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ANALYSIS OF MECHANICAL IMPEDANCE AT AORTIC RING LEVEL, BY GENDER AND AGE GROUPS

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ABSTRACT. The study of the blood circulation inside the heart by using the classical physics concepts can offer a more reliable view on the mechanism of blood pumping. We had defined, calculate and analyze the mechanical impedance that blood as a fluid have to overpass on entering the aorta ring. We had compared the variation of the mechanical impedance and E /A ratio by gender and age This analyses results allows us to say that the mechanical impedance can be used as a cardiac parameter. A general decrease with age is observed on the mechanical impedance, especially for women's. Our study is opening the gate for more biophysical studies that can be done on heart pumping mechanism.
KEYWORDS: mechanical impedance, blood speed, diastole, systole, E/A ratio,

INTRODUCTION

Physics consideration

The mechanical impedance of the fluids is defined as the ratio of the force applied to produce the flow of a fluid and its velocity

$$\mathbf{Z = dF / dv \ (1)}$$

Mechanical impedance can be used in vascular biophysics to characterize the relationship between the mechanical resistance of the circulatory system to the flow of blood in response to a heart rate pulse gradient.

Starting from these physical magnitudes we will try to achieve a biophysical study of this impedance calculated as the ratio of the compressive force of the heart muscle to the aortic ring and the rate of blood flow through the aortic ring.

Anatomic and physiologic consideration

Heart Cycle (Heart Revolution): is the functional torque formed by a period of contraction of the heart (systole) followed by a period of relaxation (diastole).

The ventricular systole. With the onset of ventricular contraction, the intracavitary pressure begins to increase and causes the mitral valve (MI) to close suddenly. This moment, considered as the beginning of the left ventricle systole, is seen both on echocardiography and on the phonocardiogram, as the first large noise vibration I. This phase lasts about 50 milliseconds and represents the isovolumic (isometric) contraction phase or isocortical contraction. When the LV pressure exceeds the blood pressure value in the aorta and the RV pressure slightly exceeds the blood pressure in the pulmonary artery, the semilunar valves open and start the next phase, the isotonic ventricular contraction phase, or the ejection. This phase comprises, in turn, the rapid ejection phase and the slow ejection phase.

Ventricular diastole. The end of the physiological protodiastole is marked by valve closure

Isovolumic relaxation is between the closing of the semilunar valves and that of the atrio-ventricular valve opening. During this phase, the ventricles are tightly closed cavities. Isovolumic relaxation ends when ventricular pressure falls below the atrial pressure, which progressively increases during this time due to venous return. The atrio-ventricular valves are now opened and ventricular filling begins.

The fast ventricular filling phase begins immediately after opening the atrioventricular valves. Blood enters ventricular velocity, based on the atrioventricular pressure gradient. During this phase, about 2/3 of the ventricular filling is achieved.

The slow ventricular filling phase begins when the blood flow through the atrioventricular valves decreases due to the decrease of the atrio-ventricular pressure gradient by emptying the atria and filling the ventricles with blood. During slow filling, also called diastasis, there is a slow increase in ventricular volume, while the atrial pressure decreases slowly, reaching almost a plateau. The rapid filling phase and diastasis are performed only based on the atrio-ventricular pressure gradient. They have a major contribution to ventricular filling, the proportion of atrial systole being much smaller.

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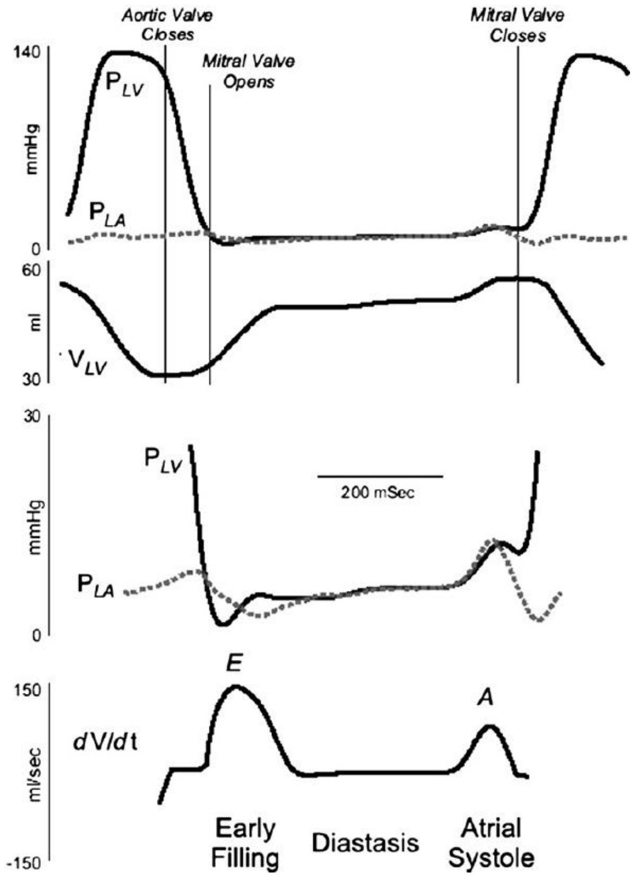
The atrial systole completes ventricular filling, to which it contributes 25-30% but is not indispensable. The presystolic ventricular filling, due to the atrial systole, is active, and it relaxes the ventricular wall, contributing to the increase in volume, thus cardiac performance. The right atrial systole precedes the left one, but the VS systole precedes that of the VD. The VD ejection period is longer than VS, because the VS is more vigorous and results in faster ejection of the blood in the aorta.

The aortic ring compression force will be calculated starting from the surface of the aortic ring and the blood pressure at the entrance to the aorta.

Through this prism of biophysics, we will try to define physical magnitudes that quantify the contraction and relaxation of the left ventricle during a cardiac cycle.

During the diastole of the left ventricle, in its various phases, the blood velocity at the entry through the mitral valve and the pressure in the ventricle are shown in the following diagram.

Fig.1. Blood speed flow, pressure and volume at mitral valve entry (Chaterine M. Otto Clinical Echocardiography)(https://www.researchgate.net/figure/5537862_fig1_Fig-1-Recording-of-left-atrial-pressure-P-LA-left-ventricular-pressure-P-LV)



We observe the two E and A waves corresponding to the isovolumic relaxation (E) and the atrial contraction (A).

The ratio of maximum speeds in wave E and wave A E / A respectively is a classic indicator of diastolic dysfunctions.

As we have seen, we can define a mechanical impedance in the aortic ring element as follows:

Impedance at the aortic ring level.

The hydrostatic force at the level of the aortic ring can be calculated as:

$$\mathbf{F_a = p_a \times S_a}$$

Than calculating the mechanical impedance as in formula (1) we have:

$$\mathbf{Za = p_a \times S_a / v_a} \qquad \mathbf{(2)}$$

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p_a – the pressure at the aortic ring
S_a – the aorta section $\quad Sa = \pi R_a^2$, $\quad R_a$ – the aortic ring radius
v_a – blood velocity at the entrance to the aorta

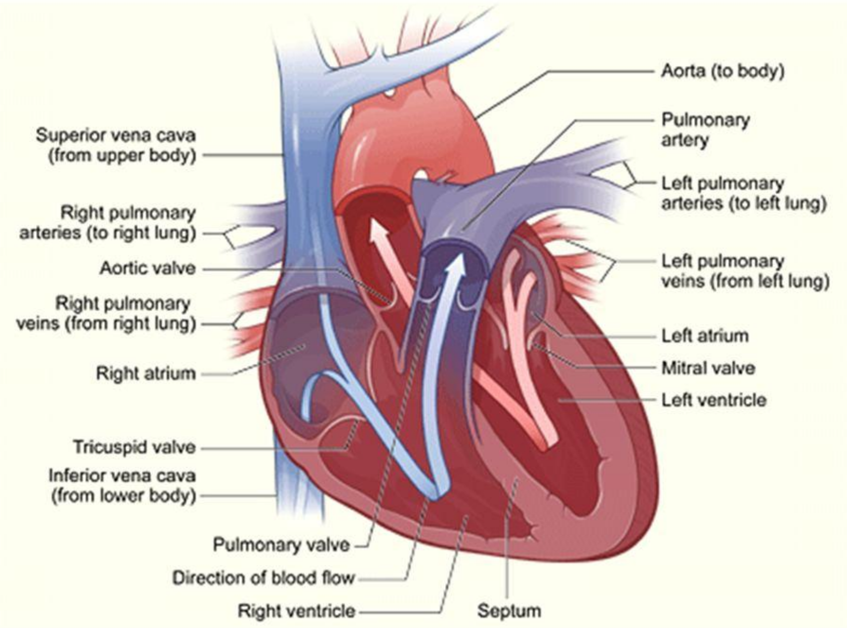

Fig. 2. Heart anatomy
http://slideplayer.com/slide/7263558/

MATERIAL AND METHOD

We had access to a continuous Doppler echograph (General Electric Vivid 7 dimension) The data has been taken over several years from 2011 to 2014.

These data were mathematically processed in Excel spreadsheets in the Microsoft Office suite. Mathematical calculations are the usual ones without entering into complex mathematical analysis.

RESULTS

We had access to data collected from 2977 patients splited by gender as follows:

Table I with gender distribution and of 2997 patients studied

Gender	**Number**	**Percentage**
Women's	1646	55%
Men's	1331	45%
TOTAL	**2977**	

For all these patients we had calculate the mechanical impedance as shown in formula (2) and the ratio E/A which represent the ratio of the speed of blood flowing through aortic ring during prefiling period (E) and filing period (A) as explained in the introduction paragraph.

The calculated data (mechanical impedance Za in the aortic ring and E / A ratio per age and gender are shown in the following table:

Table II representing the mechanical impedance Za at the aortic ring and the velocity ratio in E and A waves (E / A) for the women's in the studied group

Women's		
Age	**Za <Ns/m>**	**E/A**
0-10 years	0.34	0.98
11-20 years	0.42	1.02
21-30 years	0.30	1.00
31-40 years	0.31	0.97
41-50 years	0.30	0.98
51-60 years	0.30	1.06
61-70 years	0.28	1.02
71-80 years	0.29	0.99
over 80 years	0.27	1.02
Average	**0.30**	**1.02**

Men's		
Age	**Za <Ns/m>**	**E/A**
0-10 years	0.21	1.11
11-20 years	0.22	0.99
21-30 years	0.26	1.02
31-40 years	0.28	1.01
41-50 years	0.26	1.04
51-60 years	0.24	1.06
61-70 years	0.26	1.02
71-80 years	0.24	1.02
over 80 years	0.30	0.99
Average	**0.25**	**1.04**

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Tab. III representing the mechanical impedance Za in the aortic ring and the velocity ratio in E and A waves (E / A) for men's in the studied group.

If we graphically represent these sizes, we get the following results:

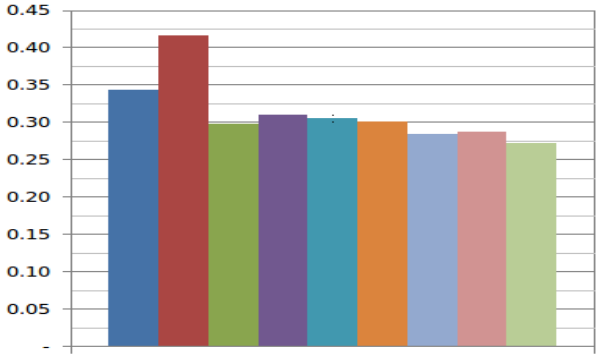

Fig. 3. Mechanical impedance at the aortic ring for women's by ages

For women, we found that the mechanical impedance in the aortic ring decreases with age, that is due to the ring narrowness or intraventricular pressure decreases with age. In the literature, it appears that with the aging process the aortic ring may narrow due to cholesterol deposition. Also, intraventricular pressure may decrease due to a decrease in cardiac muscle contractility. Figure 5 shows this decrease and that is a confirmation for using Za as an indicator in cardiac function.

Also for women it can be noticed that the ratio of speeds in wave E and wave A shows 2 maxims, one around the age of 20 years and the other around the age of 60.

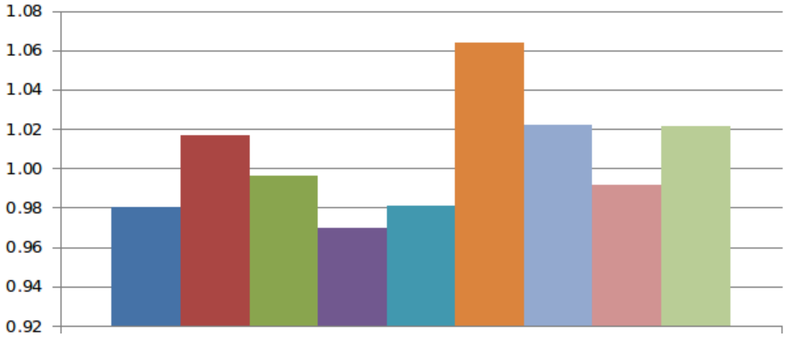

Fig.4. Speed ratios in wave E and A – women

For men, the decrease in age is not obvious even though it appears in literature.
It also maintains the E / A variance with two maxims at 20 and 60 respectively

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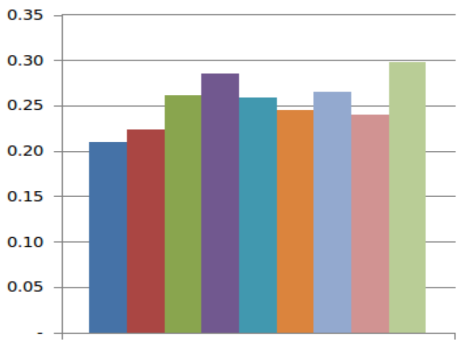

Fig. 5. Mechanical impedance Za - men

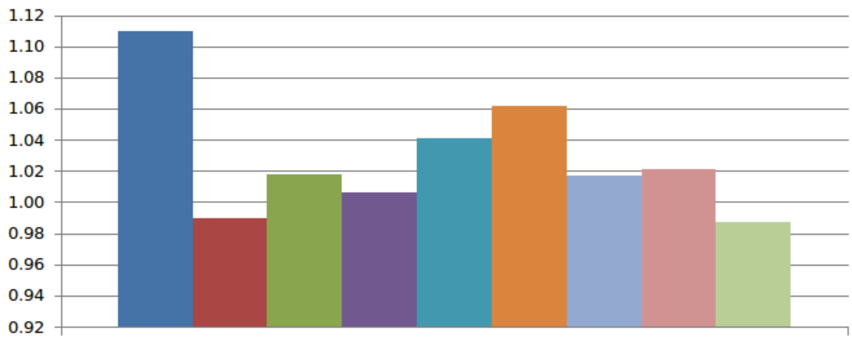

Fig. 6 E / A ratio - Men

DISCUSSIONS

Sherif F. Nagueh in his book "Recommendations for the evaluation of left ventricular diastolic function by echocardiography" - 2009 Feb 22, presents a variation table of several echocardiographic sizes by age.

Normal values for Doppler-derived diastolic measurements

	Age group (y)			
Measurement	**16-20**	**21-40**	**41-60**	**>60**
E/A ratio	1.88 ± 0.45	1.53 ± 0.40	1.28 ± 0.25	0.96 ± 0.18

We observe that there is a decrease of E/A ratio with the age.

From graphical representations of our data we can see the following:

- At women, mechanical impedance generally decreases with age which is normal knowing that the aorta ring is getting smaller with age
- At men, mechanical impedance Za has an increasing trend which is not relevant and have no physiological correspondence.
- The E / A ratio shows two maxims for both women and men which is not presented in the classical studies
- Mechanical impedance in men is on average less than in women.

CONCLUSION

As a general conclusion we can say that mechanical impedance as it was calculated in formula (2) can be a potential indicator of the health of myocardium.

Our study is just a beginning of several studies that logically came out from the discussions we presented.

The following studies can be drawn from the study:

- Since the diagnosis of people has not been taken into account, the above data are not definingly relevant. It is necessary to divide the patients according to the diagnosis to see the influence of a condition in the modification of the mechanical impedance value. Obvious the malfunction of the myocardium will influence the mechanical impedance.

- We propose to study, for diastolic dysfunction of varying degrees, the variance of the impedance Za and the E / A ratio. This will help in promoting mechanical impedance as a diagnosis marker for diastolic dysfunction.
- The E / A ratio could be replaced by the A-area reported in the E-wave area that would indicate the volume of blood in the A-wave in relation to the E-wave volume. This volume ratio would give a quick indication On diastolic dysfunction and correlated with the above coefficient of elasticity could create a set of markers with relevance to myocardial health.

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