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MORPHOMETRIC TRAITS OF SELECTED HEART VEINS OF STANDARD AND MUTATIONAL COLOUR VARIANTS OF AMERICAN MINK (*NEOVISON VISON*)

Piotr Baranowski, Krzysztof Żuk

Department of Animal Anatomy and Zoology, Western Pomeranian University of Technology in Szczecin, 71-270 Szczecin, Klemensa Janickiego 33, Poland

ABSTRACT

The aim of the study was to estimate the values of metric traits of selected mink heart veins of standard and mutation colour variants. The study was conducted on 342 hearts of seven-month-old males and 405 hearts of seven-month-old females. Mink colour, resulting from mutation or from crossbreeding mutational colour variants with each other. Metric traits of the coronary sinus, great cardiac vein, middle cardiac vein, posterior vein, and small cardiac vein were determined by photographic recording of the sub-epicardial picture of these vessels after filling them with a water-dilutable dye for acrylic paints together with a 30% food gelatin solution. In addition, the number of the veins forming the great cardiac vein and that of the posterior veins of the left ventricle were determined. Based on the measurement of the width and length of the mink hearts, the heart shape was determined. Differences were found between the traits of the mink heart vessels of standard and mutational colour variants, but they did not allow to formulate clearly the thesis about the effect of mutations on these traits.

Key words: American mink; cardiac veins, mutation

INTRODUCTION

In the improvement of the population of domestic animals, crossbreeding is used, and in some species in intensive breeding, the population is supplemented with individual animals which are characterised by the effect of a mutation. This is done among others to achieve a faster economic effect. An example of such conduct is American mink farming – in this species such randomness in the genetic material is desirable because of the attractiveness of its coat. However, genetic factors causing mutations within the genes encoding myocardial contractile and regulatory proteins [Mirza et al. 2005, Morita et al. 2005] may translate into, among others, circulatory failure and hypertrophic cardiomyopathy (HCM) or dilated cardiomyopathy (DCM). In a previous study [Baranowski and Żuk 2019], it was shown that the values of the heart morphological traits in mutational colour variant individuals, such as weight, height and depth were significantly higher than those in standard colour variant ones, but the values of the wall thickness traits for the left and right ventricles, were lower.

In the present study, it was decided to answer the question of whether there are differences between the traits of some heart vessels in minks of standard and mutational colour variants. The main purpose of the study was: 1) to estimate the values of metric traits of selected venous blood vessels in minks of Standard and colour variants, 2) to examine the correlation between the traits of cardiac venous blood vessels and between the dimensions of the heart and the traits of its venous blood vessels, 3) to determine the frequency of the number of the posterior veins of the left ventricle and the anterior cardiac veins, 4) to estimate the number of the branches forming the great cardiac vein. In addition, due to the increasingly frequent diagnostic imaging of the size of the heart and the enlargement of its silhouette in small companion animals [Gunn 1989, Litster et al. 2005, Ghadiri et al. 2008, Onuma et al. 2009], it was decided to determine the shape of the heart, the information about which can

Piotr.Baranowski@zut.edu.pl

be an important indicator of its location in the thoracic cage, which can be used for comparative studies.

MATERIAL AND METHODS

All animals, from which the hearts were collected, came from the same farm (53°40′N, 15°08′E) and were housed in identical standard breeding cages (72×30×42 cm) with wooden boxes, placed in outdoor pavilions. These buildings are located in north-south direction. The animals were kept in accordance with the European Convention for the Protection of Vertebrate Animals and complied with the conditions of the Act of 29 June 2007 in force in Poland. The animals were in good condition over the entire period to their technological slaughter at the age of 7 months which was performed during two skinning seasons: 1) 21–27 November 2012, and 2) 5–8 November 2013. The minks were fed with fresh balanced feed being administered 3 times a day directly per cage. The feed included beef, pork, poultry, fish and other by-products originating from the food industry. The feed contained about 3850 kcal/kg metabolic energy in dry mass, of which 45% were from protein, 31% from fat and 24% from carbohydrates. Animal watering system was automatic. Veterinary supervision of the farm was exercised by a District Veterinary Officer.

The rib cage of randomly selected 342 male and 405 female minks of four colour variants (standard – Black, n = 202, and Mahogany, n = 164; mutational – Silver Blue, n = 191, and Regal White, n = 190), the carcass weight (CW) of which was determined in grams (g) after taking off the skin, was opened. The lungs and the heart – from which large blood vessels were cut off at a height of about 1 cm from its base, were removed from it and weighed, after rinsing the blood off under running water, removing the pericardium and drying. The morphological parameters of mink hearts are presented in the previous work [Baranowski and Żuk 2019]. The research did not require the approval of the Ethics Committee. In order to analyse the length of selected cardiac veins, anatomical specimens were handled according to the methodology described below.

Preparation of anatomical specimens for examination of venous blood vessels

Each heart – from male minks and female minks, was placed in a hypertonic saline solution for about 12 hours to remove the blood that accumulated in it. It was then rinsed with running water using an inserted cannula. The heart, cleaned and dried with filter paper, was ready to visualise the course of coronary vessels. For this purpose, the pulmonary veins as well as the cranial and caudal vena cava were ligated, and peripheral venous catheters were introduced into the pulmonary trunk and the descending aorta, and they were ligated next. A filling consisting of a water-soluble pigment for acrylic paints together with a 30% solution of gelatine. The filling was introduced under a pressure of 120 mm Hg into the venous blood vessels, through their reverse flow from the trunk of the pulmonary arteries, to the right ventricle, then to the right atrium, and thus to the cardiac veins. In order to fix the filling, the specimen was cooled in a saline bath at 4°C for three minutes. Then the resulting sub-epicardial picture of the vessels was photographed using a Canon EOS-1000D camera with a Macro EF-S 60 mm f/2.8 lens against the background of a reproduction table with a plotted scale expressed in millimetres. Using the MultiScan v.18.03 computer software, a detailed analysis of the recorded digital image of individual vessels of the examined mink hearts was carried out. Normalisation of the results was possible through each individual scaling of the image to the reference value attached on each photo. All morphological terms applied were used as recommended by Nomina Anatomica Veterinaria [2012]. The following traits of the heart vessels were measured with the MultiScan software:

1. External diameter of the coronary sinus – measured at the widest point of the sinus.
2. Length of the coronary sinus – measured from its beginning, which is marked by the characteristic narrowing between the opening of the great cardiac vein and the beginning of the coronary sinus, to its end, i.e. to the opening to the right atrium.
3. Diameter of the opening of the great cardiac vein to the coronary sinus.
4. Length of the great cardiac vein I – measured from the connection of the branches into one main trunk to the place of intersection of the anterior interventricular groove with the coronary groove.
5. Length of the great cardiac vein II – measured in the coronary groove to the place of the opening of the great cardiac vein to the coronary sinus.
6. Length of the posterior vein of the left ventricle.
7. Length of the middle cardiac vein – measured from the apex of the heart within the posterior interventricular groove to the place of its opening to the coronary sinus.
8. Length of the small cardiac vein.
9. Number of the branches forming the great cardiac vein.
10. Number of the posterior veins of the left ventricle and the anterior cardiac veins.

Also, the data obtained from measuring the width (W) and length (L) of hearts [Baranowski and Żuk 2019] were used to determine the heart shape index (W/L).

Statistical analysis of results

The study results were statistically analysed in the Statistica v.13PL computer software. The analysis of normality of trait distribution was performed. Due to the lack of normal distribution, the Student's *t*-test, or analysis of variance, was used to estimate the values of differences between groups (sex, colour variants – standard and mutational ones), and if the assumptions about the applicability of these tests were not met, the Mann-Whitney U test, or the Kruskal-Wallis analysis, was used. Also, the cluster analysis using the k-means method was used to classify the mink heart shape based on the shape index (W/L). The values of simple correlation, rank correlation and partial correlation for vessels were estimated, eliminating sex variability according to the following formula:

$$r_{1,2,sex} = \frac{r_{x,y} - r_{x,sex} r_{y,sex}}{\sqrt{(1 - r^2{}_{x,sex})(1 - r^2{}_{y,sex})}}$$

where: x – trait 1; y – trait 2.

The effect of colour on the heart shape of the minks, frequency of the number of the branches forming the great cardiac vein, frequency of the number of the posterior veins of the left ventricle and the anterior cardiac veins was estimated by the χ^2 test with Yates's correction. Two sources of variation (sex and colour variant – standard and mutational one) were included in the analyses. The level of significance was estimated at $P \leq 0.05$ or $P \leq 0.01$.

RESULTS

Heart shape

Based on statistical analysis using the method of k-means clustering, the collected heart specimens were classified into three shape groups: 1 – with the W/L index being in the range of 56.30–70.45; 2 – with the shape index being in the range of 70.54–84.34, and 3 – with the value of W/L index being in the range of 84.46–90.77 (Table 1). Geometrically, the heart shape of group 1 was characterised by an oval shape, that of group 2 was cone-shaped with a raised up base, while that of group 3 by the shape of a sphere. The largest number of mink hearts (n = 541) was characterised by a cone shape. Only a significant ($P \leq 0.01$) effect of the colour variant (Table 2) on the heart shape of male minks (χ^2male minks = 8.41) was demonstrated.

Values of metric traits of selected venous blood vessels of the heart

Table 3 presents the results of measurements for the traits of the blood vessels examined. The effect ($P \leq 0.05$) of sex on: external diameter of the coronary sinus, diameter of the opening of the great cardiac vein to the coronary sinus, length of the great cardiac vein from both the place of connection of branches into one main trunk to the place of intersection of the anterior interventricular groove with the coronary groove and measured in the coronary groove to the place of the opening of the great cardiac vein to the coronary sinus. In the group of hearts examined, the effect ($P \leq 0.05$) of the colour variant on coronary sinus length as well as on left posterior vein length, middle cardiac vein length and small cardiac vein length was found.

Correlations between the traits of venous blood vessels and between the dimensions of the heart and the traits of its venous blood vessels

To exclude the effect of sex on the correlation of morphological traits of the mink heart and its selected vessels, the values of partial correlation coefficients were calculated. The correlation between the dimensions of the heart, the mean values of which were included in the previous paper [Baranowski and Żuk 2019], and the values of the traits of selected blood vessels, the mean values of which are presented in Table 3, was estimated. The values of partial correlation coefficients for selected cardiac vessels showed a low correlation between the these traits and no differences between correlation coefficients. Significant ($P \leq 0.05$), low and moderate correlation between the dimensions of the heart and its vessels was found (Table 5). However, the interaction of such features as coronary sinus length x heart length, coronary sinus diameter, great cardiac vein length, as well as the diameter of the opening of the great cardiac vein to the coronary sinus x coronary sinus diameter and length, was stronger in the hearts of mutational colour variant minks than in those of the minks of standard colour variant.

Frequency of the number of the posterior veins of the left ventricle and the anterior cardiac veins

Calculation of the frequency of the number of the posterior veins of the left ventricle and the anterior cardiac veins of the male and female minks showed that most often there are 5 such vessels in the hearts of individuals of standard colour variant (Fig. 1, n = 265). In the group of female minks (Fig. 2), 30% (n = 150) more individuals with 5 posterior veins of the left ventricle and the anterior cardiac veins were found than in the group of male minks (Fig. 3, n = 115). The group of female minks of mutational colour variant was larger by 42% (Fig. 2, n = 110), in which the number of the posterior veins of the left ventricle and the anterior cardiac veins is five compared to the group of male minks of this colour variant (Fig. 3, n = 77). The values estimated with the χ^2 test confirmed the significant ($P \leq 0.05$) statistical correlation of these traits ($\chi^2_{\text{male minks}} = 22.92$; $\chi^2_{\text{female minks}} = 63.89$).

Number of the branches forming the great cardiac vein

The recorded digital images of mink hearts revealed one to three branches forming the great cardiac vein. The most common were two branches in the hearts of both studied mink populations. The χ^2 test showed a significant ($P \leq 0.05$) effect of the colour variant of minks on the number of the branches forming the great cardiac vein (Table 6).

DISCUSSION

It is conventionally and commonly accepted that the heart has the shape of an irregular cone, so-called heart-shaped, without going into its basic dimensions as an organ. However, during the statistical analysis, it turned out that three types of mink heart shape can be distinguished, which clearly differentiate the value of the estimated shape index (Fig. 4). In the examined material, the dominant shape, occurring in more than 70% of minks, was

Table 1. Statistical values of the heart shape (W/L) of male and female minks of standard and mutational variants

Tabela 1. Wartości statystyczne kształtu serca (W/L) samców i samic norek odmian standard i mutacyjnej

	Heart shape – Kształt serca					
	W/L < 70.45		70.54 < W/L < 84.34		W/L > 84.50	
Colour variant Odmiana barwna	Standard Standard n = 49	Mutational Mutacyjna n = 75	Standard Standard n = 263	Mutational Mutacyjna n = 278	Standard Standard n = 55	Mutational Mutacyjna n = 40
x	66.98	67.55	77.41	77.25	88.79	88.16
sd	2.71	2.52	3.73	3.74	4.01	4.46
ME	66.96	68.12	77.49	77.09	8.81	98.36
Min.	59.30	56.50	70.63	70.54	84.50	84.46
Max.	70.43	70.45	84.34	84.34	99.77	98.36
Q1	64.66	66.60	74.15	74.49	85.61	85.58
Q3	69.53	69.45	80.51	80.24	90.66	90.27
IQR	4.87	2.84	6.36	5.75	5.04	4.70
Range	59.30–70.44	56.50–70.45	70.63–84.34	70.54–84.34	84.50–99.77	84.46–98.36

	Heart shape (irrespective of sex and colour variant) – Kształt serca (niezależnie od płci i odmiany barwnej)		
	W/L < 70.45	70.54 < W/L < 84.34	W/L > 84.50
n	124	541	95
x	67.32	77.33	88.52
sd	2.60	3.73	3.79
ME	67.89	77.24	86.28
Min.	56.50	70.54	84.50
Max.	70.45	84.34	99.77
Q1	65.76	74.24	85.61
Q3	69.49	80.43	90.65
IQR	3.72	6.18	5.04
Range	56.50–70.45	70.54–84.34	84.46–99.77

ME – median, Q1 – lower quartile, Q3 – upper quartile, IQR – interquartile range.
ME – mediana, Q1 – dolny kwartyl, Q3 – górny kwartyl, IQR – rozstęp.

Table 2. Values of χ^2 test for the assessment of the effect of mink colour variant and sex on the heart shape

Tabela 2. Wartości testu χ^2 dla oceny wpływu odmiany barwnej i płci norek na kształt serca

Colour variant – Odmiana barwna	Sex – Płeć	χ^2
Standard – Standard	male minks v. female minks samce v. samice	2.11
Mutational – Mutacyjna		1.93
Sex – Płeć	colour variant – odmiana barwna	
Male minks – Samce	standard v. mutational standard v. mutacyjne	8.41*
Female minks – Samice		0.52

Table 3. Values of the traits of selected heart vessels of male and female minks of standard and mutational colour variants (mm)

Tabela 3. Wartości cech wybranych naczyń serca samców i samic norek odmian standardowych oraz mutacyjnych (mm)

Trait Cecha	Male minks – Samce						Female minks – Samice					
	Standard – standard n = 179			Mutational – mutacyjne n = 163			Standard – standard n = 185			Mutational – mutacyjne n = 220		
	x	sd	V%	x	sd	V%	x	sd	V%	x	sd	V%
1	1.96*	0.39	19.95	1.99*	0.42	21.03	1.66*	0.31	18.82	1.70*	0.28	16.64
2	12.97*[a]	2.26	17.43	13.52*[a]	2.32	17.17	11.12*	2.30	20.73	11.36*	2.71	23.90
3	1.03*	0.20	19.41	1.02*	0.23	22.08	0.96*	0.20	20.45	0.96*	0.14	14.69
4	28.81*	5.21	18.07	29.82*	4.95	16.60	24.98*	3.71	14.86	24.56*	4.49	18.28
5	12.93*	2.91	22.54	13.55*	2.90	21.38	11.96*	2.03	16.95	11.87*	2.17	18.29
6	27.23*[a]	6.93	25.45	28.62*[a]	6.70	23.39	24.44*[b]	4.30	17.59	25.39*[b]	4.70	18.50
7	31.06*[a]	4.70	15.13	33.85*[a]	5.64	16.65	26.37*[b]	4.41	16.73	28.42*[b]	4.21	14.82
8	34.43*[a]	6.42	18.65	36.01[a]	7.41	20.59	28.03*[b]	4.98	17.78	29.57[b]	5.18	17.52
9	1.72*	0.59	32.12	1.78	0.69	30.51	1.52*[a]	0.57	37.65	1.66[a]	0.66	39.95
10	4.93[a]	0.71	14.43	4.73[a]	0.75	15.65	5.07[b]	0.43	8.49	4.62[b]	0.69	14.78

1. Coronary sinus diameter. 2. Coronary sinus length. 3. Diameter of the opening of the great cardiac vein to the coronary sinus. 4. Great cardiac vein length I. 3. Great cardiac vein length II. 4. Left posterior vein length. 5. Middle cardiac vein length. 6. Small cardiac vein length. 7. Number of the branches forming the great cardiac vein. 8. Number of the posterior veins of the left ventricle and the anterior cardiac veins. 9. Number of the branches forming the great cardiac vein. 10. Number of the posterior veins of the left ventricle and the anterior cardiac veins. Mean values marked in rows with an asterisk (*) – differences ($P \le 0.05$) between sexes; those marked with the same letter (a, b) denote differences ($P \le 0.05$) between colour variants.
1. Średnica zatoki wieńcowej. 2. Długość zatoki wieńcowej. 3. Średnica ujścia żyły wielkiej serca do zatoki wieńcowej. 4. Długość żyły wielkiej serca I. 5. Długość żyły wielkiej serca II. 6. Długość żyły lewej tylnej. 7. Długość żyły średniej serca. 8. Długość żyły małej serca. 9. Liczba gałęzi tworzących żyłę wielką serca. 10. Liczba żył tylnych komory lewej oraz żył przednich serca. Średnie oznaczone w wierszach gwiazdką (*) – różnice ($P \le 0,05$) między płciami; oznaczone tymi samymi literami a, b oznaczają różnice ($P \le 0,05$) między odmianami barwnymi.

Table 4. Values of partial correlation coefficients for the traits of mink heart vessels of standard and mutational colour variants, including sex

Tabela 4. Wartości współczynników korelacji cząstkowych dla cech naczyń serca norek odmiany barwnej standardowej i mutacyjnej z uwzględnieniem płci norek

	Trait Cecha	Mutational – Mutacyjna									
		1	2	3	4	5	6	7	8	9	10
Standard – Standard	1		0.256*	0.543*	0.191*	0.182*	0.042	0.111	0.050	–0.066	–0.011
	2	0.120*		0.256*	0.185*	0.181*	–0.065	0.024	–0.073	0.037	–0.118*
	3	0.466*	0.003		0.202*	0.112*	–0.016	0.180*	0.050	0.017	–0.082
	4	0.124*	0.041	0.124*		0.025	–0.109*	0.072	0.048	0.019	0.012
	5	0.110*	–0.004	0.284*	0.086		0.026	0.040	–0.012	–0.099	–0.38
	6	–0.024	0.059	0.075	–0.143*	0.183*		0.059	–0.016	–0.145*	–0.114*
	7	0.215*	0.009	0.217*	0.136*	0.121*	0.238*		0.016	–0.079	–0.031
	8	0.244*	0.002	0.221*	0.129*	0.054	0.159*	0.258*		0.029	0.074
	9	0.149*	0.104	0.068	–0.020	0.021	–0.065	0.130*	0.049		0.113*
	10	0.012	0.072	0.022	0.066	0.133*	0.169*	0.020	0.088	0.077	

Traits 1, 2, 3… – as in Table 3; values of correlation coefficients significant at $P \le 0.05$ are marked with an asterisk (*).
Cechy 1, 2, 3… – jak w tabeli 3; gwiazdką (*) oznaczono wartości współczynników korelacji istotne przy $P \le 0.05$.

Table 5. Values of the coefficients of partial correlation, including sex variability, for coronary sinus diameter, coronary sinus length, diameter of the opening of the great cardiac vein to the coronary sinus, small cardiac vein length with selected morphological traits of the mink heart of standard and mutational variants, excluding sex

Tabela 5. Wartości współczynników korelacji cząstkowej z uwzględnieniem zmienności płci dla średnicy zatoki wieńcowej, długości zatoki wieńcowej, średnicy ujścia żyły wielkiej serca do zatoki wieńcowej, długość żyły małej serca z wybranymi cechami morfologicznymi serca norek odmiany standard i mutacyjnej, z wyłączeniem płci

Trait – Cecha	Standard – Standard	Mutational – Mutacyjne
	r_{xy}	r_{xy}
Coronary sinus diameter – Średnica zatoki wieńcowej		
Heart length – Wysokość serca	0.402**	0.397**
Heart width – Szerokość serca	0.349**	0.384**
Heart depth– Głębokość serca	0.263**	0.243**
Heart circumference – Obwód serca	0.357**	0.379**
Heart volume – Objętość serca	0.367**	0.375**
Heart weight – Masa serca	0.375**	0.385**
Coronary sinus length – Długość zatoki wieńcowej		
Heart length – Wysokość serca	0.276**[a]	0.413**[a]
Heart width – Szerokość serca	0.313**	0.300**
Heart depth – Głębokość serca	0.154**	0.232**
Heart circumference – Obwód serca	0.310**	0.213**
Heart volume – Objętość serca	0.237**	0.339**
Heart weight – Masa serca	0.420**	0.358**
Coronary sinus diameter – Średnica zatoki wieńcowej	0.228**[a]	0.369**[a]
Great cardiac vein length – Długość żyły wielkiej serca	0.134**[a]	0.329**[a]
Middle cardiac vein length – Długość żyły średniej serca	0.168**	0.219**
Left posterior vein length – Długość żyły lewej tylnej	0.153**	0.054
Small cardiac vein length – Długość żyły małej serca	0.189**	0.116
Diameter of the opening of the great cardiac vein to the coronary sinus – Średnica ujścia żyły wielkiej serca do zatoki wieńcowej		
Coronary sinus diameter – Średnica zatoki wieńcowej	0.456**[a]	0.565**[a]
Coronary sinus length – Długość zatoki wieńcowej	0.084[a]	0.306**[a]
Great cardiac vein length – Długość żyły wielkiej serca	0.173**	0.271**
Small cardiac vein length – Długość żyły małej serca		
Heart length – Wysokość serca	0.484**	0.428**
Heart width – Szerokość serca	0.448**	0.372**
Heart depth – Głębokość serca	0.357**	0.362**
Heart circumference – Obwód serca	0.505**	0.426**
Heart volume – Objętość serca	0.446**	0.418**
Heart weight – Masa serca	0.509**	0.492**

Values of partial correlation coefficients r_{xy} marked with asterisks (**) are significant at $P \leq 0.01$, while those marked with the same letters differ significantly: a – $P \leq 0.05$.
Wartości współczynników korelacji cząstkowej r_{xy} oznaczone gwiazdkami (**) są istotne przy $P \leq 0,01$, a oznaczone tymi samymi literami różnią się istotnie: a – $P \leq 0,05$.

the shape of the heart with the outline close to the triangle with its base up. From 13 to 20% of the mink hearts that were analysed had the outline close to oval, and from 10 to 15% had a sphere-like outline. In population studies, especially on animals from mass breeding, the above results may be of little significance or not yet fully defined, except that they indicate heterogeneity of shape. The effect of the colour variant on the heart shape was found only in male minks, which does not allow generalisation for both sexes. However, in studies on companion animals such as dogs, cats or ferrets, information about the shape of the heart may be important in determining its location in the thoracic cage and its outline in a particular animal. This is important for X-rays taken or for determining the vertebral heart size, comparing the size of the outline of the heart with the length of the thoracic vertebral bodies closely related to the size of the individual's body [Lister et al. 2005, Ghadiri et al. 2008, Onuma et al. 2009].

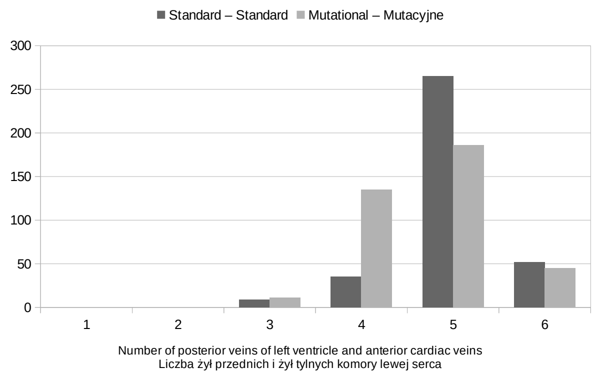

Fig. 1. Frequency of posterior veins of left ventricle and anterior cardiac veins

Rys. 1. Częstotliwość występowania żył tylnych i żył przednich lewej komory serca

The most common in the search for models of animal heart vascularisation in comparison to the human heart are vascular coronary artery analysis [Crick et al. 1998, Kaimovitz et al. 2010, Gómez et al. 2015, Gómez et al. 2017]. These searches for common features or differences between species include macroscopic measurements of the coronary sinus, such as its diameter and length [Genain et al. 2018]. In domestic mammals similar in body weight and heart weight to human weight, the coronary sinus of the pig heart has the largest diameter (9.7 mm), and only slightly smaller than the human one, 7.9 mm, the coronary sinus of the sheep heart, 7.4 mm. No analysis of correlation was found in the literature between the diameter and length of the coronary sinus in the above-mentioned species, which would help in the interpretation of relationships analysed in this material. In studies of venous vascularisation of the heart, the primary role of the coronary sinus – if it exists – is emphasised [Mantini et al. 1969, Foale et al. 1979] in the outflow of venous blood of hearts [Pejković et al. 2008]. While no significant differences were found in the diameter of the coronary sinus resulting from the effect of the colour variant, the colour variant proved to be a significant source of variation in relation to the length of the coronary sinus in the group of male minks. Also in humans, male individuals are characterised by a larger diameter of the coronary sinus [Maros et al. 1983, Ortale et al. 2001, Karaca et al. 2005].

The smallest length of the great cardiac vein among species of small pets is characteristic of a dog [Genain et al. 2018]. The length of the great cardiac vein in the examined minks, especially in the male minks of mutational colour variant, was slightly smaller than that in dogs weighing 20 kg (30.7 mm). In this case, the average carcass weight of the mink examined was in the range 1018.70 g – 1865.44 g [Baranowski and Żuk 2019]. The human heart is characterised by the length of this vessel ten times greater [Kaczmarek and Czerwiński 2007]. Both male minks of standard colour variant and female minks of both colour variants had a smaller length of the great cardiac vein than that found in dogs.

The estimated values of correlation coefficients between the traits of the heart vessels in male and female minks are low, and only the diameter of the coronary sinus and the diameter of the opening of the great cardiac vein showed moderate correlation (r_{xy} = 0.40–0.60). No correlation between the traits was probably caused by a large variation in the values of these traits (Table 3). Also in this case, no publications were found in the literature describing the correlations between the traits of these blood vessels.

The middle cardiac vein was the longest in both sexes of mutational variant minks. In small species of domestic animals [Constantinescu 2005, König and Liebich 2007], this blood vessel runs in the subsinuosal interventricular groove on the atrial surface of the heart and opens into

Table 6. Values of χ^2 test for the traits of mink heart vessels of standard and mutational colour variants

Tabela 6. Wartości testu χ^2 dla cech naczyń sercowych norek w standardowych i mutacyjnych wariantach kolorystycznych

Effect of mink colour variant on Wpływ odmiany barwnej norek na	χ^2
Number of the posterior veins of the left ventricle and the anterior cardiac veins Liczbę tylnych żył lewej komory i przednich żył sercowych	559.90*
Number of the branches forming the great cardiac vein Liczbę gałęzi tworzących wielką żyłę sercową	13.05*

the coronary sinus located on the surface of the right atrium or directly into the right atrium [Barone 1996]. The strongly developed middle cardiac vein affects the length of the posterior veins of the left ventricle and their smaller diameter [Ratajczak-Pękalska 1970]. The posterior vein of the left ventricle usually begins on the atrial surface of the heart, and in its course from below upwards usually opens to the left end of the coronary sinus [Duda and Grzybiak 1998] and is characterised by high variability [Maros et al. 1983]. There was no correlation between the length of the posterior vein of the left ventricle and the diameter and length of the coronary sinus in both sexes or the colour variant of minks in the examined material (Table 4).

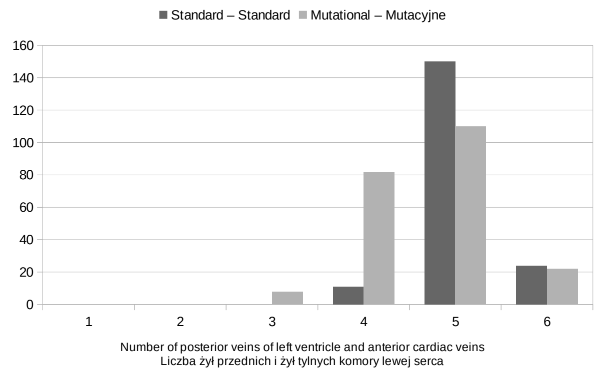

Fig. 2. Frequency of posterior veins of left ventricle and anterior cardiac veins in females

Rys. 2. Częstotliwość występowania żył tylnych i żył przednich lewej komory serca samic

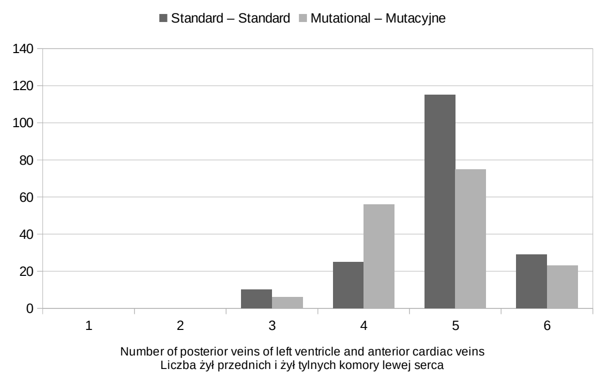

Fig. 3. Frequency of posterior veins of left ventricle and anterior cardiac veins in males

Rys. 3. Częstotliwość występowania żył tylnych i żył przednich lewej komory serca samców

What is noteworthy is the dominant ($P \leq 0.05$) length of the middle cardiac vein in both sexes of mutational colour variant minks over the male and female minks of standard colour variant, and at the same time a greater number of the posterior veins of the left ventricle and the anterior cardiac veins. With the strongly developed middle cardiac vein, the posterior veins of the left ventricle are shorter and have a smaller diameter [Ratajczak-Pękalska 1970]. Perhaps in this case the number of veins is compensated in relation to the size of these blood vessels. There are reports of the effect of individual size on differentiation of vascularisation. Admittedly, this concerned an increase in the number of vascular variants within the basal arteries of the brain in large dogs [Wiland 1973] and within the arteries of the aortic arch [Kubica et al. 2005], but the assumption that the morphological variability of the heart's own blood vessels is subject to mutation can not be abandoned.

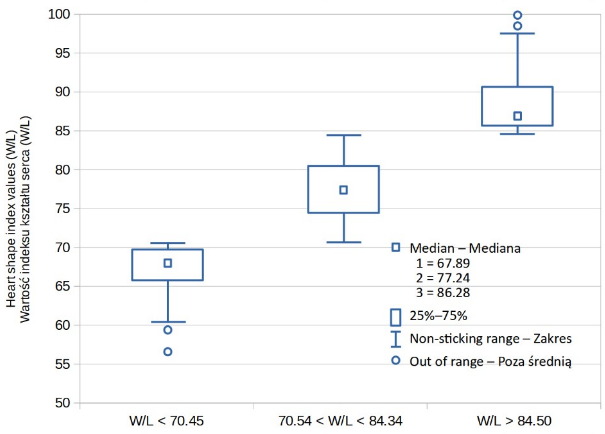

Fig. 4. Heart shape index values (W/L) in male and female mink of standard and mutational color variants

Rys. 4. Indeks kształtu serca (W/L) samców i samic odmiany barwnej standard i mutacyjnej

The great cardiac vein is the longest venous blood vessel of the heart and the largest inflow to the coronary sinus, and has variable topography and morphology [Pejković and Bogdanovć 1992, Ortale et al. 2001]. In cats, two distinct sections were found in the form of the paraconal intervetricular artery and the circumflex artery [Barszcz et al. 2014]. In our own study, two arteries also dominated in both sexes and colour variants, with a higher number of hearts with this type of vascularisation being found in the male minks of standard colour variant than in the mutational colour variant ones, and, conversely, more hearts of mutational colour variant female minks were characterised by two arteries compared to the hearts of the female minks of standard colour variant. The value of χ^2 test was not significant for sex and colour variant.

In the search for differences between the heart traits of male and female minks of both colour variants, the frequency of the number of veins and the frequency of the number of vascular branches were estimated. A significant ($P \leq 0.05$) effect of the colour variant on the frequency of the number of the posterior veins of the left ventricle and the anterior cardiac veins in minks was confirmed by the χ^2 test in both sexes (Table 6). The results obtained (Fig. 1–3) revealed a greater variety of vascular variants in the hearts of mutational colour variant mink than in those of standard colour variant. This may suggest that the breeder's interference in the selection of breeding pairs not only significantly changed the pool of genes responsible for the colour of the hair coat, but also unintentionally, as a result of this interaction, the observed phenomenon has become a result. The venous blood vessels of the mink hearts of standard colour variant compared to those of mutational colour variant minks form a more stabilised model. Analysis of the source of origin of standard colour variant minks led to the conclusion that when in 2005–2008 the farmer populated the farm and organised breeding, he imported 5000 pregnant female minks of uniform colour from Canada. Because in this country it is allowed to introduce into the herds of breeding animals the individuals coming from natural conditions in order to reduce the differences between breeding and wild populations [Tamlin et al. 2009], the supposition arises that perhaps the pressure of natural selection impressed on the offspring of the foundation stock minks is a source of morphological uniformity of this population towards optimal vascular variants.

The analysis of the morphological traits of the heart presented in a previous paper [Baranowski and Żuk 2019] and the present analysis of the traits of the venous blood vessels of the heart showed that there are differences between the hearts of minks of standard and mutational colour variants, but on this basis it is not possible to formulate a thesis on the effect of mutation on the traits of this organ in minks.

CONCLUSION

Knowledge of the the blood supply of the heart is important from the theoretical and practical point of view of the research on this organ. It is necessary for the correct interpretation of the results of diagnostic tests or therapeutic procedures in man and in various animal species. The phenomenon of biodiversity occurring in animals results in differentiation of the model of coronary vascularisation, hence undertaking comparative studies performed on organs from animals with a stable genotype, but also from modified forms, allow for in-depth interpretation of results and analyses, including the phylogeny and taxonomy of species. In addition, conducting research on the characterisation of vascular system anatomy in animals allows for the subsequent designing of experimental models that develop surgical or invasive treatment techniques before their implementation in humans, and for the assessment of limitations of such models.

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REFERENCES

Baranowski, P., Żuk, K. (2019). Morphometric traits of the heart in standard and mutational colour variants of American mink (*Neovison vison*). Int. J. Morphol., 37(2), 757–765. DOI: 10.4067/S0717-95022019000200757.

Barone, R. (1996). Anatomie comparée des mammifères domestiques, vol. 5: Angiologie. Éditions Vigot, Paris.

Barszcz, K., Kupczyńska, M., Klećkowska-Nawrot, J., Janczyk, P., Krasucki, K., Wąsowicz, M. (2014). Unaczynienie tętnicze serca kota [Arterial coronary circulation in cats]. Med. Weter., 70(6), 373–377 [in Polish].

Constantinescu, G.M. (2005). Guide pratique d'anatomie du chien et du chat. MED'COM, Paris.

Crick, S.J., Sheppard, M.N., Zen Ho, S., Gebstein, L., Ierson, R.H. (1998). Anatomy of the pig heart: comparisons with normal human cardiac structure. J. Anat., 193, 105–119. DOI: 10.1046/j.1469-7580.1998.19310105.x.

Duda, B., Grzybiak, M. (1998). Main tributaries of coronary sinus in the adult human heart. Folia Morphol., 57(4), 363–369.

Foale, R.A., Baron, D.W., Rickards, A.F. (1979). Isolated congenital absence of coronary sinus. Brit. Heart J., 42, 355–358. DOI: 10.1136/hrt.42.3.355.

Genain, M.A., Morlet, A., Herrtage, M., Muresian, H., Anselme, F., Latremuille, C., Laborde, F., Behr, L., Borenstein, N. (2018). Comparative anatomy and angiography of the cardiac coronary venous system in four species: human, ovine, porcine and canine. J. Vet. Cardiol., 20(1), 33–44. DOI: 10.1016/j.jvc.2017.10.004.

Ghadiri, A., Avizev, R., Rasekh, A., Yadegari, A. (2008). Radiographic measurement of vertebral heart size in heatlystray cats. J. Feline Med. Surg., 10, 61–65. DOI: 10.1016/j.jfms.2007.06.015.

Gómez, F.A., Ballesteros, L.E., Cortez Luz, S. (2015). Morphological expression of the pig coronary sinus and its tributaries: a comparative analysis with the human heart. Eur. J. Anat., 19, 139–144.

Gómez, F.A., Ballesteros, L.E., Estupiñan, H.Y. (2017). Morphological characterization of the left coronary artery in horses. Comparative analysis with humans, pigs, and other animal species. Ital. J. Anat. Embryol., 122(2), 137–146.

Gunn, H.M. (1989). Heart weight and running ability. J. Anat., 167, 225–233.

Kaczmarek, M., Czerwiński, F. (2007). Assessment of the course of the great cardiac vein in a selected number of human hearts. Folia Morphol., 66(3), 190–193.

Kaimovitz, B., Lanir, Y., Kassab, G.S. (2010). A full 3-D re construction of the en tire porcie coronary vasculature. Am. J. Physiol. Heart Circ. Physiol., 299, H1064-1076. DOI: 10.1152/ajpheart.00151.2010.

Karaca, M., Bilge, O., Dincal, M.H., Uceler, H. (2005). The anatomic barriers in the coronary sinus: implication for clinical procedures. J. Interv. Card. Electrophysiol., 14, 89–94. DOI: 10.1007/s10840-005-4596-0.

König, H.E., Liebich, H.G. (2007). Veterinary Anatomy of Domestic Mammals. Schattauer, Stuttgart.

Kubica, I., Indykiewicz, P., Nowiecki, W., Wiland, C. (2005). Wpływ długości ciała na zmiennośc odgałęzień łuku aorty u psa (*Canis lapus f. domestica*) [Effect of body length on the variability of the aortic arch branches in the dog (*Canis lapus f. Domestica*)]. Pr. Komis. Nauk. Rol. Biol. BTN, Ser. B, 56, 127–131 [in Polish].

Litster, A., Atkins, C., Atwell, R., Buchanan, J. (2005). Radiographic cardiac size in cats and dogs with heartworm disease compared with reference values using the vertebral scale method: 53 cases. J. Vet. Cardiol., 7, 33–40. DOI: 10.1016/j.jvc.2005.02.002.

Mantini, E., Grongin, C.M., Lillehei, C.W., Edwards, J.E. (1969). Congenital anomalies involving the coronary sinus. Circulation, New York, 33, 317–327. DOI: 10.1161/01.CIR.33.2.317.

Maros, T.N., Rácz, L., Plugor, S., Maros, T.G. (1983). Contributions to the morphology of the human coronary sinus. Anat. Anz., 154, 133–144.

Mirza, M., Marston, S., Willott, R., Ashley, C., Mogensen, J., McKenna, W., Robinson, P., Redwood, C., Watkins, H. (2005). Dilated cardiomyopathy mutations in three thin filament regulatory proteins result in a common functional phenotype. J. Biol. Chem., 280(31), 28498–28506. DOI: 10.1074/jbc.M412281200.

Morita, H., Seidman, J., Seidman, C.E. (2005). Genetic causes of human heart failure. J. Clin. Invest., 115(3), 518–526. DOI: 10.1172/JCI24351.

Nomina Anatomica Veterinaria (2012). International Committee on Veterinary Gross Anatomical Nomenclature. 5th ed. Hannover, Germany.

Onuma, M., Kondo, H., Ono, S., Ueki, M., Shibuya, H., Sato, T. (2009). Radiographic Measurement of Cardiac Size in 64 Ferrets. J. Vet. Med. Sci., 71(3), 355–358. DOI: 10.1292/jvms.71.355.

Ortale, J.R., Gabriel, E.A., Iost, C., Marquez, C.Q. (2001). The anatomy of the coronary sinus and its tributaries. Surg. Radiol. Anat., 23, 15–21. DOI: 10.1007/s00276-001-0015-0.

Pejković, B., Bogdanovć, D. (1992). The great cardiac vien. Surg. Radiol. Anat., 14, 23–28. DOI: 10.1007/BF01628039.

Pejković, B., Krajnc, I., Anderhuber, F., Kosutić, D. (2008). Anatomical variations on the coronary sinus ostium area of the human heart. J. Int. Med. Res., 36(2), 314–321. DOI: 10.1177/147323000803600214.

Ratajczak-Pękalska, E. (1970). Żyły serca [Cardiac veins]. Folia Med., 10, 45–68 [in Polish].

Tamlin, A.L., Bowman, J., Hackett, D.F. (2009). Separating wild from domestic American mink *Neovison vison* based on skull morphometric. Wildl. Biol., 15, 266–277. DOI: 10.2981/08-004.

Wiland, C. (1973). Variation of the basal arteries of the brain of dogs. Folia Morphol., 32, 63–70.

CECHY MORFOMETRYCZNE WYBRANYCH ŻYŁ SERCA STANDARDOWYCH I MUTACYJNYCH ODMIAN BARWNYCH NORKI AMERYKAŃSKIEJ (*NEOVISON VISON*)

STRESZCZENIE

Celem pracy było oszacowanie wartości cech metrycznych wybranych żył serca norek standardowych i mutacyjnych wariantów kolorystycznych. Badanie przeprowadzono na 342 sercach samców i 405 sercach samic norek. Kolor norek powstał w wyniku mutacji lub krzyżowania barwnych odmian mutacyjnych. Cechy metryczne zatoki wieńcowej, żyły wielkiej serca, żyły średniej, żyły tylnej, żyły małej serca określono na podstawie fotograficznego zapisu obrazu tych naczyń. Ponadto określono liczbę żył tworzących żyłę wielką serca i liczbę żył tylnych lewej komory. Na podstawie pomiaru szerokości i długości serc norek określono kształt serca. Stwierdzono różnice między cechami naczyń serca norek w standardowych i mutacyjnych wariantach kolorystycznych, ale nie pozwoliły one jasno sformułować tezy o wpływie mutacji na te cechy.

Słowa kluczowe: norka amerykańska, żyły serca, mutacja

Piotr Baranowski https://orcid.org/0000-0002-0033-6829
Krzysztof Żuk https://orcid.org/0000-0002-6017-960X