“BEST METHOD FOR RIGHT VENTRICULAR FUNCTION EVALUATION”
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TITLE PAGE</td>
<td>1</td>
</tr>
<tr>
<td>2. TABLE OF CONTENTS</td>
<td>2</td>
</tr>
<tr>
<td>3. SUMMARY</td>
<td>3-4</td>
</tr>
<tr>
<td>4. ACKNOWLEDGMENTS</td>
<td>5</td>
</tr>
<tr>
<td>5. CONFLICTS OF INTEREST</td>
<td>5</td>
</tr>
<tr>
<td>6. ABBREVIATIONS</td>
<td>6</td>
</tr>
<tr>
<td>7. TERMS</td>
<td>6</td>
</tr>
<tr>
<td>8. KEYWORDS</td>
<td>7</td>
</tr>
<tr>
<td>9. INTRODUCTION</td>
<td>8-9</td>
</tr>
<tr>
<td>10. AIM AND OBJECTIVES</td>
<td>10</td>
</tr>
<tr>
<td>11. LITERATURE REVIEW</td>
<td>11-30</td>
</tr>
<tr>
<td>12. RESEARCH METHODOLOGY AND METHODS</td>
<td>31-34</td>
</tr>
<tr>
<td>13. CONCLUSION</td>
<td>35</td>
</tr>
<tr>
<td>14. REFERENCES</td>
<td>36-39</td>
</tr>
</tbody>
</table>
SUMMARY

ALAA BOUKALFOUNI
“BEST METHOD FOR RIGHT VENTRICULAR FUNCTION EVALUATION”

AIM:

Our purpose of this study is to investigate the different methodologies of assessing RV functional evaluation; and which one would serve the best. Thus by increasing the ability to evaluate RV, both quantitatively and qualitatively. Starting with RV-FAV and TAPSE, reaching some new echocardiographic techniques including RV-3D EF, RV longitudinal strain which can improve our evaluation together with the continuous exponential technology.

OBJECTIVES

- To check by comparative data analysis different methods of RV functional evaluation, qualitative and quantitative results of each method performed on different ages having different cardiac or pulmonary diseases based on some clinical evidence.
- This study can help in finding new clinical characteristics and confirming old ones on a certain sample of population with the new methodologies of evaluation.
- Our hope is to develop a clearer picture and better understanding of this topic.

METHODOLOGY

The studies derived from various databases such as PubMed, Medscape, and ScienceDirect etc. The latest article published on 31 January 2017. The articles were checked for bias and proper quality and then revised by the authors’ supervisor. Followed by studies upon the statistical content and results for
various pathological and control studies; summing up all methods and coming up with the best methods for evaluating RV function.

**CONCLUSIONS**

Loads of methods used to assess the RV function, size, and mechanics. Although newly developed techniques mainly echocardiographic are highly recommended compared to CMR that requires more effort and time consuming. The exact norms for some methods are not established; such as RVOT_FS, RVOT_SE, and RV IV. Therefore a combination of several methods used for an accurate diagnosis and treatment.
ACKNOWLEDGEMENTS:

A great effort and hardwork done in order to state and explain the combination of methods and techniques of assessing the RV function and size, trying to focus on which one should be recommended to be used routinely, despite RV complex geometry.

CONFLICT OF INTEREST:

No conflict of interest
ABBREVIATIONS LIST:

CMR (Cardiac magnetic resonance)
RHF (Right heart failure)
DE (Doppler examination)
RV (Right ventricle)
PA (Pulmonary artery)
PAH (Pulmonary arterial hypertension)
PASP (Pulmonary arterial systolic pressure)
PH (Pulmonary hypertension)
RVFAC (Right ventricular functional changes)
RV-PA (Right ventricular-pulmonary artery)
RV S’ (Peak systolic tissue Doppler velocity)
TAPSE (Tricuspid annular plane systolic excursion)
DTI (Tissue Doppler Imaging)
RVMPI (Right ventricular myocardial performance index)
RV-3D EF (3D right ventricular ejection fraction)
RVMPI-DTI (RVMPI via Doppler tissue imaging)
RVSm (Peak systolic myocardial velocity by DTI)
ε (Strain)
SR (Strain rate)
PVC (Pulmonary valve closure)
PVO (Pulmonary valve opening)
LV (Left ventricle)
RVOT-FS (Right ventricular outflow tract fractional shortening)
RVOT-SE (Right ventricular outflow tract systolic excursion)
RV 2D EF (RV two-dimensional ejection fraction)
RV IVA (Right ventricular isovolumic myocardial acceleration)
AV (Atrioventricular)
KEY WORDS

Right ventricle, Right ventricular function, Two-dimensional echocardiography, Three-dimensional echocardiography, Cardiac magnetic resonance, Systolic function, Diastolic function, Doppler imaging, Deformation, Hemodynamics, Electrophysiology, Cor pulmonale, Pulmonary hypertension, Right heart failure.
INTRODUCTION

RV functional assessment parameters is one of the main topics within cardiology that is gaining loads of attention recently. Previously the LV left side of the heart always preside the RV right side. The LV is easy to assess. The invention of CMR evolved an important understanding of the geometry and the structure of the RV; together with the new echocardiographic techniques. Recent guidelines recommend assessing the RV function within every echocardiographic evaluation. Emergent data suggest that the study of RV function and size is major determinant of several diseases outcome ex (MI mortality rate can be predicted be RV EF, and its better predicting the outcome than LV EF. Early detection of RV size or functional changes may act as a marker for a mechanism of early treatment preventing overt RHF.

Assessing the RV systolic function remains challenging even with all this technology, due the complex geometry. Since right ventricular systolic function is totally significant in the management of various pathological conditions either congenital or acquired, heart failure, valvular pathologies cardiomyopathy, and pulmonary hypertension. Therefore, its necessary to study anatomically and physiologically the RV to have the ability for understanding deeply the mechanism of damage, is it either secondary to chronic pathological changes such as PH, PAH, or acts as a primary mechanism resulting in physiological, anatomical and functional changes. Sometimes the contractile function may not be impaired however; clinical syndrome of RHF may take place.

To understand its function more, several qualitative and quantitative studies stressing on old echocardiographic parameters such as RVFAV, TAPSE etc. have been compared together with various modern techniques RV-3D EF, RV longitudinal strain plus CMR. Each method has limitations, some are invasive, expensive, carry some side effects, unreliable, or done together with other techniques in order to visualize RV size and function fully. Some are recommended to be used clinically, others are still part of research tools such as right ventricular outflow tract fractional shortening (RVOT-FS), right ventricular outflow tract systolic excursion (RVOT-SE), color-coded tissue Doppler-derived S’wave velocity (color-coded RV-S’), RV 2D EF, right ventricular isovolumic myocardial acceleration (RV IVA), RV strain and strain rate.

The ideal method of assessment should be a one with the following criteria (accurate, reproducible and comprehensively asses the RV size, function, complex contractility, and hemodynamic performance, subsist the 3D geometry, architecture, retrosternal location, and the limitation of accessing all chambers landmarks. It should be widely available in hospitals and clinics, cheap, time saving independent on the pathological condition, including intra and peri-operative, and mainly safe.
However, none of the modalities validates all the following requirements mentioned above, thus understanding the advantages and disadvantage of each of the modalities in different studies and pathological conditions trying to find the best method to assess the RV function.
AIM AND OBJECTIVES

Aim

The purpose of this comparative study is to investigate the various methods of RV function evaluation and which one serves the best. Thus, by performing searches in different databases such as (PubMed, Medscape, ScienceDirect…) and collecting data on various methodologies that have been used in the evaluation of RV function with the growth of new echocardiographic techniques and technology, showing an increase in the ability to evaluate the RV, both qualitatively and quantitatively. Older echocardiographic techniques, such as right ventricular fractional area of change, tricuspid annular plane systolic excursion, and tissue, and newer echocardiographic techniques including 3-dimensional evaluation and global longitudinal strain, can improve our evaluation of RV function. These techniques provide both diagnostic and prognostic data on a large variety of clinical diseases; including pulmonary hypertension and congestive heart failure. With the continuing and exponential advances in technology, echocardiography is well poised to become the primary modality to evaluate the RV.

Objectives

- To check by comparative data analysis different methods of RV functional evaluation, showing qualitative and quantitative results of each method performed on different ages having different cardiac or pulmonary diseases based on some clinical evidence.
- This study can help in finding new clinical characteristics and confirming old ones on a certain sample of population with the new methodologies of evaluation.
- Our hope is to develop a clearer picture and better understanding of this topic.
LITERATURE REVIEW

Anatomy

Blood forwarding into the circulation is the role of both the RV and LV. Their function relies on the structure and the morphology of each. RV have a moderator band and a coarser trabecular; but its inlet and outflow valves lack fibrous continuity unlike the LV. [2] The anerior sternocostal surface of te heart is made predominantly by the RV and conain those structures:[1]
- Trabeculae Caneae Cordis (muscular column that project within the inner surface of the heart to the LV and RV)
- Papillary muscles (cone shaped muscles attached to the chordae tendineae from the anterior, posterior, and the septum tightening them and preventing the cusps from being turned back into the atrium. Thus regurgitation will be prevented.
- Chordae Tendineae (prevents cusps from being back flipped)
- Infundibulum
- Septomarginal Trabecula (Prevents overdistention of RV, and carries Purkinje fibers of AV bundle)
- IV septum.

It normally works at a low pressure than the LV thus having a thinner wall; its septum is covered dominantly by the LV resulting in a complex geometry making it complicated for understanding its function and size by invasive and noninvasive echocardiographic techniques.[1] All studies previoulsy of ventricular fibers have been studied on the LV, both ventricles intercommunicate functionally through superficial and deep fibers coursing between them.[1] RV lacks middle layer fibers unlike LV, hence it relies on longitudinal shortening.

Physiology

Understanding the anatomical structure of the RV above, giving it a unique complex structure; making its pysisology isolated and dependent on the low hydraulic impedance characterisics of the pulmonary vascular bed.[2] RV contractions relies on its loading conditions, and the kind of fibers varies
from the LV in which its muscle bundles have a faster twich velocity.[2] LV output can be evaluated approximatly depending on that of the RV that is achieved by 1/5 of that of the LV; due RV pressure-volume relationship and the low pulmonary system pressure.

(Shaver et al) was the first announcing the difference in the Isovolumic periods differ between the RV and that of LV naming it "hangout-period"-- the difference in time between both RV pressure measurement and pulmonary arterial dichronic notch using macromanometer pressure recordings.[3] Nevertheless there was no hangout period in the LV, and this hangout became short with an increase in the RV afterload.

On the 1988 the pressure-volume loop was identified by a triangular form. This is influenced by several factors one which is the hemodynamics of the breathing work impact on the right heart side; showing a direct correlation between venous return, RV preload, and inspiration resulting to an decrease in the RV stroke volume as the mean airway pressure increases, this is affected by the preload. Several studies have been conducted showing worse cardiac output due slight changes in the total pulmonary resistance by 10-15%. 30% of the RV energy need for contraction is provoked by the LV according to a physiological experiman done by Dr.Ralph Damiano.[2]

RV function is profoundly dependent on its preload and afterload. It responds differently according to pressure overload and volume overload, for pressure overload it elongates resultig in septal flattening in diastole; for volume overload it produce septal flattening in sytole. Normal condition can alter the RV morphology for example in athletes RV-end diastolic volume increases unlike end systolic volume plus bulging of its free wall.[8]

Assessment of the RV

Various diagnostic procedures are used in assesing the RV function and size, mainly within the last 2 decades after recognizing the important of the RV function and size both clinicay and prognosticaly, together with the development of new imaing techniques. As mentioned previously its complex geometry, crescentric, highly trabeculated anatomy, retrosternal position, anterior position to the LV, contraction mechanism, myocardial fibre architecture, un-defined anatomical landmarks, compound mechanism of contraction makes it difficuclt to asses and estimate normal or pathological values using a single method resulting in a different size and function depending on the axis it has been viewd from. Recent studies and guidelines have been studying which method would be safe, economically suitable, time efficient,
technically not difficult, widely available in different clinical conditions, including intra and peri-operative care, and acute conditions would best assess the RV function size and function[14]. Depending on the clinical use, section, and technique those methods have been pronounced under different titles according to several studies for example:

One study had following division[8]

- **Standard methods:** Tricuspid anular plane systolic excursion (TAPSE), fractional area change (FAC), and pulsed tissue Doppler-derived S’ wave velocity (RV S`).
- **Global RV function methods:** pulsed Doppler right ventricular index of myocardial performance (pulsed Doppler RIMP), RV dp/dt, and tissue Doppler RIMP.
- **Three-dimensional (3D) for ejection fractioned named as (RV 3D EF)**
- **Research methods:** right ventricular outflow tract fractional shortening (RVOT-FS), right ventricular outflow tract systolic excursion (RVOT-SE), color-coded tissue Doppler derived S’ wave velocity (color-coded RV S’), RV 2D EF, right ventricular isovolumic myocardial acceleration (RV IVA), RV strain and strain rate.

Another study specified special techniques used for specific filed of RV study:[9]

- Techniques for determining RV Volume and EF:

Starting from the oldest techniques such as conventional contrast angiography, followed by recent rotational angiography that is being used in coronary angiography and imaging of the pulmonary vessels. Radionuclide angiography using technetium; this method has been the gold standard because its not related to the complex geometry. Now three techniques are being used including first-pass radionuclide angiography (FPRNA), equilibrium radionuclide angiography (ERNA). Single photon emmission computed tomoraphy together with ERNA can be used providing 3D spatial information. Multidetecter computed tomography (MDCT) can reconstruct angiograms in order to study the EF. Echocardiography including conventional and recent 3D echocardiography, and finally MRI.

- Techniques to assess RV Myocardial Motion:

Stressing on the change from qualitative measures of regional motion (doppler and speckle imaging that are used for strain and strain rate), to more quantitative measures in a specific axis longitudinal, transverse wall motion or motion of a specific structure by (TAPSE using M-mode or 2D imaging, MRI).

- Techniques to assess pulmonary blood flow and hemodynamics:

Cardiac output, RV and PA pressure, PVR, and central venous can be estimated by many techniques, but only some of the those revealed reproducibility and good prognostic information (Tei index estimating the sum of isovolumetric contraction and relaxation intervals divided by ejection time, and newly tissue
doppler techniques) others were inaccurate (RV dp/dt, Bernoulli equation, and pulmonic regurgitation jet velocity).

- Techniques to assess RV myocardial perfusion and metabolism:
Nuclear perfusion scintigraphy has been used, but the thin RV wall makes it difficult obtaining noise for identification of RV ischemia. It was mentioned also that insufficient myocardial perfusion leads to RV dysfunction in pulmonary hypertension.

In the following section we will describe briefly each method its advantages, limitations, and abnormal threshold; this would be followed later by studies that have been used in several articles and reviews comparing and understanding the impact of each according their diagnostic and prognostic ability, were charts, tables and diagrams will be used.

FAC

RV end diastolic and systolic area should be measured starting from the annulus just below the trabeculations and papillary muscles to the apex, then back upwards in the apical four-chamber view.

The following equation is used to estimate RV FAC:

\[
\text{RV FAC} = \frac{\text{RVEDA} - \text{RVESA}}{\text{RVEDA} \times 100}
\]

FAC = (RV end diastolic area – RV end systolic area)/end diastolic area ×100.

FAV reflects longitudinal and radial components of the RV, estimating global right ventricular contractility.[16] It have a correlation with MRI estimating RV EF plus it can predict mortality and heart failure rates after MI, stroke, and pulmonary embolism.[6]

FAC < 35% is considered abnormal thus indicating RV systolic dysfunction. Sever RV dysfunction should be a max of 17%.

However it has an inadequate image quality and suboptimal endocardial definition.
Fig 1. Showing an impaired RV function with a fractional area change of 26%. [11]

TAPSE

Tricuspid annular plane systolic excursion is measured using an M-mode through the lateral tricuspid annulus, representing global right ventricular function showing direct correlation with increased excursion in systole, improving its function (Fig 2). This method is easy to use, prolonged analysis are not necessary, simple, reliable and independent of the image quality compared with FAC. TAPSE show a good prognostic value in CHF and PH, and correlates well with radionuclide-derived RV EF [8]. It is reference is extracardiac, the rotational and translational motion of the heart is not considered, and thus it can’t be used as a follow up method during cardiac surgery [14]. Conflict results have been noticed when compared with CMR EF [26-29]. Some limitations are present, it reflects only longitudinal function, angle dependent, omit the contribution of interventricular septum and RVOT, it describes longitudinal myocardial shortening, can’t fully diagnose RV global function after surgery and it is load dependent. [8].

Normal value is 24 ± 3.5 mm.
Abnormal threshold have been changed by the ASE and EACVI to 17mm instead 16mm. <10mm is suggestive of severe RV dystfunction.
Fig 2. TAPSE in M-mode apical 4-chamber. The distance between red line 1 and 2 represents TAPSE 2.7cm. Diagram B shows end diastolic from the apex of tricuspid valve 7.5cm. Diagram C shows end systolic measurement from the apex to the tricuspid valve plane 48cm. Assessing the difference between diagram B and C represents a 2.7cm gap. Thus both M-mode and 2-D TAPSE can be used providing same values. [12]
In order to measure RV S’ a tissue Doppler mode is used with apical 4-chamber view, placed on the tricuspid annulus lateraly of the RV free wall (Fig 3). Another alternative method used is offline color coded tissue Doppler imaging analysis, by placing a specific region required for study in the segment this will attain high rate frames (Fig 3). RV S’ is a reproducible and easy method to be used. The function of a specific segment generalizes the function of all the RV function, this can’t be applied when having RV infarction or pulmmary embolism; and it is angle dependent though it can’t present the global RV function. Abnormal values have updated from 10 cm/s to 9.5 cm/s by the ASE and EACVI.[8,16]

**Fig 3.** (A) shows RV S’ apical 4-chamber view using tissue Doppler mode. (B) shows RV S’ using offline color coded tissue doppler imaging

**Pulsed Doppler Myocardial performance index (MPI) or Tei index**

MPI pulased Doppler is the global framework of cardiac function that is calculated with the following formula MPI = (IVRT + IVCT)/ET = (tricuspid valve closure to opening time – ejection time)/ejection time (Fig 4). MPI requires 2 different beats from 2 different cardiac cycles having the same R-R interval which is challenging in some patients, but it would show more accurate results measuring the time periods. Pulsed Doppler MPI is not affected by the HR, and is independent of the RV complex geometry; thus showing a good prognosis in patients suffering from pulmonary hypertension. However wrong values can be noticed in patients with RV infarction having high right atrial pressure. The upper limit value of pulsed Doppler MPI is 0.43.[8]
Fig 4. “a” represents the time taken from the onset of the regurgitation till cessation, “b” represents RV ejection time. MPI is calculated as follow (a-b)/b. [6]

**Tissue Doppler Myocardial performance index (MPI)**

Same formula used to calculate the Tissue Doppler MPI, however this method uses a single beat so it does not require an equal R-R interval but that does not mean it can be used with irregular heart rates. RA pressure can show a false negative result. The higher limit is 0.54; any value > 0.54 indicate a RV systolic dysfunction.

**RV dp/dt**

The principles of dp/dt is the measurment of tricuspid regurgitation (TR) indicating the sum of difference in systole between the right ventricle and right atrium. TR is calculated by Continuos-Wave Doppler technique (Fig 5). Dp/dt is measured by the time required for TR jet to increase by velocity from 1-2 m/s. Bernoulli equation can be used stating an increase in pressure up to 12 mmHg in regard to velocity increase; thus measured as 12mmHg (dp)/time in seconds (dt); however when the velocity increase form 0.5-2 m/s it will be measured as 15mmHg (dp)/time in seconds (dt). Normal value should be above 400 mmHg/s. RV dp/dt is load dependent so in severe TR and elevated RA its inaccurate despite avoiding RV complex geometry. [8]
RV strain and strain rate

Both strain and strain rate measures the degree of deformation of the myocardial tissue, in which strain is the percentage of shortening from the base to the apex during systole, and strain rate is the time taken over this shortening. Values require offline analysis (Fig 7.).[8]
A new non-angle dependent method named 2D strain (2DSTE) that can measure regional and global RV function, is measured by RV myocardial contraction change between end diastole and end systole using speckle-tracking echocardiography requiring a high imaging quality [8]. The excessive motion of the RV lateral wall results in loss of speckles, thus no standard measurements are present [14].

TDI or speckle tracking 2DE (2DSTE) are being used in the evaluation of the RV myocardial abnormalities (strain and strain rate). Physiological and pathological conditions can be highly distinguished by using TDI or 2DSTE [34]. When using TDI several factors alter the accuracy of the strain and strain rate such as high systolic excursion related to thin myocardial wall, angle dependence, high frame rate, age and heart rate. [14] However, with 2DSTE that requires a higher image quality, measurements were more reproducible [35]. Making both techniques used for RV longitudinal shortening that is better related to RV systolic function, rather than circumferential shortening which requires a short axis view.[14]. The routine used of TDI and 2DSTE have been limited upon follow up of segmental function due low repeatability of regional RV strain [34], also it have been limited for apical 4 chamber view.
Evaluating functional capacity in patients with systemic hypertension and heart failure using 2DSTE RV strain, 3DE RV end diastolic volume and EF; all those methods were strongly connected and related to each other, only 2DE derived RV strain was autonomously related to peak oxygen uptake [14].

A study with strain value of $-26 \pm 4\%$ performed on 116 individuals without any cardiopulmonary diseases or risk factors was efficient according to measurements obtained from 10 studies of 486 healthy subjects with a value of $-27 \pm 2\%$ [36]. Regional strain analysis have an important role in RV pathologies, therefore normal values are required for global and regional longitudinal strain of the RV. No clear normal values for both strain and strain rate are definite; however some data states that a RV free wall strain of $> 20\%$ is likely abnormal. [8]

**Fig 7.** Showing RV strain using 2D speckle tracking echocardiography. (Upper left diagram) display the end systolic strain color-coded. (Lower left diagram) numeric display of regional end systolic strain. (Upper right diagram) represent changes in strain rate during the cardiac cycle. (Left lower diagram) M-mode color coded segmental strain rates presenting global strain.

**RV IVA**

RV IVA = peak isovolumic velocity (IVV)/acceleration time to peak velocity (AT) is the formula used (Fig 8). It is less dependent on the load and it is measured by color-coded tissue Doppler or pulsed wave tissue Doppler that is 20% lower than the latter method; both methods are angle dependent and vary upon age and heart rate. No specific values have been mentioned by the ASE and EAVCI; however other
studies mentioned that the lower value is 2.2 m/s. RV IVA is not recommended to be used for evaluating RV systolic function.

RV IVA is not recommended to be used for evaluating RV systolic function.

Fig 8. Color-coded tissue Doppler using offline analysis used for evaluation of RV IVA using the following formula IVA=IVV/AT. Peak isovolumic velocity (IVV), acceleration time to peak velocity (AT).

RVOT SF (Right ventricular outflow tract shortening fraction)

RVOT SF uses an M-mode echocardiography measuring the systolic and diastolic diameter at the aortic valve level from the parasternal short axis view (Fig 9). The following method of calculation is used: 100 × 9(RVOT diastolic diameter – RVOT systolic diameter)/RVOT diastolic diameter. This method is simple showing prognostic values in chronic heart failure, and shows connection with longitudinal function and pulmonary pressure of the RV. Accurate measurement of RVOT SF is challenging because no clear landmarks for parasternal short axis view; thus oblique section underestimates RVOT SF.

ASE, EACVI or any other recommendations, has assigned no normal specific value. Different values were suggested for different pathologies, chronic heart failure adverse outcome related to RVOT SF <20%, diagnosis of the RV dysfunction is related to RVOT SF <30% showing a sensitivity of 95% and specificity of 100%, and the diagnosis of acute pulmonary embolism showed a specificity of 95.56 % and sensitivity of 100% with an RVOT SF <24.3%. [8, 20]
**Fig 9. M-mode echocardiography evaluating right ventricular outflow tract fractional shortening**

**RVOT SE**

RVOT SE described in 2012. It is new method used for evaluating the systolic excursion of the RVOT by M-mode echocardiography at the aortic level from the parasternal short axis view. [19] This method have the same limitation as RVOT SF if measured from the oblique plane. [8] No data have been recommended; however different studies suggested various values. RV dysfunction can be evaluated when RVOT SE <5.4 mm showing a specificity of 96% and sensitivity of 98%. [19]

**RV 3D echocardiography**

RV 3D was a serious step in the evaluation of RV EV (inflow, outflow, and apex); it can sliced into different mm. Offline analyses by different software packages independent of the RV geometry are used, making it one of the most important methods without ionizing radiation. Also the ability to be used on patients with cardiac pacemakers and defibrillators [14], showing highly accurate measurements in both children and adults via mapping of endocardial surface, despite underestimated results when used in
older patients [15, 30]. The following formula used: $100 \times \frac{\text{end diastolic volume} - \text{end systolic volume}}{\text{end diastolic volume}}$ (Fig 6).

Several methods used to calculate RV volume by 3D such as disk approach and semiautomatic border detection. Recently 3D echocardiography compared together with CMR had an RV EF overestimated by 1.16% plus lowest starting from 0.59 reaching as high as 2.92% [61]. Other studies suggested a good correlation measuring RV EF using RV 3D compared with cardiac MRI in both children and adults, it is more accurate for RV size than 2D echocardiography [14, 28]. This method is load and image quality dependent during endocardial surface study in coronal view, in case of severe dilation RV can’t be visualized clearly using RV 3D. A new software is being used with no need for extraction of coronal view, its results are strongly related to CMR [25]. Irregular rhythms and acoustic images show direct impact on RV 3D EF.[16] MRI-derived volumes of RV are underestimated by 3D-derived volumes.[18] The abnormal threshold is referred back to the age, body size, and gender specific values in some labs, suggesting an abnormal value of <45%.[8]

3D echocardiography used to study the RV mechanism such as longitudinal, radial, circumferential, and RV strain; however, no clear data have been set with errors varied between 12-44.2% depending on the area of examination in the RV [14]. It is unclear if 3D echocardiography derived strain had an extra value on the other routinely used methods.

RV remodeling and shape changes has been previously studied by 2DE in parasternal short axis view, till the development of this new methodology assessing 3DE derived global and regional RV shape centered on RV curvature analysis; it has been used on normal individuals as well as patients with pulmonary arterial hypertension. Results from a study revealed changes in regional curvature in patients with pressure overload such as: increase convexity in septum body and apical portions and flattening of the free wall, RVOT became more roundly shaped. [14]
Fig 6. 3D models of the RV rendered showing different views. White frame is the end-diastolic volume. Green models are the changes that occur during the cardiac cycle, with an EDV: 155.6 ml and ESV 83.5 ml. EDV (end diastolic volume), ESV (end systolic volume), SV (stroke volume), TV (tricuspid valve), PV (pulmonary valve).

Two-dimensional echocardiography (2DE)

2DE remains the mainspring for assessing RV size; it is widely available in clinics, cheap method, fast with no side effects. Right ventricular outflow tract (RVOT) can be used proximally for diagnosing arrhythmogenic right ventricular cardiomyopathy and distally for pulmonic and systemic flow. [21] While measuring RV extent values will remarkably vary upon the position of the transducer plus its complex geometry, therefore they should be viewed using 4-chamber and parasternal short axis.[14] It is less efficient compared with cardiac magnetic resonance (CMR), also in cases when the RV is severely dilated [14, 22].

Transesophageal echocardiography can also be used to assess RVOT, this helps during peri and intraoperative procedures in noncardiac surgery cases as well [14]. In addition, five deep transgastric views can be used providing information for RV inflow, outflow, dimensions and valves. [14] Sometimes it is challenging so contrast agents are used resulting in a better view of the RV wall thickness, area to volume ratio and borders; also small apical aneurysms, masses, and arrhythmogenic right
ventricular cardiomyopathy [23, 24]. Accurate information can be detected from the subcostal 4-chamber view for RV free wall thickness evaluation [21].

After the description of new echocardiographic techniques such as TASPE, FAC, RV MPI, and peak S wave velocity of the lateral tricuspid annulus by tissue Doppler imaging (TDI); 2D echocardiography using Simpsons rule and the area length method has no longer been recommended due to its inaccurate results [14]

**Cardiac magnetic resonance (CMR)**

Quantitative and morphological assessment of RV by CMR using steady state free precession sequence (SSFP) or T1 weighted black blood turbo spin echo is “Gold standard” technique, RVOT of the method depends on a single coronal view despite its unlimited imaging planes and high resolution [26]. CMR in some studies showed equal correlations on RV mass studied using CMR and after autopsy in an experiment performed on animals [14]. 3D techniques can be used (Fig 10), plus short axis or axial SSFP to measure RV volume and ejection fraction.

Although it is the gold standard for the evaluation of the RV EF with interobserver variability of < 7%, the lack of standard software packages, diverse quality of tricuspid and pulmonary valves values may interfere with the reproducibility of quantities.

RV area strain and multidirectional RV strain has been primarily assessed using CMR. Patients with pulmonary hypertension had a decrease in the RV longitudinal strain measured using CMR at different levels (mid ventricular radial deformation, apical, mid and basal). However, CMR derived strain analysis use in patients with arrhythmogenic right ventricular cardiomyopathy (ARVC) had a high reproducibility to wall motion abnormalities [14]. A new technique was described (RV Kinetic energy with 4 dimensional flow CMR), but nothing has been mentioned whether RV Kinetic energy will add any extra values on previously mentioned methods clinically.

Limitations of CMR include, RVOT boundaries are challenging to be identified, it is expensive and unavailable widely. It is contraindicated in patients with cardiac implants, the use of contrast shows side effects in patients with GFR< 30 ml/min such as nephrogenic systemic fibrosis and allergies in others. Variabilities of some values such as end diastolic volume (EDV) <7%, end systolic volume (ESV) <14%, and RV <20% reveals high reproducibility using CMR. [14]
Tissue characterization of the RV is challenging due to the thin RV wall plus epicardial fat between the heart and the pericardium. CMR has been considered number one method by providing detailed and accurate information on pathologies such as (Myocardial fibrosis, inflammation, or intramyocardial fat accumulation) [26]. RV free wall strain may reveal the extent of RV myocardial fibrosis linking it to the patients’ functional capacity. In order to understand the mechanism of pathological process and how these affect the myocardium of RV, metabolic imaging and RV myocardial oxygen consumption maybe the solution using single photon emission computed tomography (SPECT) and positron emission tomography [14].

A study in 2009 (Table 1) on 50 (23 males) children with orthopedic disorders excluding any history of cardiovascular disease with a median age 11 (0.7-18), normal values of RV volumes and EF both in
Males: EDV 83.8 ± 0.0499\textsuperscript{b} ml, ESV 35.3 ± 0.737\textsuperscript{b} ml, SV 48.2 ± 0.0524\textsuperscript{b} ml
Females: EDV 72.7 ± 0.0499\textsuperscript{b} ml, ESV 30.2 ± 0.0737\textsuperscript{b} ml, SV 42.1 ± 0.0524\textsuperscript{b} ml
Limitations were: small cohort size, sedation have been used in 14 patients and images during free breathing [32].
\textsuperscript{b}: Logarithmic SD
Another study in 2006 (Table 1), 120 (60 males) all are healthy volunteers with an age ranging from 20-79, measurements were as follow:
Males: EDV 163 ± 25 ml, EDVi 83 ± 12 ml/m\textsuperscript{2}, ESV 57 ± 15 ml, ESVi 29 ± 7 ml/m\textsuperscript{2}, SV 106 ± 17 ml, EF 66 ± 6%,
Females: EDV 126 ± 21 ml, EDVi 73 ± 9 ml/m\textsuperscript{2}, ESV 43 ± 13 ml, ESVi 25 ± 7 ml/m\textsuperscript{2}, SV 83 ± 13 ml, EF 66 ± 6% [33]

\textbf{Table 1. Normal values for the RV volumes and EF in adults, obtained by different imaging modalities}

<table>
<thead>
<tr>
<th>Imaging modality</th>
<th>3DE</th>
<th>CMR</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>507 (247 male)</td>
<td>245 (119 male)</td>
<td>114 (55 male)</td>
</tr>
<tr>
<td>Population type</td>
<td>Healthy adult volunteers</td>
<td>Healthy adult volunteers</td>
<td>Healthy children and adult volunteers (not older than 20 years)</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>----------------------------------------------------------------</td>
</tr>
<tr>
<td>Age</td>
<td>45 ± 16 Male/Female</td>
<td>48 ± 17 Male/Female</td>
<td>12.4 ± 4.1 Male/Female</td>
</tr>
<tr>
<td>EDV (ml)</td>
<td>107 (74, 163) / 81 (58, 120) ± 14</td>
<td>99 ± 14 / 74 ± 14</td>
<td>83.8 ± 0.0499b / 72.7 ± 0.0499b</td>
</tr>
<tr>
<td>EDVi (ml/m2)</td>
<td>52 ± 8 / 46 ± 8</td>
<td>84.5 ± 12.7 / 76.9 ± 12.7</td>
<td>83 ± 12 / 73 ± 9</td>
</tr>
<tr>
<td>ESV (ml)</td>
<td>44 (22, 80) / 30 (15, 52) ± 7</td>
<td>35 ± 7 / 23 ± 7</td>
<td>35.3 ± 0.0737b / 30.2 ± 0.0737b</td>
</tr>
<tr>
<td>ESVi (ml/m2)</td>
<td>18 ± 4 / 14 ± 4</td>
<td>32.5 ± 6.4 / 28.6 ± 5.4</td>
<td>28.6 ± 5.4 / 25 ± 7</td>
</tr>
<tr>
<td>EF (%)</td>
<td>60 (45, 75) / 63 (49, 79) ± 8</td>
<td>64 ± 8 / 69 ± 8</td>
<td>61.6 ± 4.5 / 62.8 ± 4.3</td>
</tr>
<tr>
<td>SV (ml)</td>
<td>66 (40, 91) / 52 (35, 72)</td>
<td>48.2 ± 0.0524b / 42.1 ± 0.0524b</td>
<td>106 ± 17 / 83 ± 13</td>
</tr>
<tr>
<td>Study limitations</td>
<td>No comparison between RV parameters obtained by</td>
<td>No comparison between RV parameters obtained by</td>
<td>Small size cohort size.</td>
</tr>
</tbody>
</table>

14 children were examined under...
3DE and CMR.
The RV values in patients ≥ 70 years (males in particular) should be interpreted with caution, given the small size of this age group.

The RV values in patients ≥ 70 years (males in particular) should be interpreted with caution, given the small size of this age group.

Sedation and the images were acquired while freely breathing, which compromised the image quality.

Data are expressed as mean± SD or median (5th, 95th percentile) unless stated otherwise.

3DE—three-dimensional echocardiography, CMR—cardiac magnetic resonance, CT—computed tomography, EDV—end-diastolic volume, EDVi—index of end-diastolic volume, EF—ejection fraction, ESV—end-systolic volume, ESVi—index of end-systolic volume, RV—right ventricle, SV—stroke volume.

a Median (range).
b Logarithmic SD.
c Range.

Source: E. Surkova et al. / International Journal of Cardiology 214 (2016) 54–69
Fig 10. Cardiac magnetic resonance (CMR), yellow line showing the RV endocardial outline displayed on 4-chamber view and analyzes using summation disc algorithm. The red and green rendered surfaces represent systole and diastole of the LV.

Computed tomography (CT)

Patients were CMR is contraindicated due a pacemaker, any metallic material and claustrophobia, thus a cardiac CT can be used (Fig 11). Cardiac CT major limitations are, high ionizing radiation, nephrotoxic contrast, stable cardiac rhythm is required together with a low heart rate so beta blockers have to be administered in patients with tachycardia for image attainment; therefore it can’t be routinely used [27]. A good correlation of RV volume between CT and MRI noticed.

RV size, volume, free wall thickness, systemic veins, pulmonary arteries diameters, and pulmonary embolism; all the following can be assessed by cardia CT [26, 27]. Cardiac CT showed a good correlation for RV volumes compared with cardiac magnetic resonance (CMR) and nuclear imaging, however cardiac CT overestimate RV volumes because it has a lower temporal resolution [14]. Meta-analysis stated that cardiac CT is the second most accurate and reliable method after 3D echocardiography estimating RV EF, however it overestimates values by 4.67% [14]. Right ventricular wall motion abnormalities (RV WMA) requires higher temporal resolution, so cardiac CT has an inadequate use according to its current capability [14].
A study on 103 patients, 59 (males) and 44 (females) with no previous history of cardiovascular diseases and normotensive estimated a set of data showing normal values: EDV 174.9 ± 48 ml, EDVi 93.3 ± 20.3 ml/m², ESV 82.1 ± 29.2 ml, EF 57.9 ± 8. No comparison between CT and CMR has been obtained in the following study (Table 1) [28].
**Fig 11.** Cardiac computed tomography (CT). (A) Shows RV inflow with arrows pointing to the infundibular fold. (B) Shows RV outflow with an arrow pointing at the trabecula septomarginalis (TSM). (C) Arrows showing the insertion point of the pulmonary leaflets (PL). (D) Shows posterior leaflets of tricuspid valve (TV) and moderator band (MB) that is connected to anterior papillary muscle (APM). (E) CT with transparent soft tissue. Left internal mammary artery (LIMA); right internal mammary artery (RIMA), left ventricle (LV), sternum (S).

**METHODOLOGY AND METHODS**

The following section consist of two tables. Strength and limitations of 2DE, 3DE, CMR, and CT found in (Table 1); revealing some criteria of each method being compared with others, including safety, cost, availability, accuracy etc…

Echocardiographic methods used to assess RV size and systolic function, their norms, advantages and limitations are briefly pointed out in (Table 2).

---

**Table 2. Strength and limitations of 2DE, 3DE, CMR, and CT**

<table>
<thead>
<tr>
<th></th>
<th>3DE</th>
<th>2DE</th>
<th>CT</th>
<th>CMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>++++</td>
<td>++++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>High dose ionizing radiation; the use of contrast media may induce allergic reactions and is nephrotoxic. Check GFR.</td>
<td>Only used on hemodynamically stable patients; together with contrast is nephrotoxic when GFR&lt;30 ml; contraindicated for patients with metallic implants.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>++</td>
<td>+</td>
<td>+++</td>
<td>++++</td>
</tr>
<tr>
<td>Availability</td>
<td>I</td>
<td>++++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Accuracy</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>GS</td>
</tr>
<tr>
<td>Parameter</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Time (min)</td>
<td>30-35</td>
<td>25-30</td>
<td>10-15</td>
<td>40-60</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>++</td>
<td>+++</td>
<td>++++</td>
<td>+++</td>
</tr>
<tr>
<td>Real time 3D imaging</td>
<td>Present</td>
<td>Absent</td>
<td>Abscent</td>
<td>Present</td>
</tr>
<tr>
<td>Accuracy of RV Volume and EF</td>
<td>+++</td>
<td>-</td>
<td>++++</td>
<td>++++</td>
</tr>
<tr>
<td>Parameters of RV Systolic function</td>
<td>EF</td>
<td>FAC, TAPSE, TDI S</td>
<td>EF</td>
<td>EF</td>
</tr>
<tr>
<td>Abnormality threshold</td>
<td>RV 3D EF &lt; 45 %</td>
<td>RV 2D EF &lt; 44 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limitations</td>
<td>Poor quality images results in poorly defined endocardial borders</td>
<td>Endocardial border is poorly visualized RV cant be acquired in a single view</td>
<td>Cardiac rhythm should be stable and heart rate low for best image quality.</td>
<td>High dose of ionizing radiation, nephrotoxic due to contrast</td>
</tr>
<tr>
<td></td>
<td>RV mass is unknown</td>
<td>Geometric data are limited</td>
<td>The participation of RVOT to systolic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patients should be cooperative</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cardiac rhythm should be stable. Function is neglected.

+ = Low, ++ = moderate, +++ = high, ++++ = very high, 3DE = three dimensional echocardiography, 2DE = two-dimensional echocardiography, GFR = glomerular filtration rate, I = investigational, RV = right ventricle, EF = ejection fraction, FAC = fractional area change, TAPSE = tricuspid annular plane systolic excursion, RVOT = right ventricular outflow tract, TDI S = tissue Doppler imaging, systolic velocity across the lateral segment of tricuspid annulus.

Table 3. Summary of various methods assessing RV systolic function (advantages, limitations, Abnormality threshold, normal values)

<table>
<thead>
<tr>
<th>Methods</th>
<th>Normal values(^a)</th>
<th>Abnormality threshold</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAC</td>
<td>49 (± 7) %</td>
<td>&lt; 35 %</td>
<td>RV contraction longitudinally and radially are reflected</td>
<td>Neglects the contribution of right ventricular outflow tract to total systolic function</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prognostic value is present</td>
<td>Highly reliable on image quality, and requires more time for analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Correlates with RV EF CMR</td>
<td>Not recommended after surgery</td>
</tr>
<tr>
<td>TAPSE</td>
<td>24 (± 3.5) mm</td>
<td>&lt; 17 mm</td>
<td>Easily measured</td>
<td>Angle dependent, sometimes load dependent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Less dependent on image quality</td>
<td>Only longitudinal function can be observed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prognostic value is present</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Associated with radionuclide EF</td>
<td></td>
</tr>
<tr>
<td>Tissue Doppler RIMP</td>
<td>0.38 (± 0.08)</td>
<td>&gt; 0.54</td>
<td>Equal RR intervals are not required</td>
<td>When RA pressure is increased it is less reliable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heart rate has no direct effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RV complex geometry limitations are neglected</td>
<td></td>
</tr>
<tr>
<td>Pulsed Doppler</td>
<td>0.26 (± 0.085)</td>
<td>&gt; 0.43</td>
<td>Prognostic value is present</td>
<td>Equal RR intervals are required</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metric</td>
<td>Range</td>
<td>Method</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------</td>
<td>----------------------------------</td>
<td>------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>RIMP</td>
<td></td>
<td>RV complex geometry limitations</td>
<td>When RA pressure is increased it is less reliable</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>are neglected</td>
<td>Heart rate has no direct effect</td>
<td></td>
</tr>
<tr>
<td>RV dp/dt</td>
<td>&gt; 400 mmHg/s</td>
<td>Simple method</td>
<td>When RA pressure is increased and in severe TR,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 400 mmHg/s</td>
<td>RV complex geometry limitations</td>
<td>it is less reliable</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>are neglected</td>
<td>Load dependent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Not enough data is found</td>
<td></td>
</tr>
<tr>
<td>Color-coded RV S'</td>
<td>9.7 (± 1.85)</td>
<td>Multisite sampling on the same</td>
<td>Analysis are offline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cm/s</td>
<td>beat</td>
<td>Angle dependent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 6 cm/sec</td>
<td></td>
<td>After cardiac surgery, RV global function is</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>not fully represented</td>
<td></td>
</tr>
<tr>
<td>RVOT FS</td>
<td>NA</td>
<td>Simple</td>
<td>Not enough data is found</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>Prognostic value is present</td>
<td>Affected by LV systolic function</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inaccuracy while measuring</td>
<td></td>
</tr>
<tr>
<td>RVOT SE</td>
<td>NA</td>
<td>Easily measured</td>
<td>Inaccuracy while measuring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td></td>
<td>Not enough data is found</td>
<td></td>
</tr>
<tr>
<td>RV IV</td>
<td>NA</td>
<td>Correlates with severity of</td>
<td>Not enough data is found</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>illness that affects RV</td>
<td>Angle dependent</td>
<td></td>
</tr>
</tbody>
</table>

FAC = fractional area change, EF = ejection fraction, TAPSE = tricuspid annular plane systolic Excursion, RIMP = right ventricular index of myocardial performance, RV S' = pulsed tissue Doppler derived S' wave velocity, RA = right atrium, RV = right ventricle, RVOT = right ventricular outflow tract, RVOT_FS = right ventricular outflow tract fractional shortening, RVOT_SE = right ventricular outflow tract systolic excursion, IVA = isovolumic myocardial acceleration
CONCLUSION

Due to its complex geometry, the RV size and function assessment is challenging. Therefore, various physical examinations, old and modern imaging techniques, and catheterization used in a variety of ways to view both structural and functional norms and pathologies of the RV. Based on the data, pictures, and tables mentioned above, various imaging modalities fused together in order to fully study the complexity of the RV. In the last decade echocardiography improved, by using 3D echocardiography and newly based strain imaging, made it possible to quantitate the anatomy and function of the RV. Other techniques are used (Table 3), but some are still in research field (RVOT_SE, RVOT_FS, Color-coded RV S’, RV 2D EF, RV IVA, and RV strain and strain rate).

In (Table 1) no comparison of RV parameters noticed between 3DE and CMR; CMR is highly accurate but it is expensive and time consuming. However, some pathologies dependeds on a single method more than the other which is somehow routinely used.

More studies and time needed to choose a single imaging method in order to assess RV size, function, structure, vascular characteristics and mechanics that are of an important potential for advanced and new developments. Until now, several methods used together providing a deeper sight of the pathological area, summing this into an accurate diagnosis for better treatment. Echocardiography thought to become the primary method in evaluating RV size and function.
References:


29. Focardi M, Cameli M, Carbone S, Massoni A, De Vito R, Lisi M et al. Traditional and innovative echocardiography parameters for the analysis of right ventricular performance in comparison with cardiac


