# CMR in RV evaluation, does it have a competitor?

Sarah Moharem-Elgamal, MD

## Outline

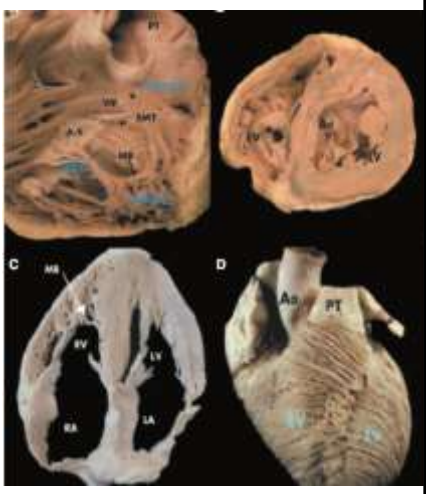
- Intro to RV
- Characteristics of an ideal imaging modality
- Different Imaging Modalities
- Comparison
- Summary of relative strengths and limitations of different modalities for RV imaging

# The Right Ventricle

- RV has long been considered a dispensable cardiac chamber that does not contribute significantly to overall cardiac function.
- Recent studies published in the last several decades have revealed that RV function has been an important independent predictor of morbidity and mortality in patients with congenital heart disease, HF, PHTN, and CAD.

# Challenges in RV Imaging

- geometry > complex than the LV;
- In contrast to the ellipsoidal shape of the LV, the RV appears triangular when viewed from the side and crescent shaped when viewed in cross section;
- 3 distinct sections: an inlet portion, a trabecular portion and a smooth outflow /infundibular portion;
- thinner walls and prominent trabeculations, more difficult to characterize;
- Retrosternal position, which creates an acoustic barrier for ultrasound waves.



## Characteristics of an ideal imaging modality

- High spatial and temporal resolution, to provide accurate measurement of dynamic changes in RV shape and size.
- High contrast-to-noise ratios, so that the RV can be easily differentiated from surrounding structures.
- Versatility, so that different anatomic and physiologic aspects of the RV can be evaluated, including tissue characterization and blood flow patterns.
- Ability to simultaneously provide information on other structures intimately related to RV performance, such as the left heart side and the pulmonary circulation.
- Complete noninvasiveness, including need for IV access.
- Harmlessness, including absence of potentially toxic contrast agents and ionizing radiation.

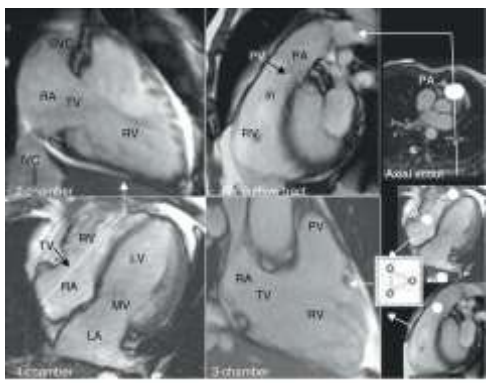
## Characteristics of an ideal imaging modality

- Rapid acquisition, which may be particularly important for the sickest patients.
- Low cost of both performance and maintenance.
- Portability, so that the test can be performed at the bedside if needed.
- Widespread availability in both inpatient and outpatient settings.
- Accuracy, being validated to provide reliable quantification of measured indices.
- Reproducibility among readers and tests.
- Robustness, allowing for the reliable performance of the technique in a wide range of individuals and clinical scenarios.

# DIFFERENT MODALITIES

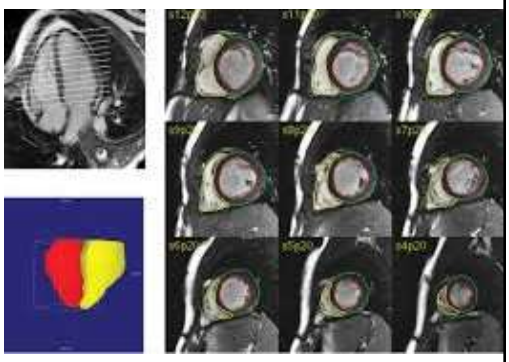
# CMR

- In the past decade, advances in CMR have significantly improved our ability to image the RV.
- The combination of high-resolution, unlimited imaging planes and absence of "acoustic" window limitations results in robust and accurate measurements of RV volumes and ejection fraction, for which CMR is currently considered the **gold** standard, and its use is regarded as appropriate.

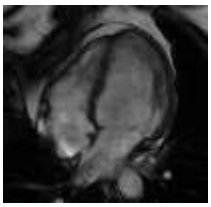


# CMR

- Cine imaging is typically performed in contiguous SAX views from base to apex, allowing for quantification using Simpson's method and without geometric assumptions.
- Because function evaluation does not require contrast and has high reproducibility and excellent safety, CMR is well suited for serial evaluations.

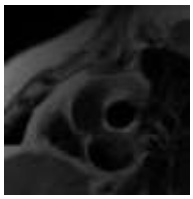


## Additional applications include



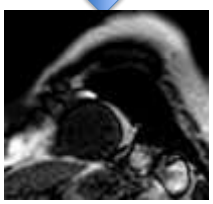
CINE imaging Function

Tagging Function

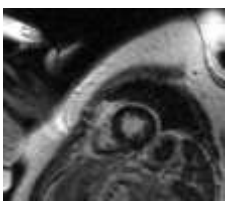


STIR Edema

Velocity Encoded Phase



Perfusion



Late Gadolinium Enhancement

# CMR

- The main limitations of CMR are:
  1. higher cost,
  2. reduced availability and expertise,
  3. and safety constraints related to the magnetic field.

# 2-Dimensional Echocardiography

- In clinical practice, echo is by far the most common modality used to image the RV, and its use is generally considered appropriate for this application, particularly in the settings of PHTN or acute coronary syndromes.
- portable, inexpensive, widely available, entirely noninvasive and poses no risk for the patient.
- simultaneously assess biventricular and valvular function and provide important hemodynamic information from Doppler flow measurements.

# 2-Dimensional Echocardiography

**Table 2**
**Echocardiographic methods for the assessment of the right ventricle**

| Method | Application |
|---|---|
| *M-mode* | RV wall thickness<br>RV outflow tract shortening<br>TAPSE |
| *2D echo* | Linear dimensions<br>Visual assessment of volumes/ejection fraction<br>Ventricular eccentricity index<br>Fractional area change |
| *Conventional Doppler* | RV systolic pressures<br>Myocardial performance index |
| *Doppler tissue imaging* | Myocardial performance index<br>IVA<br>Strain and strain rate |
| *Speckle tracking* | Strain and strain rate |
| *3D echo* | RV volumes<br>RV Ejection Fraction |

*Abbreviations:* D, dimensional; IVA, isovolumic acceleration; RV, right ventricle; TAPSE, tricuspid annular plane systolic excursion.

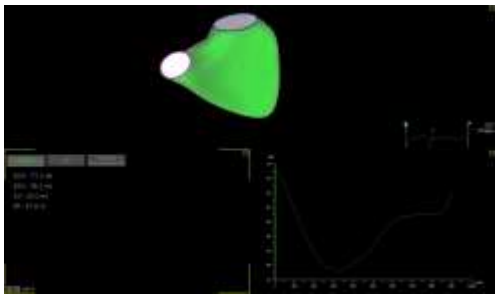
Sanz et al, 2012

# 2-Dimensional Echocardiography

- Limitations of echocardiography are:
  - RV is positioned directly behind the sternum, anterior to the LV.
  - Under normal loading conditions, the septum arches into the RV both in systole and diastole.
  - This complex geometry cannot be fitted to simple geometric models, which presents important limitations for the estimation of RV volume and function based on 2D tomographic views.

# 3-Dimensional Echocardiography

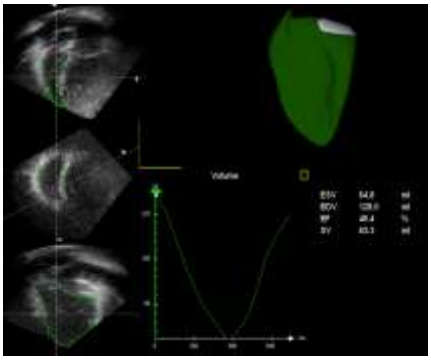
- The introduction of new matrix transducers, as well as advances in image acquisition and analysis have increased the use of real-time 3D echo in the clinical setting.
- Direct visualization of the entire RV with 3D echo is possible using the full-volume mode acquisition.
- This capability is particularly attractive for the RV, as it has the potential advantage to measure cardiac chambers without geometric assumptions at the patient's bedside.



Courtesy of Dr Hani Mahmoud

# 3-Dimensional Echocardiography

- May provide important mechanistic and prognostic value in various clinical scenarios, such as congenital heart disease or functional tricuspid regurgitation.
- Multiplane reconstruction analysis allows accurate evaluation of segmental RV geometry and function.
- However, limitations related to limited temporal resolution of real-time imaging or the need to average 4 to 7 cardiac cycles with full-volume imaging, which may cause artifacts in cases of arrhythmia.



**Off line processing of 3D echo data**. Reconstructions are performed to generate images in 4CH, SAX and right ventricular inflow-outflow views. Contours are applied in all 3 planes at end systole and diastole.
**Crean et al, 2011**

# Normal RV Echo Values

| Parameter | Mean Values (min–max) | Reference |
|---|---|---|
| RV basal diameter, mm | 33 (24–42) | Current guidelines[15] |
| RV midcavity diameter, mm | 28 (20–35) | Current guidelines[15] |
| RV longitudinal diameter, mm | 71 (56–86) | Current guidelines[15] |
| RV subcostal wall thickness, mm | 5 (4–5) | Current guidelines[15] |
| RVEDA, $cm^2$ | 18 (10–25) | Current guidelines[15] |
| RVESA, $cm^2$ | 9 (4–14) | Current guidelines[15] |
| 3DE RVEDV indexed, $mL/m^2$ | 65 (40–89) | Current guidelines[15] |
| 3DE RVESV indexed, $mL/m^2$ | 28 (12–45) | Current guidelines[15] |
| TAPSE, mm | 23 (16–30) | Current guidelines[15] |
| FAC, % | 49 (35–63) | Current guidelines[15] |
| 3DE RVEF, % | 57 (44–69) | Current guidelines[15] |
| RV strain, % | | |
| Mean RV strain | −26 (from −21 to −32) | Fine et al[53] |
| RV free wall strain | −27 (from −24 to −29) | |

Abbreviations: 3DE, 3-dimensional echocardiography; FAC, fractional area change; max, maximum; min, minimum; RV, right ventricle; RVEDA, right ventricular end-diastolic area; RVEDV, right ventricular end-diastolic volume; RVEF, right ventricular ejection fraction; RVESA, right ventricular end-systolic area; RVESV, right ventricular end-systolic volume; TAPSE, tricuspid annular plane systolic excursion.

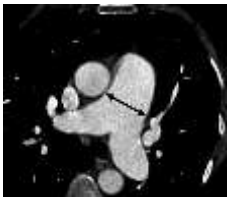
Tandic et al, 2015

# MSCT

- MSCT heart with retrospective ECG gating is accurate and reproducible for the quantification of RV volumes and function when compared with CMR.
- This requires performing SAX reformations and tracing endocardial contours in a manner comparable with CMR.
- Because of the need for potentially nephrotoxic contrast agents and ionizing radiation, CT is rarely used solely for RV function evaluation; however, it is currently considerate an appropriate indication.

## Normal RV Values Obtained by MSCT





| Characteristic | Value |
|---|---|
| Free RV wall (mm)[a] | 4 |
| RV midcavity end-systolic diameter (mm) [a] | 29.6 ± 5.3 |
| RV midcavity end-diastolic diameter (mm) [a] | 37.0 ± 5.7 |
| RV ejection fraction (%)[a] | 57.9 ± 8.0 |
| RV end-diastolic volume (mL) [a] | 174.9 ± 48.0 |
| RV end-systolic volume (mL) [a] | 82.1 ± 29.2 |
| Tricuspid annular plane systolic excursion[a] | 29.6 ± 5.3Main |
| Main pulmonary artery (mm)[b] | < 29.0 |

a Data are from Lin et al. b Data are from Kuriyama et al.

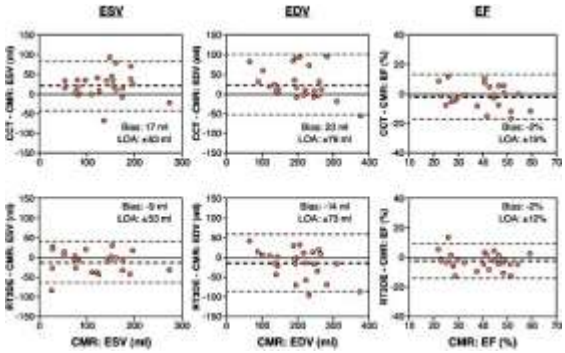
# MSCT

CT is particularly useful when echocardiography and CMR are inadequate or contraindicated.

- patients with heart failure carrying an LVAD where RV performance is an important determinant of outcome.
- adult patient with complex congenital heart disease in the presence of pacemakers or defibrillators.

# COMPARISON OF CMR TO DIFFERENT MODALITIES

## Multimodality Comparison of Quantitative Volumetric Analysis of the Right Ventricle




Bland-Altman Analyses of Right Ventricular Volumes Between Imaging Modalities
Results of Bland-Altman analysis of right ventricular ESV, EDV, and EF, calculated using volumetric analysis of CCT **(top)** and RT3DE **(bottom)** images against CMR reference values obtained in 28 patients. **Thick dashed lines** show the bias, while the **thin dashed lines** show the 95% limits of agreement (LOA).

Sugeng et al performed an elegant study about the volumetric quantification of RV volume using CMR, CT, and 3DE imaging and concluded that the elimination of analysis-related intermodality differences enabled good comparisons among these techniques

JACC: Cardiovascular Imaging, Volume 3, Issue 1, 2010, 10–18

# Comparison of CMR to different modalities

- A meta analysis of 23 studies (n= 807 subjects) revealed statistically significant underestimation of RVESV, RVEDV and EF by 3D echocardiography compared with CMR (WMD -5.5mL, 95% CI -7.6 to -3.4; I2=91%) (WMD -13.9mL, 95% CI -17.7 to -10.1; I2=96%) (WMD -0.9%, 95% CI -1.8 to -0.1; I2=80%).

- There are several potential reasons for this disagreement:
  1. Although 3DE evaluation of RV volumes is free of geometrical assumptions, it is affected by gain settings as well as the thickness and orientation of disks during disk summation.
  2. Complex RV shape might make the accurate identification of the RV margins close to the RVOT difficult.
  3. 3DE measurement is relying on the visualization of the endocardial border and the ability to differentiate trabeculae from the myocardium.

# Comparison of CMR to different modalities

- Studies published by Tamborini et al and Tandic et al investigated the normal references for 3DE RV volumes in a large number of healthy volunteers and defined age-, body size-, and sex-specific reference value, but there is yet no formal 3DE-derived volume recommendations.

- Normal CMR-derived RV reference values have been reported and published previously.

## Relative strengths and limitations of different modalities for RV imaging

| | 2DE | 3DE | CMR | CT |
|---|---|---|---|---|
| **TECHNICAL ASPECTS** | | | | |
| Availabilty | High | Moderate | Moderate | Moderate |
| Cost | Low | Low | High | Moderate |
| Typical scan duration, min | 25–30 | 30–35 | 40-60 | 10-15 |
| Safety | - | - | ✕ claustrophobia; potentially nephrotoxic contrast, allergic reaction to contrast | ✕ pts with metallic implants,claustrophobia ; potentially nephrotoxic contrast, allergic reaction to contrast; restricted only to hemodyn stable patients |
| Spatial resolution | + + + | ++ | ++ | + |
| Temporal resol. | + + + | + + | + + | + + + + |
| 3D acquisition | No | Yes | Only selected sequences | Yes |

## Relative strengths and limitations of different modalities for RV imaging

| | 2DE | 3DE | CMR | CT |
|---|---|---|---|---|
| **ASSESSMENT OF RV SIZE, GEOMETRY AND FUNCTION** | | | | |
| Evaluation of RV wall thickness | Yes | Yes | Yes | Yes |
| Determination of RV diameters | - | + + + | + + + + | + + + + |
| Accuracy of RV volume | - | + + + | + + + + | + + + + |
| Accuracy of RVEF | - | + + + | + + + + | + + + + |
| Parameters of RV systolic function | FAC, TAPSE, s | RVEF | RVEF | RVEF |
| Evaluation of RV mechanics | + + + | + | + + + + | + + + |
| Major limitations | Inabilty to acq whole RV in 1 geometric assumption, poor visualization of RV endocard border | Stable cardiac rhythm, poor visualization of RV endocard border | Cost, low availabilty | Ionizing radiation, potentially nephrotoxic contrast, stable cardiac rhythm with a low heart rate |

## Take Home Message

RV ventricular function and mechanics has been proven to be an important indicator of overall cardiac function and an important predictor of cardiovascular morbidity and mortality.

- Echocardiography remains the mainstay modality, because of its versatility, low cost, and widespread availability.
- CMR:
  - gold standard and reference test for quantification of RV volumes and EF
  - well suited for myocardial characterization.

## Take Home Message

- 3DE is particularly important due to its similarity with CMR and CT measurements and is a potential competitor for assessment of RV function.
- CT represents a robust alternative for RV evaluation at the expense of contrast and radiation administration.