The height of the sinuses of Valsalva depending on anthropometric data among Ukrainian population

Uliana Pidvalna[1], Vassyl A. Lonchyna[2], Dmytro Beshley [1,3,4], Lesya Mateshuk-Vatseba[1]

[1] *Danylo Halytsky Lviv National Medical University*
[2] *University of Chicago Pritzker School of Medicine*
[3] *Ukrainian-Polish Heart Center "Lviv"*
[4] *Lviv Regional Clinical Hospital*

SUMMARY

Sinuses of Valsalva height is an important parameter in planning cardiac surgery, percutaneous coronary intervention and transcatheter aortic valve implantation (TAVI). The aim of the study is to analyze the height of the sinuses of Valsalva depending on height, weight, body mass index, body surface area, and sex using computed tomography angiography images in Ukrainian population. 59 chest computed tomography angiography examination for non-cardiac reasons were retrospectively evaluated. Data were collected from Ukrainian citizen. The height of the Sinuses of Valsalva was measured as the distance between aortic annulus and sinotubular junction.

All three sinuses of Valsalva height were higher in men than in women ($p<0.001$). In men, three Sinuses of Valsalva had a correlation with height and body surface area (BSA) ($p<0.05$). In women, a correlation has been confirmed only between anthropometric measurements and the height of left and right coronary sinuses ($p<0,05$). The left coronary sinus height had a correlation with height, weight, body mass index (BMI) and BSA ($p<0,05$). The right coronary sinus height had a correlation with weight, BMI, and BSA ($p<0.05$). The parameters of the non-coronary sinus in women do not have confirmed direct correlations with any anthropometric measurements observed. The sinuses of Valsalva height is higher in males. The most significant confirmed correlations were between height and left and right coronary sinuses in men and women. Increased size of sinuses in men correlated with an increase of height, weight and decrease of BMI and BSA values.

Keywords: Aortic Anatomy – Aortic root – Sinuses of Valsalva – Height – Computed Tomographic Angiography

INTRODUCTION

The sinuses of Valsalva are components of the aortic root. It is differentiated into the right aortic sinus (RAS), the left aortic sinus (LAS) and the posterior or non-coronary sinus (NAS). The names of the Valsalva sinuses correspond to the right, left, and posterior (non-coronary) semilunar leaflets of the aortic valve (Razzolini et al., 2011). Semilunar leaflets of the aortic valve are

Corresponding author:
Uliana Pidvalna. Department of Anatomy, Danylo Halytsky Lviv National Medical University, Pekarska st, 69, Lviv, Ukraine, 79010. Phone: +380963551782. E-mail: uljaska.p@gmail.com

Submitted: March 21, 2022. **Accepted:** May 2, 2022

https://doi.org/10.52083/IYMG4367

named according to their corresponding location in the fetus. Postnatally, the names of the leaflets do not change, but their location does. The right semilunar leaflet is located in the anterior part, the left semilunar leaflet has a posterior-left position, and the posterior semilunar leaflet has a posterior-right position. Correspondently, the right aortic sinus is also known as the anterior aortic sinus, the left as the left posterior aortic sinus, and the posterior as the right posterior aortic sinus (Nasr and El Tahlawi, 2018). In clinical medicine the names are determined by the coronary artery ostia normally contained in these sinuses: the right coronary, the left coronary and the non-coronary sinuses (Ho, 2009). The height of the sinus of Valsalva is defined as the distance from the aortic annulus to the sinotubular junction (Hennessey et al., 2020). Syntopy of the sinuses of Valsalva occurs with the aortic valve leaflets, the leaflet attachments and the interleaflet trigones (Berdajs, 2016). The morphology of the sinuses of Valsalva correlates with the functioning of the aortic valve and the corresponding coronary artery blood supply to the left ventricle (Ho, 2009).

Classical cardiac surgery (using a sternotomy or mini-thoracotomy), endovascular procedures (coronary angiography, coronary artery stenting, transcatheter aortic valve implantation (TAVI)) and hybrid procedures require thorough knowledge of all components of the aortic root. Preoperative planning which takes into account the morphometric parameters of the aortic root allow for successful intervention and reduces the risk of possible complications (Freeman et al., 2013; Hennessey et al., 2020).

Within the general structure of the heart and main vessels, there are gender differences (Merz & Cheng, 2016; Taqueti, 2018) that must be taken into consideration. Gender differences affect the clinical findings, diagnostics and choice of treatment tactics (Merz and Cheng, 2016). The height of the person also influences the state of the cardiovascular system, especially in coronary artery disease (Nelson et al., 2015; Silventoinen et al., 2006). Studies have shown that people of short stature have a 50% higher risk of coronary artery disease and a higher mortality rate (Plonek et al., 2019; Rosenberg et al., 2014).

The aim of the study is to use computed tomography angiography (CTA) to compare the height of the right, left and posterior sinuses of Valsalva in men and women without any pathology of the heart and ascending aorta.

MATERIALS AND METHODS

Patient population. Patients of the Ukrainian-Polish Heart Center "Lviv" (Lviv, Ukraine) were involved in the given study. Inclusion criteria: patients without any signs of heart or ascending aorta disease undergoing contrast-enhanced Computed Tomography (CT) chest examination. Exclusion criteria: improper visualization of the aortic root, incomplete clinical data, refusal to be involved in the study, patients with anomalies of the heart, ascending aorta or coronary vessels. All patients signed the informed consent (signed by the patient or official representative) according to the Declaration of Helsinki and the national legal regulations (Ethics Committee Approval: Bioethics Commission of Danylo Halytsky Lviv National Medical University, protocol No. 10, 20 December 2021).

CTA images of 59 patients were selected with the following gender distribution: 43 men and 16 women. The patients were scanned using the MDCT scanner LightSpeed VCT XT, GE (General Electric, USA) with 64-row chest CT with administration of the contrast agent Ultravist 470 (Bayer Healthcare, Germany). CT angiography images were evaluated on a dedicated CT workstation (General Electric, USA) by two independent observers with experience in assessment of contrast-enhanced CT images of the chest. The following parameters were measured: the distance between the aortic annulus and the sinotubular junction, labeled as the height of the right, left and non-coronary sinuses. All measurements were done according to the updated 2019 Guidelines (Blanke et al., 2019). Each aortic cusp was first identified and then the height of each sinus of Valsalva was measured. The body surface area (BSA) was calculated as the square root of the height multiplied by the weight divided by 3600 (Mosteller formula). The body mass index was calculated as weight (in kilograms) divided by the height in meters squared.

The results of the study were analyzed using the methods of descriptive and analytical statistics. The statistical analysis was conducted using the SPSS version 22.0 for Windows (IBM Corp., Armonk, NY, USA). The normality of data distribution was assessed using Shapiro-Francia test. Values are presented in mean ± standard deviation. Student's *t*-test was performed to compare means. P-value of <0.05 was considered significant. The correlation between the observed variables has been calculated using Pearson's linear correlation method (r). Multiple correlation and regression analysis have been performed in Statistica 10, allowing for accurate calculations and their visual presentations.

RESULTS

A total of 59 CTA examinations were collected from adults of both sexes and same ages: 43 (73%) males, aged 53 ± 14 years, and 16 (37%) females, aged 56 ± 13 (p = 0.33). All patients were free of structural heart and ascending aortic disease. Men's height differed significantly from that of women: men 1.76 ± 0.07 m and women 1.63 ± 0.04 m (p <0.001). Clinical characteristics of patients are presented in Table 1.

Table 1. Characteristics of the patients.

Parameters	Male (n=43)	Female (n-16)	P value
Age (y)	52.56±13.52	56.38±13.34	0.33
Height (m)	1.76±0.07	1.63±0.04	<0.001*
Weight (kg)	84.74±14.14	76.5±13.48	0.04*
BMI (kg/m^2)	27.54±4.74	28.79±5.19	0.40
BSA (m^2)	2.03±0.18	1.85±0.17	0.001*

BMI: Body mass index; BSA: Body surface area; * P-value of <0.05 was considered significant

CTA images received in the course of the study were analyzed in double oblique multiplanar reconstruction. The height of the sinuses of Valsalva was measured from the level of the aortic annulus to the sinotubular junction. All measurements were performed on a perpendicular plane to the long axis of the vessel.

There is a statistically significant difference in the height of the sinuses of Valsalva (as measured between the aortic annulus and the sinotubular junction) in men and women. The height of the anterior (right) sinus of Valsalva was 24.27 ± 3.83 mm in men and 18.59 ± 2.25 mm in women. This was 5.68 mm higher (1.3 times) in men than in women (p <0.001). The height of the left sinus of Valsalva in men is 4.62 mm higher (1.31 times) (p <0.001) than in women (23.49 ± 3.33 mm and 17.87 ± 1.82 mm respectively). The height of the non-coronary sinus of Valsalva in men is 1.26 times higher (p <0.001) than in women (24.83 ± 3.59 mm and 19.71 ± 2.17 mm respectively) (Fig. 1).

In view of the abovementioned, it appeared reasonable to study the correlation between sinuses of Valsalva height and anthropometric measurements of men and women. For this purpose, multiple correlation and regression analysis have been used. Key impact factors have been selected based on Pearson's correlation analysis. Essential independent variables are presented in Tables 2, 3.

Correlation analysis has confirmed a correlation between height and BSA and sinuses of Valsalva measurements in men: strong direct correlation with height (r = from +0.71 to +0.75, p<0.05) and moderate direct correlation with BSA (r = from +0.31 to +0.42, p<0.05). In women, a correlation has been confirmed only between anthropometric measurements and the sizes of left and right coronary sinuses. Left coronary sinus size has a moderate direct correlation with height (r=+0.41, p<0.05), weight (r=+0.52, p<0.05), BMI (r=+0.40, p<0.05) and BSA (r=+0.57, p<0.05); right coronary sinus size has a correlation with weight (r=+0.33, p<0.05), BMI (r=+0.31, p<0.05) and BSA (r=+0.32, p<0.05). The parameters of the non-coronary sinus in women do not have confirmed direct correlations with any anthropometric measurements observed. It has been additionally established that there is no confirmed correlation between age and the height of sinuses of Valsalva in men and women.

Based on the findings obtained, multiple correlation coefficient R has been calculated, which points to the strength of correlation between the dependent variables (sinuses of Valsalva) and the combination of independent variables (height, weight, BMI, BSA) (Table 4).

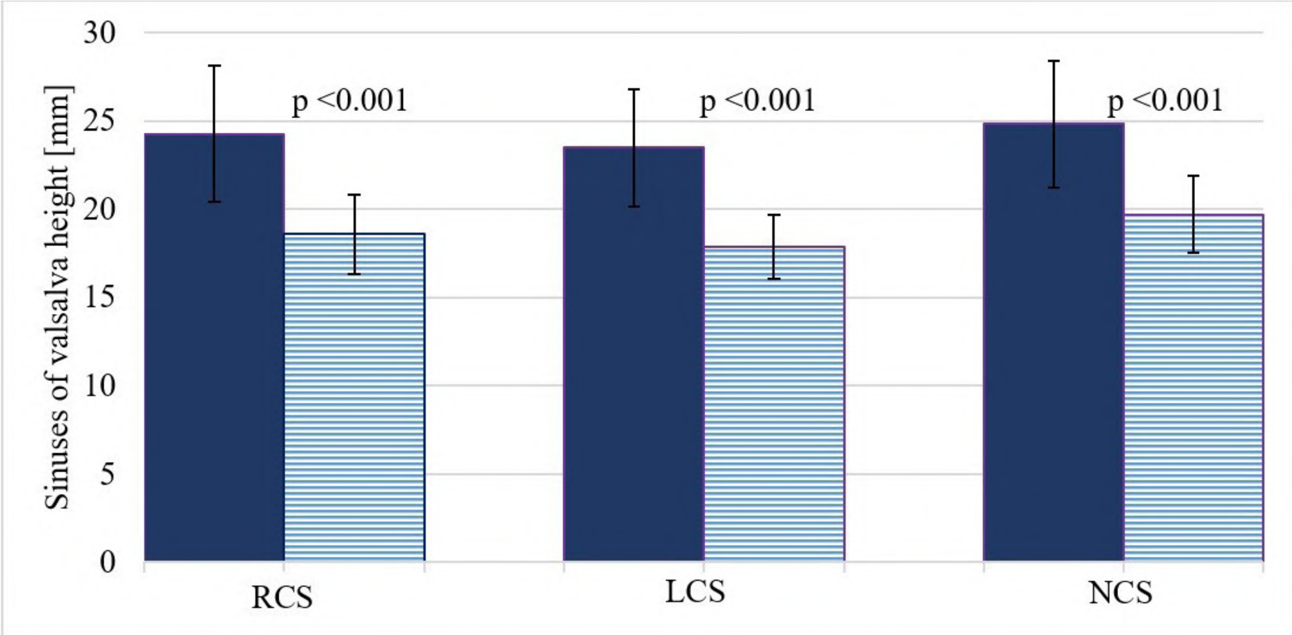

Fig. 1.- Differences between the height of the sinuses of Valsalva in the male *(solid bar)* and female *(striped bar)* cohorts. Values are presented as mean ± standard deviation. See measurements in Tables 2 and 3. *RCS*, Right coronary sinus; *LCS*, Left coronary sinus; *NCS*, Non-coronary sinus.

Table 2. Correlation relationship (r) between anthropometric measurements and sinus of Valsalva height in men.

Parameters	Age (y)	Height (m)	Weight (kg)	BMI (kg/m²)	BSA (m²)	LCS (mm)	RCS (mm)	NCS (mm)
Age (y)	-	-0.28	0.03	0.14	-0.03	-0.10	-0.06	-0.30
Height (m)	-0.28	-	0.18	-0.27	0.40*	0.75*	0.71*	0.74*
Weight (kg)	0.03	0.18	-	0.90*	0.97*	0.27	0.16	0.20
BMI (kg/m²)	0.14	-0.27	0.90*	-	0.78*	-0.07	-0.16	-0.13
BSA (m²)	-0.03	0.40*	0.97*	0.78*	-	0.42*	0.31*	0.35*
LCS (mm)	-0.10	0.75*	0.27	-0.07	0.42*	-	0.86*	0.74*
RCS (mm)	-0.06	0.71*	0.16	-0.16	0.31*	0.86*	-	0.63*
NCS (mm)	-0.30	0.74*	0.20	-0.13	0.35*	0.74*	0.63*	-

BMI: Body mass index; BSA: Body surface area; RCS: Right Coronary Sinus; LCS: Left Coronary Sinus; NCS: Non-Coronary Sinus.
Note. * - confirmed ($p<0.05$) correlation

Table 3. Correlation relationship (r) between anthropometric measurements and sinus of Valsalva height in women.

Parameters	Age (y)	Height (m)	Weight (kg)	BMI (kg/m²)	BSA (m²)	LCS (mm)	RCS (mm)	NCS (mm)
Age (y)	-	-0.12	0.00	0.03	0.02	0.14	-0.12	-0.14
Height (m)	-0.12	-	0.06	-0.22	0.20	0.41*	0.06	0.25
Weight (kg)	0.00	0.06	-	0.96*	0.99*	0.52*	0.33*	0.01
BMI (kg/m²)	0.03	-0.22	0.96*	-	0.91*	0.40*	0.31*	-0.06
BSA (m²)	0.02	0.20	0.99*	0.91*	-	0.57*	0.32*	0.03
LCS (mm)	0.14	0.41*	0.52*	0.40*	0.57*	-	0.56*	0.24
RCS (mm)	-0.12	0.06	0.33*	0.31*	0.32*	0.56*	-	0.43*
NCS (mm)	-0.14	0.25	0.01	-0.06	0.03	0.24	0.43*	-

BMI: Body mass index; BSA: Body surface area; RCS: Right Coronary Sinus; LCS: Left Coronary Sinus; NCS: Non-Coronary Sinus.
Note. * - confirmed ($p<0.05$) correlation

Table 4. Results of calculations for multiple correlation and regression analysis of the sinuses of Valsalva height and anthropometric measurements observed in men and women.

Parameters	Males		Females	
	R	p	R	p
NCS (mm)	0.76	0.00001	0.46	0.75
LCS (mm)	0.77	0.000002	0.72	0.014
RCS (mm)	0.73	0.00002	0.36	0.90

NCS: Non-Coronary Sinus; LCS: Left Coronary Sinus; RCS: Right Coronary Sinus.

A strong direct correlation has been identified in men between the anthropometric measurements observed and the sinuses of Valsalva height indicators (R = from +0.73 to +0.77, $p<0.001$). Increased size of sinuses in men correlated with an increase of height, weight and a decrease of BMI and BSA values.

Within the group of women, multiple correlation and regression of independent variables (anthropometric data) have been confirmed only for the dependent variable «left coronary sinus» (R=+0.72, p=0.014), while for other sinuses the correlation was insufficient ($p>0.05$). The size (increase) of the left coronary sinus in women was affected by the increase of height and BMI and decreased BSA. Fig. 2 and Fig. 3 visualize the above-described correlations between left coronary sinus parameters and anthropometric data in men and women.

DISCUSSION

The present study represents a single-center data of the height of the sinuses of Valsalva in subjects without heart disease or ascending aorta disease undergoing contrast-enhanced CT. Data assessed by CTA is considered the fastest and one of the most accurate methods of measuring the aorta, with very high spatial resolution (Blondheim et al., 2016). We studied the relationship of variations with sex and height. Patients were distributed by gender (43 men vs 16 women).

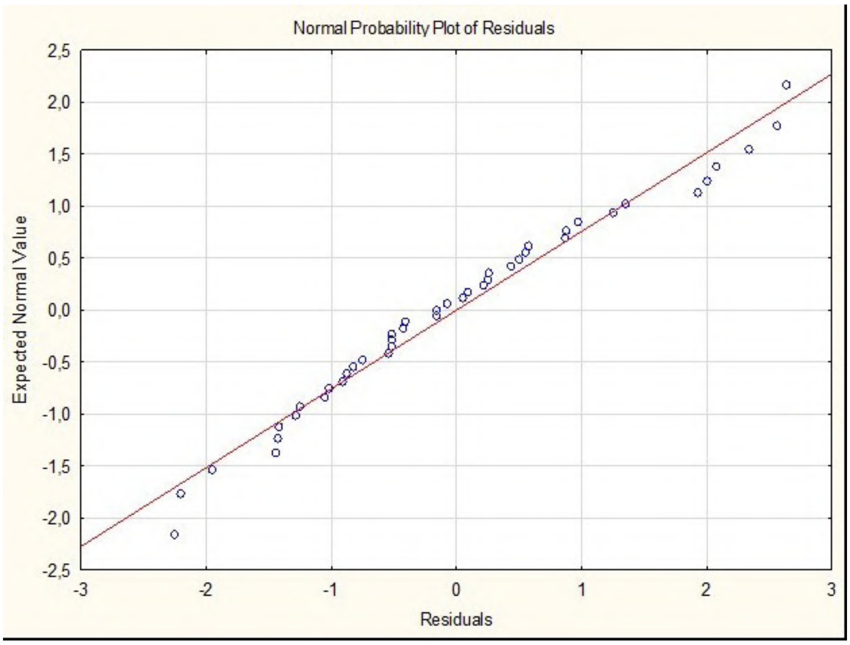

Fig. 2.- Visualization of multiple correlation and regression analysis of the left coronary sinus of Valsalva and anthropometric measurements observed in men.

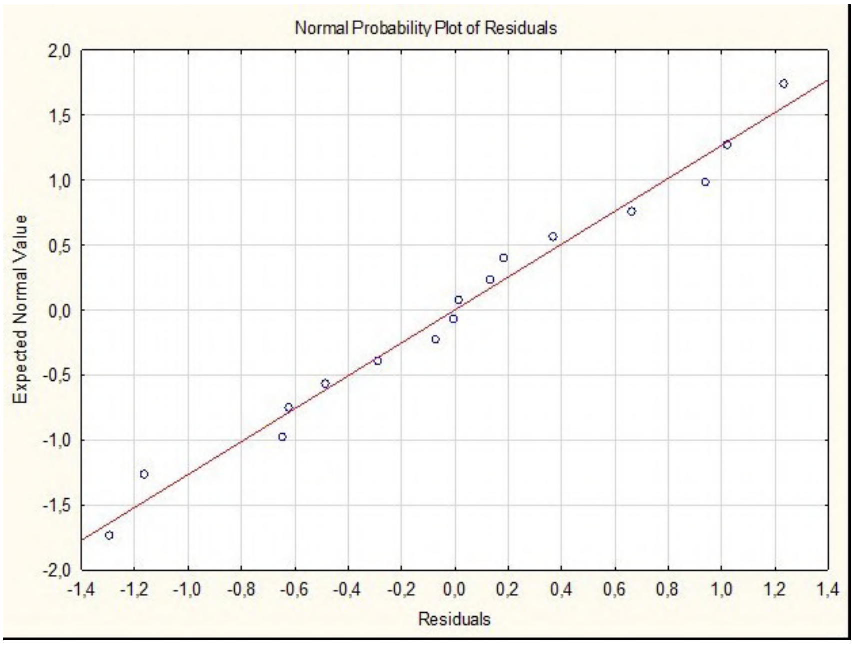

Fig. 3.- Visualisation of multiple correlation and regression analysis of the left coronary sinus of Valsalva and anthropometric factors observed in women.

We found a constant difference in the size of the right, left coronary and non-coronary sinuses of Valsalva in the male as compared to the female cohort. The sinuses of Valsalva are higher in men than in women ($p < 0.001$). The left sinus of Valsalva in men is 1.31 times higher than in women, and almost the same difference is observed in the height of the right (1.3 times) and the non-coronary sinus of Valsalva (1.26 times). Our results are in general agreement with published studies, i.e., that right and left coronary sinuses of Valsalva are greater in males (Knight et al., 2009; Stolzmann et al., 2009). Those publications reporting differences in both the left and the right coronary sinuses omitted measurement of the non-coronary sinus of Valsalva. It could be explained by their focus on precise location of the coronary artery ostia only. The shorter the right sinus of Valsalva, the lower the location of the right coronary artery ostium. This is an important consideration in patients undergoing aortic valve surgery. A high location of the right coronary artery ostium with a sufficient height of the right coronary sinus allows for easier and safer aortic valve replacement. It is, however, a frequent location of air embolism occurrence during the de-aeration stage of cardiac surgery, which can lead to sudden life-threatening arrhythmias. The height of the left coronary sinus is important because of the location of the left main coronary artery ostium.

The anatomy of the non-coronary sinus of Valsalva should not be omitted in measurements. The reason is that the posterior sinus of Valsalva lies in the interatrial groove, thus bordering with right and left atrium simultaneously. Additionally, the height of the non-coronary sinus is important in clinical practice, as in choosing the type of aortic valve prosthesis, the position of implantation (annular, sub- or supra-annular), and the method of suturing the aortic valve prosthesis. Low height of the non-coronary sinus is always identified with the higher percentage of the intraoperative conduction disturbances, as the length of the aortic-mitral junction decreases and, as a result, the conduction bundle passes closer to the aortic annulus in the projection of the non-coronary sinus (Charitos and Sievers, 2013). With the bicuspid aortic valve and the sagittal location of the effective orifice (Sievers type I), the plane of the non-coronary sinus is 1/3 lower than the other fused sinus (Stephens et al., 2015). Thus, surgeons have to take into account the given anatomical feature to prevent the displacement of the plane of the implanted aortic valve prosthesis towards the left ventricle outflow tract. The height of the non-coronary sinus is also crucial for the choice of patch height in patients with a narrow aortic annulus in the aortic root dilatation operations (Nicks and Manouguian techniques) (Massias et al., 2021). In the present study, the non-coronary sinus in men correlates with height and BSA, and does not have confirmed direct correlations with any anthropometric measurements in women.

The geometry of the sinuses of Valsalva is of the considerable importance in surgery aiming at the aortic root reimplantation into the vascular prosthesis (David I-V operations) (Miller, 2003) as well as in aortic root remodeling (Yacoub Procedure, Urbanski operation) (Yacoub et al., 2018), because the most accurate restoration of all the anatomical structures of the aortic root ensures appropriate and long-term functioning of the aortic valve. The length and height of the aortic root sinuses are the main indicators in the operation of neocuspidation of the aortic valve (Ozaki operation) (Alhan, 2019).

Authors have reported that age (Vriz et al., 2013) and gender (Koepke et al., 2018) have an impact on the cardiovascular system. With age, the number of collagen fibers increases and replace the elastin fibers changing the histological structure of aorta (Komutrattananont et al., 2019). Many authors pay attention to increasing aortic diameter with age (Bahlmann et al., 2011; Komutrattananont et al., 2019; Vriz et al., 2013). Changes in the geometry and diameter of the sinuses of Valsalva affect the hemodynamics and the nature of the flow at the aortic root (Kivi et al., 2020). The results of the present study do not confirm a correlation between age and the height of sinuses of Valsalva in both gender groups. It should be noted that the previously published studies compare horizontal measurements (diameter) of the aorta. The probable aging changes in the height of the sinuses of Valsalva require further investigation.

Height correlates with the cardiovascular events. Tall people have lower incidence and mortality rate from the coronary heart disease (Nelson et al., 2015; Rosenberg et al., 2014; Silventoinen et al., 2006). Short stature has an association with a higher incidence of cardiovascular disease events (Paajanen et al., 2010). Therefore, the patient's height is one of the indicators that might be considered to predict risks of cardiovascular disease. The current study confirms a strong direct correlation between height and the size of all the three sinuses of Valsalva in men. In female cohorts only the size of the left coronary sinus of Valsalva has a moderate direct correlation with height. The impact of gender on the aortic root anatomy may be considered an additional factor. Interestingly, the degree of correlation in women is lower than in men.

BMI and BSA, which are calculated with formulas using height and weight, have a different correlation with the sinuses of Valsalva measurements in two groups. In men, correlation analysis has confirmed a moderate direct correlation between BSA and right, left and non-coronary sinus. In female cohorts, left and right coronary sinus size have a moderate direct correlation with BMI and BSA.

Multiple correlation coefficient R, which was used to point to the strength of correlation, showed a strong direct correlation in men between the anthropometric measurements (height, weight, BMI, BSA) and the sinuses of Valsalva height indicators ($p<0.001$). Increased size of sinuses in men correlated with an increase of height, weight and decrease of BMI and BSA values. Within the group of women, the increased size of the left coronary sinus was affected by the increase of height and BMI and decreased BSA.

In conclusion, we found an association between gender and patient height and the height of the sinuses of Valsalva. The sinuses of Valsalva height is higher in males. The most significant confirmed correlations were between height and left and right coronary sinuses in men and women. Increased size of sinuses in men correlated with an increase of height, weight and decrease of BMI and BSA values.

Limitations of the study

The study design was limited to a group of patients consisting of Ukrainians and was not repeated with different ethnic groups. Intra- and inter-group variability of the sinuses of

Valsalva height was measured only with CTA, and no comparison was made with other possible diagnostic methods (ECHO, MRI, IVUS).

Sources of Funding

The study was conducted within the scientific research program of the Department of Normal Anatomy at Danylo Halytsky Lviv National Medical University (Lviv, Ukraine) according to the research topic “Morphofunctional features of organs in pre- and post-natal ontogenetic periods under the influence of opioids, food additives, reconstructive surgeries and obesity”; the research program is funded from the State Budget of The Ministry of Health of Ukraine.

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