DEFINITION AND STUDY OF MYOCARDIUM ELASTICITY COEFFICIENT, BY GENDER AND BY AGE GROUP

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Abstract: We will, try to define a measure for the way of filling of the human heart left ventricle having in background the elastic behaviour of the myocardium. We will note this measure as the elasticity coefficient and the calculation formula will be deducted from energetic consideration. Rely on basic heart and blood flow mechanics, a mathematical formula for elasticity coefficient was defined. The formula includes usual parameters: blood density, left ventricle longitudinal dimension, ejection fraction, blood speed through the mitral valve during E wave. By analyzing new elasticity coefficient values (k) across a cohort of 2977 patients we observed that E/A ratio (the ration of blood speed in E and A wave, respectively) and k have the same trendline with age. This can be an indication that k can define myocardium activity, but for a validation of this new parameter further studies have to be made.

Key words: Elastic coefficient, myocardium.

INTRODUCTION

At present days, there are a lot of models presenting the mechanical motion of the left ventricle during the cardiac cycle. We are not trying to propose another model. We propose a different type of approaching the cardiac mechanics; the "energy conservation" way. Always the energy conservation way is a simpler, but not simplistic, way to characterize a mechanical motion. Our scope of works is in general to present the echocardiography as a quantitative method of medical exploring and in specific to define a new data that will help in cardiac diseases diagnosis.

Starting from the conservation of mechanical energy we will try to define a coefficient that will characterize the filling of the human heart left ventricle (LV) having in background the mechanical elasticity which undoubtedly the

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myocardium present. We will name this ‘coefficient of elasticity’, and the definition formula we will calculate as presented in next paragraph.

First let’s have some physiological consideration about cardiac cycle, especially for diastolic phase. On entering the left ventricle (LV), blood that comes from the left atrium (LA), passes through the mitral valve. The filing of the ventricle in made in two steps. First step is the prefilling period in which the blood pass the mitral valve without any contraction of the left atrium. This period is named “E wave”. The second step is the filling of the left ventricle by blood passing through the mitral valve pumped by the left atrium. This period is named “A wave”.

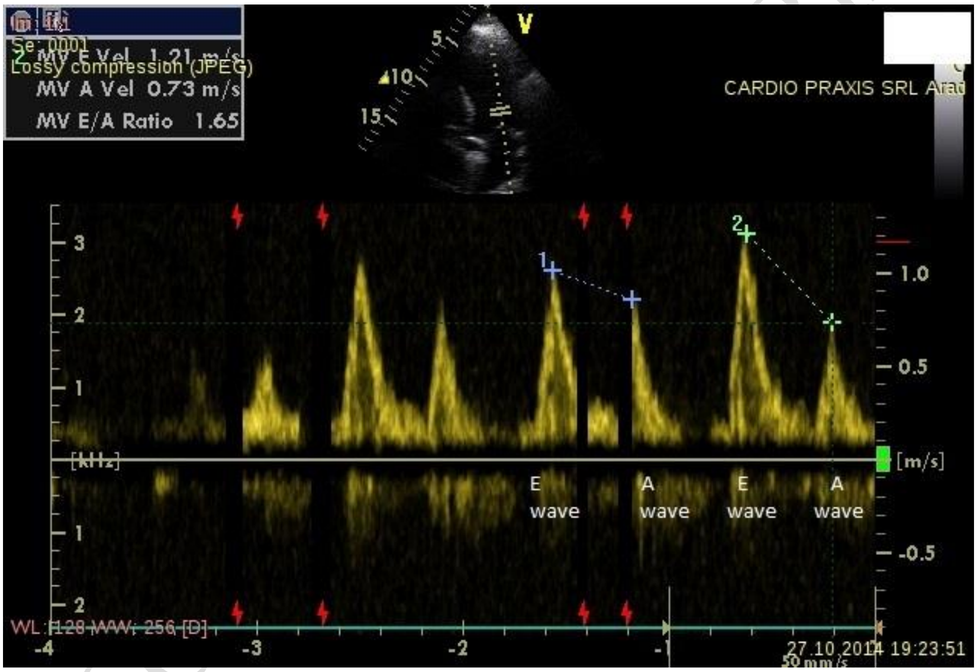


Fig. 1. E and A waves on a Doppler echocardiography.

During prefilling, i.e. during E wave, blood passes through the mitral valve only due to a negative pressure created by left ventricle elasticity. We will consider that the kinetic energy, imprinted to blood during E wave, is due solely to the elastic energy stored in the LV muscle (myocardium part).

THEORY

In our study, we had made the following assumption as working hypothesis using basic concepts in theoretical description of heart functioning [2, 3]: (1) the shape of the left ventricle (LV) is a cylinder, and (2) during contraction of LV the transversal deformation (strain) is much bigger than the longitudinal deformation (strain).

Elastic energy stored in the myocardium is:

$$E_{\mathrm{pe}} = k\frac{\Delta x^2}{2} \quad (1)$$

where: E_{pe} – elastic energy, k – myocardium elasticity coefficient, Δx – transversal deformation (strain) of LV. Δx is the variation of the length of the transversal muscle fibber.

The kinetic energy of blood at the entrance through the mitral valve during E wave is:

$$E_{\mathrm{c}} = m\frac{v^2}{2} = \rho V\frac{v^2}{2} \quad (2)$$

where: E_{c} – kinetic energy, M – mass of blood, ρ – blood density, V – blood volume, v – blood speed through the mitral valve during E wave.

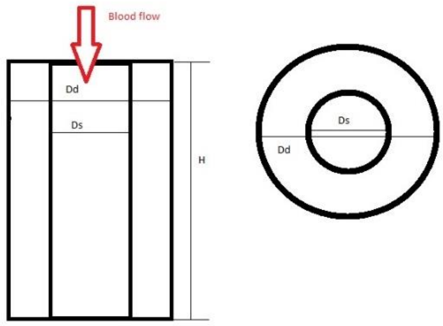


Fig. 2. Schematic filling of LV; *D*d – diastolic diameter of LV; *D*s – systolic diameter of LV; *H* length of LV).

Applying normal geometry, we can calculate (using parameters defined in the legend of Fig 1) the blood volume entering to the LV (Eq. 3),

$$V = \frac{\pi H}{4}\left(D\mathrm{d}^2 - D\mathrm{s}^2\right) \quad (3)$$

the transversal deformation Δx (The transversal deformation represents the variation of the muscular fibre length. We had considered that the muscular fibre is transversal so the variation if his length is the difference of the length of the circle in diastolic phase versus the systolic phase.) (Eq. 4),

$$\Delta x = \pi\left(D\mathrm{d} - D\mathrm{s}\right) \tag{4}$$

and the ejection fraction (*EF*) (Eq. 5).

$$EF = 1 - \left(\frac{D\mathrm{s}}{D\mathrm{d}}\right)^2 \tag{5}$$

By applying the energy conservation law as equation (1) = equation (2) and using equations (3), (4), and (5) we get as follows:

$$E_{\mathrm{pe}} = E_{\mathrm{c}}, k\frac{\Delta x^2}{2} = \rho V\frac{v^2}{2} \Rightarrow k = \frac{\rho\pi H}{4}\frac{\left(D\mathrm{d}^2 - D\mathrm{s}^2\right)v^2}{\pi^2\left(D\mathrm{d} - D\mathrm{s}\right)^2} \tag{6}$$

resulting in:

$$k = \frac{\rho H}{4\pi}\left(1 - 2\sqrt{1 - EF}\right)v^2 \tag{7}$$

That is the formula we will use for calculating k in analysing recorded data on patients.

EXPERIMENTAL

The measurements have been done using a continuous Doppler echograph Vivid 7 Dimension (General Electric, USA).

Data were taken over 4 years from 2011 to 2014. These data were processed in mathematical Excel tables. Mathematical calculations are the usual's without going into complex mathematical analysis.

RESULTS

We had calculated in parallel the *E/A* ratio which represent the blood speed in E wave / blood speed in A wave and k coefficient calculate as in formula (7) for 2977 patients. We decide to use *E/A* ratio because is a large scale used parameter for cardiac diseases diagnosis. We are comparing our coefficient of elasticity k with the consecrate parameter E/A. Because we are interested in the variation of this coefficient and correlation between k and E/A, in formula (7) we had ignored the constant coefficient $\rho H/4\pi$.

The variation of E/A and k with age and gender we had represented in the following diagrams (Fig. 3, 4, 5). We had represented $k/50$ because of presentation reasons:

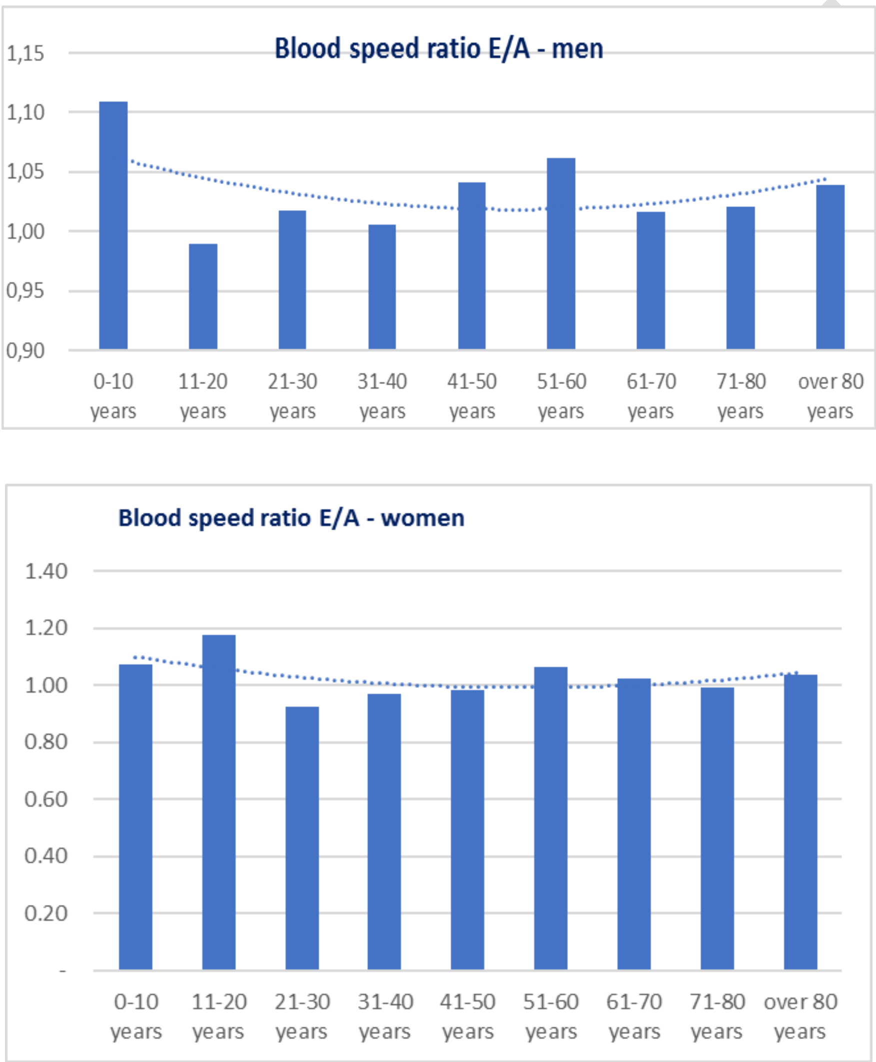


Fig. 3. Blood speed ratio E/A Trend line calculated as a 2-nd order polynomial function.

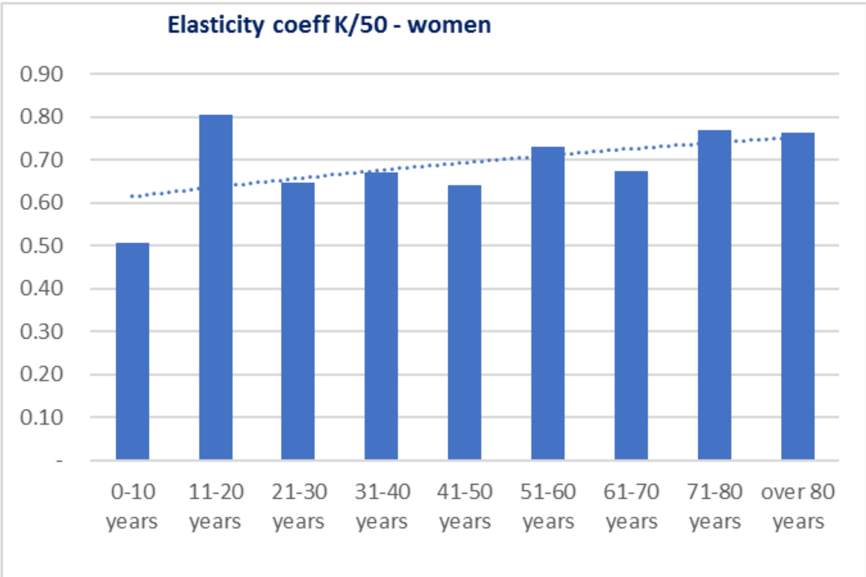
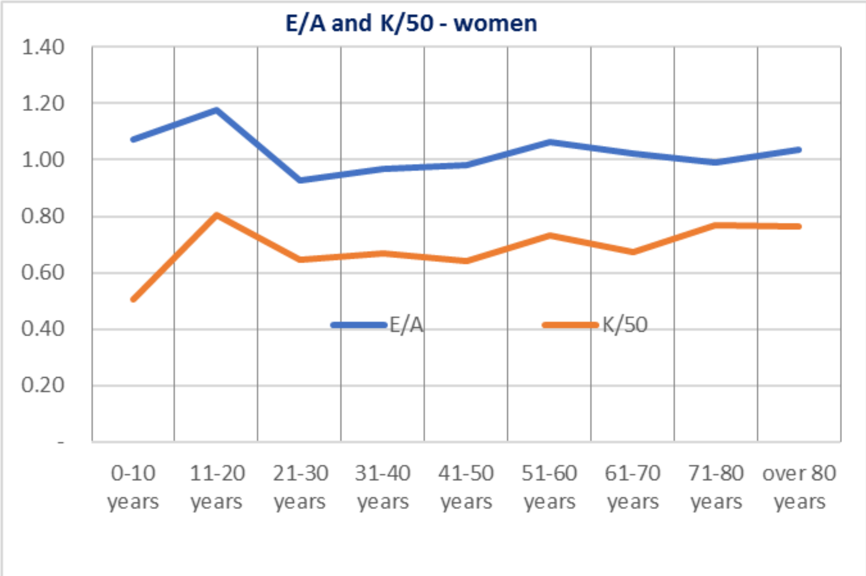


Fig. 4. Elasticity coefficient *k*/50. Trend line calculated as a 2-nd order polinomial function.



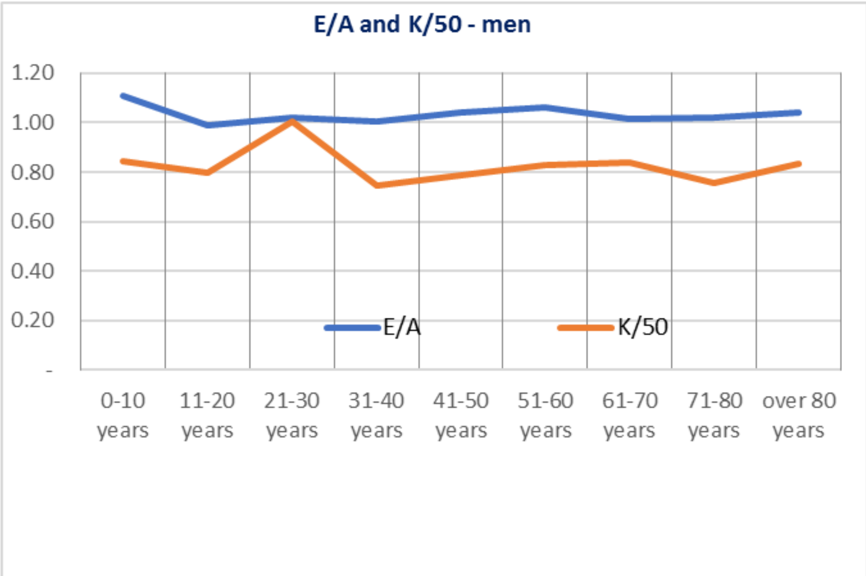
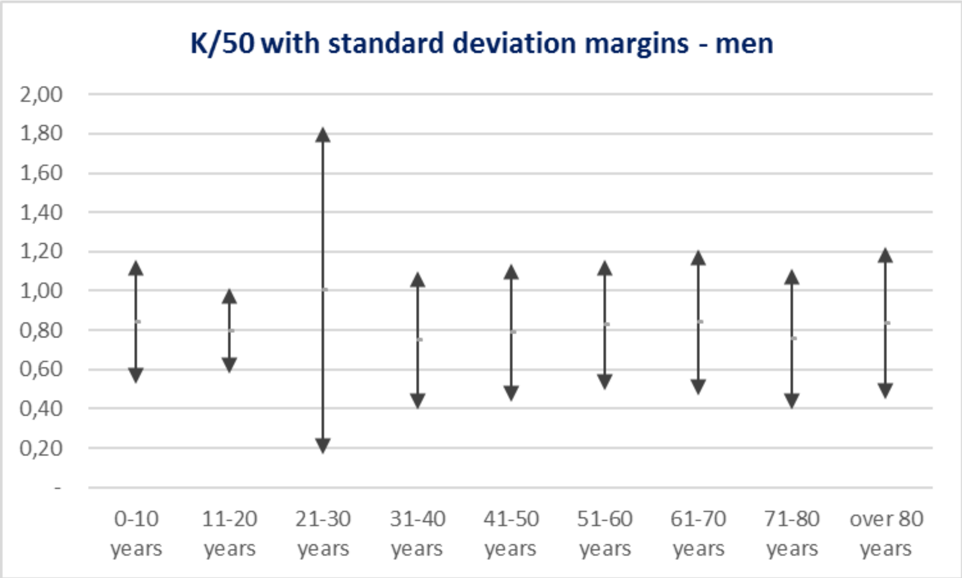


Fig. 5. *E/A* and *k*/50 represented on the same diagram to see the variation.



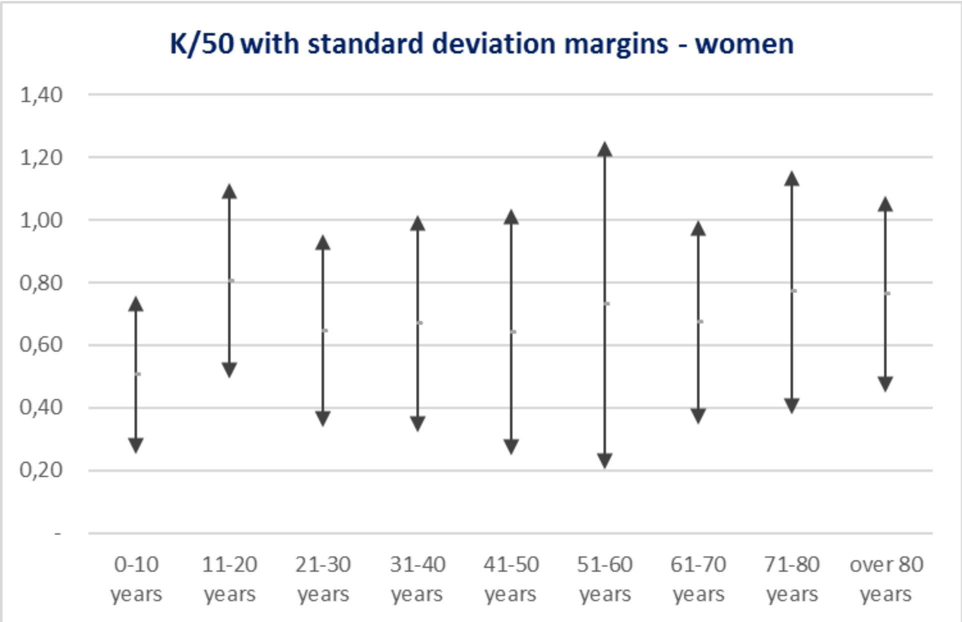


Fig. 6. The minimum and maximum error of determination for elasticity coefficient *k*/50.

Table 1

Correlation between *E/A* and *k* values for men and women

Correlation	Women		Men	
	E/A	*k*/50	*E/A*	*k*/50
E/A	1		1	
k/50	0.426	1	0.113	1

What we can see is that *E/A* and *k* have very similar variation fact shown also by the correlation analysis (Table 1).

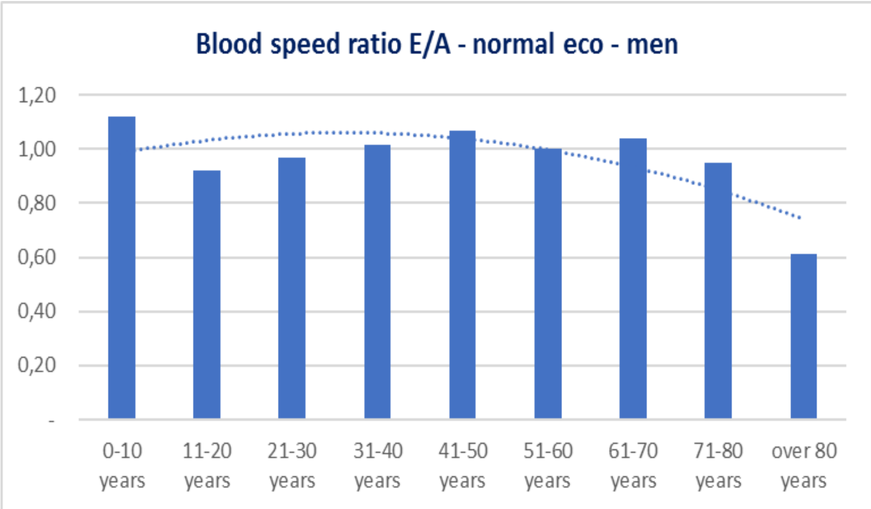
The database contains data from subjects with different diagnosis. Obvious the two parameters, *E/A* and *k* have different variation on different maladies. From the database, we can select the data for the subjects that have the diagnosis „normal echograph image”. We had done this selection and it had result a database of 563 subjects, 299 women’s and 264 men’s. The same diagrams are looking as can be observed in Figures 7, 8 and 9. The correlation between *E/A* and *k* of these selected subsets of patients are presented in Table 2.

Table 2

Correlation between *E/A* and *k* values for selected groups of patients

Correlation	Women		Men	
	E/A	*k*/50	*E/A*	*k*/50
E/A	1		1	
k/50	0.29	1	0.63	1

Now, for the „normal echo” subjects, the correlation between *E/A* and *k* is more pronounced. We can see it also from the diagrams and also from the correlation coefficient above.



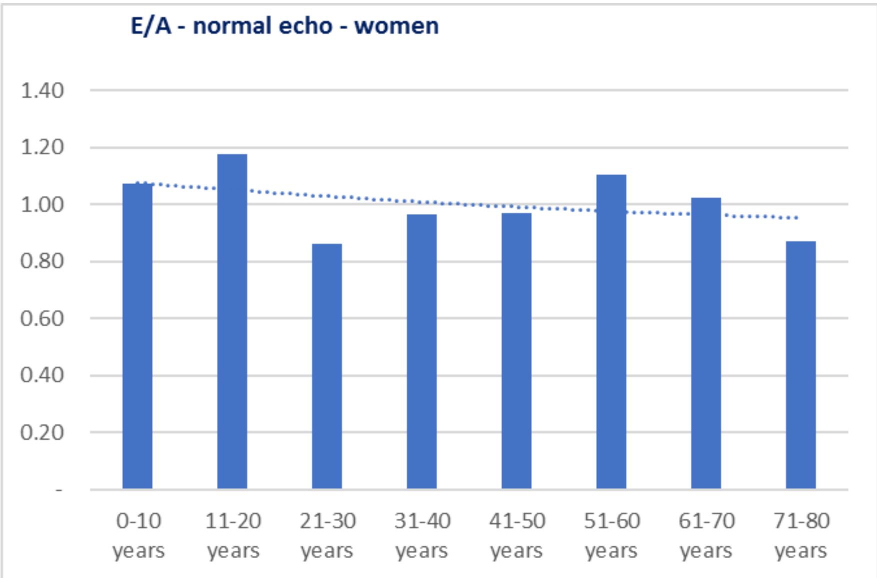


Fig. 7. Blood speed ratio *E/A* Trend line calculated as a 2-nd order polynomial function.

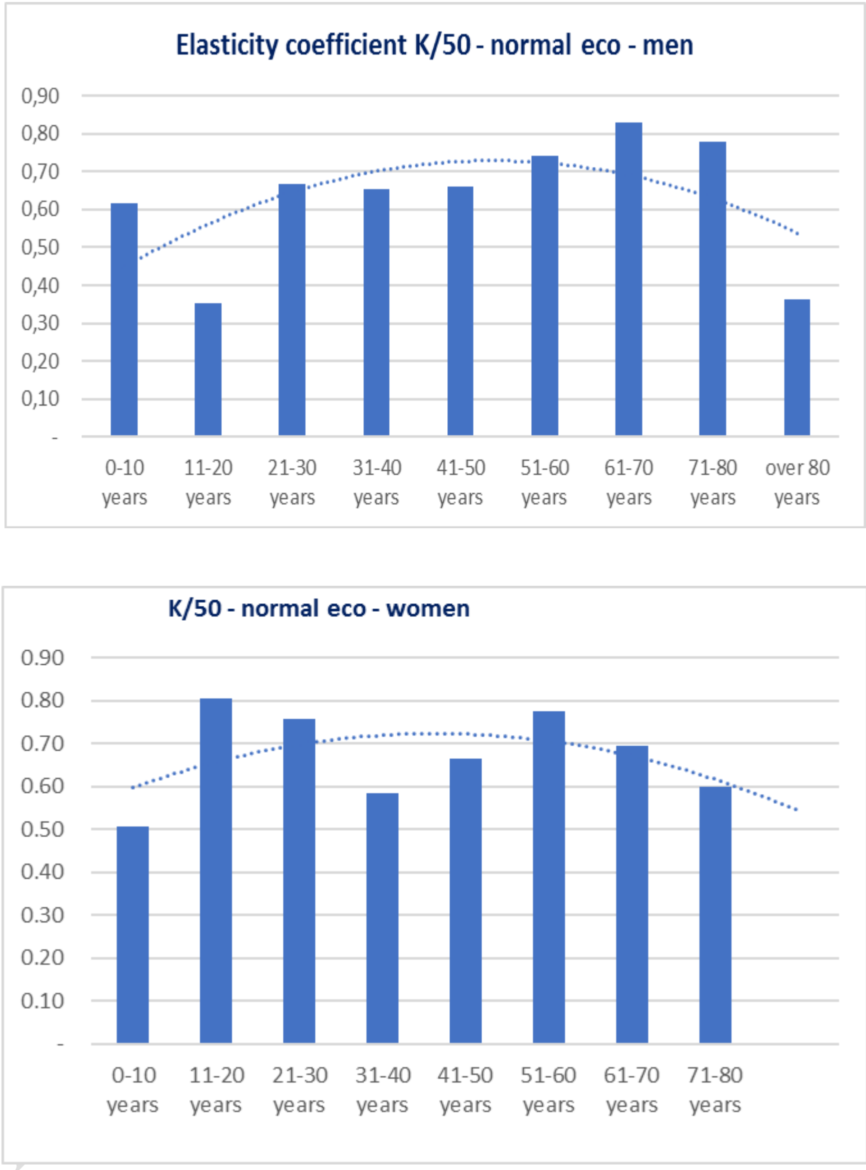
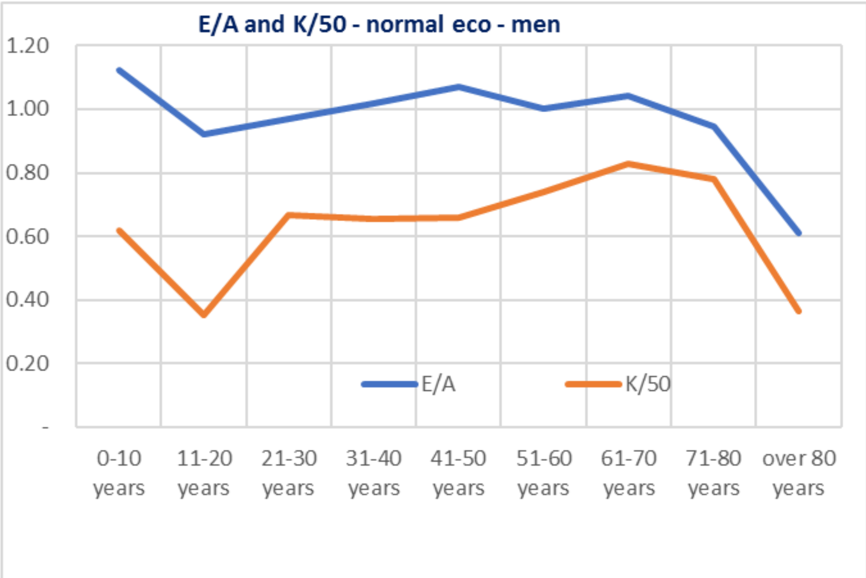


Fig. 8. Elasticity coefficient *k*/50. Trend line calculated as a 2-nd order polynomial function.



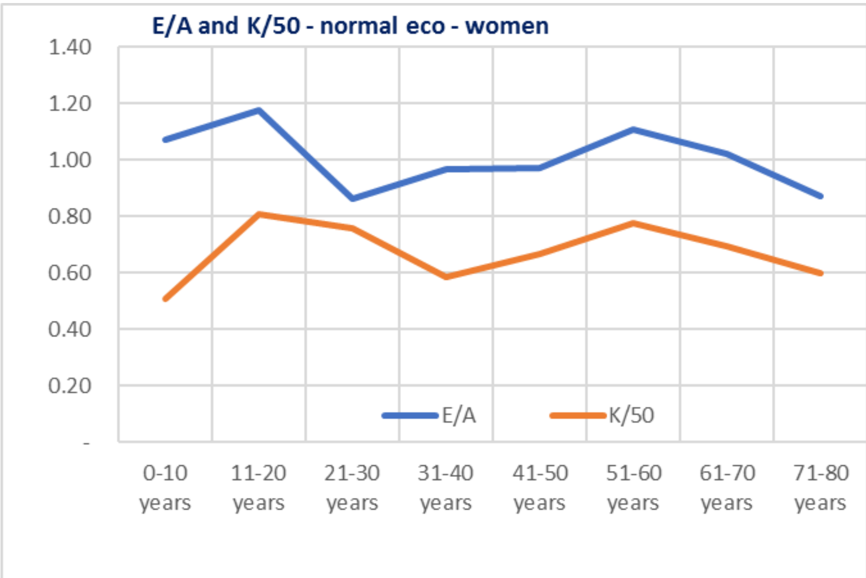
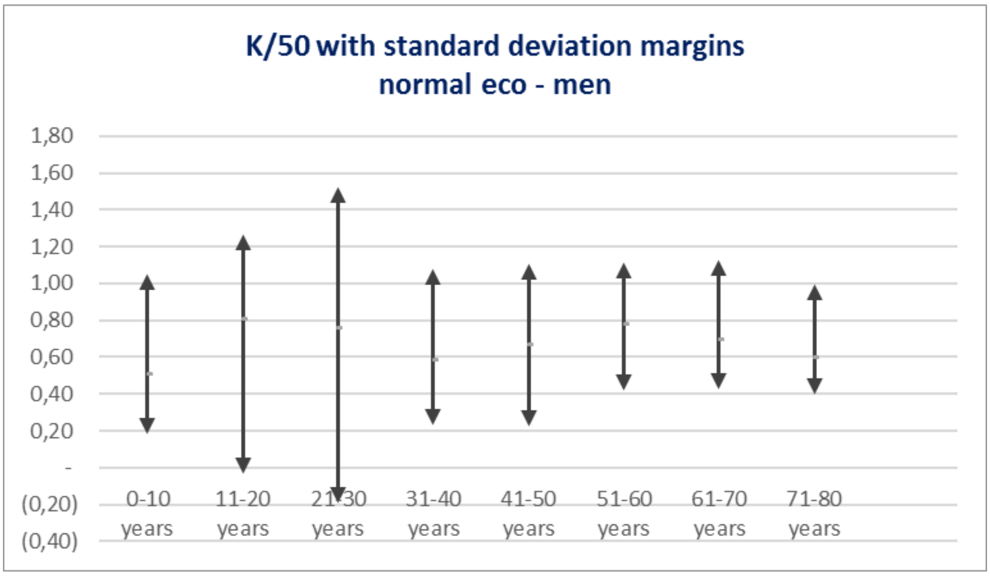


Fig. 9. *E/A* and *k*/50 represented on the same diagram to see the variation.



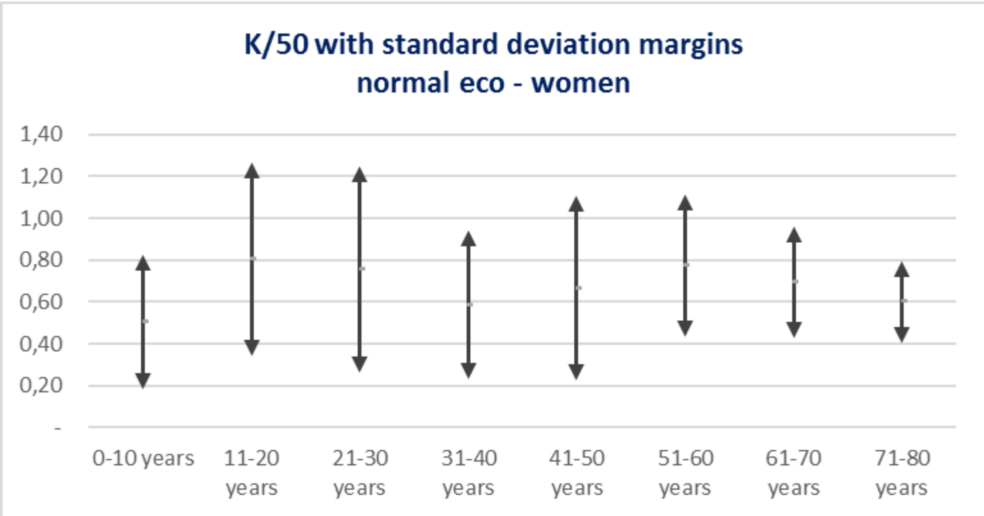


Fig. 10. The minimum and maximum error of determination for elasticity coefficient *k*/50.

DISCUSSION

In literature, there are some qualitative considerations on the elasticity coefficient. We can mention here a study made by V. Mor-Avi and his colleagues [1]. The authors have put in evidence the movement of the LV as a torsion movement.

In our research we try to study the elastic characteristic of the myocardium. We want to ad a measure to his elasticity and there is no better way than to calculate an elasticity coefficient and to prove that this coefficient is linked with the others parameters classically used in describing the health state of the myocardium. That is what we had done by comparing the coefficient *k* we propose with *E/A* ratio very well known by cardiologists. We are not trying to propose a mechanical model, we want to put in evidence the elasticity of the myocardium.

The main consideration that we had done is that the prefilling of LV in the period known also as E wave is due only by the elastic energy accumulated in the myocardium. The filing of LV in the period which comes after, known also as A wave is due to the pumping done by the left atrium.

We can denote several aspects of vascular elasticity that bring them in support of this study. Thus, it is known that with aging blood vessels lose their elasticity even become brittle**.**

If we will compare the volume of blood that enter in the LV in E wave and in A wave than we can see if the heart is functioning based on elastic proprieties or based on contraction power. We think that this is different from patient to patient and we also believe that as long the functioning is based on the elastic proprieties the heart work much easy than based on contraction power. Obvious this is changing with age but also is changing in different maladies such as diastolic dysfunction.

From previous graphic representations (Fig. 3, 4, 5, 7, 8, 9) can be seen as follows:

1. For women and for men with normal echograph image the elasticity coefficient of the myocardium, *k*, have a maximum value around 50 years old and then decrease. That is in concordance with the general known loss of elasticity of tissues with age.
2. The coefficient *k* has different variation when we have selected only the subjects with normal echography image. This shows that *k* is depending on the maladies and can offer information about these maladies. A study of *k* separately on different maladies can provide some marker values.

CONCLUSION

After the study, the following conclusions can be drawn:

E/A ratio and *k* have the same trendline with age. This is an indication that the coefficient *k* has a potential as a marker in diastolic disease diagnostic and many other maladies of the heart.

The two steps of the diastolic period of the cardiac cycle characterize the function of the heart. First step, the prefiling, is showing the heart like a suction pomp. The elastic energy stored in the myocardium is transformed in kinetic energy of the blood passing through the mitral valve, during E – wave. The second step, the filing of LV by atrium contraction, is showing the heart like a contracting pump. The potential energy developed by the myocardium is transformed in to kinetic energy of the blood. Our opinion is that the weight of each of the two steps, suction and contraction, is different from subject to subject and is varying with age and of course is depending on the maladies that heart might have.

Researches about *k* values in different maladies are welcome and can offer marker values for *k*.

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