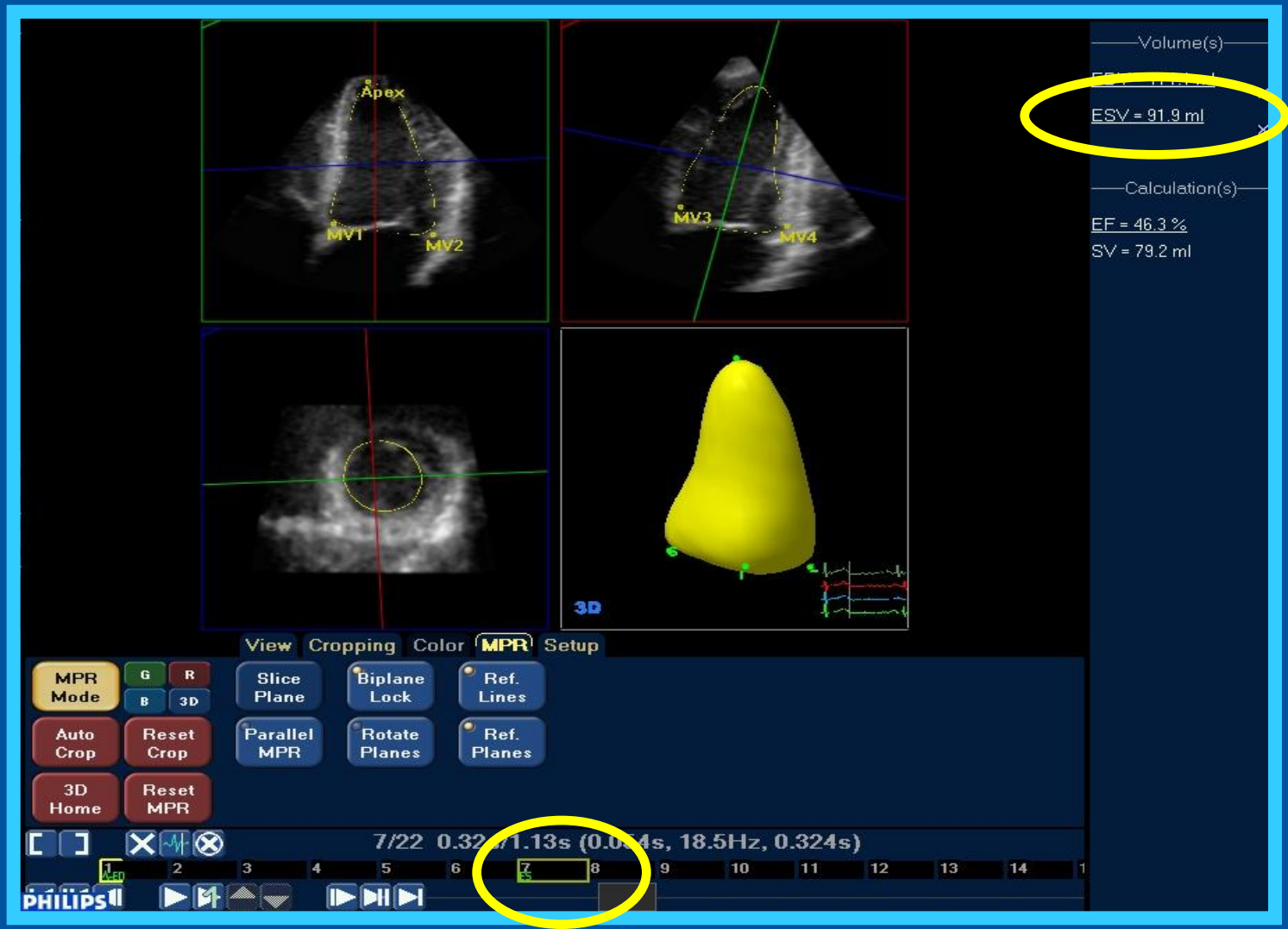

RT3D Analysis of LV volumes

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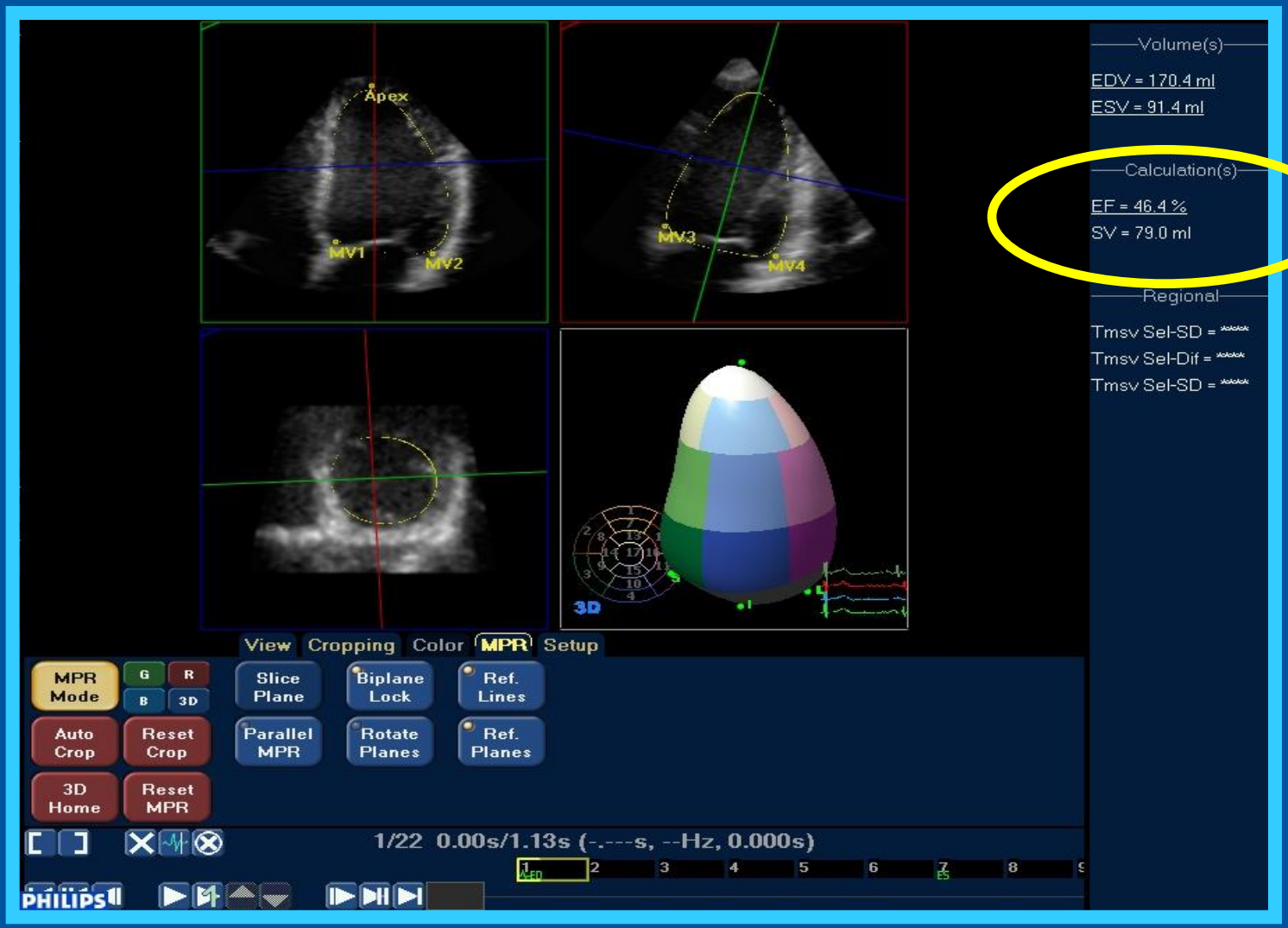

RT3D Analysis of LV volumes

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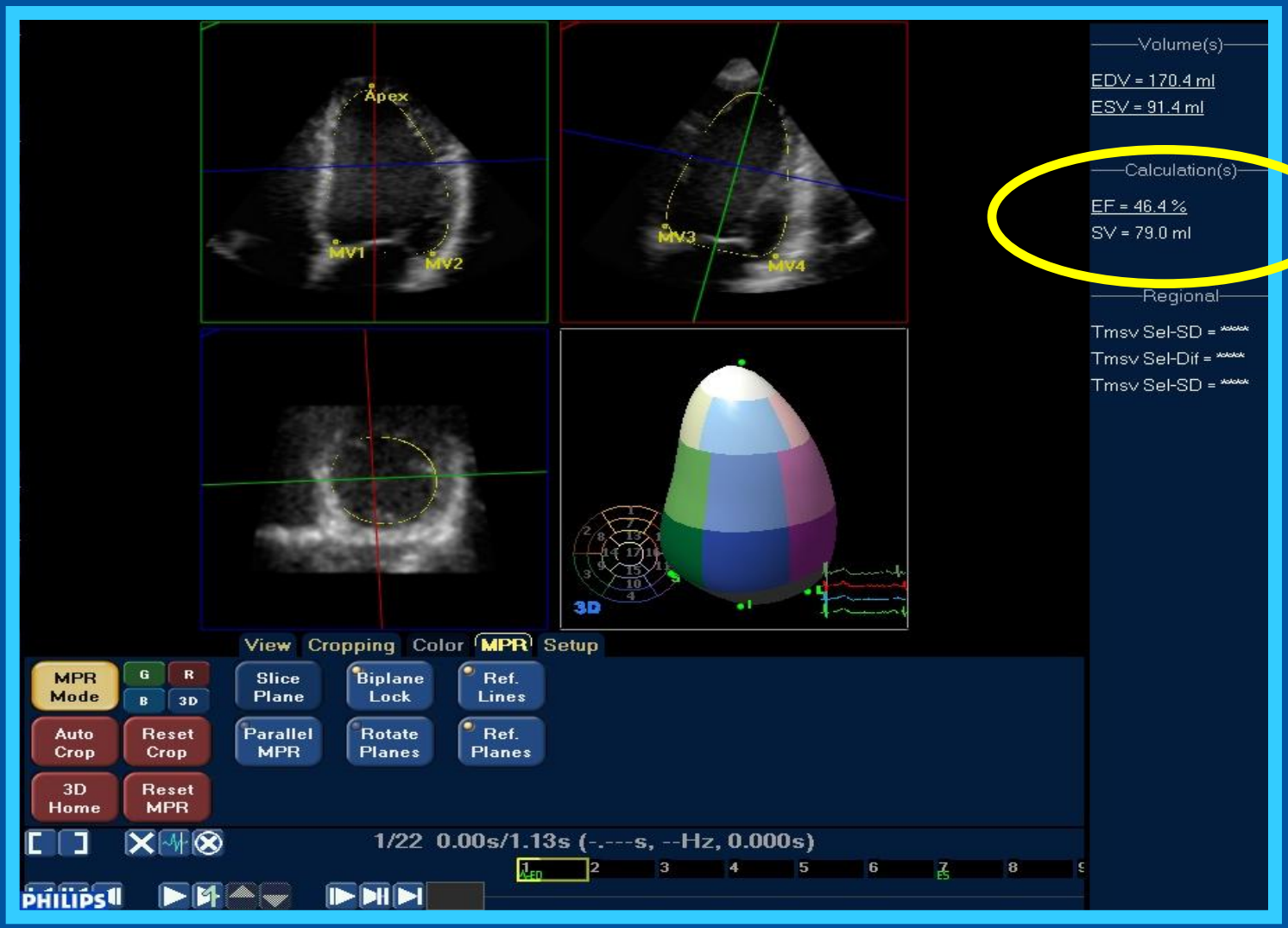

• < 5 min

Conclusion: 3D echo & LVEF

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- < 5 minutes acquisition & analysis:
  - *reproducible EF*
  - *Better and faster than bi-plane Simpson*
  - *More robust in your multi-echotec echo lab*

Conclusion: 3D echo & LVEF

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- < 5 minutes acquisition & analysis
- Provided
  - *Regular (sinus) rhythm*
    - Volumes “stitched” together, based on R-waves
  - *Adequate echo quality*
    - In 60 – 70% of the patients
    - Poor 2D quality is poorer 3D quality

Conclusion: 3D echo & LVEF

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- < 5 minutes:
  - ➢ *reproducible EF in a large proportion of your patients*

Conclusion: 3D echo & LVEF

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- < 5 minutes:
  - ➢ *reproducible EF in a large proportion of your patients*

  - ➢ *established in clinical practice:*
    - ➢ when you ask EF – you get a 3D-EF

Conclusion: 3D echo & LVEF

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- < 5 minutes:
  - ➢ *reproducible EF in a large proportion of your patients*
  - ➢ *Can/should bestablished in clinical practice:*
    - ➢ when you ask EF – you get a 3D-EF
  - ➢ *Poor echo quality:*
    - ➢ Contrast 3D echo = difficult
    MRI or CT

Conclusion: 3D echo & LVEF

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- < 5 minutes:
  - ➢ *reproducible EF in a large proportion of your patients*
  - ➢ *established in clinical practice:*
    - ➢ when you ask EF – you get a 3D-EF
  - ➢ *Poor echo quality:*
    - ➢ Contrast 3D echo = difficult
      MRI or CT
  - ➢ *If not feasible because of non-sr: ?*

What is *relatively* new 3D & LV function?

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- Regional LV volumes
- Parametric imaging
- Role regional volumes in CRT

Regional LV volumes

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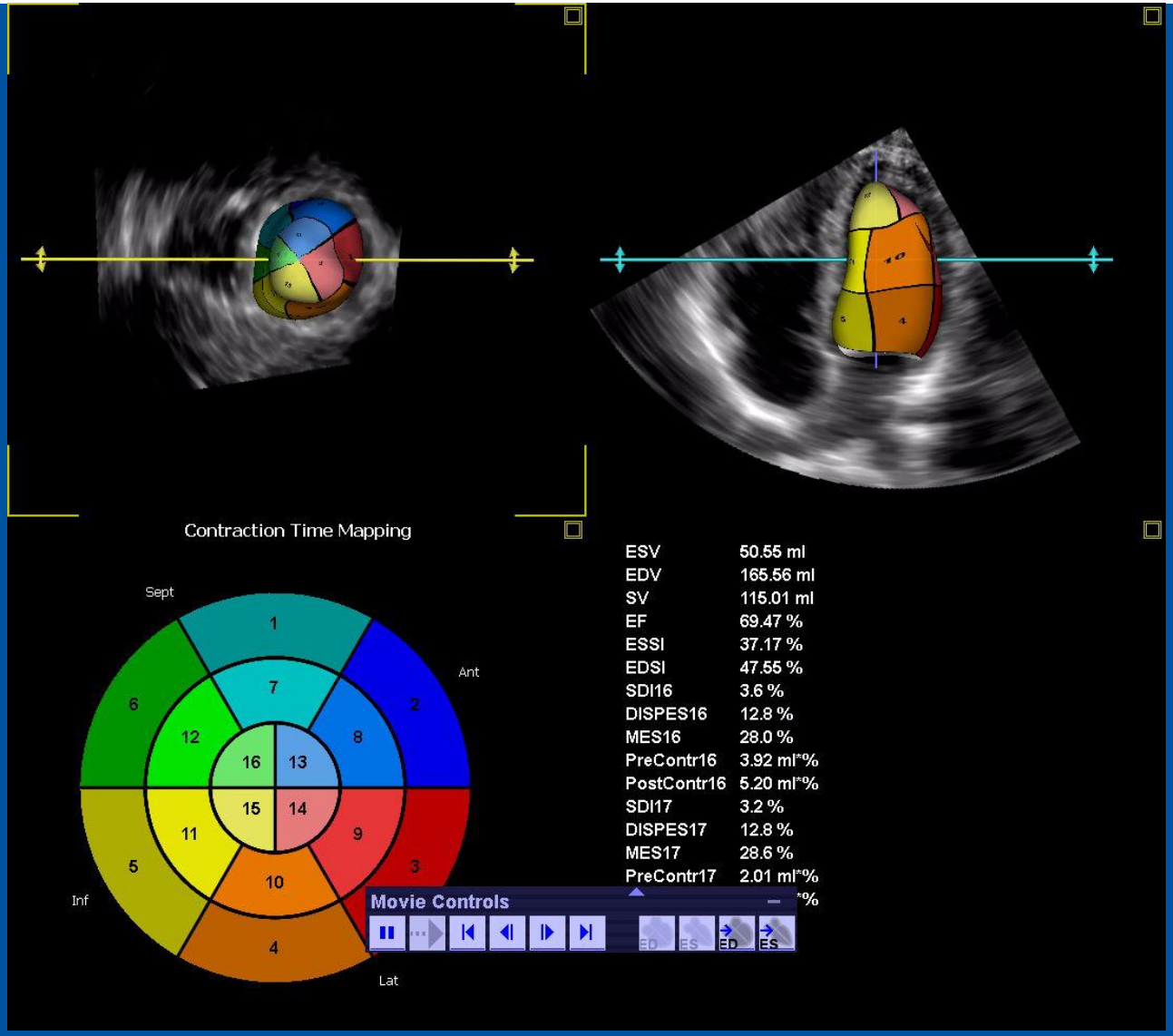

CRT; Regional volumes

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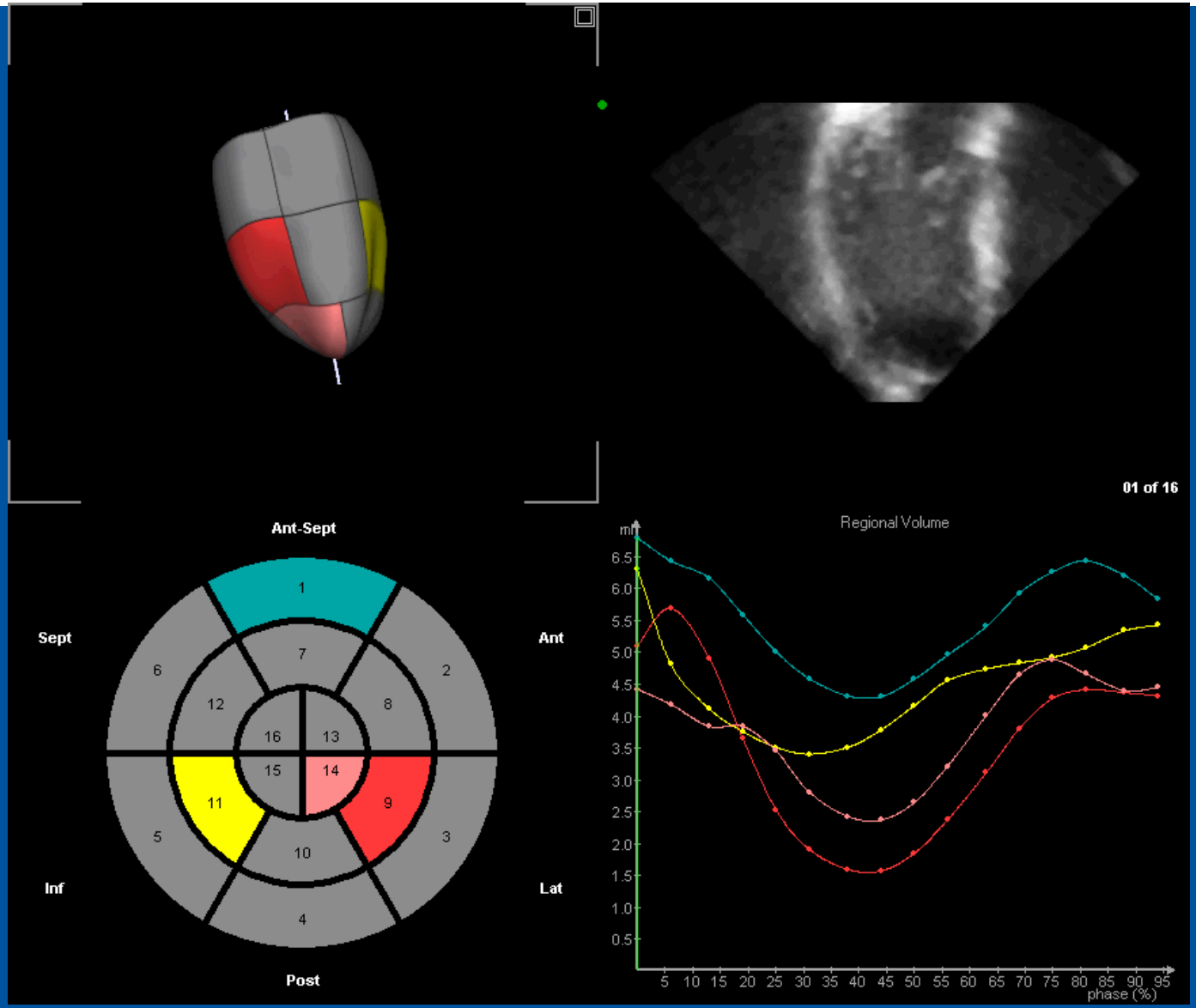
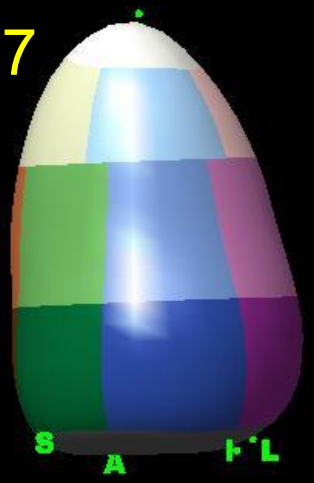
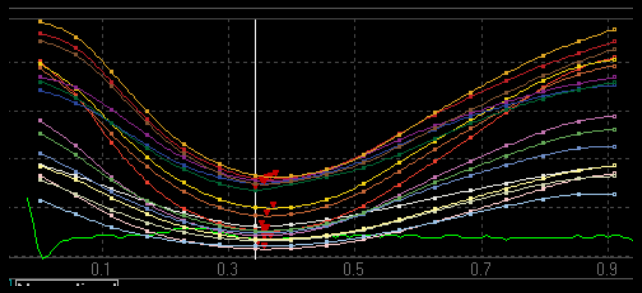


•#17

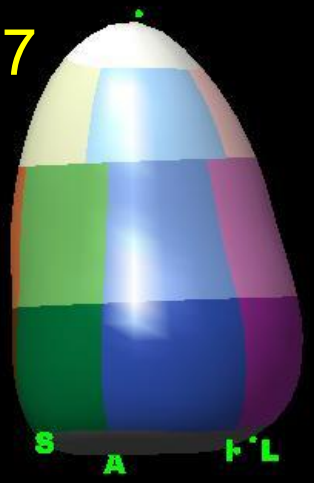


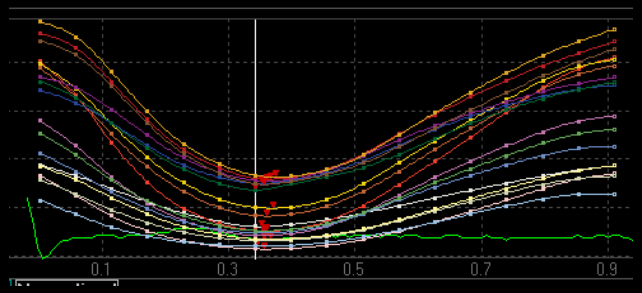


Tmsv 16-SD*	7	ms
Tmsv 12-SD	8	ms
Tmsv 6-SD	5	ms
Tmsv 16-Dif	23	ms
Tmsv 12-Dif	23	ms
Tmsv 6-Dif	13	ms
Tmsv 3-6	7	ms
Tmsv 3-5	-1	ms
Tmsv Sel-SD	----	ms
Tmsv Sel-Dif	----	ms
R-R Time	1034	ms

•16 or 17 segments

•#17





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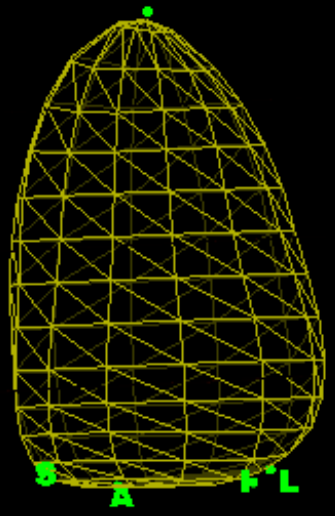
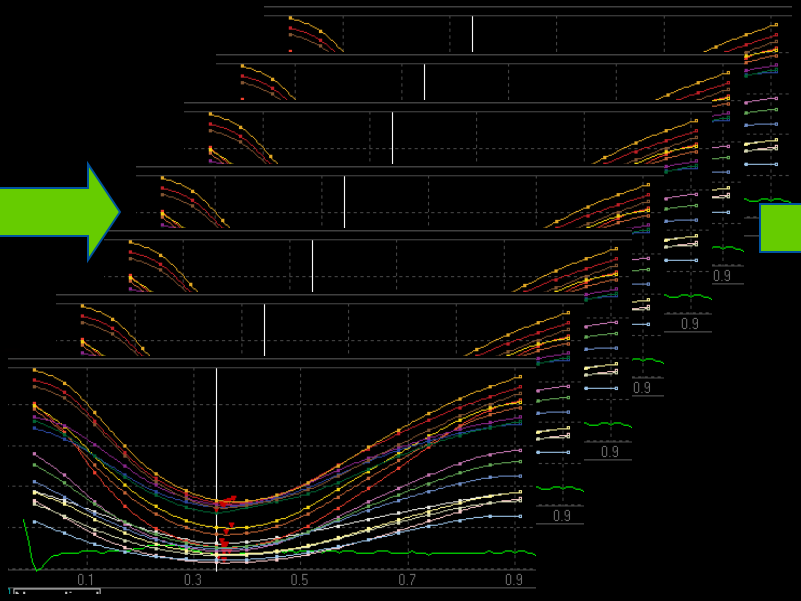
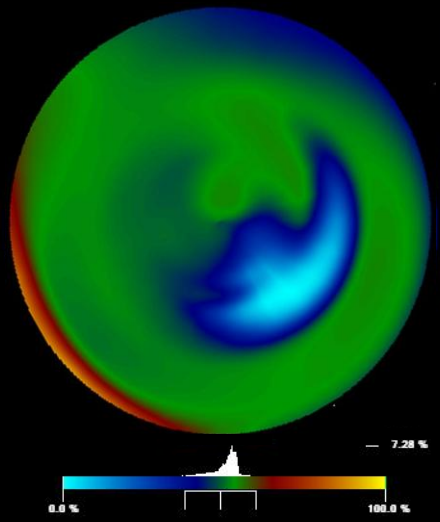
Tmsv 3-5	-1	ms
Tmsv Sel-SD	----	ms
Tmsv Sel-Dif	----	ms
R-R Time	1034	ms

•# Hundreds







“Parametric Imaging”
imaging of a specific parameter in a 3D data

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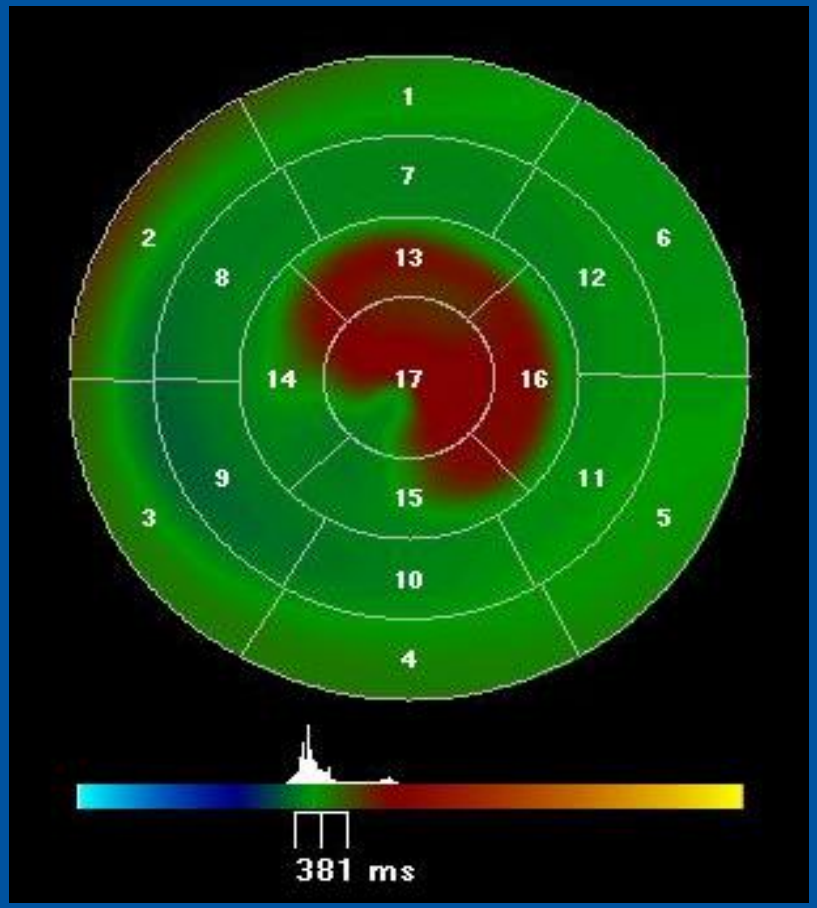

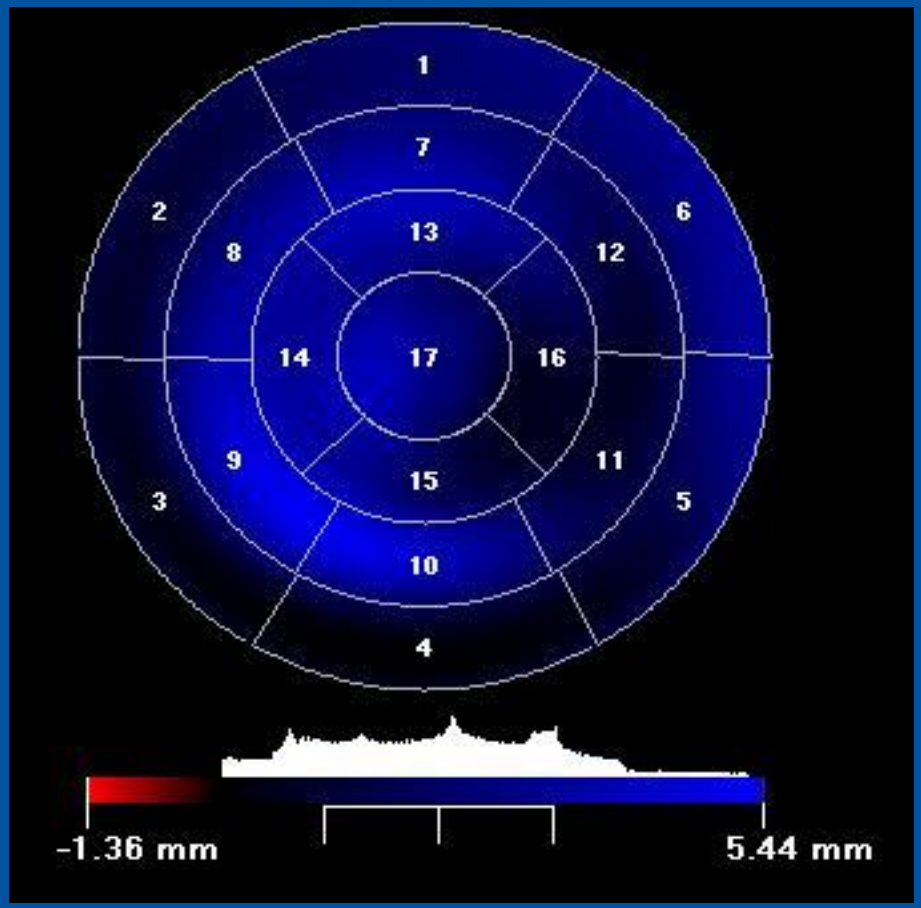

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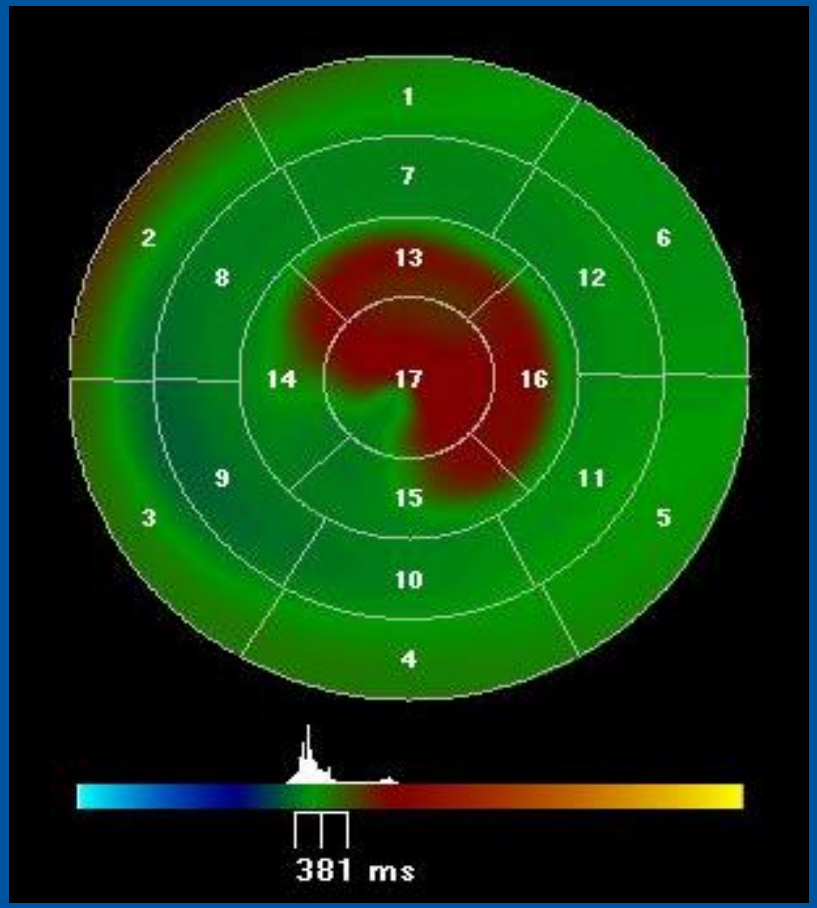
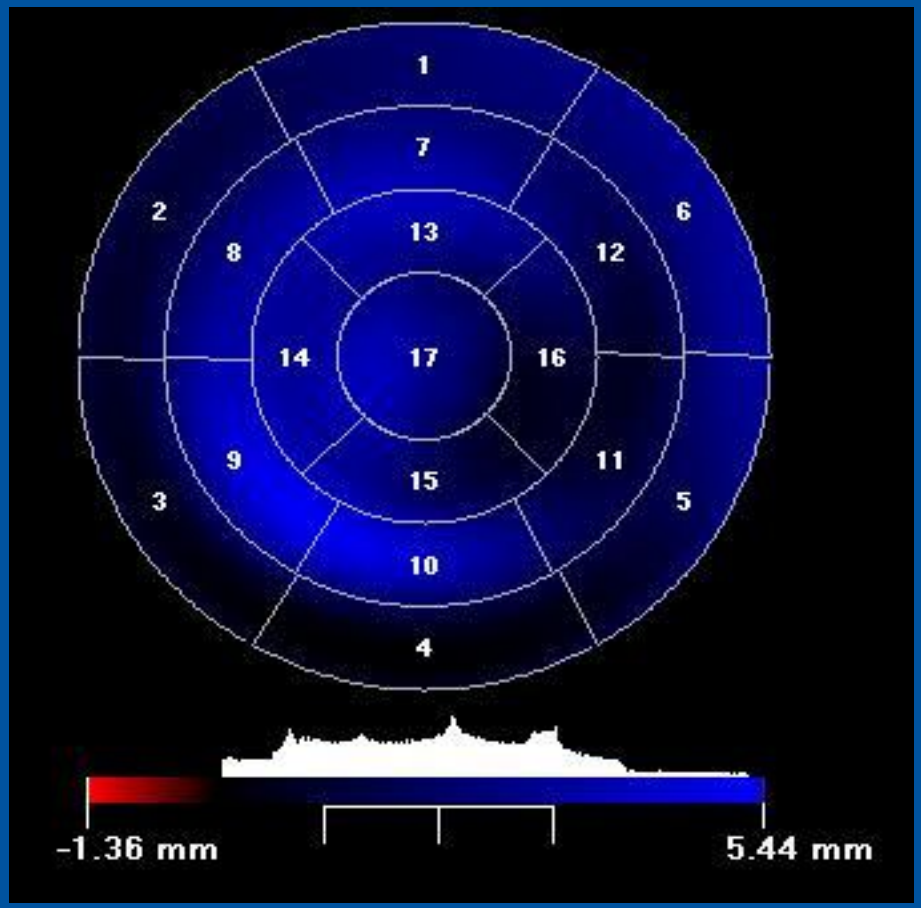


Timing: CRT



Excursion: ischaemia

Parametric Imaging
parameter = timing

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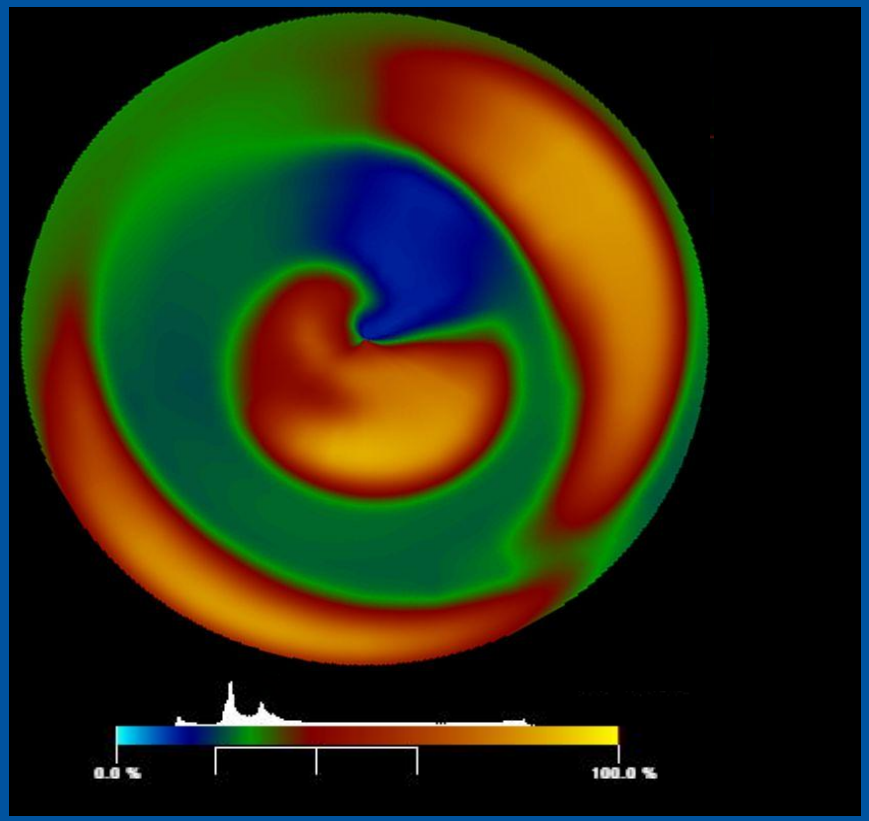

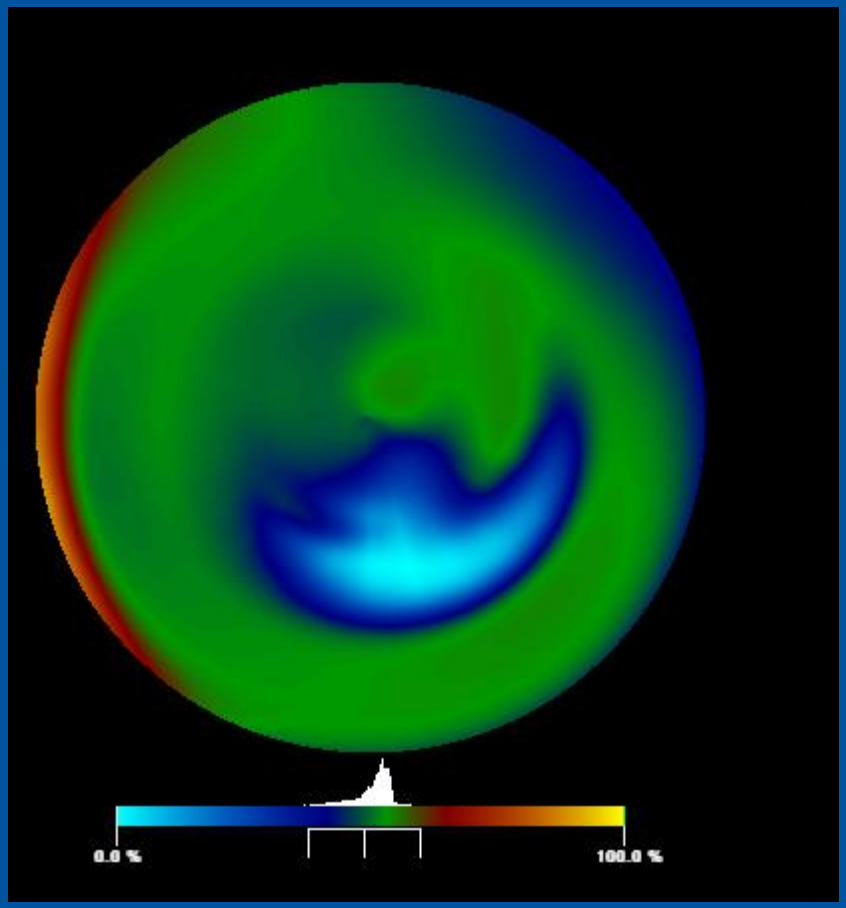

Parametric Imaging parameter = excursion

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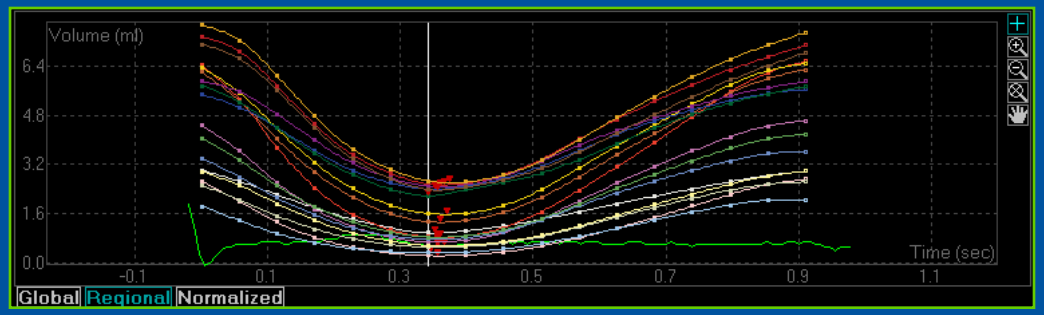

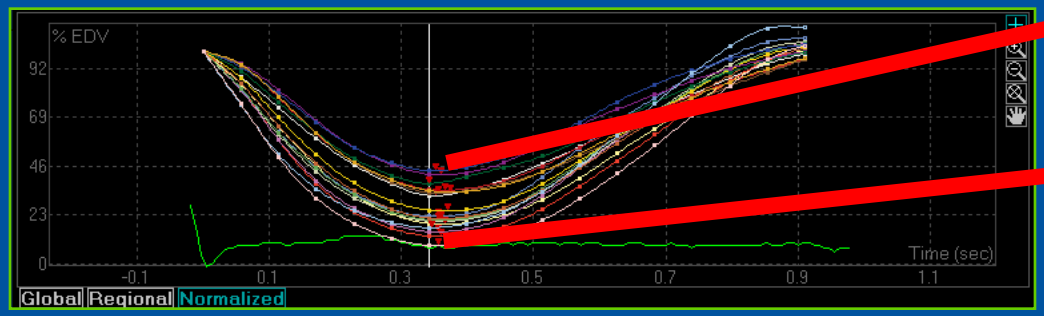

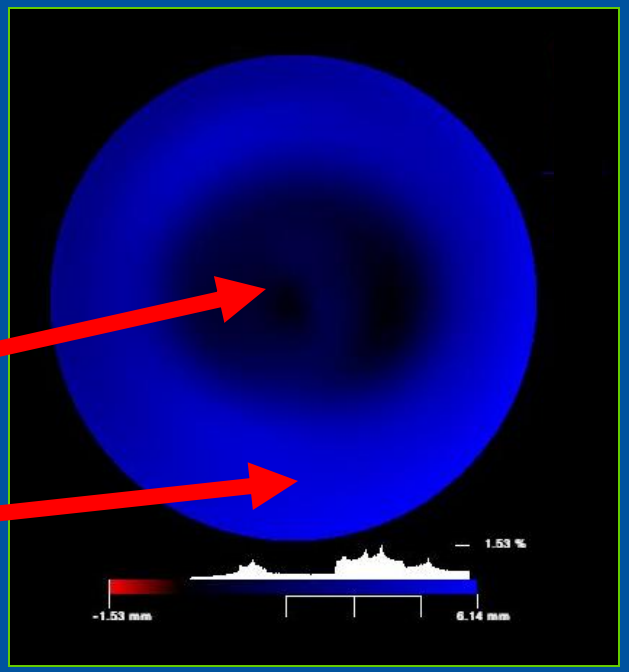

- Excursion PI = Representation of wall motion

Evaluation of CRT

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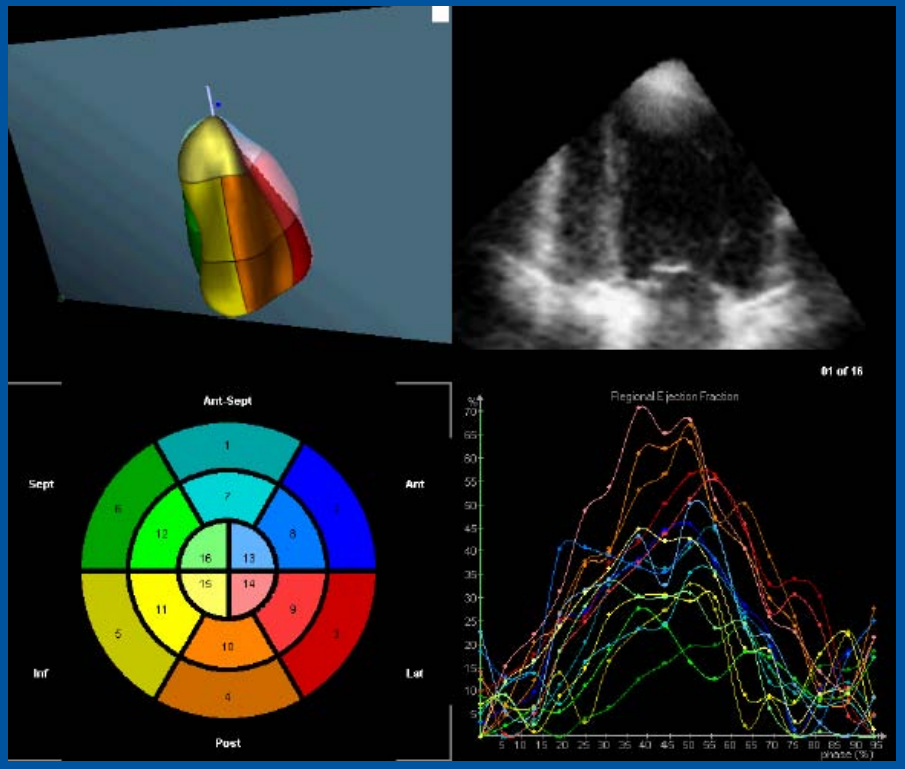

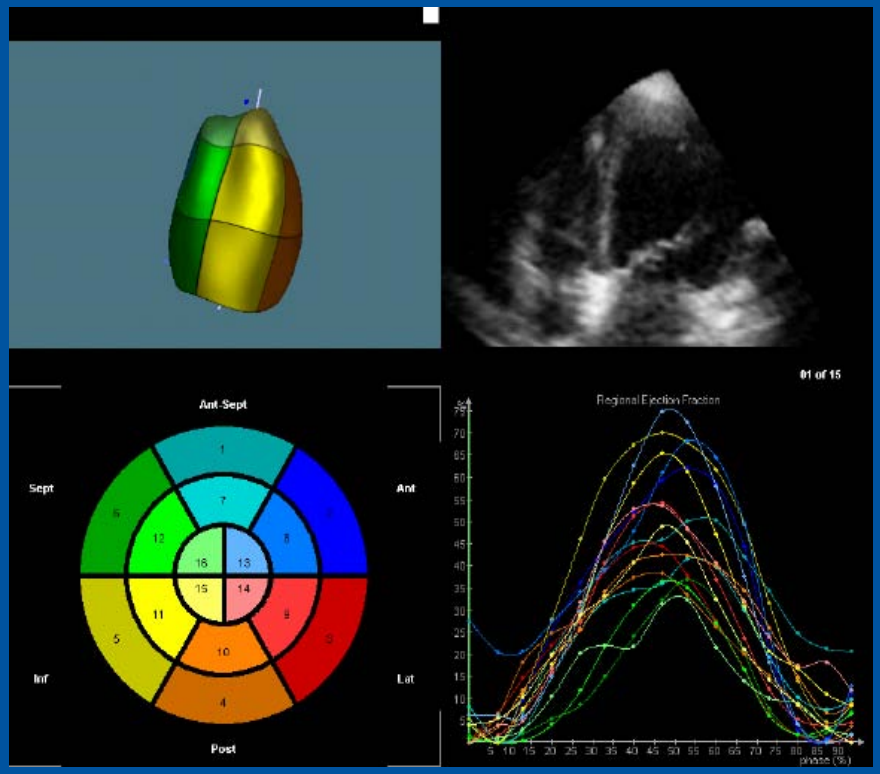

Dyssynchrony ----------→ synchronized by dual chamber pacing

3D echo & CRT

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- Limited use so far
- Wall *motion* is assessed on basis of endocardial border detetction
  - *No discrimination active – passive motion*
  - *Not (necessarily) representative for contraction/myocardial function*

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→ *Work in progress*

What is new for RT3D echo & LV function?

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What is new for RT3D echo & LV function?

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- Philips has been market leader for many years
- Other vendors producing 3D paltforms
  - *GE, Toshiba, Siemens/Acuson*
  - *Full-volume in a single heart beat*
  - *Actual real-time 3D for volumetrics*
- 3D speckle tracking (Acuson)

Current method for full volume 3D

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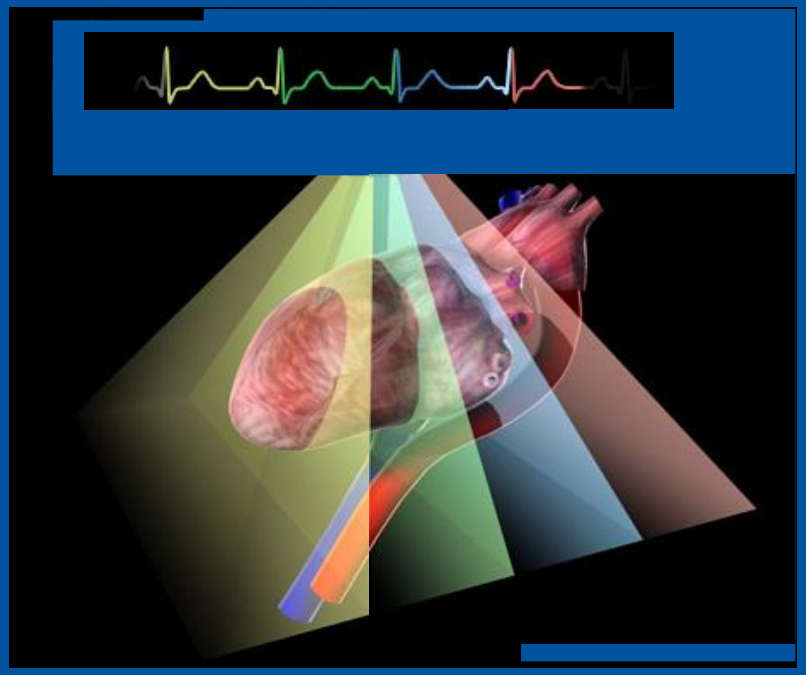

- Four or more R-R intervals required for full volume acquisition.
- **This is not real time**

New Acuson (=Siemens) platform

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Imaging

Information Rate determines the image quality potential of an ultrasound system

Drives diagnostic confidence and speed of workflow

Novel Imaging Engine:

- 10 times the rate of other systems
- Up to 64 paralleled beams
- Up to 160 M voxels/sec

Enables:

- 90° x 90 ° volume at > 20 volumes/sec at depth of 16 cm
- 40° X 40° volume color flow at 20 volumes/sec at depth of 16cm

Full-volume acquisition in single heart beat

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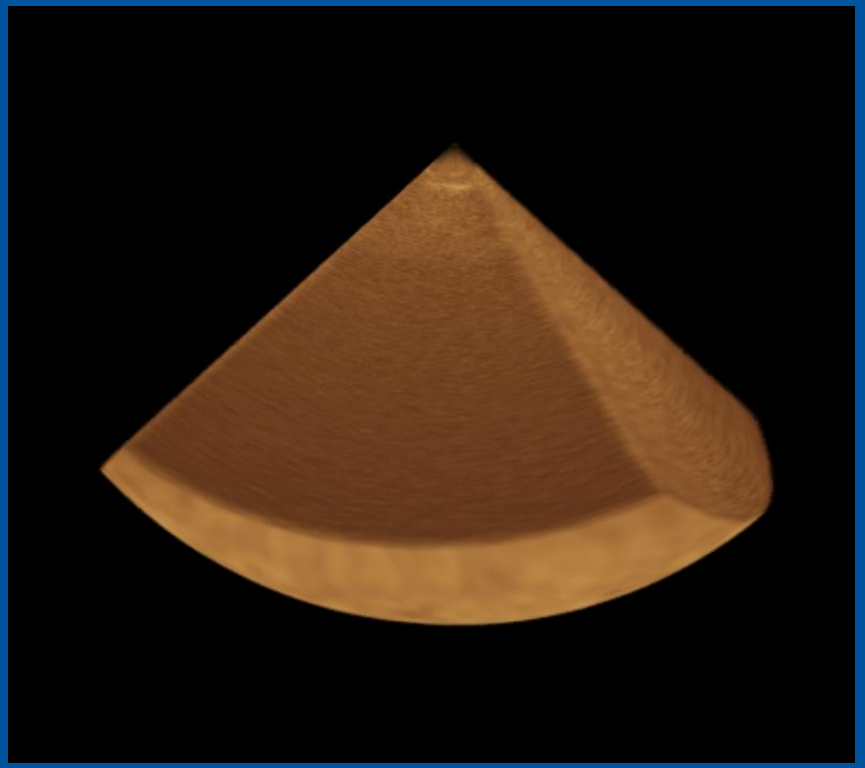
Imaging

- *Volume acquisition, 90x90 degree @ 20 vol/sec minimum*
- *Entire heart in one cardiac cycle rather than four cycles*

- **No** stitching artifacts
- **Reduced** impact of respiration
- **Reduced** impact of arrhythmia

- Real workflow improvements

- Broader clinical application



Full-volume set from a single heart beat

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Acquisition is fast

Full-volume in on heart beat: currently trade-of with

- *image resolution*
- *sector width*
- *Volume rate*

Solutions:

- *Flexi-volume (GE and Toshiba)*
- *Much faster systems (Siemens)*

Full-volume set from a single heart beat

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Sector width is important for encompassing the entire LV

Resolution is not so important for volumetrics

A step forward for volume measurements

Also pts with a fib. or inabilty for breath-hold can have 3D LV-volumetrics

What else is new for the LV?

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3D Speckle Tracking (3D ST)

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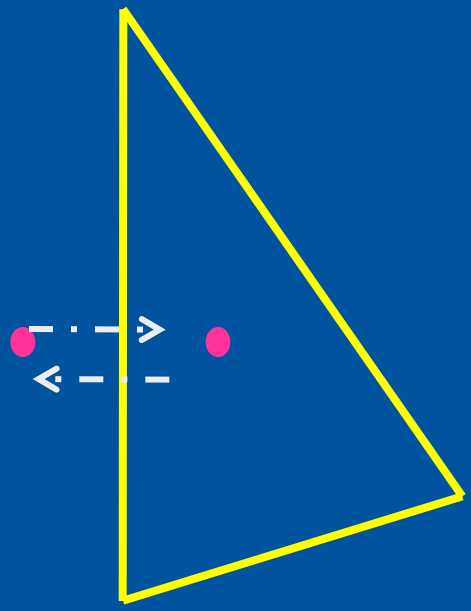
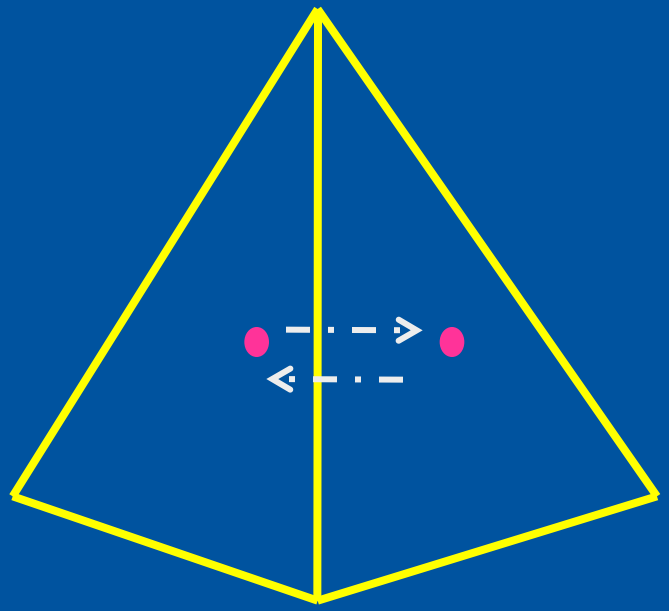
- Cardiac motion is 3 dimensional, 2D Speckle Tracking (2DST) is limited because it cannot assess movement in the 3rd dimension.
- The same technique used in 2DST can be applied to 3D data in time (4D) by tracking 3 dimensional cubic templates through the cardiac cycle.

2D ST vs 3D ST:



In 2D ST: the speckle is moving out of the scanning plane: the scanning plane is analyzed



In 3D ST: the speckle can be followed and analysed

3D speckle:

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- In 3DST, a speckle can actually be followed in 3D space
  - *velocity, amplitude, direction: 3D vector*
  - *Unlimited number of vectors can be constructed*
    - *The essence of myocardial function*
    - *Very complicated data*
    - *Difficult to visualize/analyse*

3D speckle:

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    - *The essence of myocardial function*
    - *Very complicated data*
    - *Difficult to visualize/analyse*

  - *The first "tries" in 3DST are sophisticated 2DST*
    - Showing multiple 2D cross-section, derived from 3D data set, throughout cardiac cycle

Insights in LV function
Systolic Radial strain: thickening

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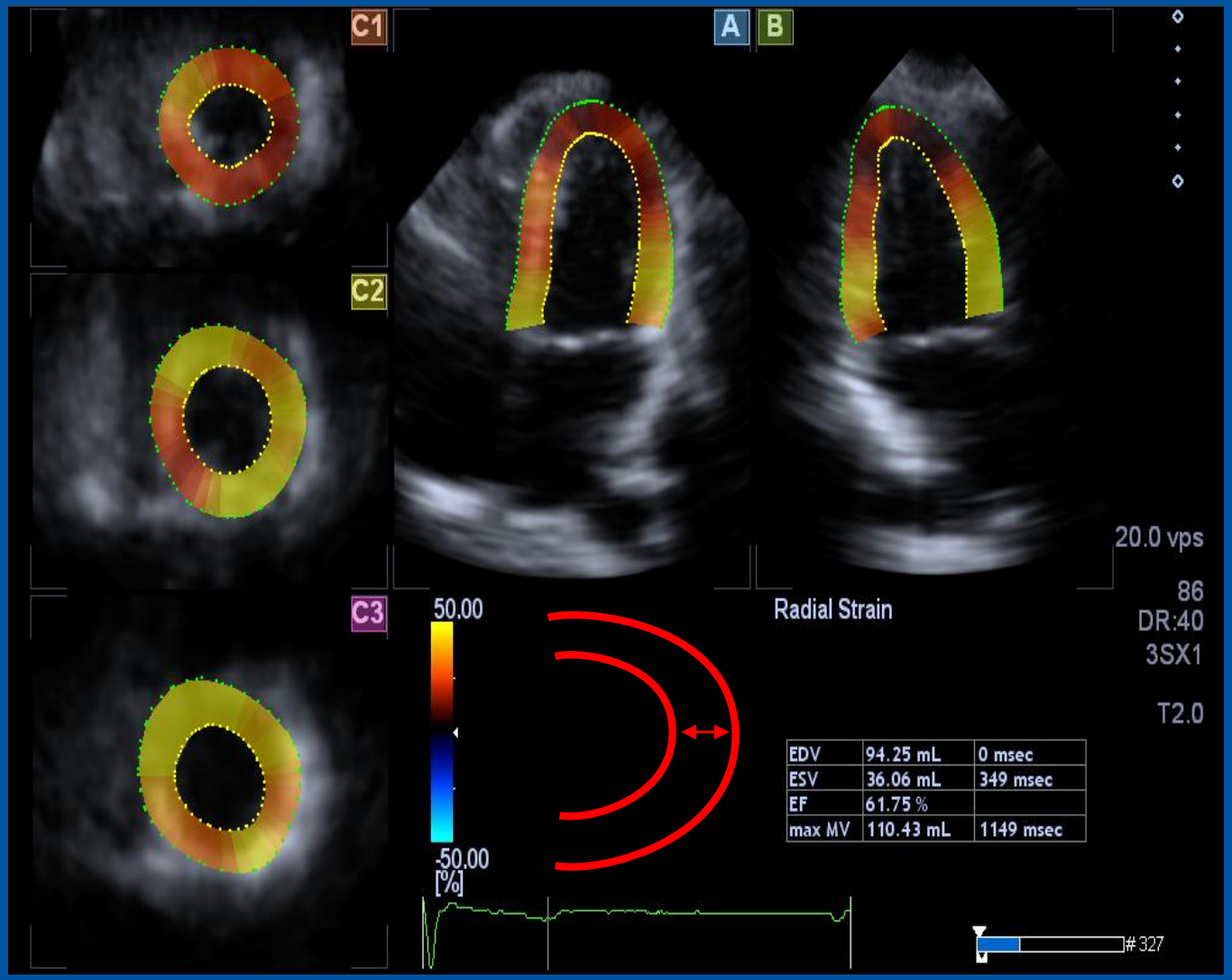
End systolic frame



Insights in LV function

Systolic Circumferential strain: shortening

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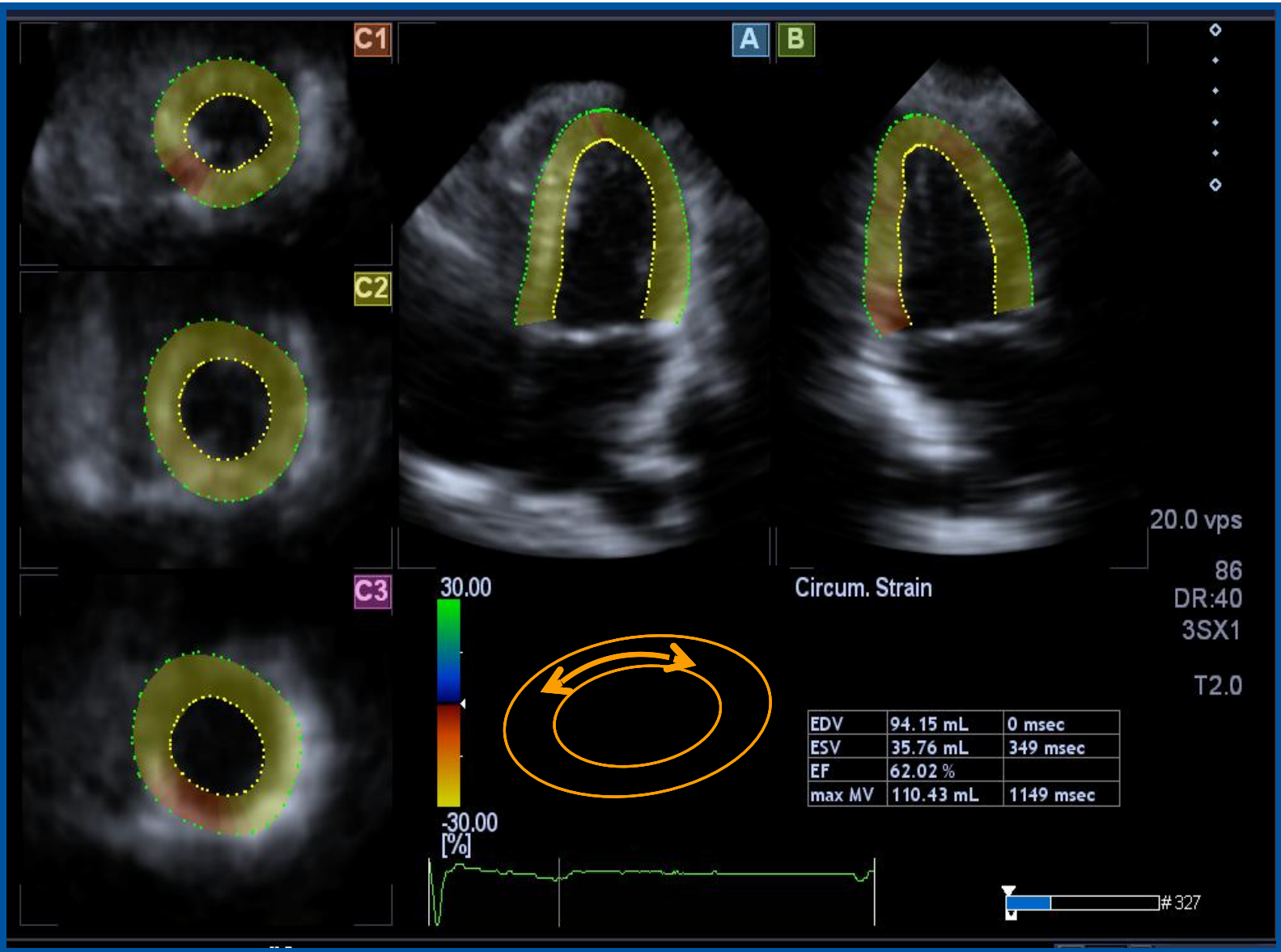

End systolic frame

Insights in LV function

Systolic longitudinal strain: shortening

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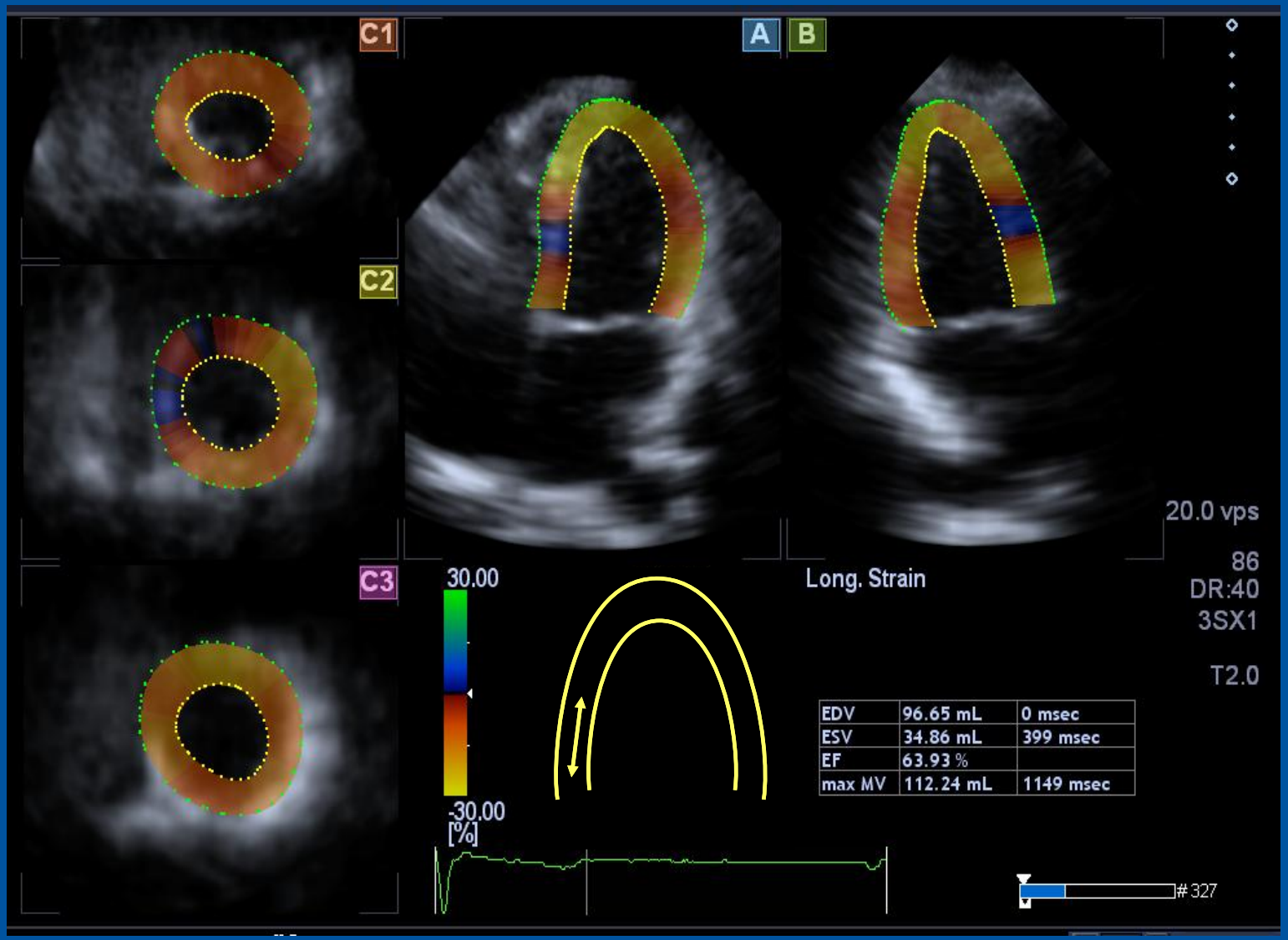

End systolic frame

Insights in LV function
Rotation: (degrees°)

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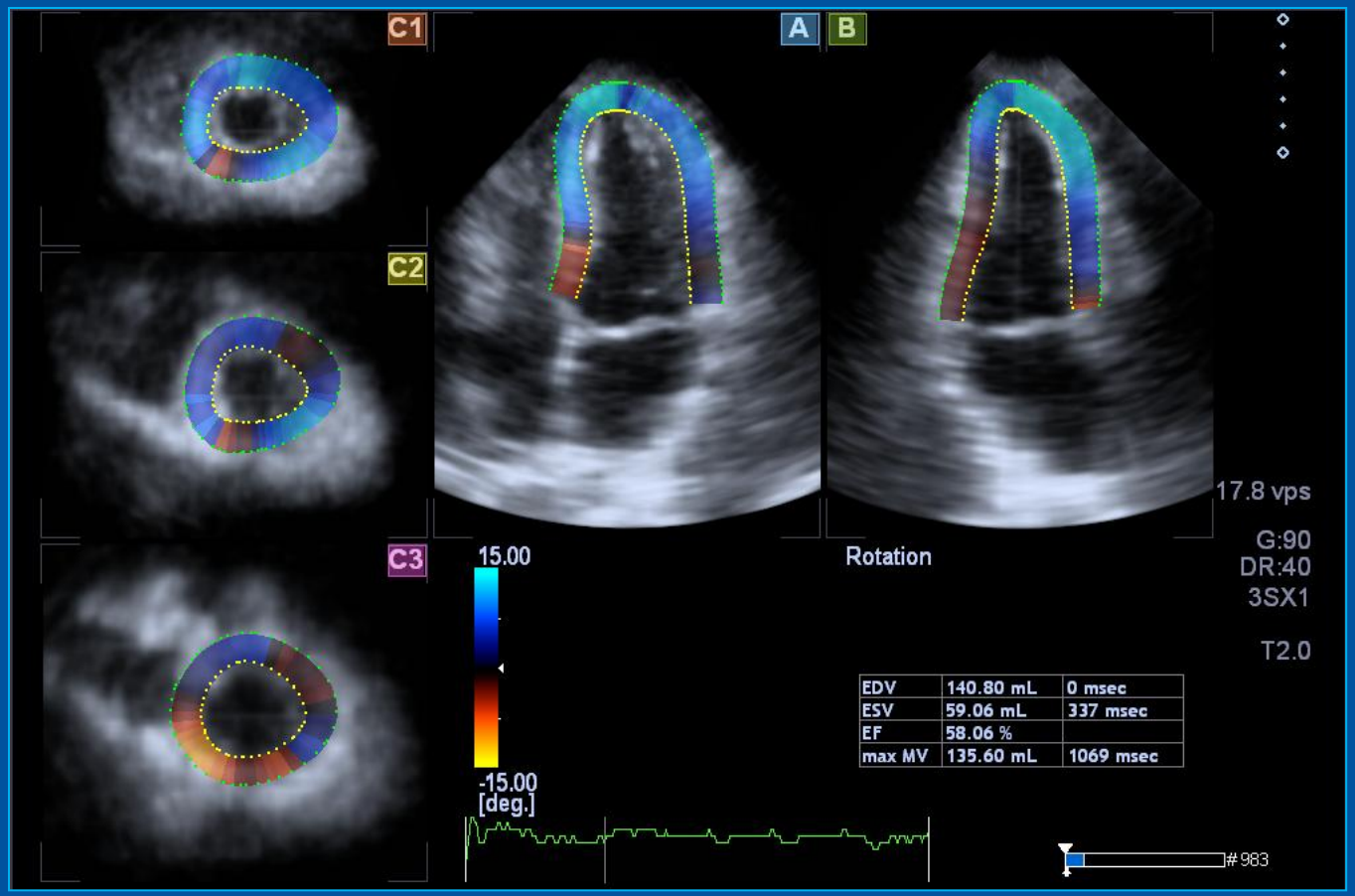
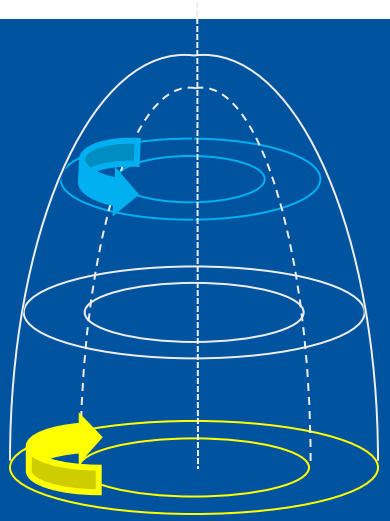
- End systolic frame





Insights in LV function
Twist (degrees °)

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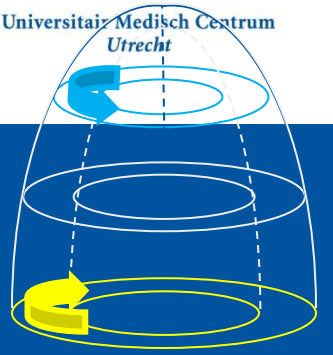
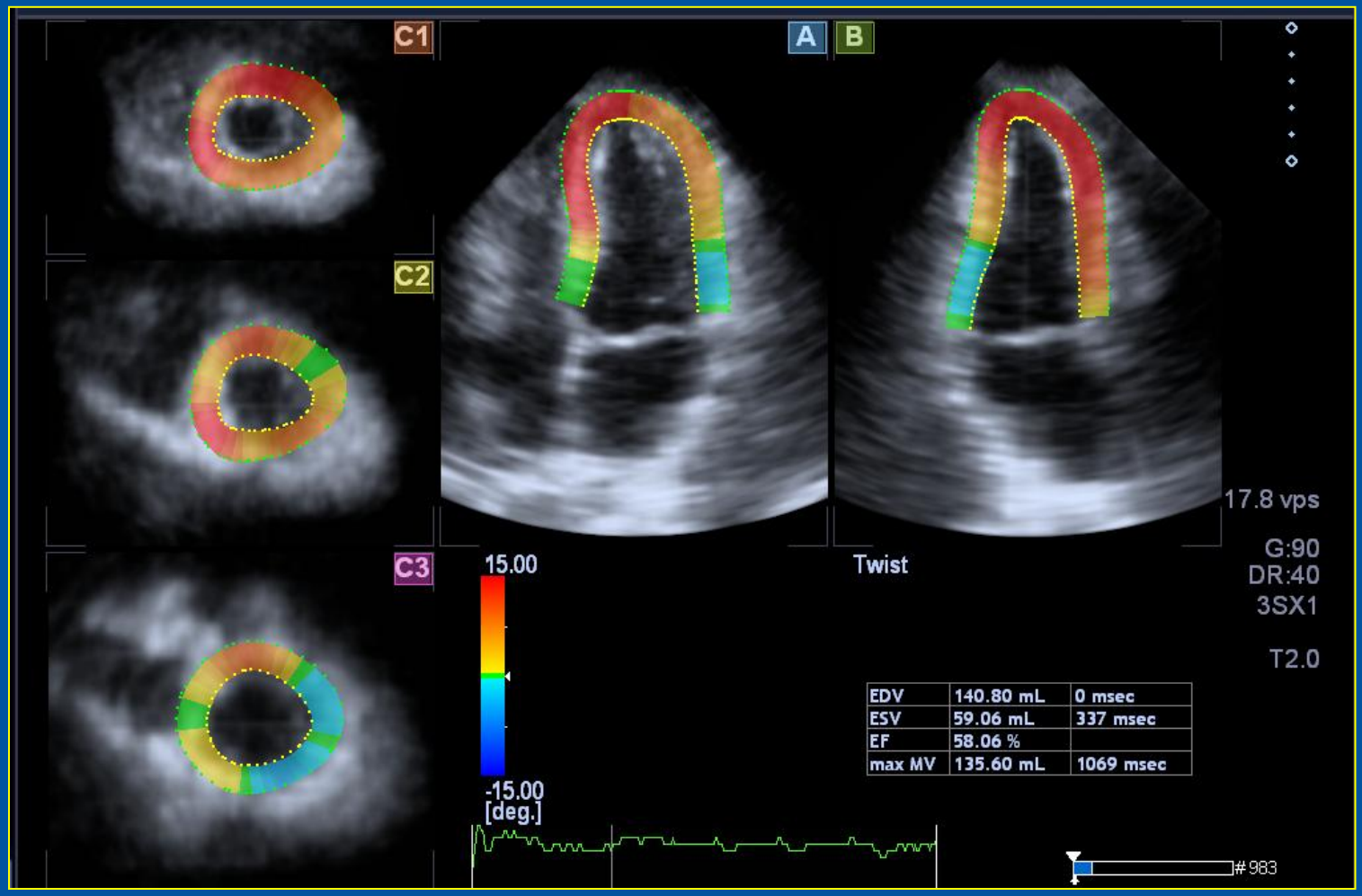


Twist = difference in rotation between segments



Insights in LV function torsion

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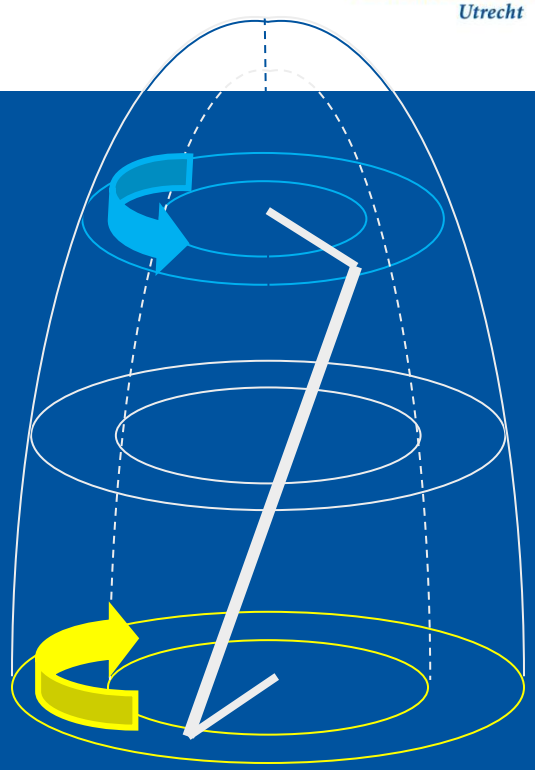
Torsion (degrees ° /cm)=
Twist/Distance
of the C planes



•3DST provides relation between segments allowing calculation of the rotation value in 2 different SAX views in the same cardiac cycle and the distance between the same two planes otherwise hard to do with 2DST.

RT3D echo & LV function: what is new?

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- Increase in calculation power
  - *Up to 10 x faster than existing systems (containing 140 Pentium 4 processors stacked in the echo transducer)*

- Full volume in a single heart beat
  - = *actual real-time 3D*

- 3-way trade-off between:
  volume, resolution and volume rate

- 3D speckle
  - *Follow a speckle in space*

What is new in 3D echo?

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- ***RV volumes & EF***

Assessment of RV function: 2D echo

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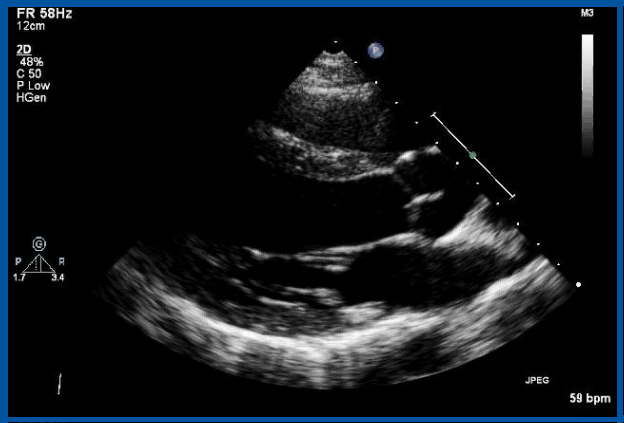

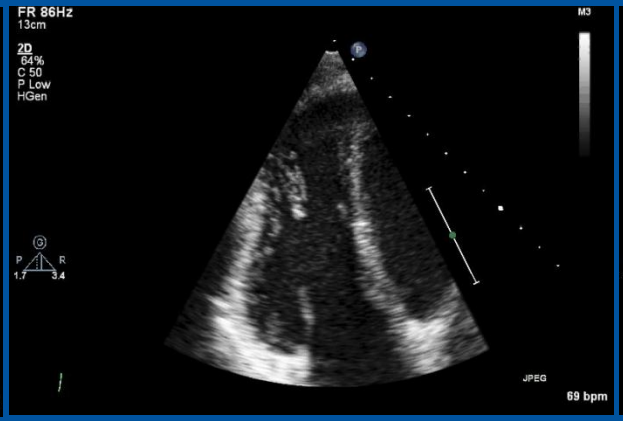

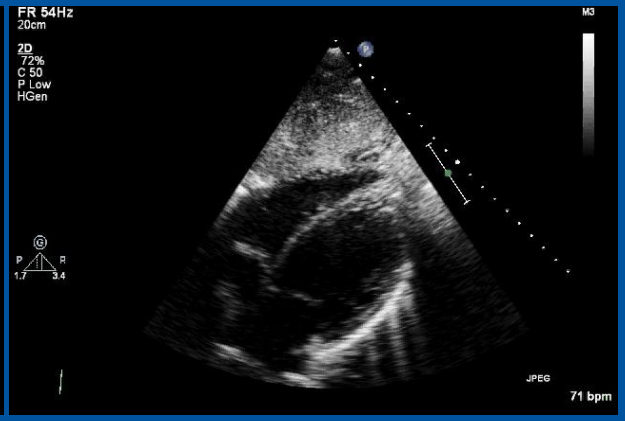

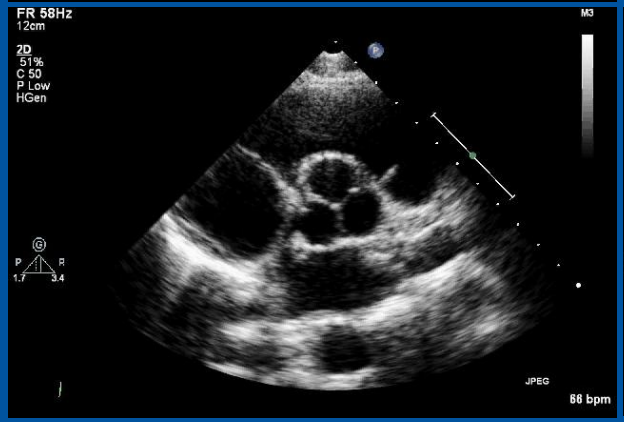

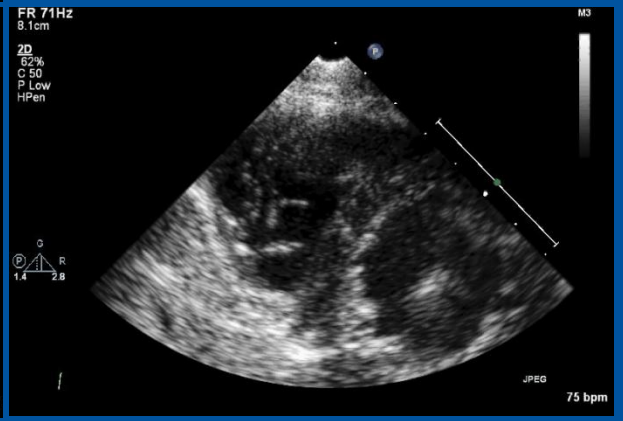

Assessment of RV function: 2D echo

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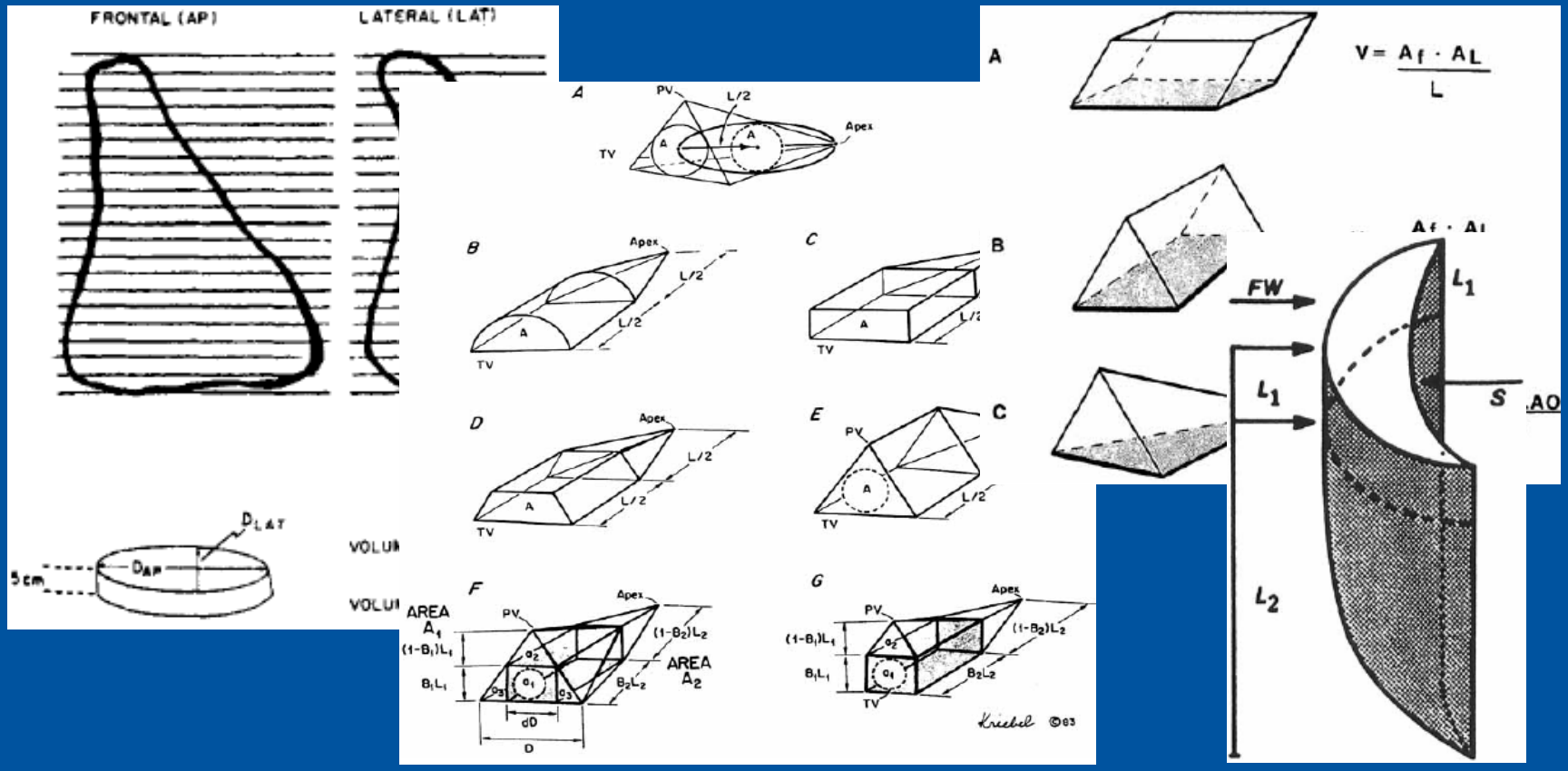

- *Jiang et al. Echocardiography 1997 Mar; 14(2): 189-206*

Assessment of RV function: 2D echo

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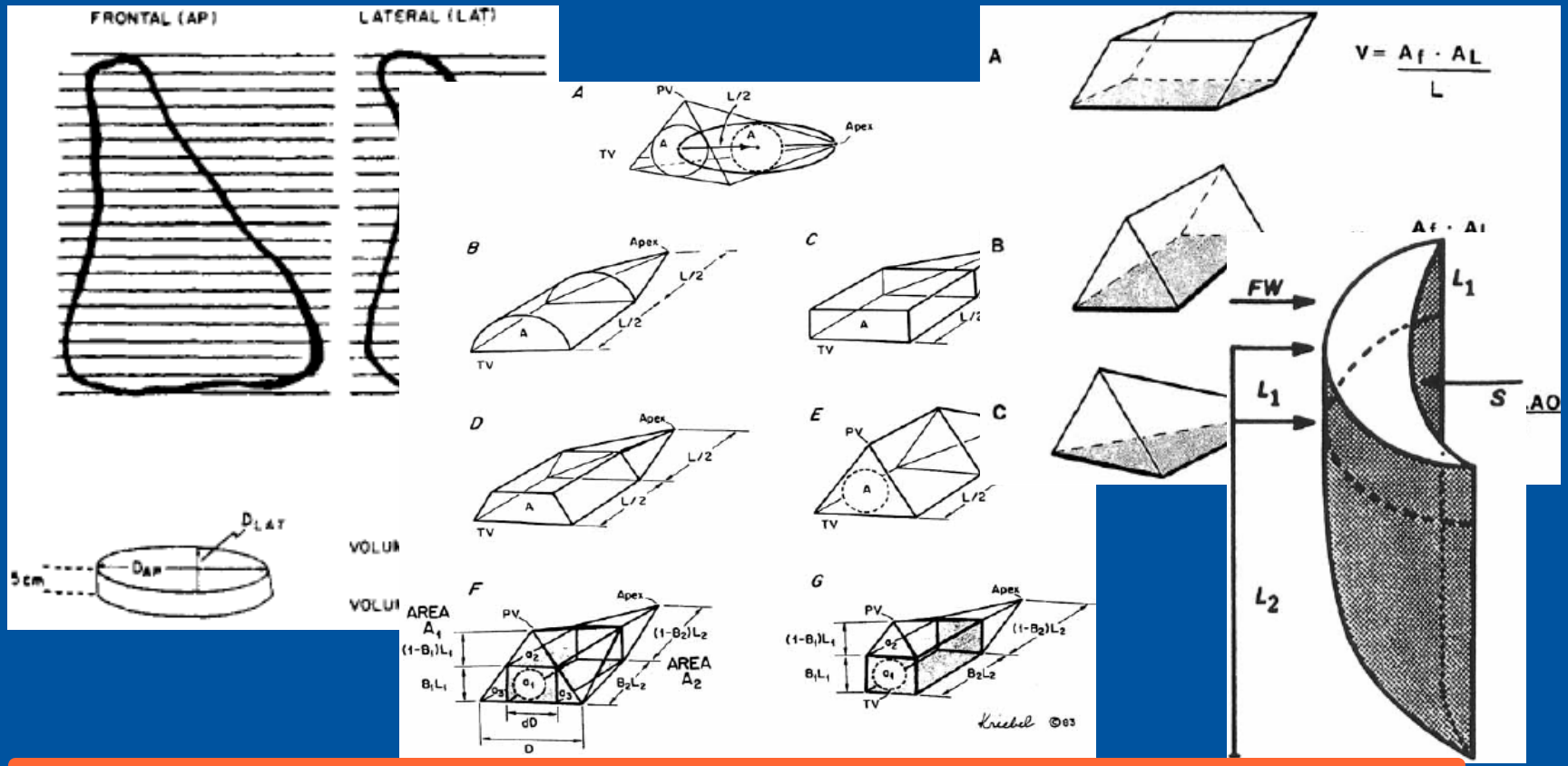

- Assessment of RV ejection fraction not possible with 2D echo → MRI

Assessment of RV function: MRI

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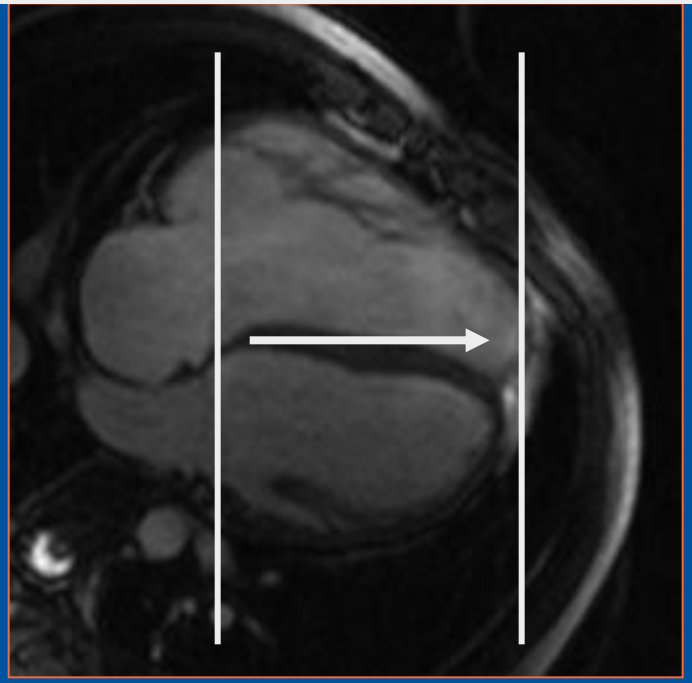
MRI is the current standard for assessment of RV volumes and function

Method of disk summation



Assessment of RV function: MRI

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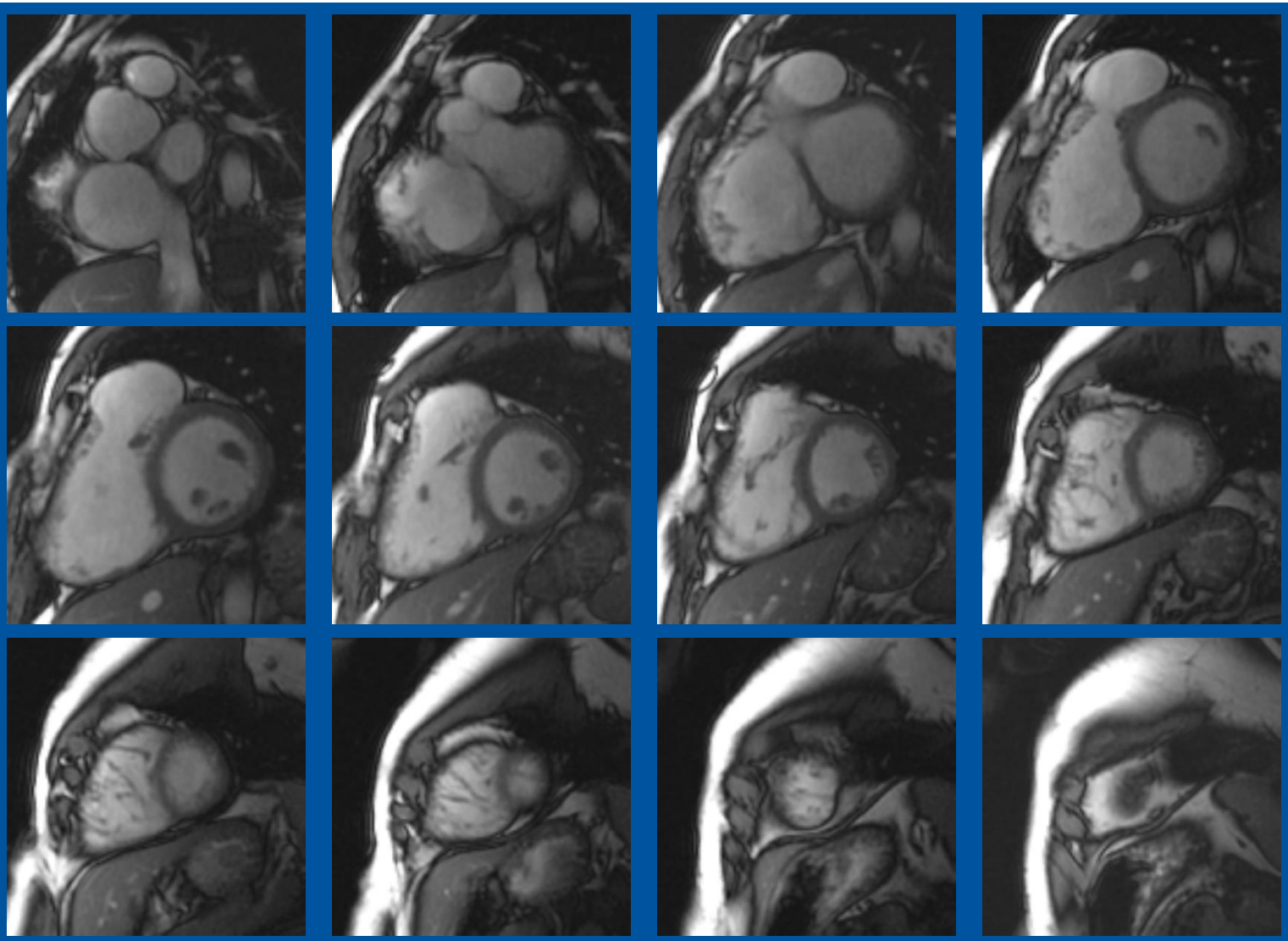

Assessment of RV function: MRI

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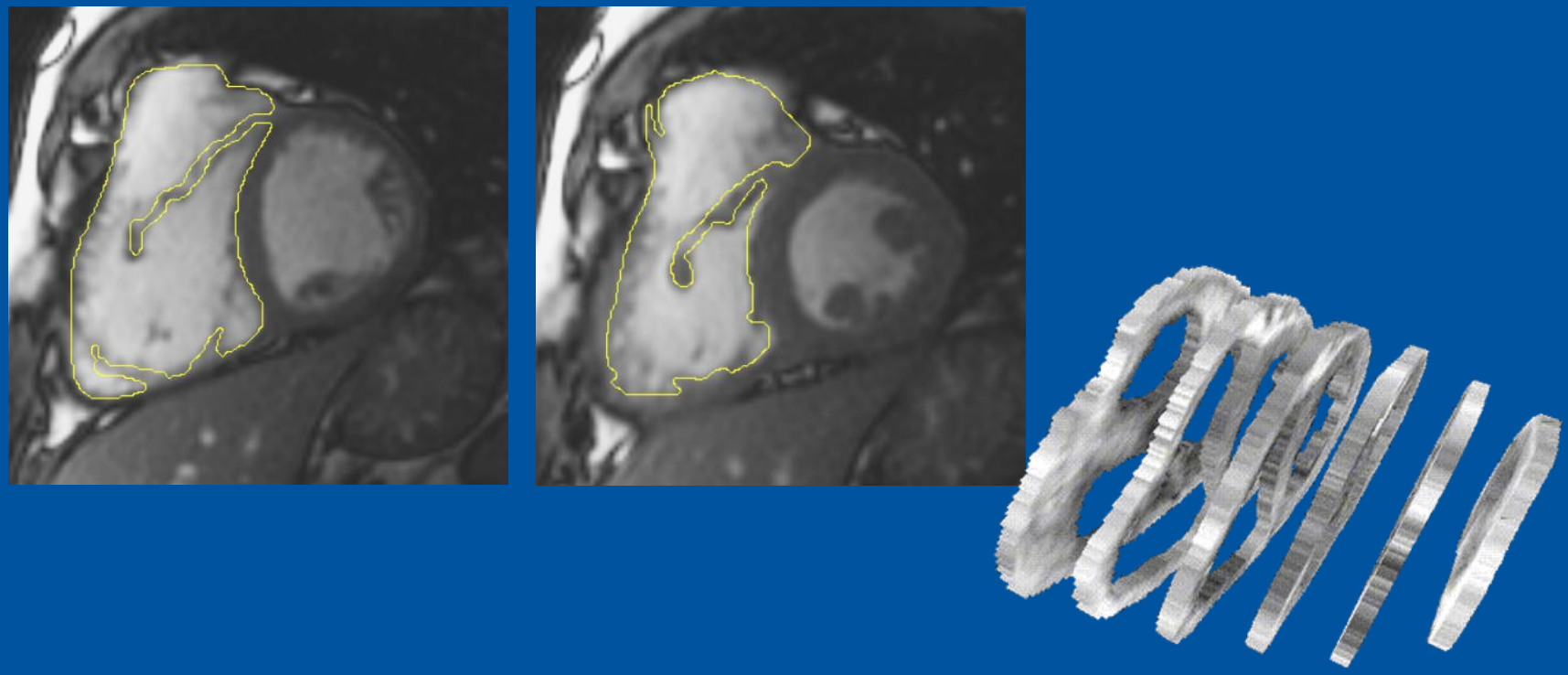

3D echo assessment of the RV

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- 3D dataset encompassing the RV
  - *Easier said than done*
- RV endocardial border detection
  - *In 3 orthogonal planes*
- Algoritm-based calculation of RV volumes

RT3DE: orthogonal views

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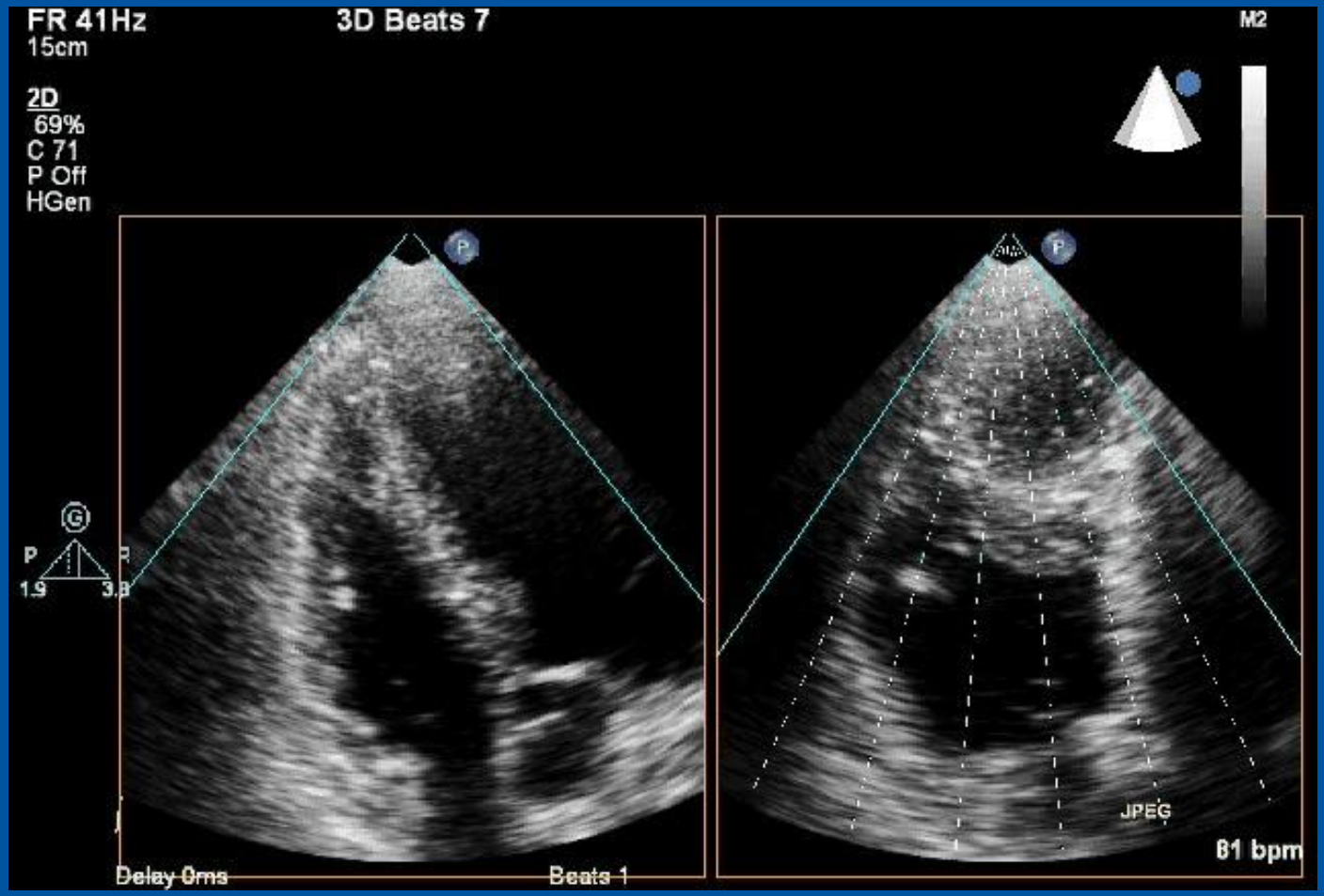

RT3DE: acquisition dataset

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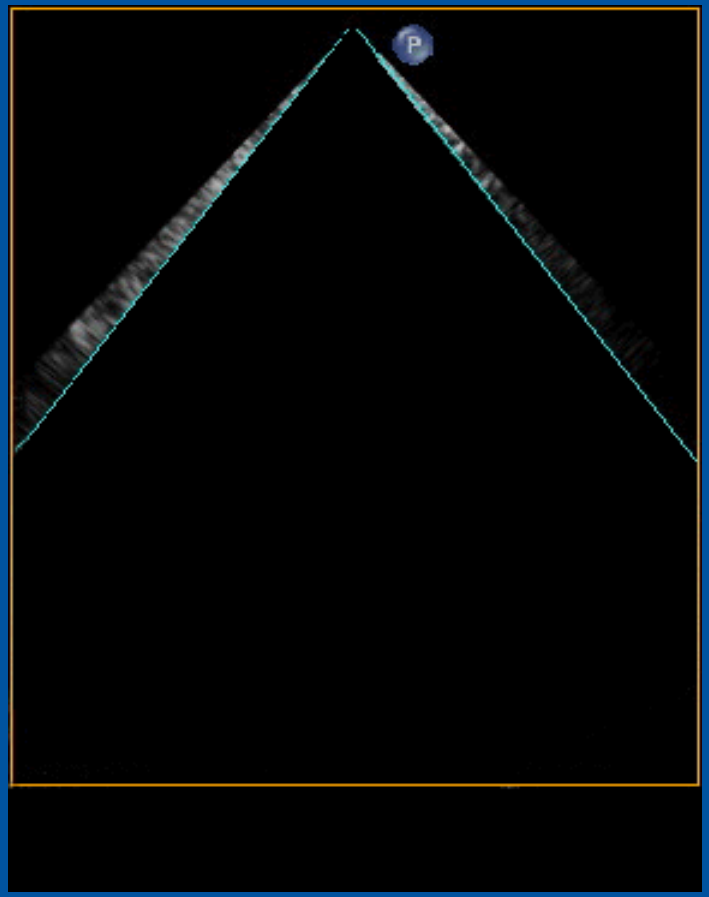

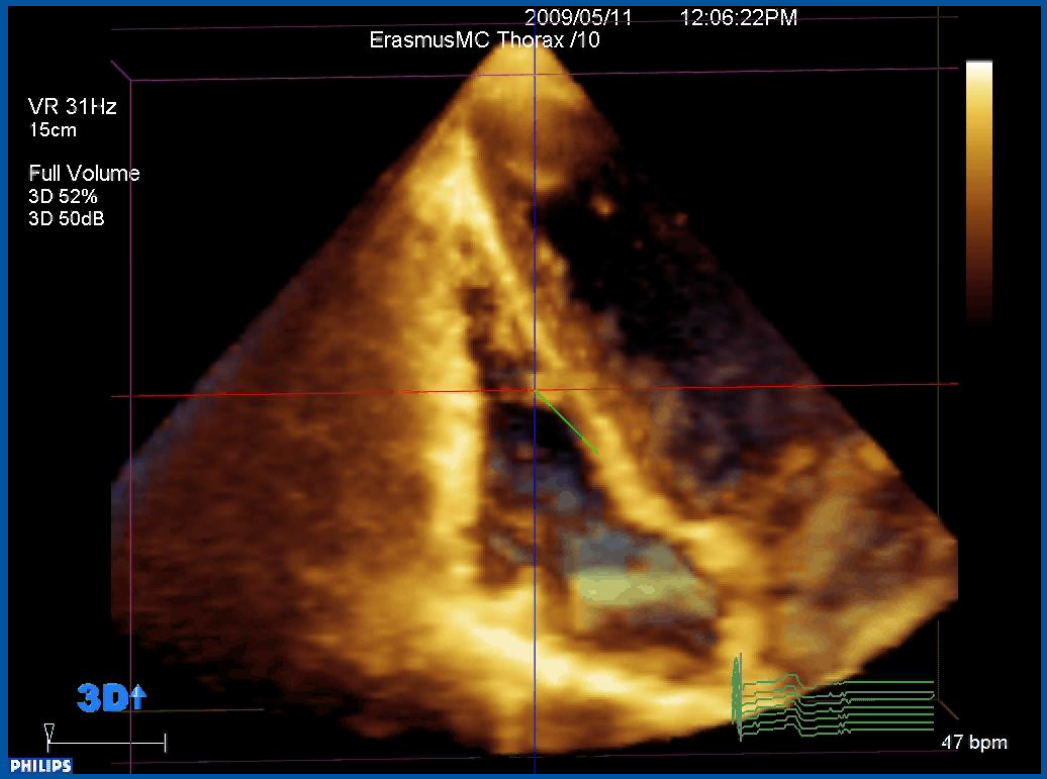

3D & RV

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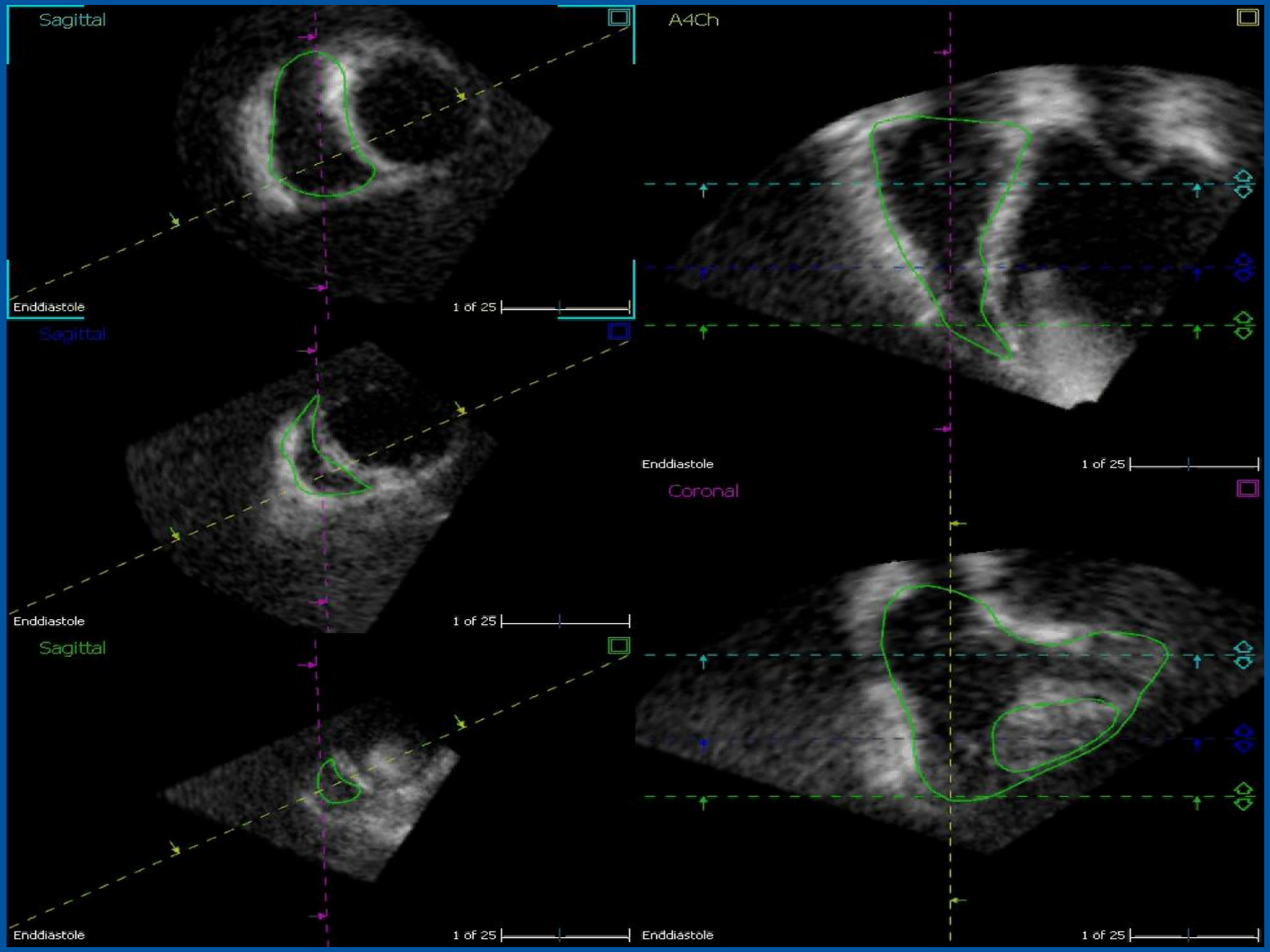

Comparison between RT3DE and MRI

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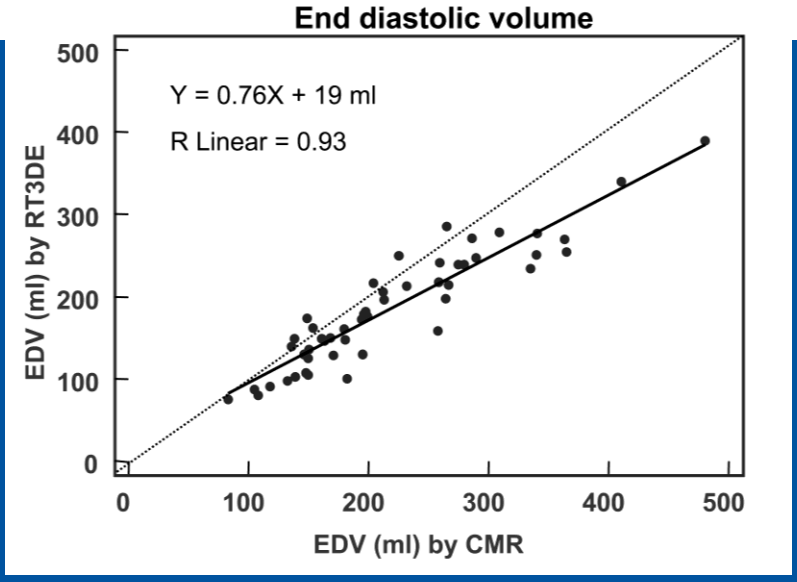

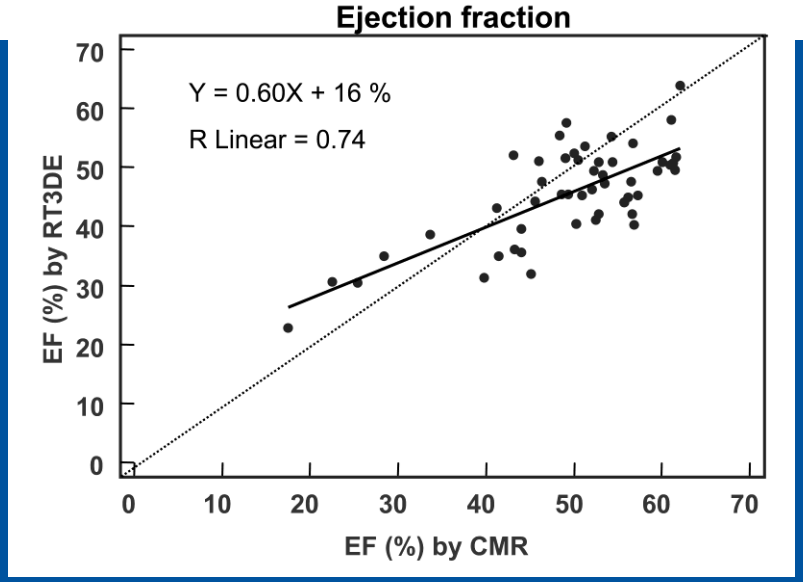

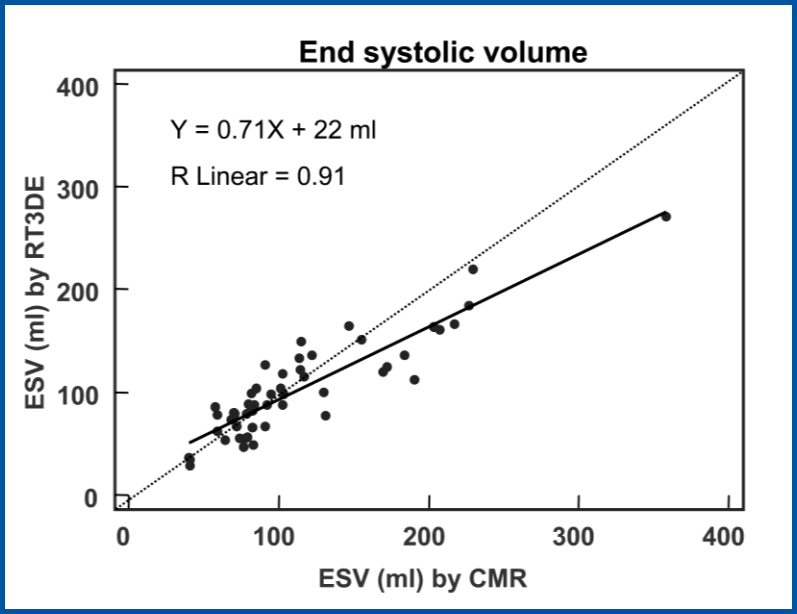

- Good correlations volumes & EF

- Heleen van der Zwaan et al, JASE, in press

Results:

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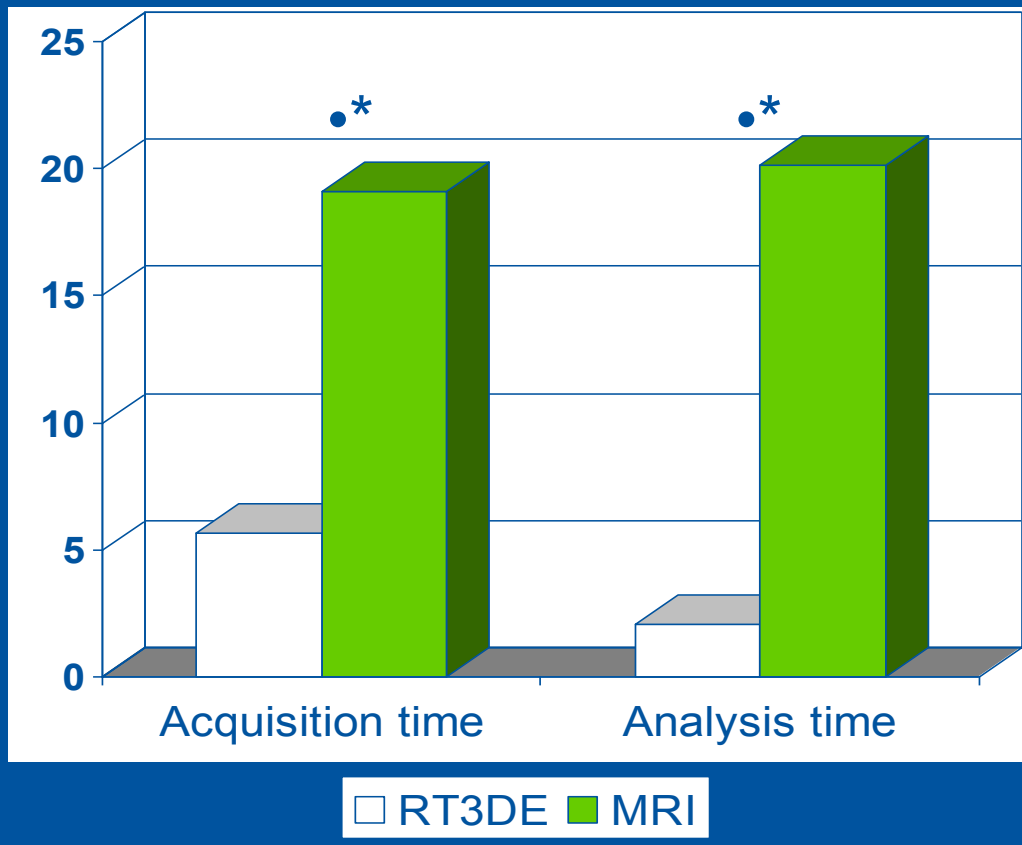
Reproducibility

	Inter-observer	Intra-observer
RV EDV (ml)	5 ± 13	0 ± 10
RV ESV (ml)	10 ± 14	2 ± 8
RV EF (%)	9 ± 13	4 ± 9



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Universitair Medisch Centrum Utrecht

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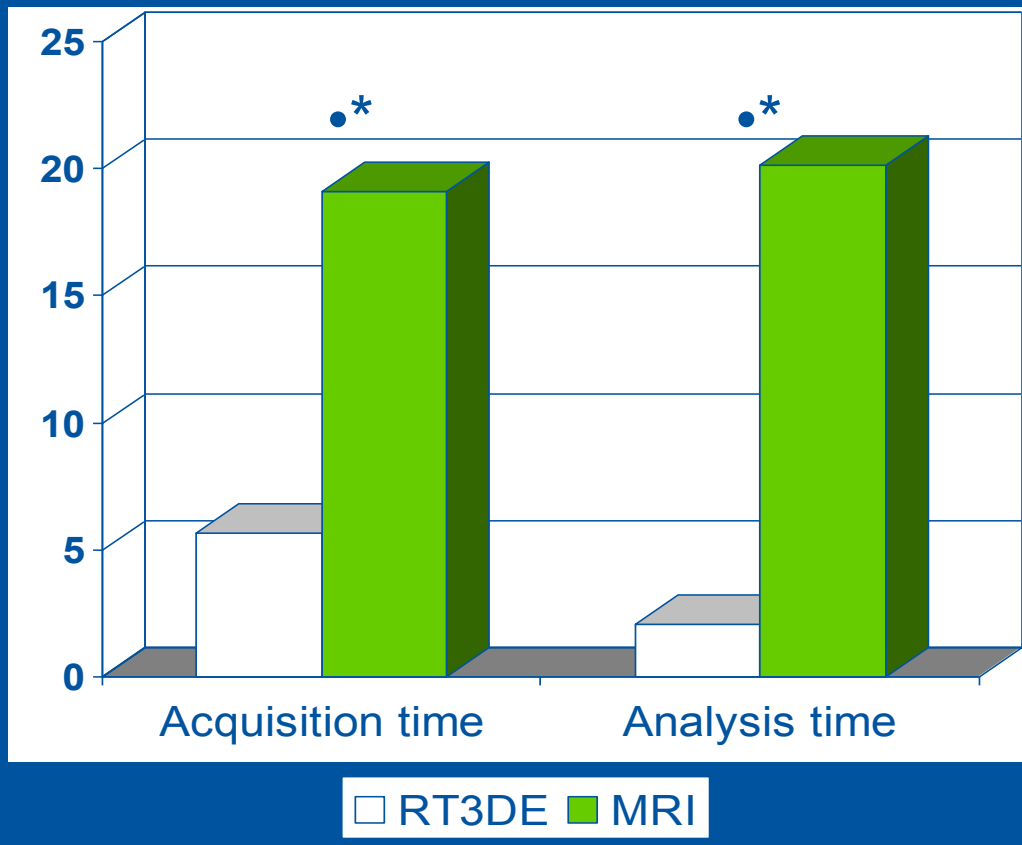

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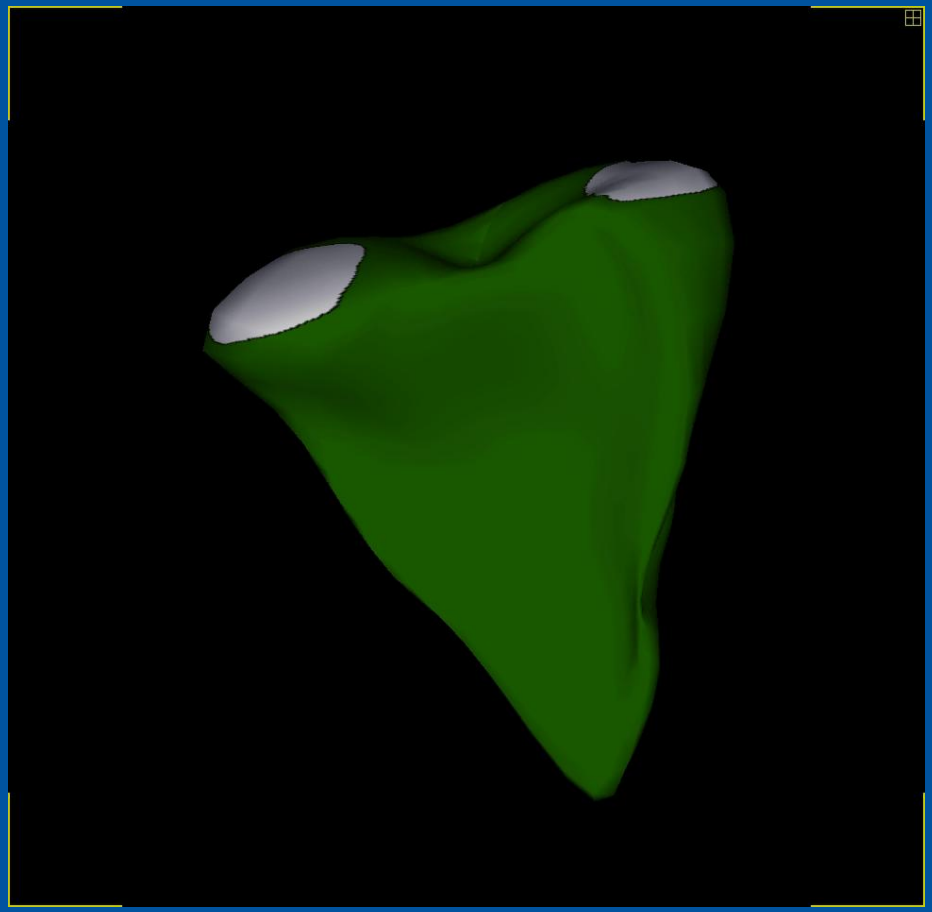

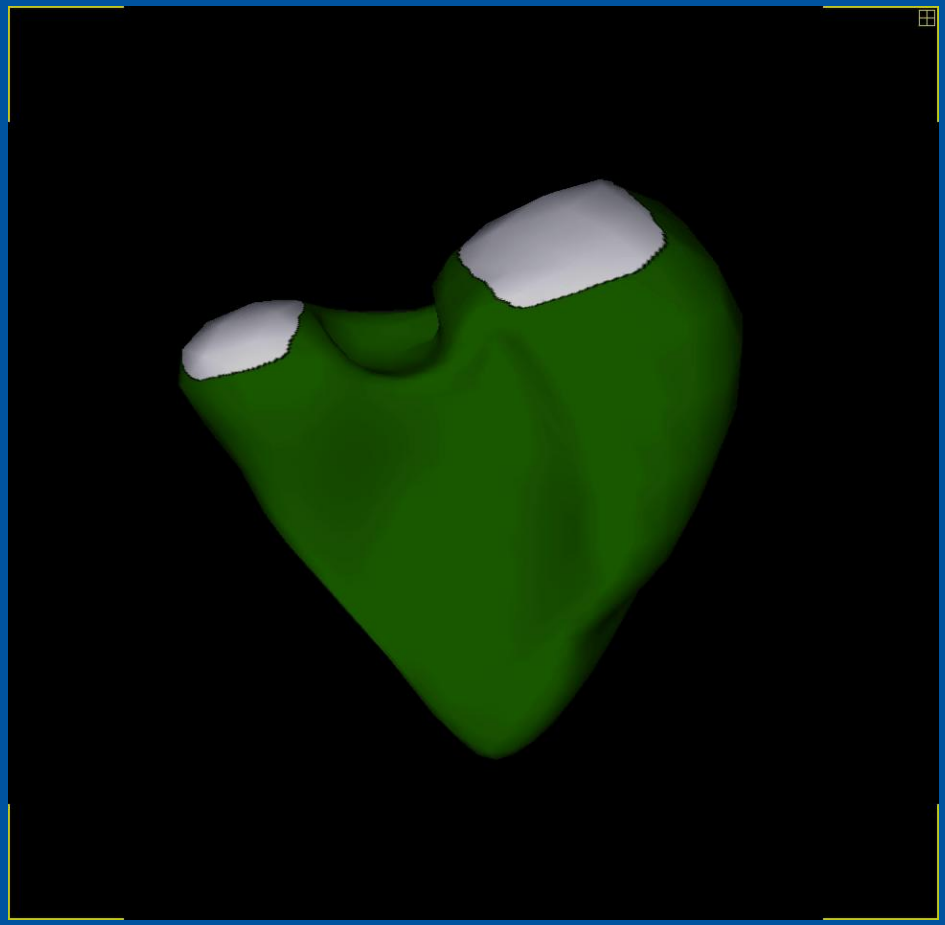

•Normal RV

Tetralogy of Fallot

Conclusions

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- 80% feasibility in patients with ConHD
- Good agreement between RT3DE and MRI; underestimation of volumes
- inter- en intra-observer values ± acceptable
- RV acquisition and analysis by RT3DE cost only few minutes

Conclusions

Universitair Medisch Centrum Utrecht

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- RV acquisition and analysis by RT3DE cost only few minutes

Methodological differences RT3DE- MRI

Further research needed with the expectation that RT3DE will be clinically applicable

Analysis with same software: still differences

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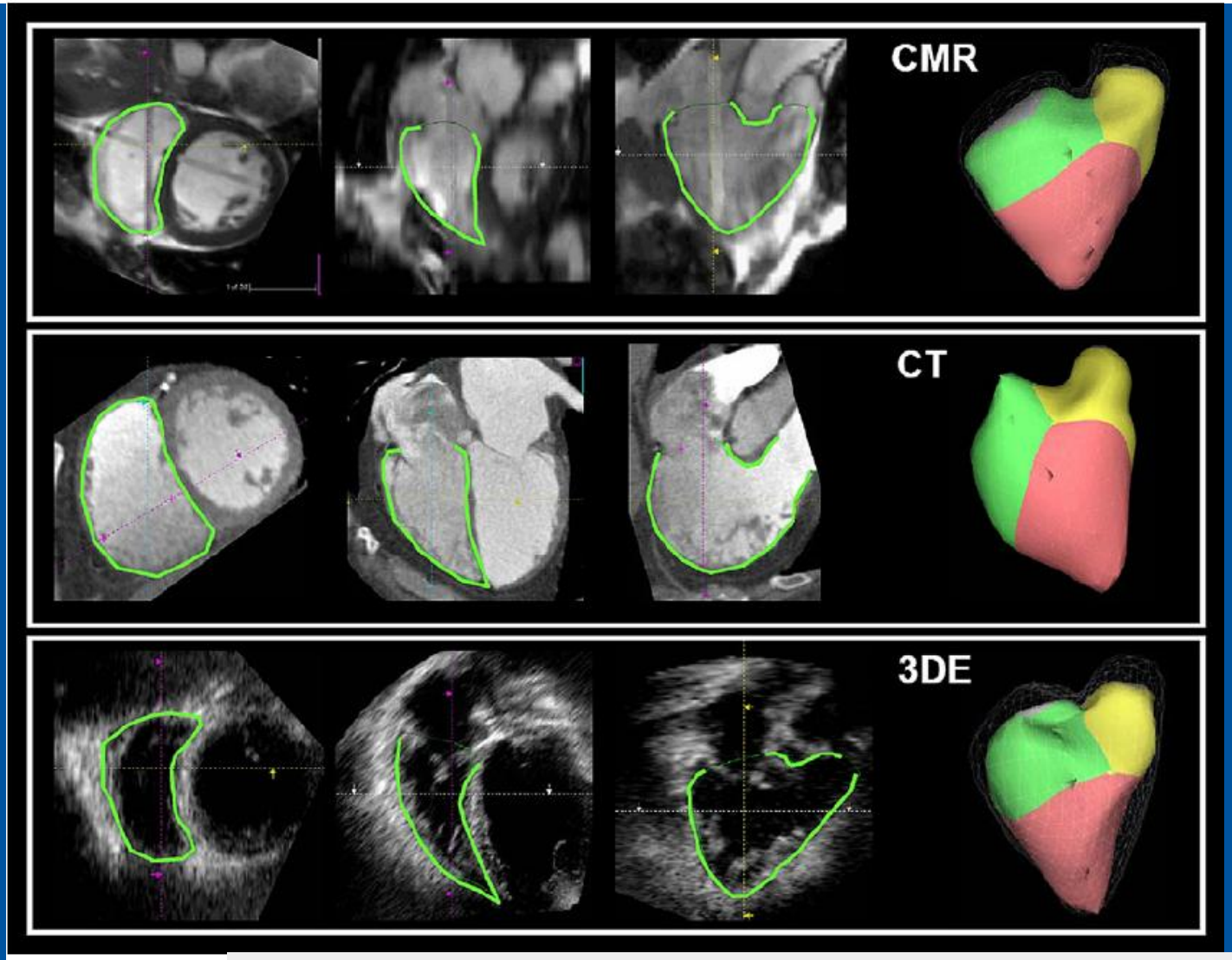

- Sugeng et al. JACC Cardiovasc imaging Jan 2010

RT3D echo: what is new?

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RT 3D TEE

Realtime TEE (X7-2t) matrix transducer:

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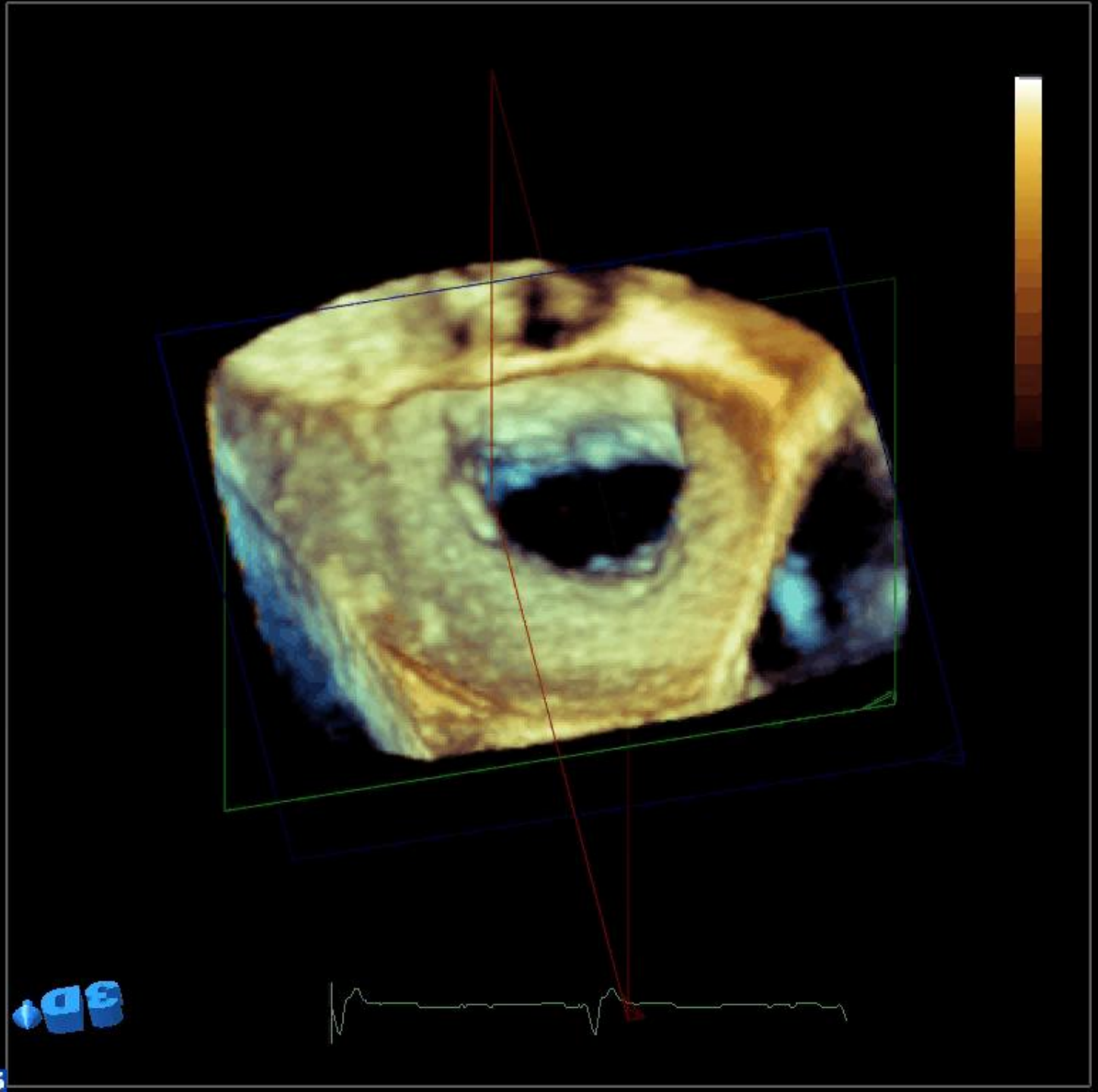
PHILIPS


PHILIPS

•Mitral valve quatification-bookmark

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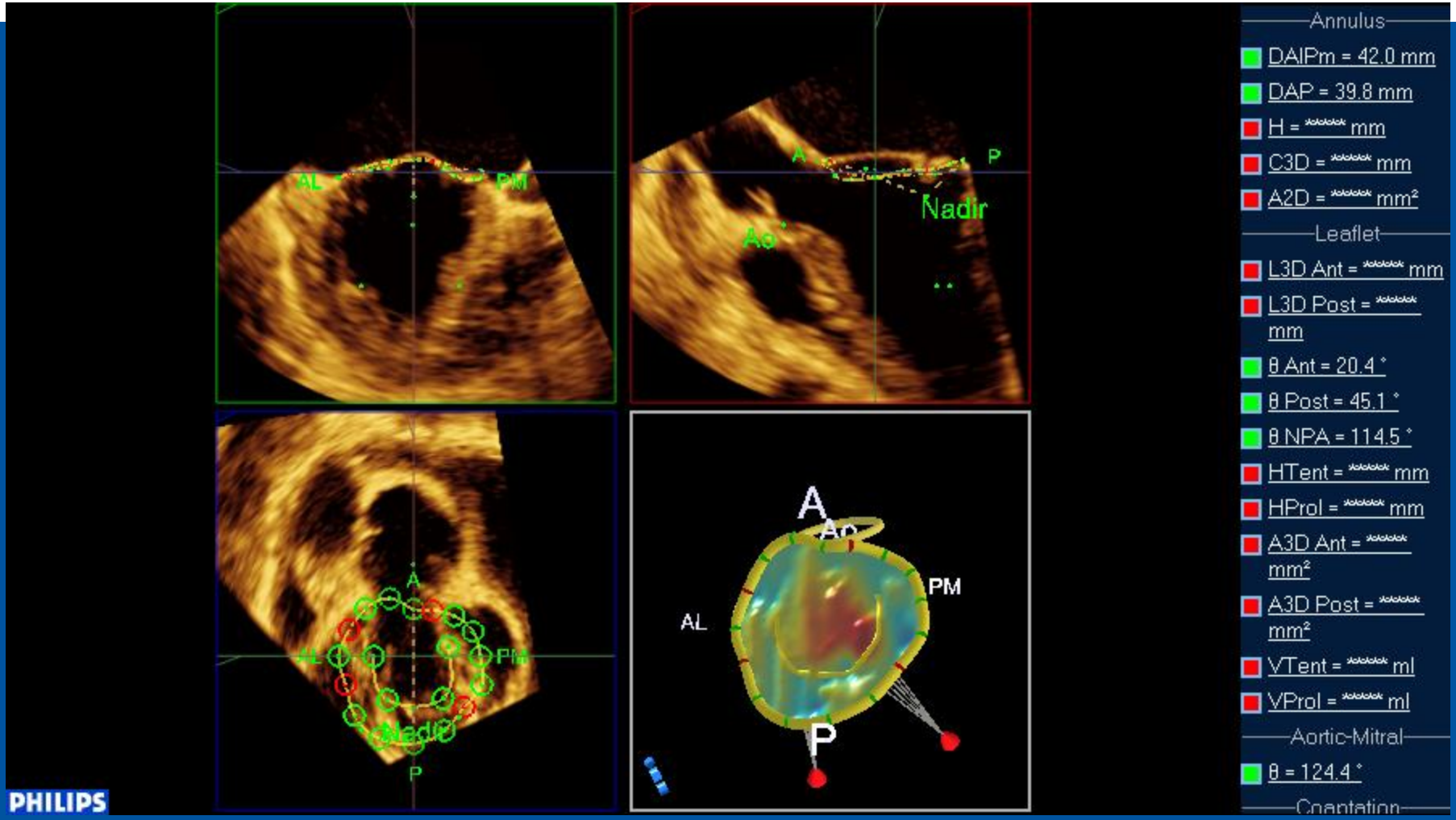
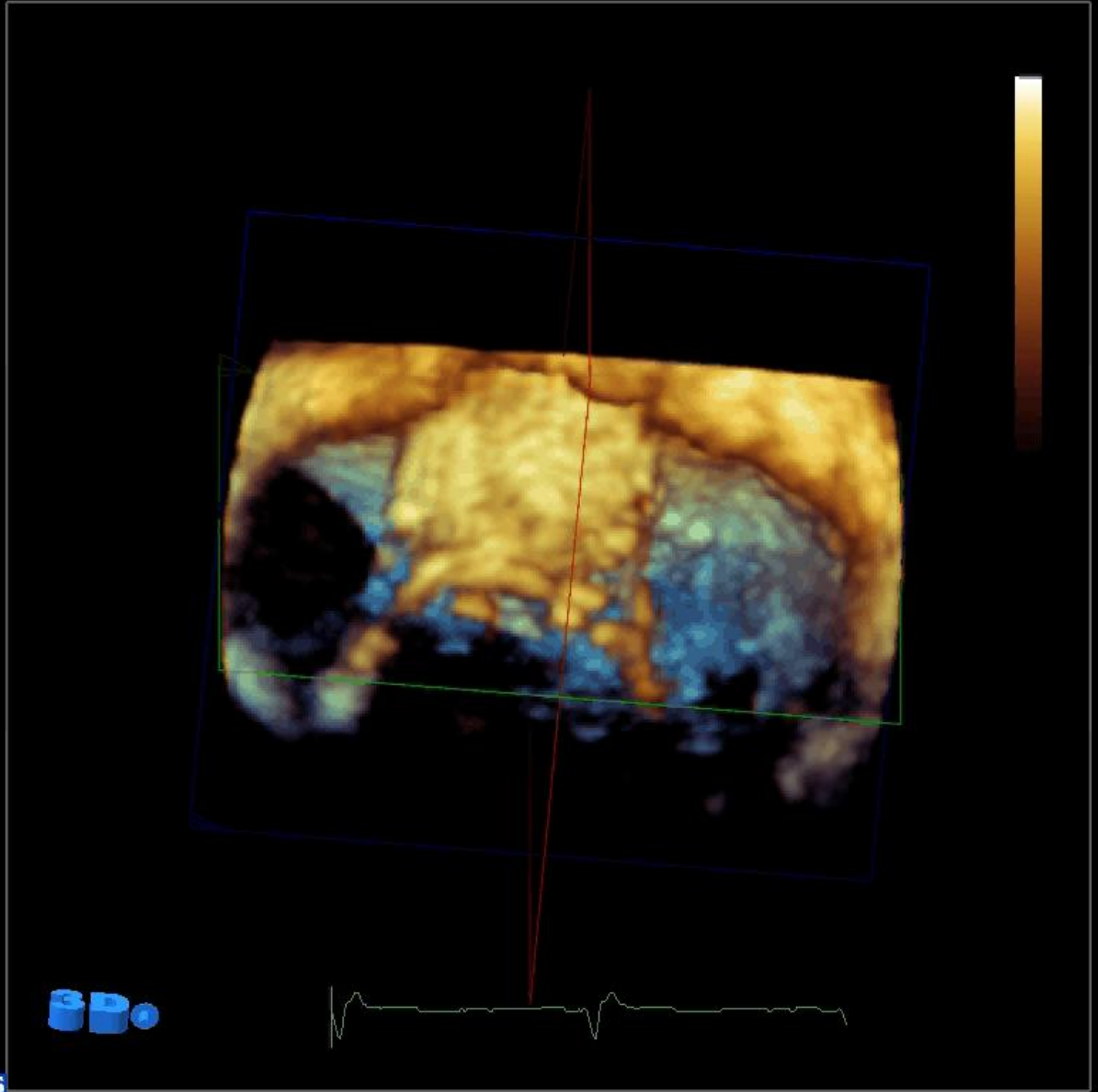
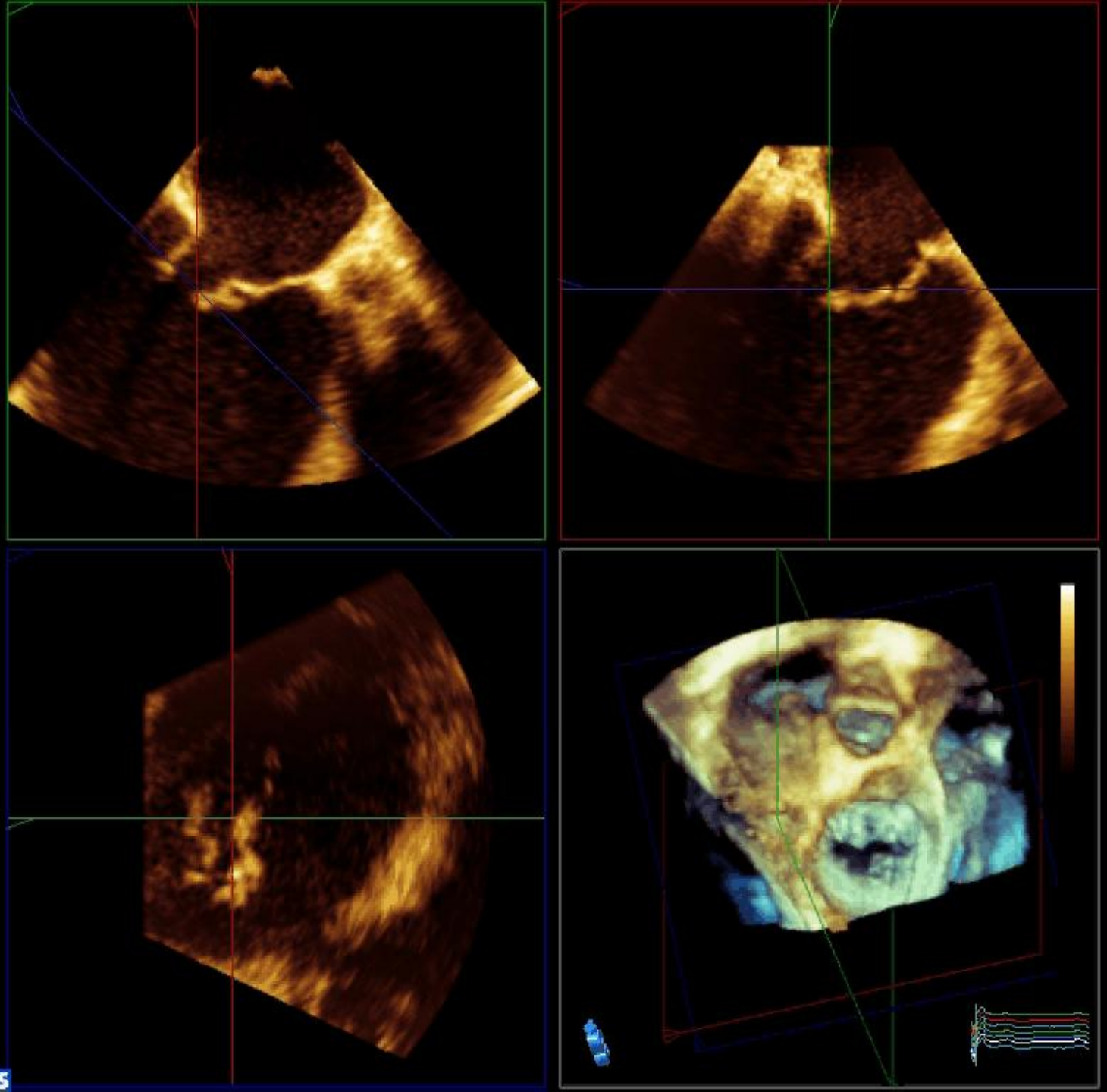



3D
PHILIPS


PHILIPS

3D TEE Aortic valve

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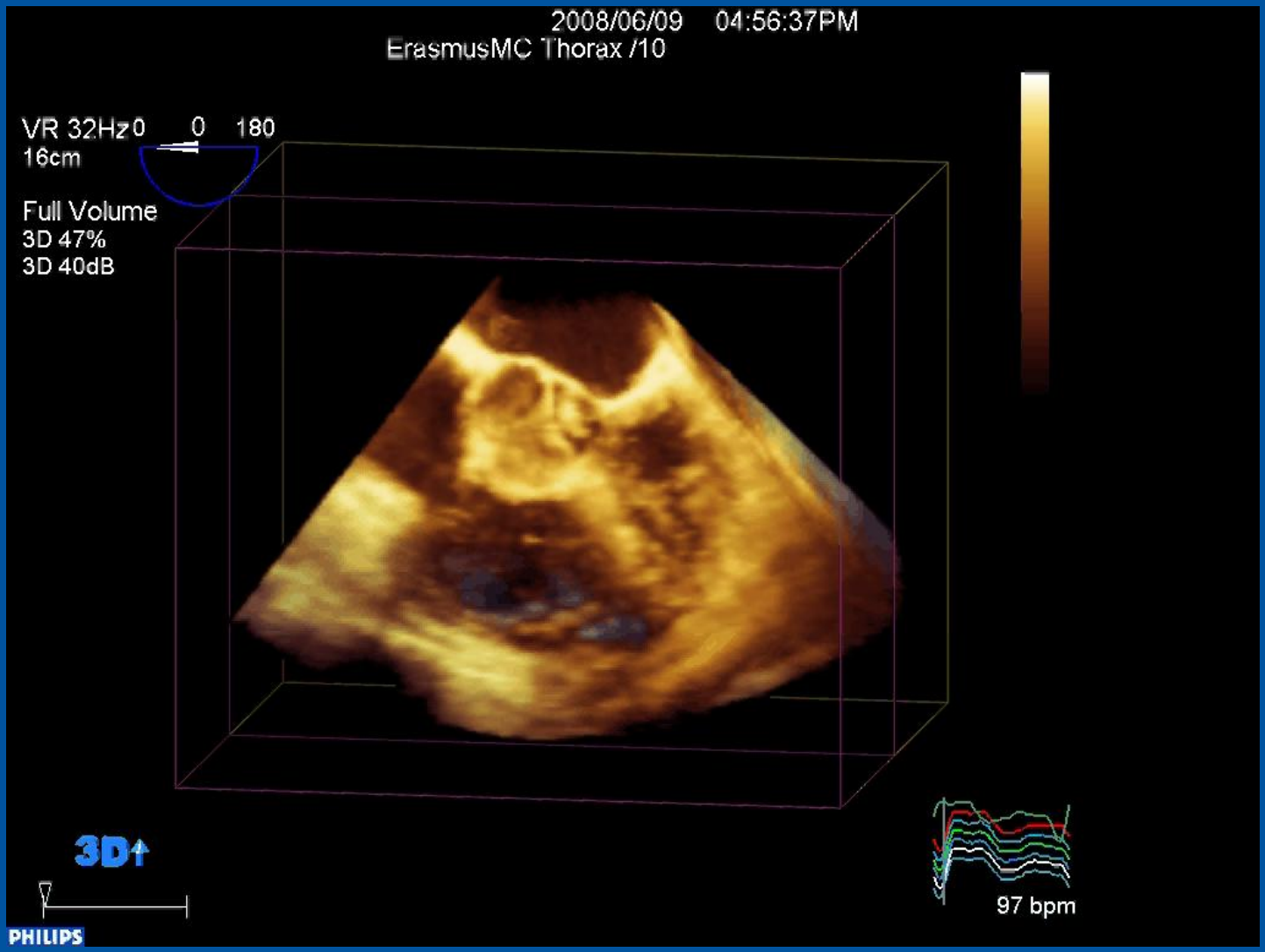

3D TEE - pAVSD

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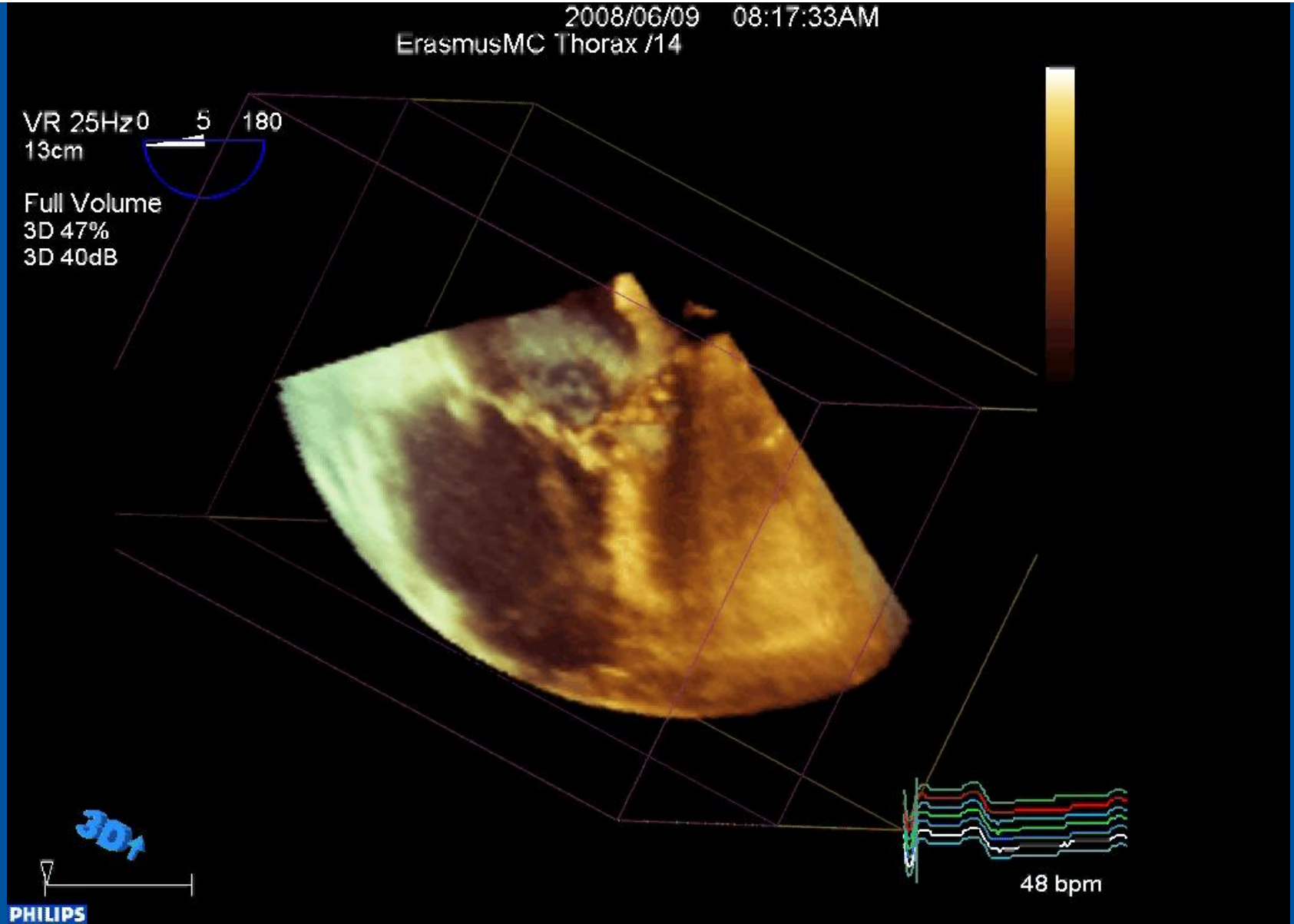

3D TEE - pAVSD

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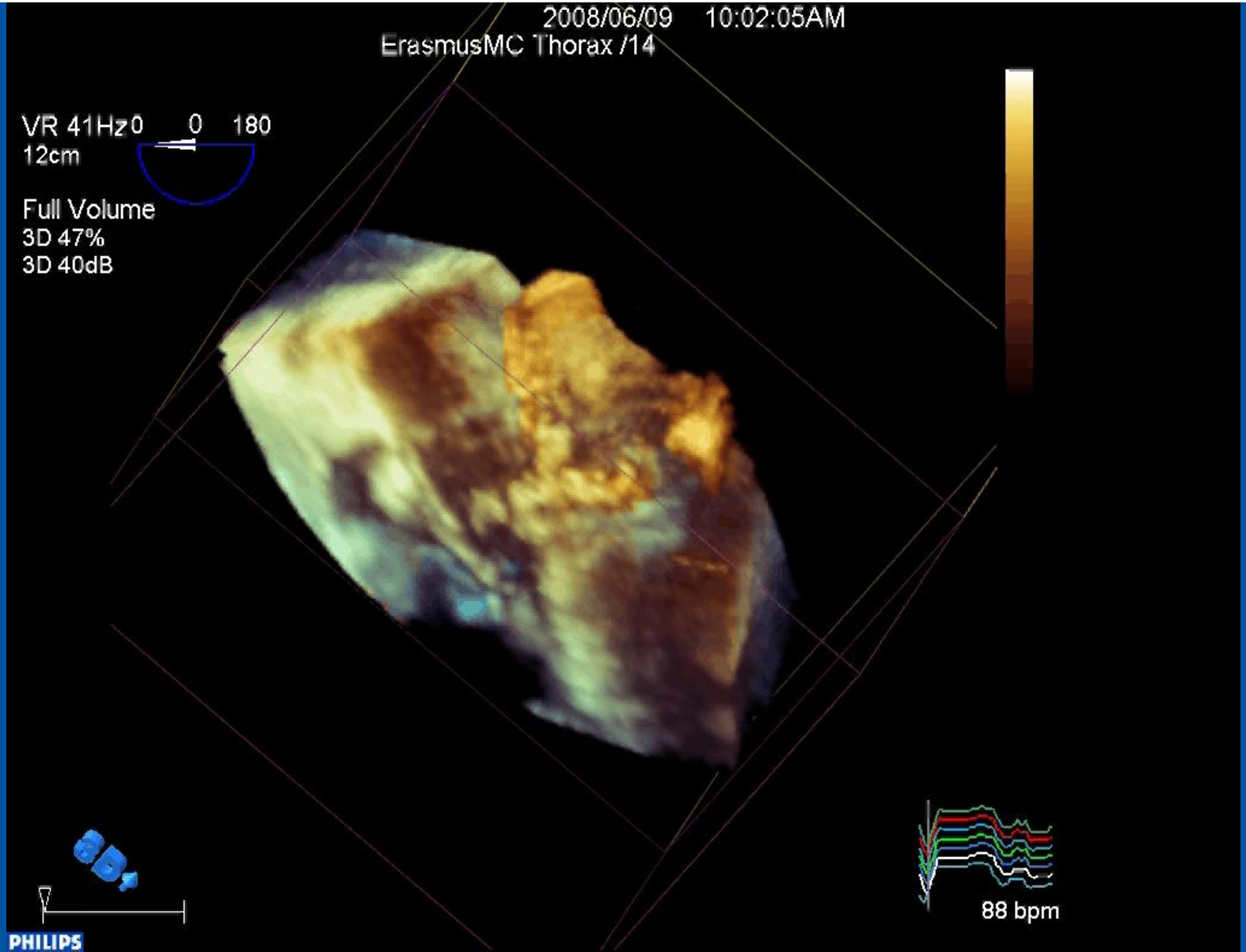

RT 3D TEE: Conclusion

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Makes understanding of anatomy (MV) much easier

Accessible for non-experts

Unequivocal presentation of anatomy

Contributes to the understanding of the MV, also for experts

3D echo & morphology

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3D echo & morphology

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- Current place of 3D echo for morpholgy:
  - *In selected patients*
  - *For specific questions*
  - *On top of 2D – not instead of*
  - *Costs extra time*

3D echo & morphology

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- Current place of 3D echo for morpholgy:
  - *In selected patients*
  - *For specific questions*
  - *On top of 2D – not instead of*
  - *Costs extra time*
    - Weigh – for every patient – whether the extra time needed for RT3D echo will be worth the effort.

3D echo & morphology

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- Current place of 3D echo for morpholgy:
  - *Not established yet*
  - *No recommendations/guidelines*

- 2 books will be out shortly:
  - *Buck& Monaghan*
  - *Lang*

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3D TTE: normal aortic valve

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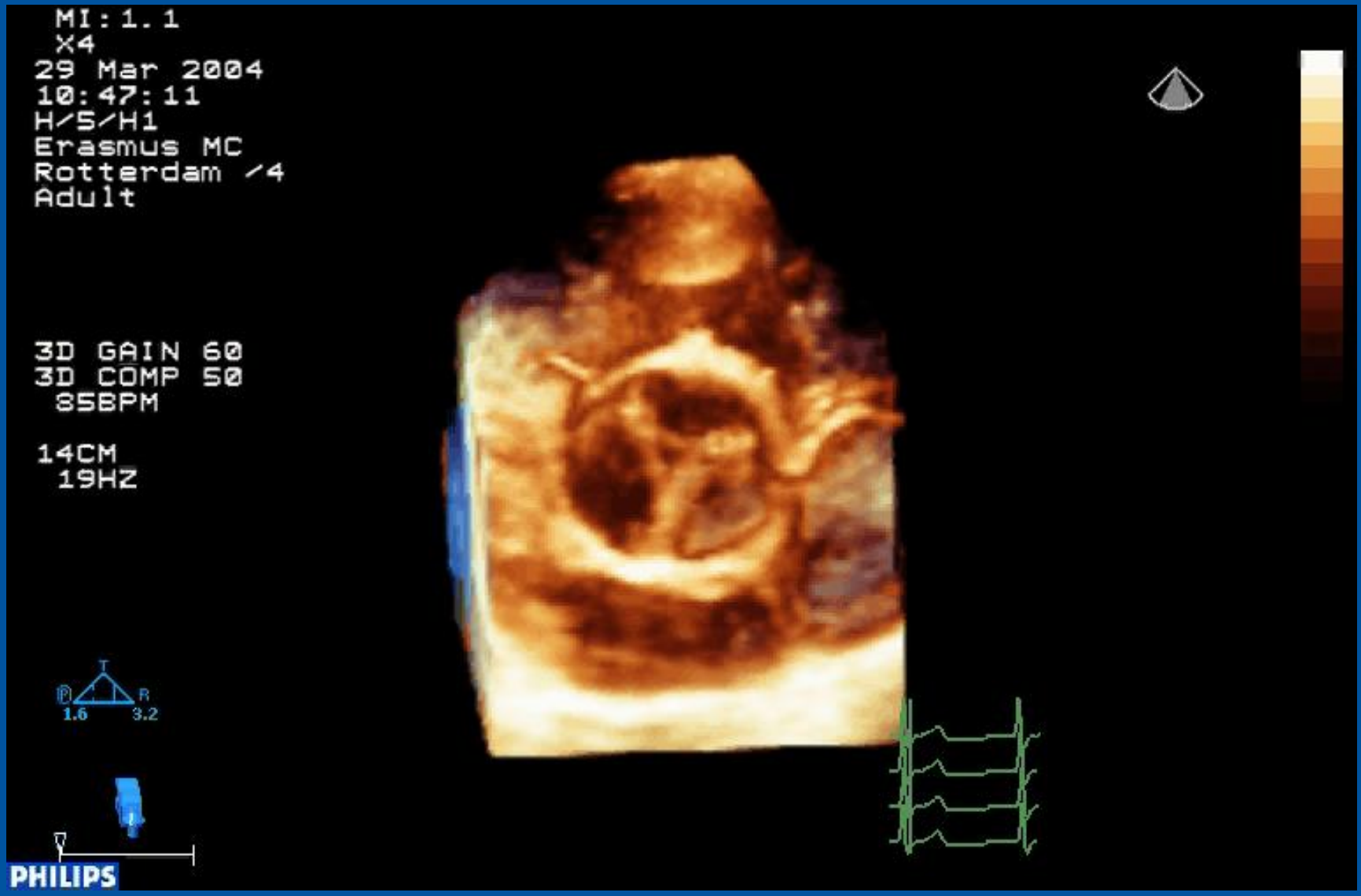
3D TTE: Bicuspid aortic valve



3D TTE – normal MV

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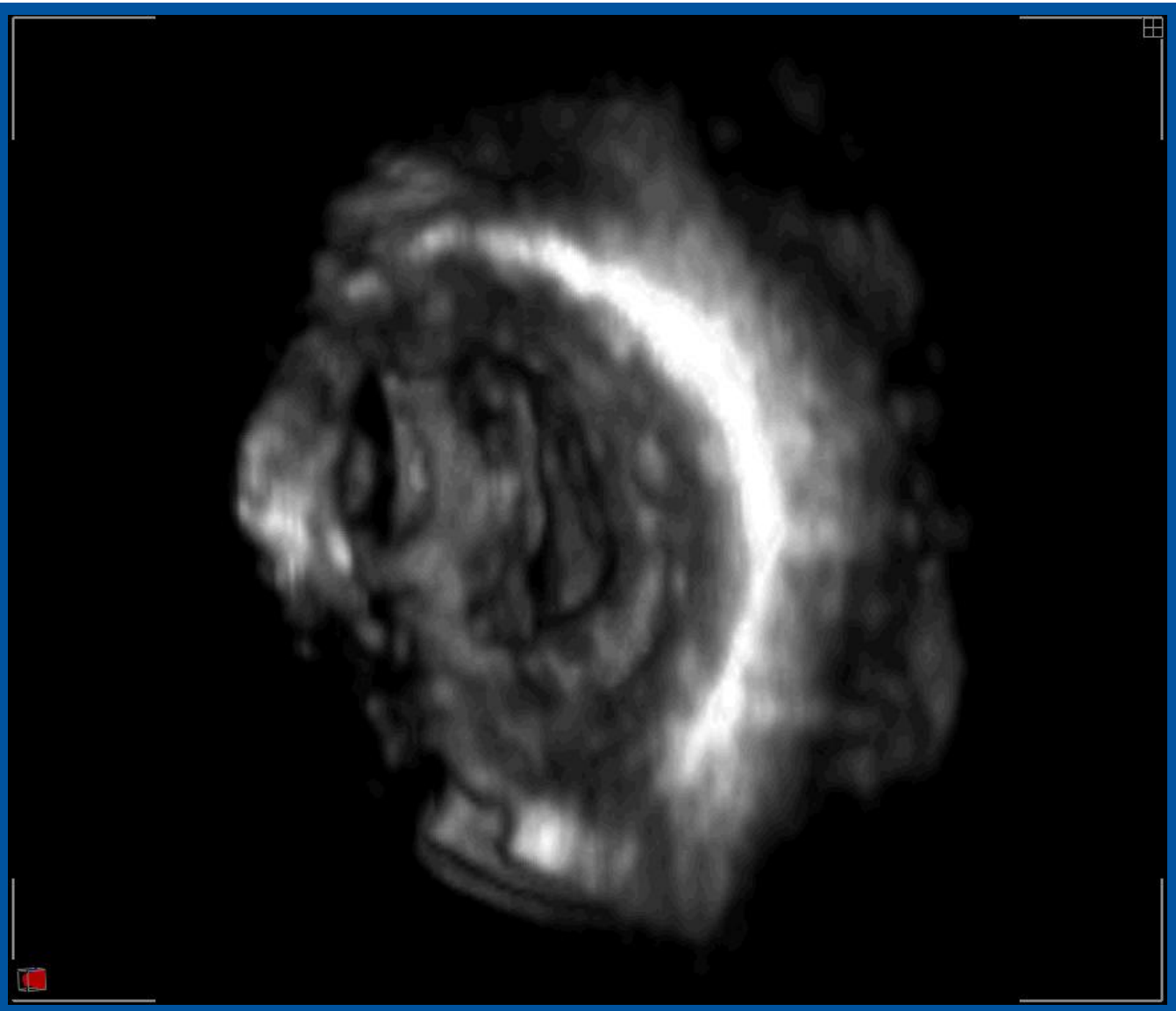

3D TTE new generation

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Full-volume set from a single heart beat

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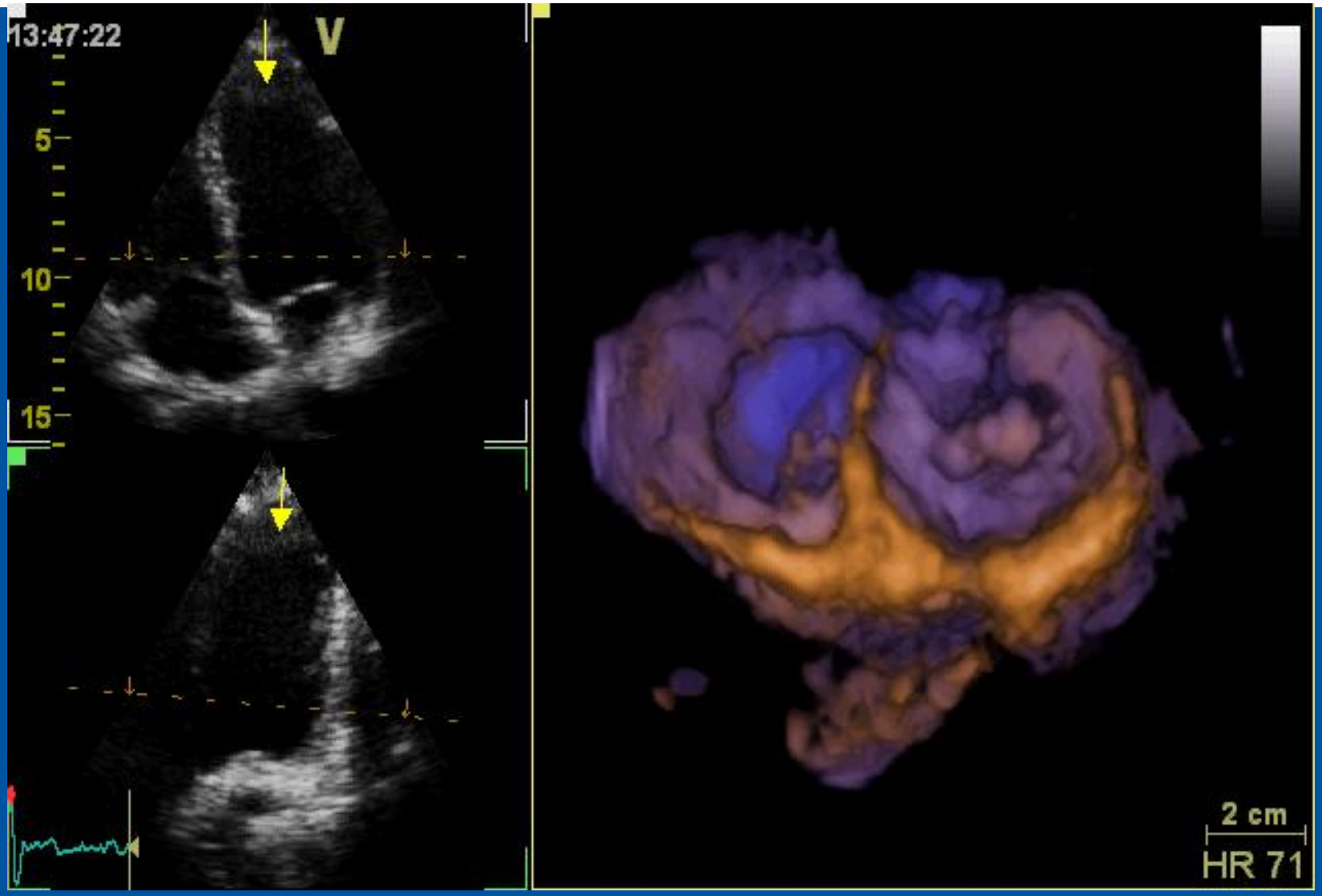
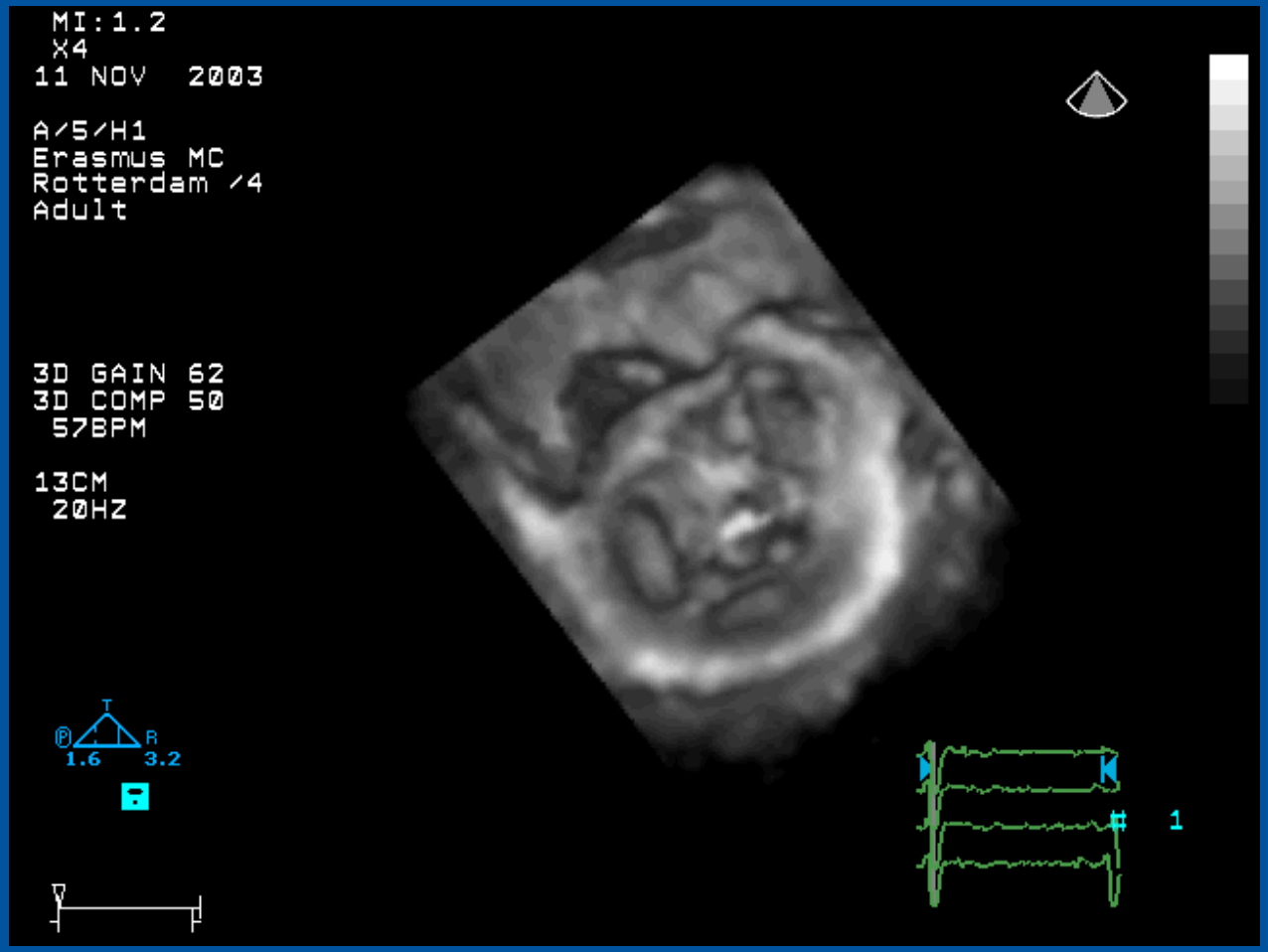


pAVSD – septal commissure



pAVSD – septal commissure

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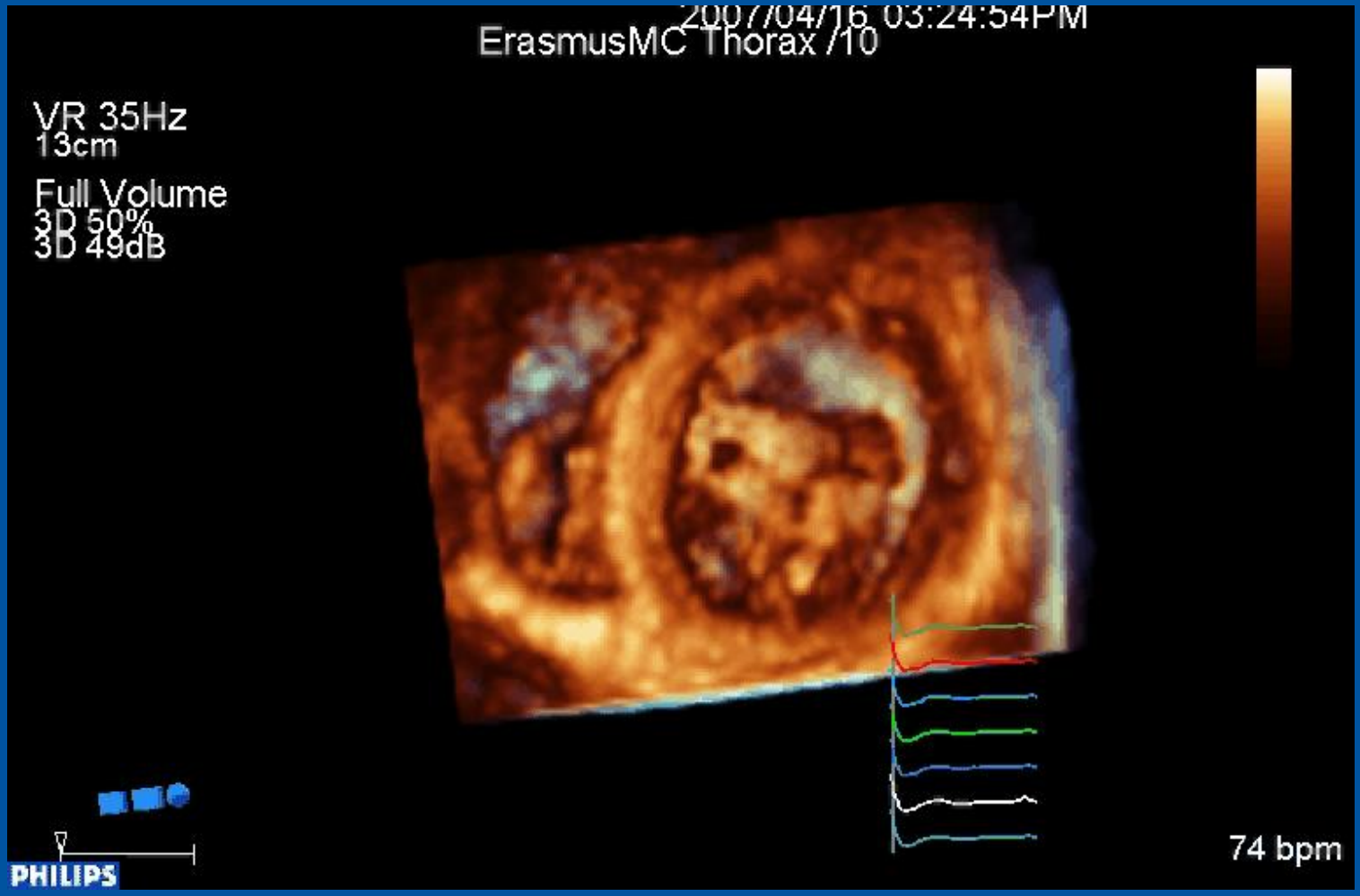

3D echo for morphology

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- how to analyse the data?
- Dedicated software
  - *Every vendor its own system*
  - *Do not communicate with each other*
  - *Tomtec*
- 3D data on a flat screen – missed opportunity

3D viewing of 3D data sets

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I-space 3D viewing system

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3D Personal Space System

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3D viewing of 3D data sets

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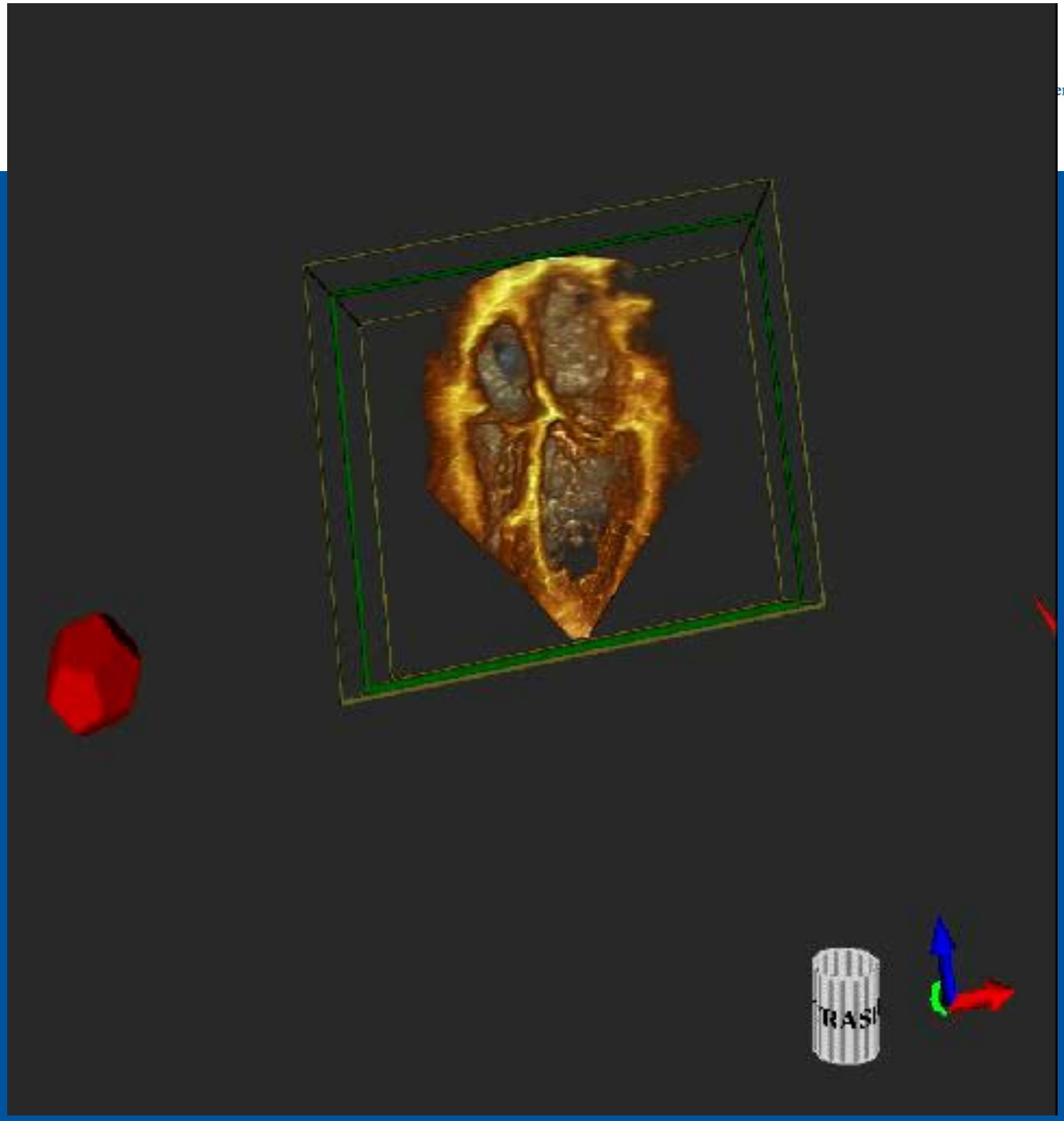
- Intuitive navigation through 3D data sets
- more accessible for non-(echo)experts
  - *Cardiac surgeons*
  - *Interventional cardiologist*
  - *Electro-physiologists*


TRASH

Creating surgical view of the heart

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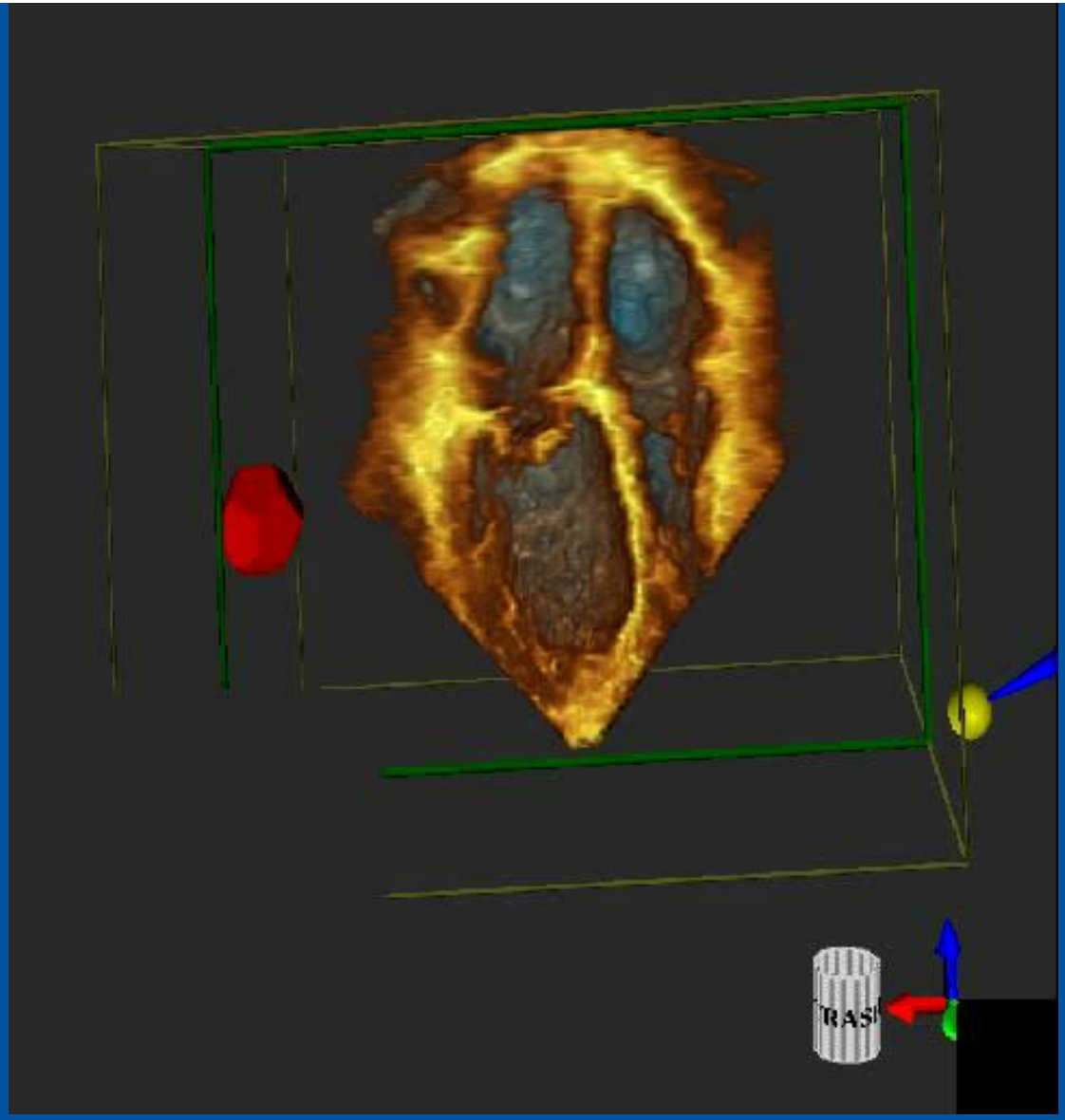
head



toes

Mimicking atriotomy

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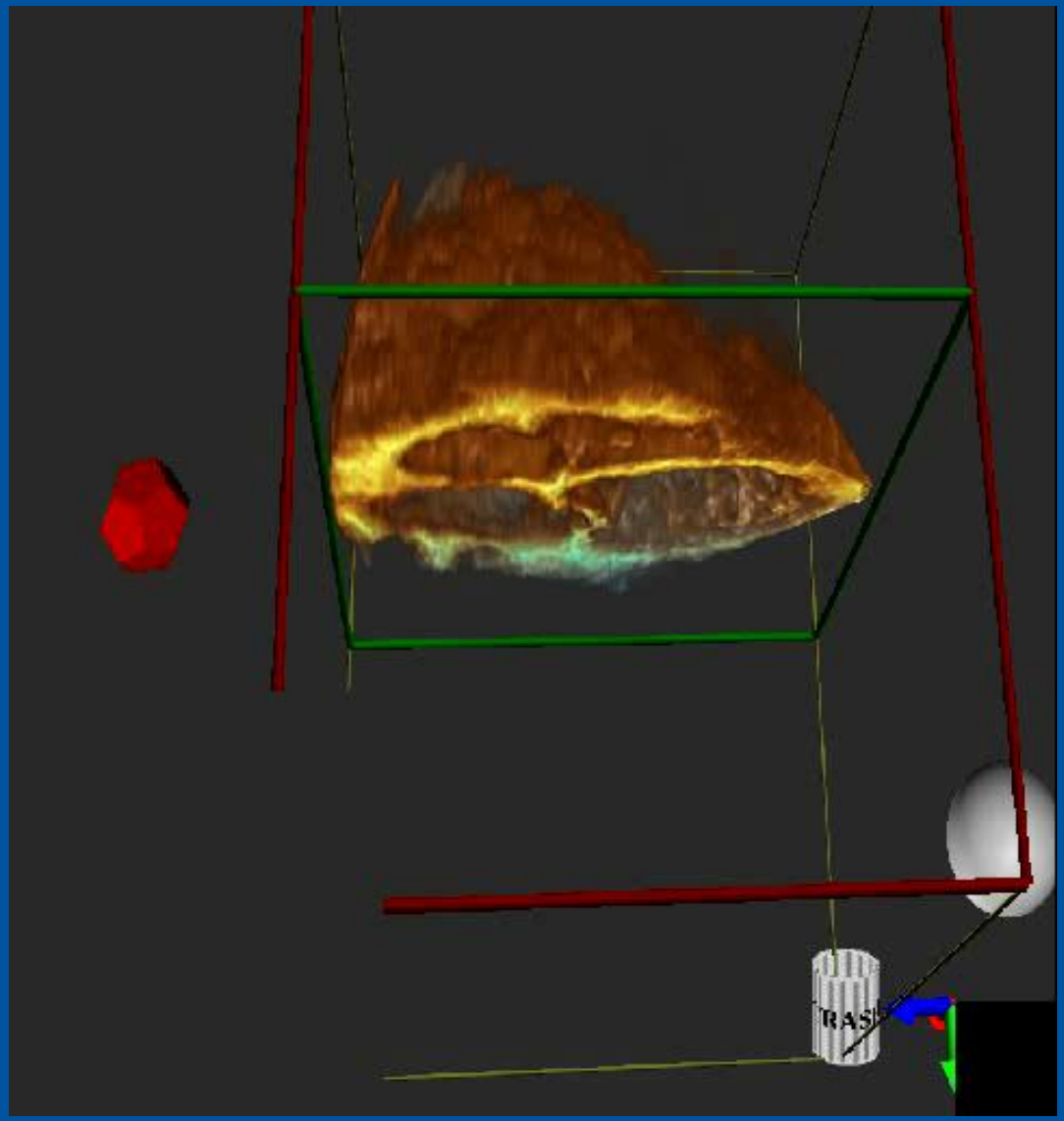

Mimicking atrial septostomy

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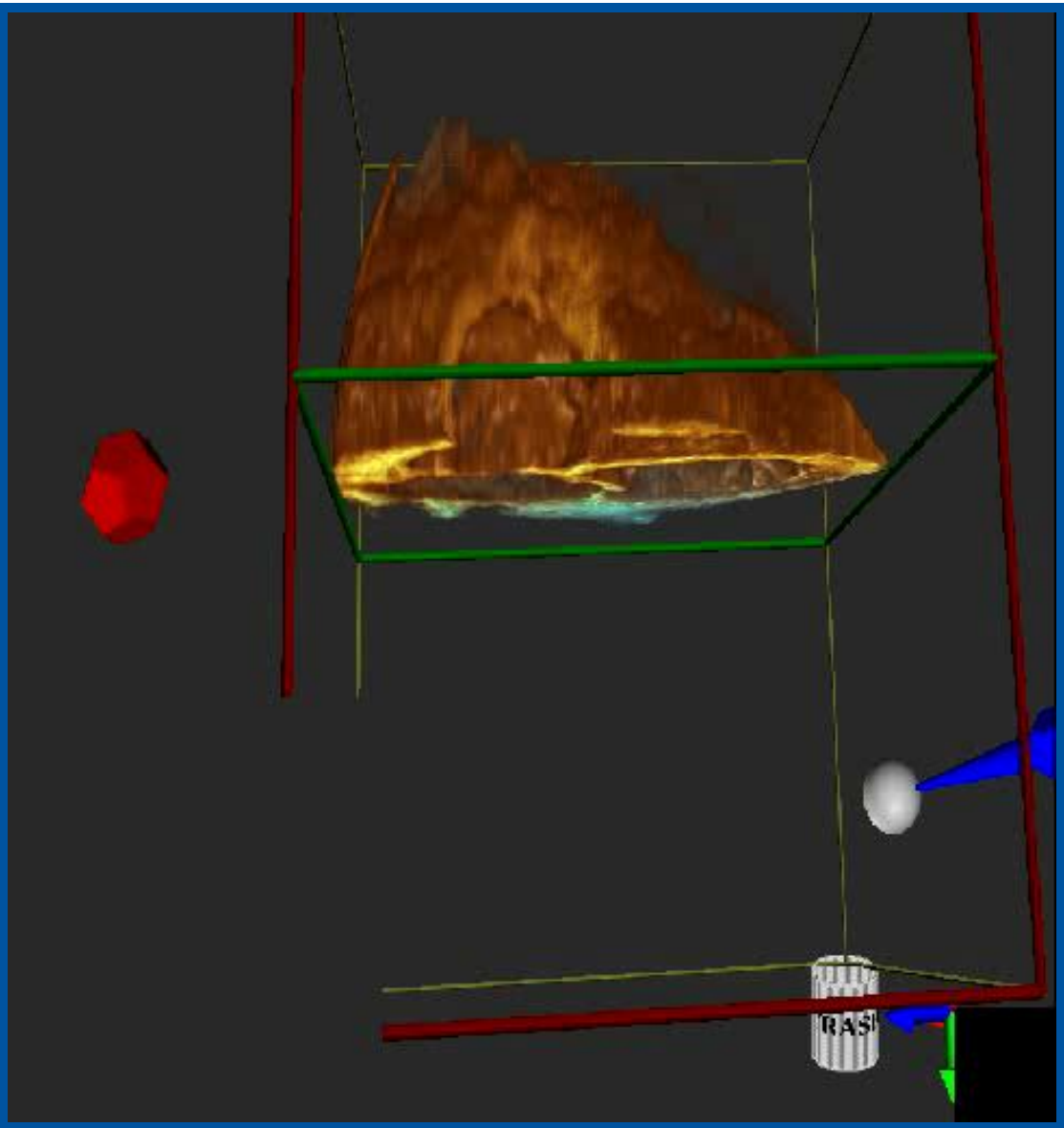

Conclusion 3D echo

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- Ready for clinical practice for
  - *LV function – superior to 2D*
  - *Intracardiac anatomy*
    - MV
    - AoV
    - TV
    - Congenital HD

Additional information, on top of 2D echo, for selected patients

Conclusion 3D echo

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- Work in progress
  - *RV function*
  - *3D full volume single heart beat*
  - *3D-speckle*
  - *3D display of 3D data*


NHD, Willemstad, Curacao, 30 januari 2010
Thank you very much