BASIC SCIENCE

Geometry of Koch's triangle

Wiesława Klimek-Piotrowska[1], Mateusz K. Hołda[1]*, Mateusz Koziej[1], Kinga Sałapa[2], Katarzyna Piątek[1], and Jakub Hołda[1]

[1]Department of Anatomy, Jagiellonian University Medical College, Kopernika 12, 31-034 Cracow, Poland; and [2]Department of Bioinformatics and Telemedicine, Jagiellonian University Medical College, Cracow, Poland

Aims	The first aim of this study was to determine the size of the Koch's triangle. The second one was to investigate relation between its dimensions and other individual-specific and heart-specific parameters as well as to create universal formula to estimate triangle dimensions based on these parameters.
Methods and results	This study is a prospective one, presenting 120 randomly selected autopsied hearts dissected from adult humans (Caucasian) of both sexes (31.7% females), with mean age of 49.3 ± 17.4 years. The length of triangle sides and angles were measured and the triangle area was calculated as well. Sixteen additional heart parameters were measured in order to analyse potential relationship between the dimensions of Koch's triangle and other dimensions of the heart, using linear regression analysis. The mean ($\pm$ SD) length of the anterior edge was approximated to 18.0 ± 3.8 mm, the posterior edge to 20.3 ± 4.3 mm, and the basal edge to 18.5 ± 4.0 mm. The average values of the apex angle, the Eustachian angle, and the septal leaflet angle were $58.0 \pm 14.4°$, $53.8 \pm 10.6°$, and $67.6 \pm 14.4°$, respectively. The mean value of the Koch's triangle area was 151.5 ± 55.8 mm^2. The 95th percentile of triangle's height (the distance from the apex to the coronary sinus) was 21.8 mm.
Conclusion	Mean values and proportions of triangle's sides and angles were presented. Koch's triangle showed considerable individual variations in size. The dimensions of the triangle were strongly independent from individual-specific and heart-specific morphometric parameters; however, the maximum triangle's height can be estimated as 22 mm.
Keywords	Eustachian ridge • Coronary sinus ostium • Atrioventricular node • Tendon of Todaro • Triangle of Koch

Introduction

Koch's triangle is an important area of human heart, which is located in the superficial paraseptal endocardium of the right atrium, used as an anatomical landmark to locate the atrioventricular (AV) node. Despite the fact that 100 years elapsed since its first description by Walter Koch in 1909,[1] this conception did not lose its importance, and even recent developments in the invasive electrocardiological techniques for treatment of AV nodal re-entry tachycardia rise its significance.

The knowledge of Koch's triangle dimensions is extremely important to safely perform radio frequency catheter ablation within the right atrium, because undesirable ablation of the AV node inside Koch's triangle presents a risk of nodal injury and complete AV block. Despite the past discussions and even proposals to abandon this concept,[2] Koch's triangle still remains useful in both clinical and experimental way.[3]

The present study was conducted with two aims. The first one was to determine the size of Koch's triangle in adult Caucasian population. The second one was to investigate the relation between its dimensions and other individual-specific and heart-specific parameters, as well as to create a universal formula to estimate triangle dimensions based on these parameters, which might be useful for clinicians.

Methods

Study population

This study was conducted in the Department of Anatomy, Jagiellonian University Medical College and was approved by the Bioethics Committee of Jagiellonian University Medical College, Cracow, Poland (KBET/ 51/B/2013). One hundred and twenty randomly selected autopsied human hearts (Caucasian) of both sexes (31.7% females) with mean age of 49.3 ± 17.4 years and average measured body mass index (BMI) of

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* Corresponding author. Tel: +48 12 422 95 11; fax: +48 12 422 95 11. *E-mail address:* mkh@onet.eu

What's new?

- The dimensions of the Koch's triangle are strongly independent from individual-specific and heart-specific morphometric parameters.
- The maximum triangle's height can be estimated as 22 mm.
- The anatomical boundaries of Koch's triangle were precisely defined.

27.7 ± 5.7 kg/m^2 and body surface area (BSA) of 1.9 ± 0.2 m^2 were examined. All heart specimens were collected precisely during routine forensic medical autopsies performed in the Department of Forensic Medicine, Jagiellonian University Medical College from July 2013 to October 2014. The main causes of death were suicide, traffic and home accidents, and murders. Exclusion criteria included severe anatomical defects, states post surgeries and heart grafts, evident severe macroscopic pathologies of the heart or vascular system found during autopsy (aneurysms, storage diseases), heart trauma, and macroscopic signs of cadaver decomposition. None of the 120 individuals had history of any arrhythmia types.

Dissection and measurements

All hearts were removed together with proximal portions of great vessels: the ascending aorta, the pulmonary trunk, the superior and the inferior vena cava (up to 1 cm of length in each case), and all pulmonary veins (up to the lung hilum). After dissection, all hearts were weighted and then fixed in 10% paraformaldehyde solution for a maximum of 2 months before the measurement time. All 120 heart specimens were opened in routine way using an incision extending from the orifice of the superior vena cava to the orifice of the inferior vena cava, without orifices being sectioned. If necessary, additional cuts were made in order to present the investigated area in a better way.

The anterior, the posterior, and the basal edges, as well as all internal angles of Koch's triangle, were identified and measured. The Koch's triangle components were precisely defined as follows (*Figure 1*):

- The apex—point located in the centre of the central fibrous body, identified by its translumination
- The anterior edge (*a*)—closed line segment bounded by the apex on the left side and the point where the basal edge touches the tricuspid annulus on the right side and tangential to the attachment line of the septal tricuspid leaflet
- The basal edge (*b*)—closed line segment tangential to the left contour of the coronary sinus, bounded by the point where it touches the tricuspid annulus anteriorly and the Eustachian ridge posteriorly
- The posterior edge (*c*)—closed line segment bounded by the apex at the left side and by the point where basal edge touches the Eustachian ridge on the right side (the line running in the extension of the Eustachian ridge)
- The Apex angle (*A*)—angle included between the anterior and the posterior edge
- The Eustachian angle (*E*)—angle included between the basal and the posterior edge
- The septal leaflet angle (*S*)—angle included between the basal and the anterior edge

Prior to measurements, all vertices of Koch's triangle were marked using pins and its *edges* were drawn using a permanent marker. All linear measurements were taken using a 0.03 mm YATO (YT-7201) precision electronic calliper. Angle measurements were taken using 1° precision half circle protractor. All measurements were taken by two independent researchers in order to reduce bias. If differences between results among researchers were >10%, both measurements were repeated.
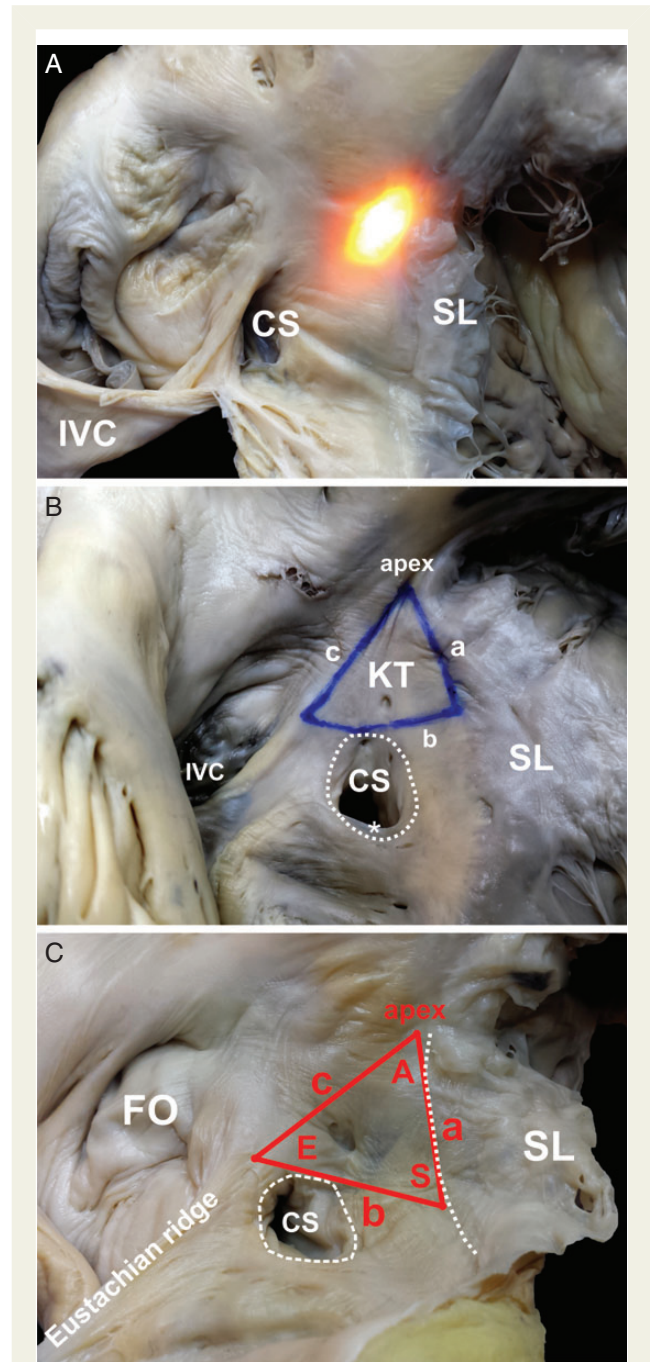

Figure 1 Photograph showing cadaveric heart specimens with the view of the Koch's triangle area. (*A*) Translumination of the central fibrous body (the apex of the Koch's triangle)—source of light placed in the left ventricle; (*B*) Koch's triangle marked on a specimen; (*C*) schematic view of the Koch's triangle. a, anterior edge; A, apex angle; b, basal edge; c, posterior edge; CS, coronary sinus; E, Eustachian angle; FO, fossa ovalis; IVC, inferior vena cava; KT, Koch's triangle; S, septal leaflet angle; SL, septal leaflet of the tricuspid valve; *Thebesian valve.

The mean out of two measurements was calculated, with approximation to the 10th decimal place. The area of the Koch's triangle (P) was calculated using Heron's formula:

$$P = \frac{1}{4}\sqrt{(a+b+c)(-a+b+c)(a-b+c)(a+b-c)},$$

where a, b, and c are lengths of the triangle edges.[4] Having taken the measurements of edges and internal angles of all triangles, their correctness was tested using mathematical formulas describing a triangle (the sum of the interior angles equals $180°$), the measurements were repeated in case of deviations.

Next, 16 additional heart parameters (such as anteroposterior and mediolateral diameters of the inferior and the superior vena cava ostia; the tricuspid, the mitral, the aortic, and the pulmonary trunk ostia diameters; the coronary sinus ostium diameter; the craniocaudal and the anteroposterior fossa ovalis diameters; the interatrial septum height and width from the right atrial view; the central and the inferolateral cavo-tricuspid isthmus; and the Eustachian ridge length) were measured in order to assess potential relationship between the dimensions of Koch's triangle and other dimensions of the heart.

Statistical analysis

Quantitative features were presented as mean value $\pm$ standard deviation or as median with two other quartiles (Q_1, Me, Q_3), as appropriate. Minimum and maximum values were added in case of more important variables. Qualitative features were characterized by frequencies and percentages. In order to compare average results between two different groups, t-test or non-parametric Mann−Whitney test were performed in case of no normality. In case of comparing the average results of two different measurement methods applied to the same subject, paired t-test or non-parametric Wilcoxon signed-rank test were performed as appropriate. Normal distribution was assessed using Shapiro−Wilk test. To verify correlation between two quantitative variables, the Pearson's correlation coefficient or the Spearman's rank correlation coefficient were used as appropriate. The linear regression was performed to investigate the impact of parameters such as age, BMI, BSA, heart weight, human weight, height, and the 16 additional heart-specific features as well as their combination on the dimension of each edge of Koch's triangle. The statistical significance was set at $P < 0.05$. The statistical analysis was performed using StatSoft Inc. software (STATISTICA v10, Tulsa, OK, USA).

Results

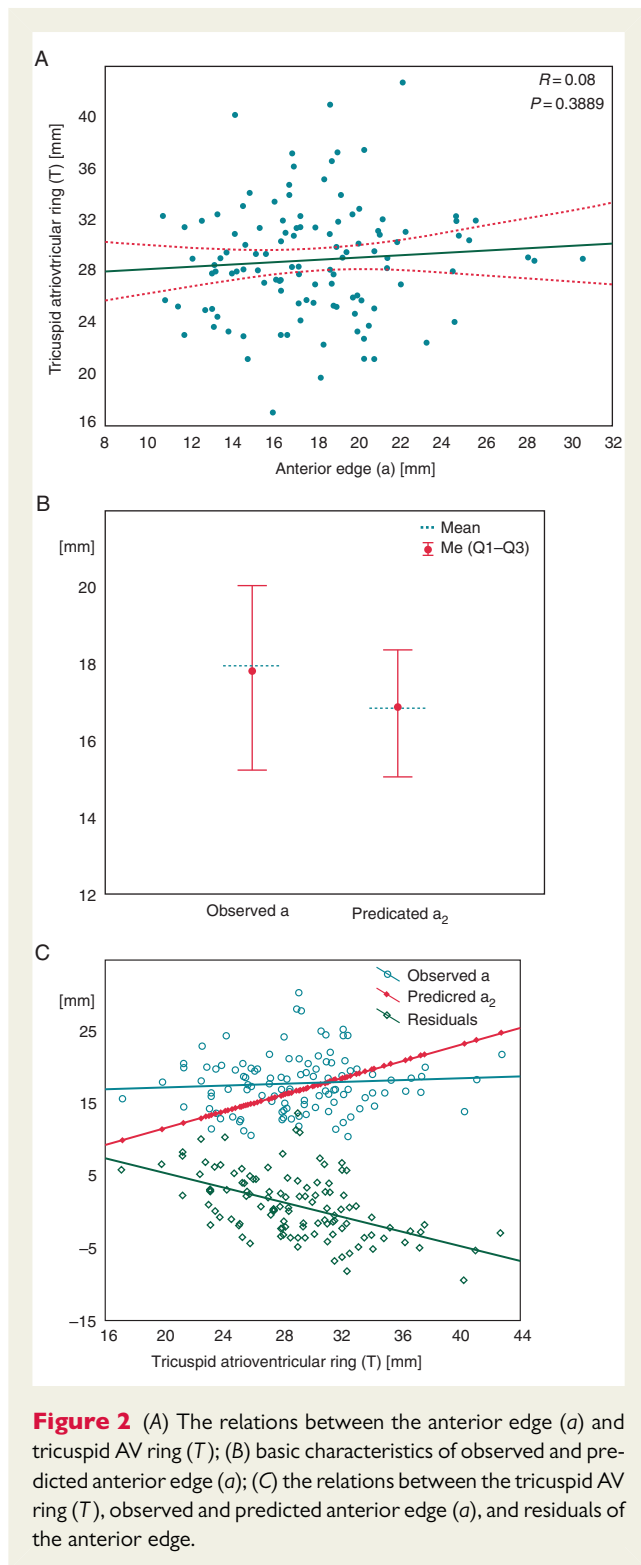Mean heart weight was 455.1 ± 110.4 g. Table 1 shows measurements of Koch's triangle edges and angles. The average shortest distance from the coronary sinus ostium contour to the apex of the Koch's triangle, perpendicular to the basal edge (the height of the triangle) was 16.0 ± 3.7 mm. The mean diameter of the coronary sinus ostium was 9.3 ± 2.8 mm and the mean diameter of the tricuspid AV ring was 28.9 ± 4.5 mm. The average length measured along the septal tricuspid leaflet from the point where the Koch's triangle basal edge touches the tricuspid annulus, to the right edge of the septal tricuspid leaflet was 20.2 ± 3.7 mm. The mean values of other heart dimensions were as follows: the anteroposterior, 23.7 ± 5.9 mm, and the mediolateral, 24.1 ± 6.1 mm, diameter of the inferior vena cava ostium; the anteroposterior, 18.7 ± 3.3 mm, and the mediolateral, 19.4 ± 3.5 mm, diameter of superior vena cava ostium; mitral ostium, 21.4 ± 5.4 mm; the aortic ostium, 22.5 ± 4.3 mm; the pulmonary trunk ostium, 20.6 ± 3.9 mm; the craniocaudal, 11.9 ± 3.8 mm, and anteroposterior, 13.9 ± 3.7 mm, diameter of the fossa ovalis; the height and the width of the interatrial septum from the right atrium side were 35.0 ± 7.3 and 29.5 ± 8.1 mm, respectively; the central cavo-tricuspid isthmus, 23.5 ± 3.8 mm; the inferolateral cavo-tricuspid isthmus, 28.8 ± 4.1 mm; and the Eustachian ridge length, 25.6 ± 4.2 mm. The mean anterior/posterior edge ratio was 0.9 ± 0.17, and anterior/basal and posterior/basal ratios were 1.0 ± 0.23 and 1.13 ± 0.26, respectively.

All results of simple and multiple linear regressions were highly insignificant. This means that parameters such as age, BMI, BSA, heart weight, human weight and height, and the 16 additional heart-specific features, as well as their combinations, have no meaningful impact on dimension of each Koch triangle's edge. However, one relation was rendered as the most promising after the initial calculations. Its aim was to define the anterior edge of the triangle (a) using the diameter of the right AV ring (T) (Figure 2A). The direct relation between the (T) value, the (a) value, and the length (D) measured along the septal tricuspid leaflet between the point of Koch's triangle base reaching the tricuspid annulus and the right end of the septal tricuspid leaflet was used. D/T and $T/(a + D)$ proportions were created. These two proportions were calculated for each individual, and then the mean values were obtained: $D/T = 0.755$ and $T/(a + D) = 0.759$. Based on these equations, it is possible to present that $a = 0.5594 \times T$. Next, the Koch's triangle anterior edge's (a) length measured post-mortem was compared with the obtained using the (T) to (a) equation (a_2). The median of the observed anterior edge [17.85 (15.25−20.05) mm] was not significantly different from the median of the predicted one ([6.92 (15.05−18.37) mm]

Table 1 Results of obtained Koch's triangle dimensions measurements ($n = 120$)

	Mean	SD	Min	Max	Median	Q_1	Q_3
Anterior edge (a), mm	18.0	3.8	10.7	30.6	17.9	15.3	20.1
Posterior edge (c), mm	20.3	4.3	10.9	32.0	20.3	17.5	22.9
Basal edge (b), mm	18.5	4.0	9.8	29.4	18.1	15.8	21.0
Triangle area (P), mm^2	151.5	55.8	61.2	365.0	147.1	106.2	183.5
Apex angle (A), degrees	58.0	14.4	27	115	57	48	66
Eustachian angle (E), degrees	53.8	10.6	30	82	52	46	60
Septal leaflet angle (S), degrees	67.6	14.4	30	114	67	58	77

SD, standard deviation; Q1 and Q3, lower and upper quartiles.

Figure 2 (*A*) The relations between the anterior edge (*a*) and tricuspid AV ring (*T*); (*B*) basic characteristics of observed and predicted anterior edge (*a*); (*C*) the relations between the tricuspid AV ring (*T*), observed and predicted anterior edge (*a*), and residuals of the anterior edge.

Figure 3 (*A*) Box–whisker plot presenting the Koch's triangle height vs. the BMI groups; (*B*) box–whisker plot presenting the triangle height in men and women; (*C*) the relations between the triangle height and age.

($P = 0.056$, Wilcoxon signed-rank test) (*Figure 2B*). Although the presented relationship between (*a*) and (*T*) seems to be reasonable and there is no significant difference between the average observed and predicted (a_2) values, it should be noted that the correlation did not show linear relation between these two variables. Moreover, the residual analysis (difference between observed and predicted
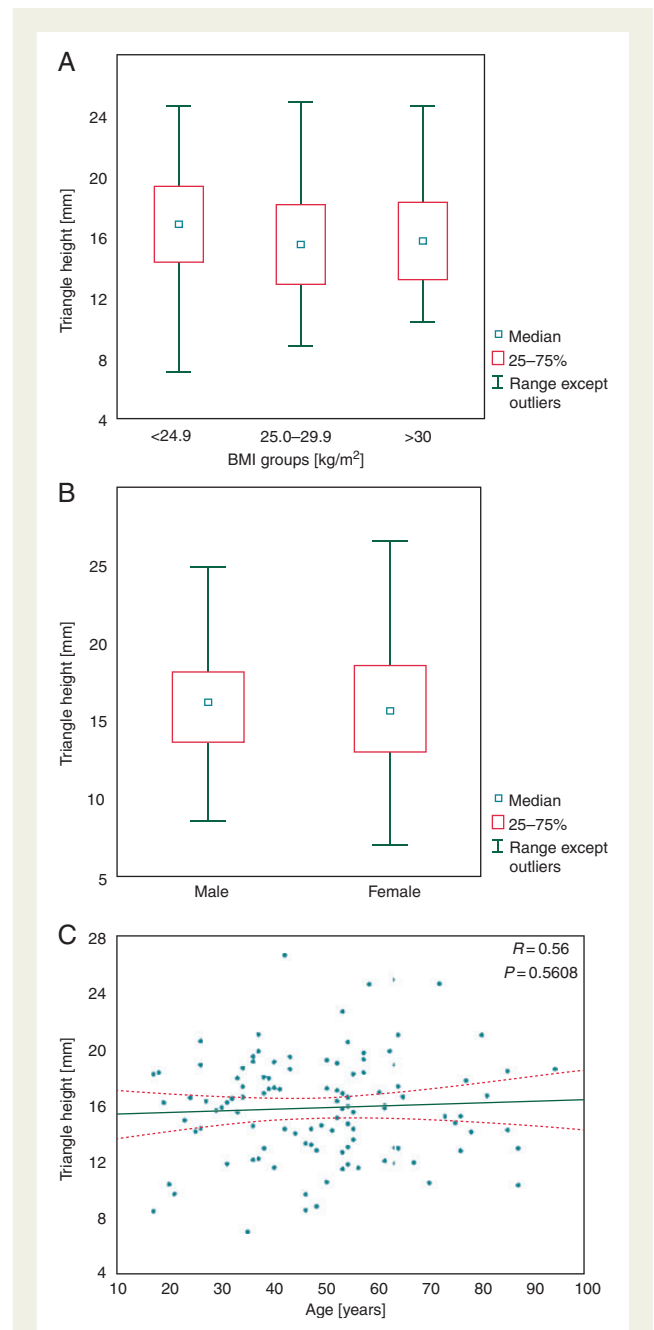
value for each individual) indicated lack of model's goodness-of-fit in relation to the data (*Figure 2C*). The points representing the residuals are definitely not randomly dispersed around the horizontal zero line, i.e. a negative linear pattern is shown.

The next stages of the analysis focused on the Koch's triangle height. The triangle height was not correlated with age, gender, or with BMI (*Figure 3*; $P > 0.05$). The individuals were divided into three groups according to WHO classification of obesity.[5] Cases were considered normal when BMI was in the range of $18.5–25.0$ kg/m^2 ($n = 40$),

overweight with BMI of 25–30 kg/m^2 ($n = 46$), and obese when BMI of >30 kg/m^2 ($n = 33$). The one individual who had BMI equal to 17.2 kg/m^2 (underweight) was excluded from further analysis. As shown in *Figure 3*, triangle height presented similar maximal range in each group and there was no statistically significant differences observed between these groups ($P > 0.05$). The Koch's triangle height value of 22 mm exceeded the 95th percentile, thus this threshold point could be considered to be a safe, maximum triangle limit in all cases. In order to clarify: in all cases, the operator should expect Koch's triangle area and because of that also the AV node in the area extending from the base of the interatrial septum for a maximum distance of 22 mm in the right direction. Manipulations at greater distances from the interatrial septum are safe.

Discussion

The Koch's triangle concept is useful in both clinical and experimental work.[3,6–8] The revision of literature showed that the boundaries of the Koch's triangle seem to be the same in every study: the tendon of Todaro, septal leaflet of the tricuspid valve, and coronary sinus ostium.[3,9–12] However, attempting to accurately mark a triangle on the heart specimen is problematic, because descriptions of triangle edges and vertices are inaccurate. There is a great freedom of interpretation observed, which introduces significant discrepancies in the triangle dimensions. Because of that, direct comparison of triangle sizes between different studies is pointless. This study shows precise definitions of all crucial Koch's triangle components (*Figure 1*).

It should be emphasized that the Koch's triangle concept is used clinically to locate the compact AV node, therefore its boundaries should be set based on the AV node position, which is located near the apex.[13] The triangle base and its relation to the coronary sinus ostium is the first area of disagreement. Some authors marked the basal edge as the line passing through the central part of the coronary sinus ostium.[9,10,14,15] Such a setting significantly increases the lengths of all triangle edges and the area; however, there is no clinical justification for such extension of triangle's dimensions in this direction, where the AV node is absent (the lumen of the coronary sinus ostium). We suggest that the basal edge should be tangential to the left contour of the coronary sinus ostium.

The second area of disagreements is the already discussed problem of defining the posterior triangle's edge using the tendon of Todaro.[2,3] The tendon of Todaro is a collagenous band within the subendocardium of the right atrium that constitutes a part of the fibrous skeleton of the heart, and it runs from the central fibrous body towards the Eustachian ridge.[16] The tendon is regarded as a permanent structure in almost all human hearts[16–18]; however, one has to be aware of the huge difference between the macroscopic and microscopic appearance of this structure. Indeed, the tendon of Todaro is observable using a microscope in almost all hearts, yet this appearance is not reflected in its macroscopic visibility in the operating room or on the dissection table. Macroscopically, the tendon is clearly visible only in foetal and infant hearts as a very well-developed, white structure.[16] In human ontogenesis, macroscopic involution of the tendon of Todaro occurs with age, and its relevance as an important topographical structure in the hearts of older adults is minimal. The tendon of Todaro therefore presents more

histological importance, than anatomical, as a landmark of the Koch's triangle posterior edge and it should not be used for this purpose.[2] In our study sample, consisting of adults hearts, we were able to follow the course of Todaro's tendon macroscopically only in 10.8% of all hearts, mainly in the younger specimens. Because of that, in this study, we abandoned the tendon of Todaro concept and defined the posterior edge of the triangle as the closed line segment bounded by the apex at the left side and by the point where basal edge touches the Eustachian ridge at the right side (the line running in the extension of the Eustachian ridge), which largely corresponds with the microscopic course of Todaro's tendon.

We also noticed some inaccuracies in calculating the area of Koch's triangle. Most authors regard this triangle as a right-angled triangle and calculate its surface area based on the Pythagorean theorem,[10,14] meanwhile in this study the septal leaflet angle was right-wise ($90 \pm 10°$) only in 15% of all cases. In this study, we used the Heron's formula to calculate the area. When using the methodology that assumes the right-angled triangle, the results are significantly different (151.5 ± 55.8 vs. 169.8 ± 63.5 mm^2; $P = 0.02$).

This study attempted to create the universal formula to estimate the dimensions of Koch's triangle in human beings based on other individual-specific and heart-specific parameters, yet it was rendered unsuccessful. In the present study, Koch's triangles show considerable individual variations in size. The parameters of Koch's triangle in adults do not depend on sex, age, BMI, BSA, and intracardiac morphometric parameters. Also, in a study conducted on an adult population, McGuire *et al.*[19] concluded that the dimensions of the triangle were also not predictable by measurements of body habitus. Nevertheless, we cannot confirm the statement of McGuire *et al.*[19] that 'Koch's triangle is of relatively uniform size'. This study and others document considerable individual variations in Koch's triangle dimensions.[9,20]

In contrast to the findings in adults, the dimensions of Koch's triangle in children vary directly and significantly along with patients' height, weight, BSA, age, and heart weight.[21] There are simple formulas for Koch's triangle edges and surface area based on BSA that were proposed by Goldberg *et al.*[21] The use of these formulas in adult population resulted in complete failure. The explanation is simple: in children, the morphometric parameters most often correlate with each other (which is not observed in adults) and thus the triangle dimensions may also be predicted using each of those factors. Also, the study sample was small (14 cases) and homogeneous.

The main limitation of this study is that all the measurements were taken from autopsied heart specimens after formalin fixation, which may result in slight changes in size and shape of the heart. Therefore, we cannot draw any conclusions regarding the behaviour and dimension changes of Koch's triangle area within the cardiac cycle. Despite these limitations, we believe that they do not obstruct the morphological analysis of relations between individual heart structures and their relative dimensions.

Conclusion

Koch's triangle show considerable individual variations in size. We provided mean values and proportions of the triangle sides and angles. The dimensions of the triangle are strongly independent from individual-specific and heart-specific morphometric parameters;

however, the maximum triangle's height could be determined as 22 mm.

Acknowledgements

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