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Basic axes of human heart in correlation with heart mass and right ventricular wall thickness

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A comparison of the data published in anatomy textbooks and anthropological tables does not reveal any change in basic heart dimensions during the period since the beginning of the 20th century to nowadays. However, normal values of many other parameters have changed up to 30% over the same period. These changes may be caused by the acceleration phenomenon or the extension of average lifespan. The progress of laboratory medicine methodology permitted the introduction of new biochemical tests in myocardial infarct diagnosis, such as myoglobin and troponins T and I measurement, as well as better understanding of cardiac metabolism. Parameters describing the direction and intensity of metabolic changes are substrate extraction and metabolic equilibrium. The expression describing metabolic equilibrium contains heart mass value. Therefore, as studying heart mass in vivo *is not possible, it may be important to study it* in vitro.
The study was performed on a group of 107 formalin-fixed human hearts. The organs came from adults of both sexes: 30 women and 77 men, aged 18 to 90 years. None of the hearts carried signs of macroscopic developmental abnormalities or pathologic changes.

Key words: human heart, right ventricle, morphometry, basic axes

INTRODUCTION

A comparison of the data published in anatomy textbooks and anthropological tables does not reveal any change in basic heart dimensions during the period since the beginning of the 20th century to nowadays. However, normal values of many other parameters have changed up to 30% over this period [2, 18]. These changes may be caused by the acceleration phenomenon or the extension of average lifespan.

During autopsy, many hearts without macroscopic developmental abnormalities or pathological changes weight more than 300 g. Hearts with a mass lower than 300 g are rare in cadavers of elderly people.

Rapid diagnosis and immediate therapy is a basic condition for success of myocardial infarct treatment. The progress of methodology in laboratory medicine permitted the introduction of new biochemical tests in myocardial infarct diagnosis, such as myoglobin or troponins T and I level measurement, as well as a better understanding of cardiac metabolism. Parameters describing the direction and intensity of metabolic changes are substrate extraction and metabolic equilibrium. The expression describing metabolic equilibrium contains heart mass value. Therefore, as studying heart mass *in vivo* is not possible, it may be important to study it *in vitro* [2, 11].

MATERIAL AND METHODS

The study material consisted of 107 formalin-fixed human hearts coming from adults of both sexes (30 women and 77 men), aged 18–90 years,

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Table 1. Comparison of right ventricle wall thickness in group 1 (heart mass ≤ 400 g) and group 2 (heart mass > 400 g)

Heart mass	x_1-x_2	$s^2(x)$	t	False rejection of true hypothesis	
				$\mu1 = \mu2$	$\mu1 \leq \mu2$
≤ 400 *vs.* > 400	–0.32	0.557141	1.29954	20%	10%

Table 2. Dimensions of basic heart axes for heart mass ≤ 400 g

Age group	Women				Men			
	Mass	X	Y	Z	Mass	X	Y	Z
18–40	289.44 ± 62.97	109.67 ± 12.37	74.00 ± 15.38	63.44 ± 9.82	311.92 ± 54.42	110.28 ± 11.95	76.76 ± 13.46	62.60 ± 7.55
41–65	320.31 ± 53.09	108.59 ± 13.63	81.44 ± 13.81	62.34 ± 9.34	346.20 ± 43.16	112.04 ± 12.56	79.20 ± 12.34	66.20 ± 9.76
Over 65	341.25 ± 51.05	115.00 ± 22.11	90.75 ± 11.32	64.75 ± 2.5	352.00 ± 56.62	117 ± 10.42	84.2 ± 12.58	68.4 ± 11.19

in which no macroscopic developmental abnormalities or pathologic changes were found. Hearts weighing up to 400 g were divided into 3 age groups: coming from cadavers of people dead at 18–40 years of age (9 female and 39 male), 41–65 years of age (14 female and 25 male), and over 65 years of age (4 female and 5 male).

An additional group of 11 hearts weighing over 400 g has been isolated. In these hearts we did not find any macroscopic developmental abnormalities or pathologic changes neither, but their mass exceeded the normal value according to classic textbooks, even with the acceleration phenomenon considered (plus 30%) [1, 3, 4, 8, 12, 13, 17, 18, 20]. In this group mean heart mass was 450.45 ± 48.50 g and mean age was 53.91 ± 14.92 years. The group consisted of 27% women and of 73% men.

The measurements performed in our study were as follows:

- X-axis — longitudinal heart dimension, measured from the apex of the heart to the aortic bulb;
- Y-axis — largest transverse heart dimension, measured at the level of auricles;
- Z-axis — sagittal heart dimension, measured just over the coronary sulcus level;
- right ventricle thickness — measured just below the tricuspid valve level along the shortest section between epicardium and trabeculae carneae;
- heart mass — the organs were weighted after removing the pericardium and great vessels and cleaning blood clots.

The age groups were tested for normal distribution ($p < 0.005$) using the Shapiro-Wilk test. The results showed Gaussian distribution, which confirms a correct age group selection [9, 15].

RESULTS

Right ventricle wall thickness was measured. We examined the hypothesis of a different right ventricle wall thickness in the groups of hearts weighing up to 400 g and above 400 g. In the first group, right ventricle wall thickness was 4.23 ± 0.76 mm and in the second group 4.55 ± 0.55 mm. Table 1 presents the statistical tests results concerning right ventricle wall thickness differences between these groups. For all tables, "$\mu1$" stands for the first group described in column 1 (in the case of Table 1, hearts with a mass ≤ 400 g), and "$\mu2$" stands for the second group described in column 1 (in the case of Table 1, hearts with a mass > 400 g). Column "x_1-x_2" in all tables shows the difference between mean values in the two groups. "$\mu1 = \mu2$" stands for the probability of an equivalence between the two groups, and "$\mu1 \leq \mu2$" stands for the probability of the calculated difference between the groups.

Results of the t-Student test show that with a 95% probability right ventricle wall thickness value is smaller in the group of hearts weighing up to 400 g than in hearts weighing over 400 g. Right ventricle wall thickness was larger than the normal value established with echocardiography [6].

Mean dimensions ± standard deviation (SD) of basic heart axes are presented in Tables 2 (for hearts weighing ≤ 400 g) and 3 (for hearts weighing ≤ 400 g).

Table 3. Dimensions of basic heart axes for heart mass > 400 g

X	Y	Z
129.18 ± 11.13	93.41 ± 7.15	73.36 ± 9.13

Table 4. Dependence of dimensions of main axes of hearts between male and female hearts in particular age groups

Age group	X	Y	Z	χ^2
18–40	0.003434	0.098986	0.011322	0.113741
41–65	4.144198	0.136809	0.503441	4.784449
Over 65	2.962963	0.536352	0.194773	3.694088
χ^2	7.110595	0.772147	0.709537	8.592279 $\alpha = 7\%$

We started the analysis by comparing differences in basic heart axes dimensions (X, Y, and Z axes) between male and female hearts within particular age groups, for hearts weighing ≤ 400 g. χ^2 test has been applied; results are presented in Table 4. We found that dimensions of basic heart axes differ in men and women, with the largest differences in the group of 41–65 years of age.

By comparing basic heart axes with χ^2 test we found the following:

- the largest differences in all parameters appear in the age group of 41–65 years ($\chi^2 = 4.78449$)
- the dimension which differs the most in all groups is X, the longitudinal heart axis ($\chi^2 = 7.110595$); other parameters differ much less but show a similar distribution.

Next step was comparing X, Y and Z dimensions within particular age groups, separately for both sexes. These dimensions were found to be statistically independent in both sexes and in all age groups. Conclusions for particular age groups are:

• 18–40 years:

- there are clear correlations between X and Y dimensions and between Y and Z dimensions both in female and male hearts. These correlations are stronger in female hearts (higher Pearson coefficient). Other correlations are not clear;

• 41–65 years:

- there is a clear correlation between X and Y dimensions in female hearts. Other correlations are weak;
- in male hearts correlations are similar. There exists a clear correlation between X and Y dimensions, but it is weaker than in the female subgroup. Other correlations are not clear;

• Over 65 years:

- in female hearts there exist a considerable correlation between X and Y and a clear correlation between Y and Z. However, the correlation between X and Y is weak;
- in male hearts a clear correlation between X and Y appears, other correlations are not clear.

Final conclusions from the above calculations are:

- dimensions X, Y, Z are statistically independent for both sexes and in all age groups;
- correlation between X and Y is stronger than the others;
- all correlations are stronger in female than in male hearts;

Tables 5 and 6 compare particular heart axes dimensions in different age groups. Table 5 shows the results for the female subgroup and Table 6 for the male one. Results are presented separately for every main heart axis.

According to Table 5, it can be neither confirmed, nor excluded that longitudinal heart axis dimension (X) in female hearts changes with age. Transverse heart dimension (Y) clearly increases across age groups, but differences between particular age groups are not clearly marked. Sagittal heart dimension (Z) is constant after the age of 18.

Table 5. Relation between main heart axes dimensions within particular age groups in female hearts

Women	18–40	41–65	Over 65	Compared age groups	x_1-x_2	$s^2(x)$	t	Hypothesis	
								$\mu1 = \mu2$	$\mu1 \leq \mu2$
X	109.7	107.7	115.0	18–40_41–65	1.96667	173.632	0.353979	0.726725	0.363362
SD	12.4	13.6	22.1	41–65_over 65	–7.30000	238.935	0.839231	0.412986	0.206493
				18–40_over 65	–5.33333	244.545	0.567543	0.581744	0.290872
Y	74.000	81.267	90.750	18–40_41–65	–7.26667	215.702	1.173464	0.253158	0.12658
SD	15.379	14.276	11.325	41–65_over 65	–9.48333	190.481	1.221050	0.238732	0.11937
				18–40_over 65	–16.75000	206.977	1.937461	0.078781	0.03939
Z	63.444	61.833	64.750	18–40_41–65	1.611111	91.68434	0.399061	0.693696	0.346848
SD	9.825	9.430	2.500	41–65_over 65	–2.916667	74.32843	0.601185	0.555649	0.277825
				18–40_over 65	–1.305556	71.90657	0.256207	0.802519	0.40126

Table 6. Dependence of dimensions of main axes of hearts between particular age groups in male hearts

Men	18–40	41–65	Over 65	Compared age gropus	x_1-x_2	$s^2(x)$	t	Hypothesis	
								$\mu1 = \mu2$	$\mu1 \leq \mu2$
X	110.3	112.0	117.0	18–40_41–65	–1.75795	148.635	0.562805	0.575597	0.287798
SD	12.0	12.6	12.7	41–65_over 65	–4.96000	158.338	0.804607	0.427826	0.213913
				18–40_over 65	–6.71795	144.617	1.176030	0.246206	0.123103
Y	76.756	79.200	84.200	18–40_41–65	–2.443590	169.910	0.731696	0.467111	0.233555
SD	13.456	12.338	12.050	41–65_over 65	–5.000000	151.225	0.829951	0.413587	0.206793
				18–40_over 65	–7.443590	177.660	1.175650	0.246356	0.123178
Z	62.603	66.200	68.400	18–40_41–65	–3.59744	71.79177	1.657174	0.102537	0.051268
SD	7.552	9.755	11.194	41–65_over 65	–2.20000	99.471429	0.450265	0.655987	0.327993
				18–40_over 65	–5.79744	63.530708	1.531211	0.133215	0.066608

Table 6 presents the results found for the male subgroup. Here, transverse heart dimension (Y) increases in consecutive age groups with an 88% probability. Sagittal heart dimension (Z) increases between the first and the second group (18–40 and 41–65 years, respectively) with a probability of 94%. Changes of longitudinal dimension (X) in male hearts are ambiguous.

DISCUSSION

Hearts weighing up to 400 g were divided into 3 age groups: coming from cadavers of people dead at the age of 18–40 years, 41–65 years, and over 65 years. Additionally, we distinguished a group of 11 hearts weighing over 400 g.

Distinguishing this group was caused by the fact that a comparison of anatomy textbooks and anthropological tables data from the period since the beginning of the 20th century to nowadays is not indicative of a significant change in basic heart dimensions, while it shows a change of up to 30% in the normal values of other parameters over the same period [3, 20]. These changes may be caused by the acceleration phenomenon as well as by the population ageing.

As anatomical investigations are performed on formalin-fixed organs, it seems essential to study heart mass and dimensions using hearts prepared in the same way. Time elapsed from death till collecting organs for studies also seems to play a role, because of *rigor mortis* and posthumous changes that are stopped by formalin. Literature concerning heart mass and main axes dimensions is incoherent and fragmentary.

Right ventricle wall thickness in hearts weighing up to 400 g conformed to the normal value established by Hudson [6]. Echocardiographic normal range is wider and includes values ≤ 5 mm [7]. This difference is related to the fact that right ventricle wall thickness measurement in cadavers does not include *epicardium* nor *endocardium*, while echocardiographic measurement includes both those layers. Right ventricle wall thickness in hearts weighing up to 400 g was 4.26 mm, and 4.55 mm in hearts with a mass over 400 g. The difference between our result and the normal value according to Hudson [6] was smaller than the measurement accuracy. Therefore, right ventricle wall thickness can be considered normal in the group of hearts weighing up to 400 g.

In Bochenek [1] anatomy textbook the same values of heart parameters reappear in consecutive editions. According to this source, normal heart mass is equal to 300 g. Sokołowska-Pituchowa [16] also recognizes 300 g as a normal heart mass value (280–340 g for male hearts and 220–280 g for female hearts). Unlike Bochenek [1], this author distinguishes heart dimensions in living humans and in cadavers. According to her, normal values are the following: longitudinal heart axis 14–15 cm *in vivo*, against 12 cm in cadavers; transverse axis 10–15 cm against 8–9 cm, respectively; sagittal axis 8 cm, against 6 cm. Normal heart mass according to Lippert [10] is 300 g in males and 220 g in females. This author does not give values of main heart axes dimensions, but in contrast to Sokołowska-Pituchowa [16] he describes the values in cadavers as being usually larger than *in vivo*. According to Testut [18, 19], normal values are the following — heart mass in males: 270–275 g, in females: 250 g, male heart longitudinal axis: 105 mm, height: 98 mm (he does not define whether "height" means a transverse, or a sagittal dimension). According to this author, dimensions of the main axes in a female heart are 5–10 mm smaller than in men. According to Rouviere [14], normal heart mass is 270 g in men and 260 g in women. This author does not describe the dimensions of main axes. According to Hoffman et al. [5], in turn, average mass of a male heart is 280–340 g, and of a female heart 230–280 g. This author gives the following dimensions of main heart axes, regardless of the sex — longitudinal: 12 cm, transverse: 8–9 cm, and sagittal axis: 6 cm. Kruś [8] describes in detail heart mass and main dimensions within particular age groups. His choice of age groups is different from ours, and he presents heart dimensions from fetal life to the age of 80.

Our results of heart mass are about 30% larger than the results of all cited studies excluding Kruś [8]; however, his textbook has been based on a study from 1975. This increase in heart mass may be ascribed to the phenomenon of acceleration, as well as to the population ageing [3, 20]. Results of heart mass measurement are coherent with other authors in the youngest age group studied (18–40 years of age), and partly in the second group (41–65 years). Our results are coherent with normal values established by Kruś [8], except for the age group of 56–80 years according to his division. In this group, average heart mass was higher than 400 g, and it seems that results presented in his textbook are population data rather than standards. In our study group, most hearts with a mass of more than 400 g were taken from bodies of people older than 55 years. In the study by Kruś [8], values of basic heart dimensions are not accompanied by corresponding ventricle wall thickness values. It is therefore not possible to establish whether all examined hearts were normal, or a part of them carried signs of hypertrophy.

Our results concerning basic heart axes dimensions are consistent with Sokołowska-Pituchowa [16] in two age groups: 18–40 and 41–65 years. The difference in the age group of over 65 years is probably related to human life extension. The values given by Sokołowska-Pituchowa [16] do not take into consideration the factors of age and sex. Some of the mentioned authors do not give these values at all [10, 14]. Our obtained longitudinal heart axis value is larger than the one given by Testut [18, 19]. This author does not precise whether the dimension value corresponds to a living heart or to a cadaver. Our results agree numerically with the data given by Hoffman et al. [5], but she describes them as the dimensions of a heart in maximal relaxation, while our results concern a contracted heart. This considered, our results are larger than the ones of Hoffman et al. [5].

Establishment of new and actual normal values of main heart axes dimensions in adult humans is still an open subject. This question should be investigated on larger study groups and the correlation with both left and right ventricle wall thickness should be examined. The above problems will be the subject of our next study.

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