



Symmetry of cardiac function assessment

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Abstract

Both right and left ventricles are developed from two adjacent segments of the primary heart tube. Though they are different with regard to shape and power, they mirror each other in terms of behavior. This is the first level of symmetry in cardiac function assessment. Both cardiac muscle contraction and relaxation are active. This constructs the second level of symmetry in cardiac function assessment. Combination of the two levels will help to find some hidden indexes or approaches to evaluate cardiac function. In this article, four major indexes from echocardiography were analyzed under this principal, another seventeen indexes or measurement approaches came out of the shadow, which is very helpful in the assessment of cardiac function, especially for the right cardiac function and diastolic cardiac function.

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1 Introduction

Symmetry has long fascinated the great minds in many disciplines from art to theoretical physics. In the field of medicine, this principle could help to better evaluate functions by asserting equal opportunities. The circulation system is powered mainly by cardiac muscle and valves activities, which are specifically the coherent dilation and contraction of right and left ventricles. Complete and accurate cardiac function assessment is essential in many clinical scenarios. Today, left ventricular systolic function evaluation has become routine in most clinical settings; left ventricular diastolic function measurement is getting more and more attentions; unfortunately, satisfactory assessment of right ventricular function is still a dream by clinicians due to lack of available reliable indexes. A number of new indexes introduced in this paper as a result of the symmetry concept will enable us to obtain a much better picture of cardiac function.

2 Symmetry in cardiac function assessment

The authors think two levels of symmetry exist in cardiac function assessment. The first level of symmetry is both

right and left ventricles have mirror activities. This is easy to understand with many cardiac clinicians/researchers having already taken advantage of it. The second level of symmetry is systole and early diastole, which is based on the fact that both systolic and early diastolic processes are active. This will lead to the finding of counterparts of indexes used only in either systolic or early diastolic process. Combination of the two levels of symmetry will be productive. However, there is no farther endeavor to systemically explore how far and deep this theory can go.

At the beginning of human development, both the ventricles developed from two adjacent segments of the primary heart tube. Later, they will have to manage two different circulation systems. The left ventricle will pump up the systemic circulation, while the right ventricle needs to provide energy to the pulmonary circulation. In the pulmonary system, the circulation resistance is approximately a third of that in the systemic circulation, which makes the right ventricle wall thickness roughly half of its left neighbor. Since the left ventricle is much stronger, the interventricular septum is captured in the regular daily task of left ventricular contraction and relaxation. In terms of shape and power, both ventricles are asymmetric. With our interests focusing on the behavior of contraction and relaxation, the symmetry principle can still apply. Both ventricles deliver contraction and relaxation. Both contraction and relaxation are active.

3 Application in echocardiography

Echocardiography branches from medical imaging where

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ultrasound waves are used to exam the structure and function of the heart. Here, we are interested in what the symmetry principle will bring us in this rapidly evolving field.

Symmetry of both left and right ventricular activity with regard to behavior is supported by some indexes describing both ventricles.^[1-4] In 1989, Bargiggia, *et al.*^[1] introduced dp/dt to describe left ventricular systolic function, ten years later, Oh, *et al.*^[2] pushed it on the right side of the heart. Another example is the Tei index,^[3,4] which is also developed to evaluate both ventricular functions.

Symmetry of both diastolic and systolic processes is suggested by the fact that both are active. Due to left ventricular relaxation is active, left ventricular diastolic time constant is discovered and well accepted to be the most established index to describe left ventricular diastolic function. Since left ventricular contraction is also an active process; it is reasonable for us to think that left ventricular systolic time constant exists. This idea can be tested with a similar experiment conducted by Weiss, *et al.*^[5] except focusing on the systolic process. Interestingly, based on the developed computational and mathematical methods, we can prove the symmetry between left ventricular systole and diastole. To introduce the proof, we first examine the calculation of Tau, which is: $\text{Tau} = 1.2 (t1 - t3)$, $(t1 - t3)$ is the time interval from 3 m/s to 1 m/s on the descending branch of continuous wave Doppler mitral regurgitation spectrum.^[6] This means, $(t1 - t3)$ is the core to evaluate left ventricular diastolic function.

In terms of left ventricular systolic function evaluation by dp/dt, we can find that $\text{dp/dt} = 32/(t3 - t1)$, $(t3 - t1)$ is the time interval from 1 m/s to 3 m/s on the ascending branch of continuous wave Doppler mitral regurgitation spectrum. Since only $(t3 - t1)$ is a variable, it is the key to evaluate left ventricular systolic function.^[1]

It is interesting to ponder upon the question as to how much this symmetry of systole and diastole principal can cover. The systole includes isovolumic contraction and ejection phases. However, there are four phases in diastole: isovolumic relaxation, rapid inflow, diastasis and atrial systole. From the above analysis, we come to a conclusion that there could be symmetric Tau and dp/dt, which reveals the symmetry exists between isovolumic contraction and isovolumic relaxation. It deserves to mention that during isovolumic periods, both the aortic and mitral valve are closed, which makes it the best time to evaluate cardiac function due to relative independence of foreload and afterload. The next comes the systolic ejection phase and the diastolic rapid inflow phase. Since the active cardiac muscle movement is still a driving force of these periods, especially in the early stage of the phase, symmetry should still apply.

For example, the color M-mode flow propagation velocity could be measured in both phases. In the late stage of the phases, the active systolic contraction/diastolic relaxation comes to an end, which shows that the symmetry is ready to phase out. This is for systolic and diastolic symmetry of Tei index. Further investigation is needed to determine how much the symmetry principle is applied here. The last two phases of diastole, diastasis and atrial systole, cannot be found in systole. Apparently, no more symmetry exists ever since.

So far, there are two levels of symmetry in cardiac function evaluation, one is the symmetry of left and right ventricles, and the other is the symmetry between systole and early diastole. Under this principal, we introduce a list of new indexes that can be valuable in cardiac function evaluation. They can be validated using the same experimental design for the known counterparts.

3.1 Ventricular contractility assessment (dp/dt)

The dp/dt is used to describe both left and right ventricular systolic function (Figure 1A, C). Today, dp/dt is integrated into many echo machines on the market for evaluation of left and right ventricular systolic function. With the symmetric contraction and relaxation on mind, we can introduce two new indexes to evaluate left and right ventricular diastolic function from dp/dt. This will be of great interest to clinicians and/or researchers, who have been enthusiastic with the systolic dp/dt (s). The same measurement can be done on the other branch of the regurgitation spectrum (Figure 1A, C). With regards to the methodology, dp/dt measurement can also be done on aortic or pulmonary regurgitation spectrum (Figure 1B, D). The dp/dt measurements are summarized in Table 1.

3.2 Left ventricular diastolic time constant

The left ventricular diastolic time constant, Tau is the most established index to describe left ventricular diastolic function. With increasing interests focusing on the non-invasive endeavors in echo lab, and blessed by the fast digital technology progress, Tau could be measured in our local clinic in the near future.^[6-12] The non-invasive calculation of Tau is based on the measurement performed on either the descending branch of the continuous-wave Doppler mitral regurgitation spectrum, or the ascending branch of continuous-wave Doppler aortic regurgitation spectrum (Figure 1A, B). Suggested by the symmetry principle, the following three types of missing Tau will come into light: (1) Left ventricular systolic time constant; (2) right ventricular diastolic time constant; and (3) right ventricular systolic time constant.

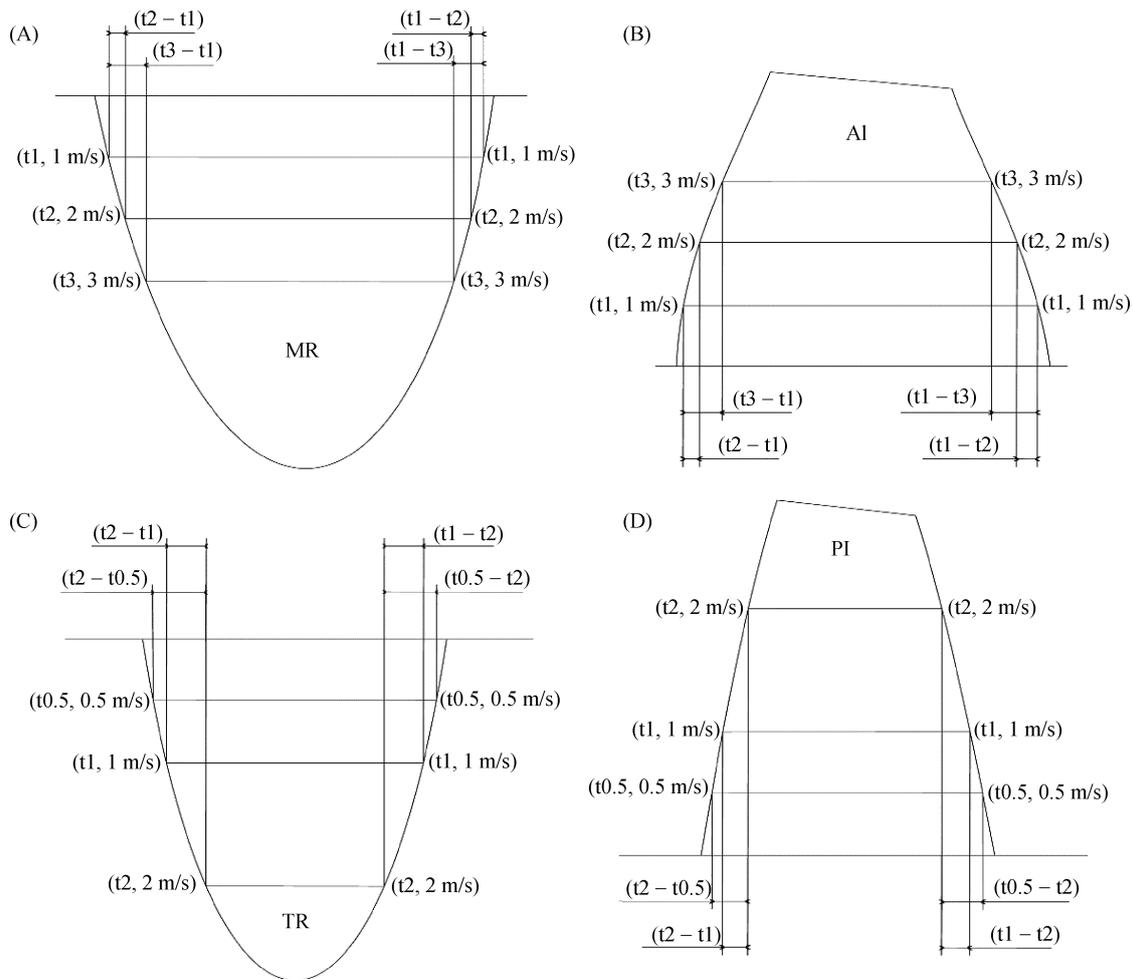


Figure 1. Schematic description of measurement on continuous wave Doppler regurgitation spectra. (A): MR. LV systolic $dp/dt = 32/(t_3 - t_1)$. LV diastolic $dp/dt = 32/(t_1 - t_3)$. (B): AI. LV systolic $dp/dt = 32/(t_1 - t_3)$. LV diastolic $dp/dt = 32/(t_3 - t_1)$. (C): TR. RV systolic $dp/dt = 12/(t_2 - t_1)$. RV diastolic $dp/dt = 12/(t_1 - t_2)$. (D): PI. RV systolic $dp/dt = 12/(t_1 - t_2)$. RV diastolic $dp/dt = 12/(t_2 - t_1)$. AI: aortic insufficiency; LV: left ventricle; MR: mitral regurgitation; PI: pulmonary regurgitation; RV: right ventricle; TR: tricuspid regurgitation.

Universal Tau could be of great value to cardiac function evaluation. Left ventricular diastolic time constant is the most established index to describe left ventricular diastolic function. All the other tau(s) will play a role in their own category. Right ventricular Tau(s) are even more pragmatic since there are more pulmonary and tricuspid regurgitations,

compared with aortic and mitral valve regurgitations. Furthermore, right ventricular Tau(s) are more valuable since few satisfactory indexes exist to describe right ventricular function due to its irregular shape (Dr Sherif Nagueh, personal communication). Universal Tau is summarized in Table 2.

Table 1. Symmetric dp/dt .

	Systole	Diastole
MR	LV systolic $dp/dt = 32/(t_3 - t_1)$? LV diastolic $dp/dt = 32/(t_1 - t_3)$
LV	Bargiggia, <i>et al.</i> ^[11]	
AI	? LV systolic $dp/dt = 32/(t_1 - t_3)$? LV diastolic $dp/dt = 32/(t_3 - t_1)$
TR	RV systolic $dp/dt = 12/(t_2 - t_1)$? RV diastolic $dp/dt = 12/(t_1 - t_2)$
RV	Oh, <i>et al.</i> ^[2]	
PI	? RV systolic $dp/dt = 12/(t_1 - t_2)$? RV diastolic $dp/dt = 12/(t_2 - t_1)$

AI: aortic insufficiency; LV: left ventricle; MR: mitral regurgitation; PI: pulmonary regurgitation; RV: right ventricle; TR: tricuspid regurgitation.

Table 2. Symmetric cardiac function time constant.

	Systole	Diastole
		LV diastolic time constant
MR	? LV systolic time constant	Chen, <i>et al.</i> ^[10] , Nishimura, <i>et al.</i> ^[7]
LV		Scalia, <i>et al.</i> ^[8] , Bai, <i>et al.</i> ^[12]
AI	? LV systolic time constant	LV diastolic time constant
		Kazuhiro ^[13] , Bai, <i>et al.</i> ^[12]
TR	? RV systolic time constant	? RV diastolic time constant
RV		
PI	? RV systolic time constant	? RV diastolic time constant

AI: aortic insufficiency; LV: left ventricle; MR: mitral regurgitation; PI: pulmonary regurgitation; RV: right ventricle; TR: tricuspid regurgitation.

Table 3. Symmetric myocardial performance index.

	Systole	Diastole
LV	LV Tei index focuses on systole Tei, <i>et al.</i> ^[3]	? Left ventricular Tei focuses on diastole
RV	RV Tei index focused on systole Tei, <i>et al.</i> ^[4]	? Right ventricular Tei focuses on diastole

LV: left ventricle; RV: right ventricle.

3.3 Myocardial performance index

Myocardial performance index or Tei index is used to evaluate both the left and right ventricular function.^[3,4] Both the Tei indexes focus on systolic elements. Following the two level symmetry principle, there should be two more Tei indexes focusing on diastolic elements. Summary of updated Tei indexes is shown in Table 3.

3.4 Color M-mode flow propagation velocity

This index is measured with color Doppler M-mode when the mitral valve opens from the four-chamber view.^[14] The M-mode cursor is placed in the center of the column of mitral valve. Color M-mode flow propagation velocity is used to evaluate left ventricular diastolic function. By applying symmetry principle, we will get three new indexes: (1) The first one can be used to evaluate left ventricular systolic function with the Color Doppler M-mode cursor placed in the center of left ventricular outflow tract. (2) The second one can be used to evaluate right ventricular diastolic function with the Color Doppler M-mode cursor placed in the center of the column of tricuspid valve. (3) The third one can be used to evaluate right ventricular systolic function with the Color Doppler M-mode cursor placed in the center of the right ventricular outflow tract. All about color M-mode flow propagation velocity is in Table 4.

So far, only four Doppler major indexes in echocardiography have been analyzed based on the two level symmetry principle. We are showing another seventeen (question marks in the tables) indexes or measurement approaches under symmetry principle in this paper. Clinicians and/or researchers working with other cardiac imaging facilities may try this symmetry principal in their own field as well. The idea of symmetry in cardiac function assessment will fly when all indexes in the tables are tested one by one in the future.

Table 4. Symmetric color M-mode flow propagation velocity.

	Systole	Diastole
LV	? Sampled in LVOT to assess left ventricular systolic function	Sampled in MV to assess Left ventri- cular diastolic function Brun, <i>et al.</i> ^[13]
RV	? Sampled in RVOT to assess right ventricular systolic function	? Sampled in TV to assess right ventricular diastolic function

LV: left ventricle; LVOT: left ventricular outflow tract; MV: mitral valve; RV: right ventricle; RVOT: right ventricular outflow tract; TV: tricuspid valve.

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