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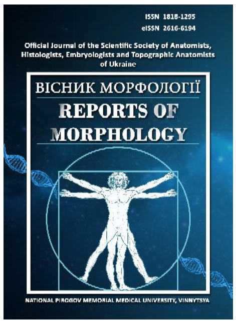

Modeling of Valsalva sinuses and coronary artery ostia height parameters, depending on age-anthropometric indicators in healthy men based on computed tomography

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Computed tomography is the "gold standard" for performing aortic morphometry during preoperative planning in invasive cardiology and cardiac surgery. Predictive modeling of indicators can significantly save resources. The purpose of the study: to make modelling of Valsalva sinuses and coronary artery ostia height parameters depending on age-anthropometric indicators in healthy men based on computed tomography. The material is represented by contrast-enhanced computed tomography images of the aorta and coronary arteries of forty-three men under normal conditions. Methods: morphometric and statistical analyses. A multifactorial correlation-regression analysis was conducted to establish the complex influence of age-anthropometric parameters on sinuses of Valsalva and coronary artery ostia height. The reliability of the obtained indicators was confirmed by Fisher's test (F). Using the Durbin-Watson autocorrelation criterion, the correctness of the built model was proved. In healthy men, weight (direct effect) and body mass index (inverse effect) significantly influenced the height of the lower edge of the right coronary artery ostia. The regression coefficient is R = +0.632, with p<0.001, the standard error of estimation (SEE) is 2.951. The obtained linear equation of the prognostic model: the level of the height of the departure of the lower edge of the right coronary artery ostia = 0.359 x A1 - 1.099 x A2 + 16.53. The correctness of the built model was checked using the Durbin-Watson autocorrelation test (2.181). The prognostic model for calculating the height of the left aortic sinus was formed by height and weight indicators (strong direct influence): R = +0.759, p<0.001, SEE = 2.208. The adjusted coefficient of multiple determination was $R2_{adj}$ *= +0.562. The Durbin-Watson autocorrelation criterion was within the normal range (2.241). The linear equation of the prognostic model with the obtained β-coefficients: the level of the height of the left sinus of the aorta = 35.83 x A1 + 0.033 x A2 - 42.22. The work of prognostic models for individuals with different anthropometric and age parameters was verified. Thus, a model of the dependence of the indicator of the height of the left sinus of the aorta on height and weight was created; of the height of the deviation of the lower edge of the right coronary artery from weight and body mass index in healthy men based on computed tomography.*

Keywords: *coronary artery ostia, anatomy, computed tomography, aorta.*

Introduction

According to the Global Burden of Disease (GBD), mortality from cardiovascular diseases in Ukraine is 64.3 % [15, 19]. It is important that the sex aspect is clearly observed in the structure of morbidity. Men get sick more often than women. This tendency is typical in the global and Ukrainian incidence structure. In Ukraine, men have almost twice the incidence rate. According to the European society of cardiology (ESC) 772.1 cases per 100,000 men and 440.9 per 100,000 women) (2017 data) [1, 2].

Computed tomography (CT) is the "gold standard" modality for diagnosing the state of the cardiovascular system [10, 18]. Morphometry of the aortic bulb is necessary for preoperative planning in invasive cardiology and cardiac surgery [3, 7]. Morphometric data of the aorta differ between countries, while research on this topic in Ukraine is rather isolated. However, an increase in the number of performed diagnostic procedures will necessitate a quick and, most importantly, detailed analysis of the cardiovascular system, measurements of target structures. Modeling is one option that can significantly save radiologists' time and reduce overall economic costs.

Using CT images, in previous studies, we performed a morphometric analysis of the aortic bulb and established a correlation between the values of the height of the aortic sinuses, the height of the exit of the coronary arteries and anthropometric indicators in healthy men [11, 12]. The results of the research led to the next stage - prognostic modeling of height indicators, to prove the correctness of the constructed logical model and to test it by calculating the predicted values of vascular parameters for two men with different anthropometric and age parameters without damage to the cardiovascular system, who were interpreted as the norm.

The purpose of the study: to make modelling of Valsalva sinuses and coronary artery ostia height parameters depending on age-anthropometric indicators in healthy men based on computed tomography.

Materials and methods

For the purpose of prognostic modeling of Valsalva sinuses height parameters depending on age and anthropometric parameters, a multifactor correlation-regression analysis was performed to establish the complex influence of age-anthropometric parameters on the parameters of the studied structures.

This is a single-center, prospective study conducted on the basis of the Lviv Regional Clinical Hospital and the Ukrainian-Polish Heart Center "Lviv" from 2019 to 2022. Inclusion criteria: male subjects (1) who underwent computed tomography (CT) with coronary contrast arteries and aorta (2), without structural changes in the heart and aorta that could potentially affect the measurements (3). Exclusion criteria: birth defects, structural changes of the studied structures, history of cardiac surgery, artifacts, incomplete clinical data. 43 persons included in the study met the set criteria.

Measurements have been made: sinuses of Valsalva height (distance from the aortic valve annulus to the sinotubular junction) and coronary artery ostia height (distance from the aortic valve annulus to the lower edge of the coronary artery ostia) were performed at a CT station with licensed software (General Electric, USA). Diagnostic modality: tomograph LightSpeed VCT XT, GE (General Electric, USA). Contrast agent - Ultravist 470 (Bayer Healthcare, Germany). Data taken into account: age, height, body weight, body mass index, body surface area (calculated according to the Mosteller formula).

Primary data were based on morphometric analysis of the height of the right sinuses of Valsalva (1), left sinuses of Valsalva (2), posterior sinuses of Valsalva (3), coronary artery ostia height (4), left coronary artery ostia height (5) in men without lesions of the heart and ascending aorta (normal), which underwent a computed tomography (CT) study with contrast of the aorta, heart, and coronary arteries. Predictors of influence: age (1), height (2), weight (3), body mass index (4), body surface area (5).

The study was conducted in accordance with the Declaration of Helsinki "Ethical principles of medical research with human participation as a research object" and was approved at the meeting by the conclusion of the Bioethics Commission of Danylo Halytsky Lviv National Medical University (protocol No. 10 of December 20, 2021).

Statistical analysis was performed using R software version 4.0.5 (R Core Team, 2021) and R Commander (version 2.7-2, GNU General Public License) based on the Windows operating system. We calculated the regression coefficient (R), the adjusted coefficient of multiple determination R2adj, which would prove the influence of the specified predictors in X % of cases. The reliability of the obtained indicators was confirmed by Fisher's test (F). Using the Durbin-Watson autocorrelation criterion, the correctness of the built model was proved. The results of logistic regression calculations for predicting the level of vascular parameters were presented in the form of tables and presented graphically. For clarity of operation of the logistic model, it was tested by calculating the predicted values of vascular parameters for two individuals from the research group who differ in anthropometric and age parameters.

Results

The age and anthropometric characteristics of men (n = 43) under normal conditions are presented in Table 1. A multifactorial regression analysis was performed for each vascular parameter (dependent predictors) of healthy men with the selection of the most optimal set of independent predictors of influence (age and anthropometric indicators), which reliably strongly influenced value of each morphometric parameter in healthy men. During the study, the most optimal balanced two forecasting models were selected by stepwise selection: for the value of the height of the lower edge of the right coronary artery ostia and for the height of the left sinuses of Valsalva, which were confirmed by the appropriate reliability criteria.

It was established that the height of the lower edge of the right coronary artery ostia was significantly influenced

Table 1. Age and anthropometric characteristics of men without structural damage to the heart and ascending aorta during a computed tomography study.

Parameters	Men (n = 43)
Age (years)	52.56±13.52
Height (m)	1.756±0.067
Weight (kg)	84.74±14.14
Body mass index (kg/m^2)	27.54±4.74
Body surface area (m^2)	2.033±0.181

Table 2. Results of logistic regression calculations for predicting the level of the height of the lower edge of the right coronary artery ostia in healthy men.

Indexes	Conventional designation	b-coefficients	p
Constant		16.53	<0.001
Weight	A1	0.359	<0.001
Body mass index	A2	-1.099	<0.001

by weight (direct influence) and body mass index (inverse influence). The regression coefficient is R = +0.632, with p<0.001 (according to Fisher), the standard error of estimation (SEE) is 2.951. The adjusted coefficient of multiple determination $R2_{adj}$ = +0.361 indicates that the complex influence of independent predictors of weight and body mass index on the value of the height of the lower edge of the right coronary artery ostia was present in 36.02 % of cases in healthy men. The main data for building the model are given in Table 2.

By substituting the calculation data from the table, we get a linear equation of the prognostic model: *the height level of the coronary artery ostia lower right edge* = 0.359 x A1 - 1.099 x A2 + 16.53.

The correctness of the built model was checked using the Durbin-Watson autocorrelation criterion, the obtained value of 2.181 is within the normal range (1.5-2.5).

The calculated average predicted value of the height of the lower edge of the eye of the right coronary artery is 16.67±2.31 mm (minimum value 11.59 mm, maximum 21.30 mm), which actually completely coincides with the available average value of healthy men: 16.67±3.69 mm.

A graphic representation of the normal probability of the influence of the obtained independent anthropometric predictors on the predicted value of the height of the lower edge of the right coronary artery ostia in healthy men is presented in Figure 1.

To practically confirm the work of this prognostic model,

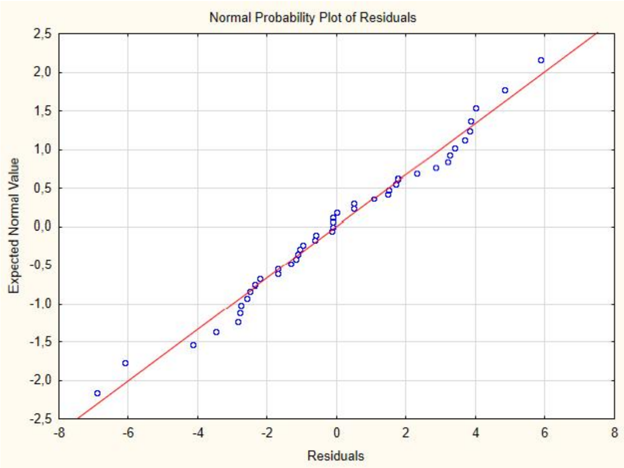

Fig. 1. The normal probability of influence of predictors of weight and body mass index on the predicted value of the height of the lower edge of the right coronary artery ostia in healthy men.

we will consider two real examples of calculations for different anthropometric and age parameters of the studied persons.

Example № 1. Person No. 10 from the database of healthy men: man, 65 years old, height 1.81 m, weight 90 kg, body mass index 27.47 kg/m^2, body surface area 2.127 m^2, height of the lower edge of the right coronary artery ostia 18.50 mm.

We substitute the necessary weight and body mass index data into the formula of the linear logistic regression equation and get the result: *height level of the right coronary artery ostia* = 0.359 x 90.00 - 1.099 x 27.47 + 16.53 = 18.62 mm.

Comparing the actual (18.50 mm) and predicted (18.62 mm) value of the height of the lower edge of the right coronary artery ostia, we get a difference of 0.12 mm, which does not exceed the permissible 5 % error.

Example № 2. Person No. 43 from the database of healthy men: man, 44 years old, height 1.65 m, weight 85 kg, body mass index 31.22 kg/m^2, body surface area 1.974 m^2, height of the lower edge of the right coronary artery ostia 12.60 mm.

Enter the required personal data into the linear logistic regression equation: *height level of the right coronary artery ostia* = 0.359 x 85.00 - 1.099 x 31.22 + 16.53 = 12.71 mm.

Thus, the calculated value of the height of the lower edge of the right coronary artery ostia of 12.71 mm differs slightly from the actual value of 12.60 mm obtained during the CT scan - the difference is 0.11 mm, which confirms the effectiveness of this prognostic model in practice.

To form a prognostic model for calculating the height of the left sinus of Valsalva in healthy men, a set of independent predictors was optimal, which included height and weight indicators (strong direct influence): R = +0.759, p<0.001, SEE = 2.208. The adjusted coefficient of multiple determination was $R2_{adj}$ = +0.562, which confirms the dependence of the value of the height of the left sinus of Valsalva in 56.09 % of cases on the age-anthropometric indicators of healthy men. The Durbin-Watson autocorrelation criterion was within the normal range - 2.241. The necessary data for building the model are given in Table 3.

The linear equation of the prognostic model with the obtained β-coefficients will have the following form: *left sinus of Valsalva height level* = 35.83 x A1 + 0.033 x A2 - 42.22.

The calculated average predicted value of the height of the left sinus of Valsalva is similar to the actual value: 23.49±2.54 mm and 23.49±3.33 mm, respectively. The minimum prognostic value is 17.41 mm, the maximum is 28.95 mm.

Figure 2 shows a graph of the normal probability of the influence of the obtained independent anthropometric predictors on the predicted value of the height of the left sinuses of Valsalva in healthy men.

We will test the performance of the prognostic model on two individuals with different anthropometric and age

Table 3. Results of logistic regression calculations for predicting the height of the left sinus of Valsalva in healthy men.

Indexes	Conventional designation	b-coefficients	p
Constant		-42.22	<0.001
Weight	A1	35.83	<0.001
Body mass index	A2	0.033	>0.05

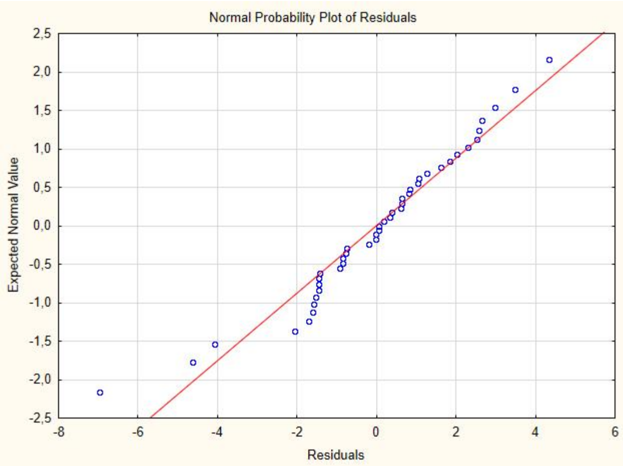

Fig. 2. The normal probability of influence of predictors of height and weight on the predicted value of the height of the left sinus of Valsalva in healthy men.

parameters.

Example № 3. Person No.13 from the database of healthy men: male, 49 years old, height 1.65 m, weight 65 kg, body mass index 23.88 kg/m^2, body surface area 1.726 m^2, left aortic sinus height 19.10 mm.

Enter the height and weight of the person into the formula and get the result: *left sinus of Valsalva height level* = 35.83 x 1.65 + 0.033 x 65.00 - 42.22 = 19.04 mm. The obtained predicted value of the height of the left sinus of Valsalva (19.04 mm) does not significantly differ from the actual (19.10 mm) level of the parameter of this vessel (p>0.05).

Example № 4. Person No. 41 from the database of healthy men: male, 53 years old, height 1.84 m, weight 80 kg, body mass index 23.63 kg/m^2, body surface area 2.022 m^2, left sinus of Valsalva height 26.40 mm.

We substitute the relevant personal data into the linear regression equation: l*eft sinus of Valsalva height level* = 35.83 x 1.84 + 0.033 x 80.00 - 42.22 = 26.34 mm.

Therefore, comparing the forecast (26.34 mm) and the actual value (26.40 mm), we get an insignificant difference between the indicators of 0.06 mm, which proves the effectiveness of this forecast model.

Discussion

Modeling of parameters of Valsalva sinuses and coronary artery ostia height depending on age-anthropometric parameters in forty-three healthy men was carried out. It is based on the morphometric analysis of computed tomography images. The most optimal balanced two prediction models were selected: for the value of the height of the lower edge of the right coronary artery ostia and for the height of the left sinus of Valsalva, which were confirmed by the appropriate reliability criteria. Testing the models proved the correctness of the constructed logical model. Thus, the complex influence of weight (direct) and body mass index (inverse) on the level of the height of the lower edge of the right coronary artery ostia and a strong direct influence of height and weight on the calculations of the height of the left sinus of Valsalva have been established.

Various age-anthropometric dependences on the morphometry of the aorta in different groups of subjects are described. S.Y. Ho describes that the size of the aorta increases with age [5]. X. Wang et al. conducted a study among the Chinese population (3018 patients), excluding individuals with heart valve pathology and probable coronary heart disease, and found that aortic diameters correlated with age in men (p<0.05). Scientists decided to make a correction to the surface area of the body. According to the results of which the correlation with age was again confirmed in men [20]. Dividing the 1286 selected patients into age groups, the researchers found that there was no gender difference in the diameter of the ascending aorta in the group of people under 30 years of age and the group of people over 70 years of age [20].

In the study of T. Plonek et al. [13] describe the lack of correlation between the maximum and minimum diameters of the aortic root and height (r=0.115, p=0.115), weight (r=0.029, p=0.768), body surface area (r=0.079, p=0.426). The lack of correlation with the size of the aorta and the surface area of the body does not coincide with the data of X. Wang et al. [20], P. Nagpal and others. [9], who described it. Concordance between the works of T. Plonek et al. [13], X. Wang and others. [20] about the lack of correlation between the height and the diameter of the ascending aorta, does not coincide with the statement of P. Nagpal et al. [9], who established a correlation between height and the dimensions of the thoracic part of the aorta by measuring it on CT images.

A wide range of diagnostic possibilities, a different approach to measurement, and the heterogeneity of groups in studies lead to the fact that the dimensions and, accordingly, the correlation will differ between populations [4, 6, 17]. Modeling is the next stage. That is why numerous studies are carried out with a focus on the morphometric requirements of manufacturing companies [16, 21], approaching the creation of unified protocols [8, 14], which will make it possible to create models and predict measurements of the studied parameters.

The obtained results create prospects for the implementation and involvement of the proposed models in clinical practice. For Ukraine, radiological research in the anatomical aspect is somewhat new, which requires additional study with the involvement of a larger amount of data.

Conclusion

A model of the height indicator of the left sinus of Valsalva based on height and weight was created; the level of the height of the lower edge of the right coronary artery ostia from weight and body mass index in healthy men based on computed tomography.

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МОДЕЛЮВАННЯ ПОКАЗНИКІВ ВИСОТИ ПАЗУХ АОРТИ ТА ВІЧОК ВІНЦЕВИХ АРТЕРІЙ В ЗАЛЕЖНОСТІ ВІД ВІКОВО-АНТРОПОМЕТРИЧНИХ ПОКАЗНИКІВ У ЗДОРОВИХ ЧОЛОВІКІВ НА ОСНОВІ КОМП'ЮТЕРНОЇ ТОМОГРАФІЇ

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Комп'ютерна томографія є "золотим стандартом" для проведення морфометрії аорти при передопераційних плануваннях в інвазивній кардіології та кардіохірургії. Прогностичне моделювання показників може суттєво зекономити ресурси. Мета дослідження: провести моделювання показників висоти пазух аорти та відходження вічок вінцевих артерій в залежності від віково-антропометричних параметрів у здорових чоловіків на основі комп'ютерної томографії. Матеріал представлений комп'ютерно-томографічними зображеннями аорти та вінцевих артерій з контрастуванням сорока трьох чоловіків за умов норми. Методи: морфометричний та статистичний аналізи. Мультифакторний кореляційно-регресійний аналіз проведено для встановлення комплексного впливу віково-антропометричних параметрів на показники висоти пазух аорти та відходження вічок вінцевих артерій. Достовірність отриманих показників підтверджувалась критерієм Фішера (F). За критерієм автокореляції Дурбіна-Уотсона доводили правильність побудованої моделі. У чоловіків в нормі на рівень висоти відходження нижнього краю вічка правої вінцевої артерії суттєво впливали вага (прямий вплив) та індекс маси тіла (зворотній вплив). Коефіцієнт регресії становить R = +0,632, при p<0,001, стандартна похибка оцінки (SEE) 2,951. Отримане лінійне рівняння прогностичної моделі: рівень висоти відходження нижнього краю вічка правої вінцевої артерії = 0,359 x A1 - 1,099 x A2 + 16,53. Правильність побудованої моделі перевірено за допомогою критерію автокореляції Дурбіна-Уотсона (2,181). Прогностичну модель розрахунків рівня висоти лівої пазухи аорти формували показники зросту та ваги (сильний прямий вплив): R = +0,759, p<0,001, SEE = 2,208. Скоригований коефіцієнт множинної детермінації становив $R2_{adj}$ *= +0,562. Критерій автокореляції Дурбіна-Уотсона був у межах норми (2,241). Лінійне рівняння прогностичної моделі з отриманими β-коефіцієнтами: рівень висоти лівої пазухи аорти = 35,83 x A1 + 0,033 x A2 - 42,22. Пройдено перевірку роботи прогностичних моделей для різних за антропометричними та віковими параметрами осіб. Таким чином, створено модель залежності показника висоти лівої пазухи аорти від зросту та ваги; рівня висоти відходження нижнього краю вічка правої вінцевої артерії від ваги та індексу маси тіла у здорових чоловіків на основі комп'ютерної томографії.*

Ключові слова: *вічка вінцевих артерій, анатомія, комп'ютерна томографія, аорта.*