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Number of Coronary Ostia in Syrian Hamsters (*Mesocricetus auratus*) with Normal and Anomalous Coronary Arteries

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Summary

Little attention is being paid to the presence of accessory coronary artery ostia in man and non-human mammals due to their limited clinical relevance. However, information about their frequency and the cardiac territories irrigated by the vessels arising from them is of interest to obtain an accurate survey of the establishment of the coronary artery system in each species. The aim here was to compare the incidence and significance of the accessory coronary ostia in Syrian hamsters with normal coronary arteries and several coronary anomalies characterized by the absence of a left coronary artery originating from the left aortic sinus. The hearts from 2829 hamsters were examined using a corrosion-cast technique, micro-dissection, histochemical techniques, and scanning electron microscopy. Overall, 148 specimens displayed accessory ostia. A limited number of them belonged to the conal artery which supplies the wall of the right ventricular outflow tract. The other accessory ostia led to the septal artery, a vessel which irrigates the most part of the interventricular septum. The incidence of accessory ostia in normal and anomalous coronary artery patterns was quite similar. This suggests that the morphogenetic deviations producing the coronary artery anomalies reported in this study do not alter the connections of the septal and conal arteries to the aorta. The present observations lead to the notion that in the Syrian hamster, the septal artery should be regarded as a third coronary artery.

Introduction

In 1926, Grant and Regnier pointed out that in mammals, blood supply to the heart takes place through two coronary arteries, right and left, arising from the right and left aortic sinuses, respectively. Since then, this arrangement is considered to be the normal coronary artery pattern; it is concomitant with the presence of two coronary ostia, right and left.

The occurrence of accessory, or supernumerary, coronary artery ostia, co-existing with the normal, right and left coronary orifices, has been reported in man (for review, see Becker, 1981; Angelini, 1989; Petit and Reig, 1993; and Angelini et al., 1999) and several non-human mammalian species belonging to the orders Insectivora (Berg, 1964), Chiroptera (Rowlatt, 1967), Rodentia (Aikawa and Kawano, 1985; Durán et al., 1991a; Sans-Coma et al., 1993), Primates (Colborn, 1966; Nikolic et al., 2004), and Artiodactyla (Berg, 1962; Basson and McCully, 1969; Wallach and Howcroft, 1969; Bishop et al., 1970).

Experts on coronary arteries pay great attention to the existence of a solitary coronary ostium in the aorta and the ectopic location of one or both coronary ostia because such conditions, which are considered coronary artery malformations, may entail the risk of clinical complications. In contrast, accessory coronary ostia have no clinical relevance, and, therefore, their existence is usually regarded as a mere variant of the normal coronary artery pattern. Nonetheless, data on the occurrence of accessory coronary ostia and knowledge of the cardiac territories irrigated by the vessels arising from such ostia are of interest to obtain a more accurate survey of the establishment of the coronary artery system in each species.

On this basis, we conducted a study of the coronary ostia in Syrian hamsters belonging to a laboratory-inbred colony with a high incidence of coronary artery anomalies. The aims of the study were (1) to estimate the incidence of accessory coronary ostia in hamsters with normal and anomalous coronary arteries, (2) to assess the contribution of the arterial vessels arising from the accessory ostia to the blood supply of the heart, and (3) to evaluate these results in the light of the current knowledge on coronary artery development.

Prior to stating our observations, we will briefly describe the main features of the normal coronary artery pattern of the Syrian hamster, as observed in a large number of specimens (Sans-Coma et al., 1993). In this rodent species, both coronary arteries, right and left, become intramyocardial shortly after their origin from the aorta. The right coronary artery, which supplies the right side of the heart, runs parallel to the right atrioventricular sulcus, reaching usually the dorsal interventricular boundary. After going across the acute margin of the heart, the vessel gives off a branch that crosses the right ventricle dorsal wall more or less obliquely. Thereafter, this branch turns towards the apex of the heart as a dorsal interventricular branch. The left coronary artery, which irrigates the left side of the heart, divides into the left circumflex and the obtuse marginal arteries. The interventricular septum is supplied by one, or rarely two, well-developed septal arteries arising from the right or from the left coronary artery.

Materials and Methods

Animals. The Syrian hamsters we examined belonged to a family subjected to systematic inbreeding by crossing siblings. As described elsewhere (Fernández et al., 1998, 2000; Sans-Coma et al., 1992), the incidence of anomalies of the cardiac semilunar valves and coronary arteries is relatively high in this inbred family. However, the present study concerns 2829 (1332 male, 1497 female) juvenile and adult hamsters with normal (tricuspid) aortic valves.

The animals were handled in accordance with the Spanish Regulations for the Protection of Experimental Animals (Real Decreto 22.03.1988; B.O.E. 18/03/1988). They were housed in polypropylene cages in a room in which both the temperature and the photoperiod were controlled. Commercial mouse food (A.04; UAR/Panlab, Barcelona, Spain) and water were given ad libitum from the time of weaning. There was no known exposure of the animals to teratogenic agents. The hamsters examined were killed by overdosing with chloroform or with carbon dioxide at a concentration of 75%.

In 1310 specimens, the arrangement of the coronary arteries was examined using a corrosion-cast technique. In the remaining 1519, the origin and proximal course of the coronary arteries was assessed by means of a Leica MZ12 stereomicroscope (Leica, Heerbrugg, Switzerland). When an anomalous arrangement was suspected, the heart was studied using histochemical techniques for light microscopy. In several cases, the aortic valve was removed and processed by scanning electron microscopy to show the location of the coronary ostia.

Corrosion-cast technique. The heart was exposed by means of a thoracotomy at the level of the fifth inter-costal space. Vinyl resin (Rhodopas® AX85/ 15; Rhone-Poulenc; Courbevoie, France) in a 20% ketone solution was injected via a cannula placed in the ventral aorta through the apex of the left ventricle. When an anomalous origin of a coronary artery from the pulmonary trunk was suspected, the right ventricle and the pulmonary artery were also injected. Internal casts of the ventricles and arterial vessels were obtained by macerating the specimens in a 20% hydrochloric acid bath.

Histochemical techniques for light microscopy. The heart was fixed in 10% neutral formalin buffered with magnesium carbonate (fixative volume-to-tissue volume ratio, 80:1), and embedded in Paraplast (Sigma Chemical Co., Poole, England). Serial transverse sections (10 lm) for light microscopy were stained with haematoxylin and eosin or Mallory's trichrome stains. Observations were made with a Leica DMLS microscope (Wetzlar, Germany).

Scanning electron microscopy. The aortic valve was removed and fixed by immersion in 1% paraformaldehyde and 2% glutaraldehyde in 0.05 m sodium cacodylate buffer (pH 7.3) with osmolarity adjusted to 330 milliosmol/l for 3 h (ratio of fixative-to-tissue volume, 80:1). Then, the specimen was dehydrated in increasing concentrations of ethanol, dried by the critical point method, and coated by gold sputter. Observations were made using a Jeol JSM-840 scanning electron microscope (Jeol, Tokyo, Japan), operated at 10 kV.

Results

In this study, differences related to sex were not observed with regard to the occurrence of accessory coronary ostia. Therefore, male and female data were pooled. All the hamsters examined possessed a normal (tricuspid) aortic valve. The valve had three aortic sinuses, right, left and dorsal, three leaflets, and a fibrous interleaflet triangle between each adjacent leaflet. Overall, therefore, three inter-leaflet triangles were present in the subaortic outflow tract.

The specimens could be classified into two main groups, according to the arrangement of the coronary arteries. Group I included those displaying two normal coronary arteries, right and left. Group II composed of those in which no coronary arterial vessel arose from the left aortic sinus.

Overall, 2494 specimens belonged to Group I. In 2363 of them, there were two coronary ostia, one in the right and the other in the left aortic sinus, from which the right and left coronary arteries arose, respectively (Fig. 1,Ia). The other 135 specimens had accessory coronary ostia. In 57 of these cases, there was a second ostium in the left aortic sinus; the ostium led to the septal artery (Fig. 1,Ib). As revealed by the internal casts, this left septal artery displayed a normal course: the vessel crossed the infundibular portion of the interventricular septum and then, it turned to the apex of the heart. In another 58 cases, an accessory coronary ostium located in the right aortic sinus led to the septal artery (Figs 1,Ic, 2, 3 and 4a) which coursed through the interventricular septum to the apex of the heart. In a further 16 cases, the conal artery, which supplied the wall of the right ventricular outflow tract, arose from a separate ostium placed in the right aortic sinus (Figs 1,Id and 4b). In the remaining four specimens, there were two accessory ostia in the right aortic sinus. One of them gave rise to the septal artery, and the other to the conal artery (Fig. 1,Ie). In summary, a septal artery arising from a separate ostium in the aorta occurred in 119 (4.8%) of the 2498 hamsters with normal right and left coronary arteries, whereas 20 (0.8%) animals displayed a conal artery originating directly from the aortic root.

Group II included the remaining 331 specimens of the whole series examined. In 191 cases, a single coronary artery trunk arose from the right aortic sinus (Fig. 1,IIa). In other 35 specimens, the right coronary artery arose from the right aortic sinus, and the left coronary artery from the dorsal aortic sinus (Fig. 1,IIb). In a further 92 cases, the right coronary artery originated from the right aortic sinus, and the left coronary artery from the left sinus of the pulmonary valve (Fig. 1,IIc). In 12 of the remaining 13 hamsters belonging to Group II, the septal artery arose from a separate ostium located in the right aortic sinus. In three cases, the ostium of the septal artery co-existed with another ostium leading to a coronary artery trunk that bifurcated into right and left coronary arteries (Fig. 1,IId). In five more cases, the septal artery arising from a separate ostium occurred in association with a normal right coronary artery and a left coronary artery originating from the dorsal aortic sinus (Fig. 1,IIe). In the other four cases, the septal artery arising directly from the aorta was associated with the anomalous origin of the left coronary artery from the pulmonary trunk (Fig. 1,IIf). Overall, therefore, a separate coronary ostium giving rise to the septal artery occurred in 12 (3.6%) of the 331 hamsters devoid of a coronary artery arising from the left aortic sinus. In the remaining specimens (0.3%) of the 331 belonging to Group II, the right coronary artery arose from the right aortic sinus, the left coronary artery from the pulmonary trunk, and the conal artery from a own ostium, located in the right aortic sinus (Fig. 1,IIg).

Discussion

The septal artery arose from a separate ostium in 4.8% of the present Syrian hamsters, displaying a normal coronary artery pattern. This does not deviate from the data reported by

Sans-Coma et al. (1993), who estimated that in this rodent species, the septal artery originates from an accessory ostium in 4.5% of cases. A conal artery arising from a separate ostium located in the right aortic sinus occurred in 0.8% of the hamsters studied. This incidence is quite similar to that (0.9%) reported by Sans-Coma et al. (1993).

From the preceding data, it can be concluded that in the Syrian hamster, the separate origin of the septal artery cannot be considered a coronary anomaly. Indeed, according to the current statistical criteria of normality used in the studies of coronary arteries (Teplitsky et al., 1987; Angelini, 1989; Angelini et al., 2002), this arrangement should be better seen as a variant of the normal coronary artery pattern. The separate origin of the conal artery is less frequent; yet, it occurs in almost 1% of the specimens, a percentage which is considered to be the cutoff point between normality and abnormality (Angelini, 1989; Angelini et al., 2002).

The presence of more than two coronary ostia in the aorta is relatively frequent in several mammalian species. The conal artery originates from a separate ostium in the aorta in 33% to 51% of humans (Bianchi, 1904; Crainicianu, 1922; Schlesinger et al., 1949; Angelini, 1989; Petit and Reig, 1993), in 50% of common squirrel monkeys, *Saimiri sciureus*, (Colborn, 1966), and in 8% of pigs (Berg, 1962). One coronary ostium in every three aortic sinuses was reported in 11% to 45% of mice belonging to three different laboratory strains (Aikawa and Kawano, 1985), as well as in 11% of Virginian white-tail deer, *Odocoileus virginiensis*, a species which shows a wide variation in the coronary orificial pattern (Bishop et al., 1970). Moreover, a third coronary artery arising from the dorsal (noncoronary) aortic sinus occurred in all of the seven Cape elands, *Taurotragus oryx*, in one of the four greater kudus, *Tragelaphus strepsiceros*, and in one of the four brindled gnus, *Connochaetes taurinus*, examined by Basson and McCully (1969). In this latter species, Wallach and Howcroft (1969) detected an unforeseen variation in the number of coronary artery ostia involving all three aortic sinuses: two coronary ostia, right and left, occurred in only one of the 15 specimens examined, whereas there were three ostia in ten other specimens, four ostia in a further three, and five ostia in the remaining one. A third coronary artery arising from the right aortic sinus occurred in almost 2% of hearts from grivet monkeys, *Cercopithecus aethiops*, and crab-eating monkeys, *Macaca fascicularis*, studied by Nikolic et al. (2004). A third, accesory coronary ostium in the aorta was detected by Durán et al. (1991a) in 7% of the specimens belonging to eight wild living rodent species of the families Arvicolidae, Muridae and Gliridae. In most cases, the third ostium led directly to the septal artery; sometimes, however, it gave off an atrial or a ventricular branch. Accessory coronaria ostia were recorded in one of the three hedgehogs, *Erinaceus europaeus*, by Berg (1964) and in three of 77 fruit-eating bats, *Eidolon helvum*, by Rowlatt (1967).

Studies on the formation of the coronary arteries in birds and mammals have been usually carried out assuming that, in both taxa, the presence of two coronary ostia located in the right and left aortic sinuses constitutes the normal coronary artery condition. The classical hypotheses on this subject based on the concept that the proximal coronary arteries develop as coronary artery buds that hollow out from the aorta to connect with the peritruncal plexus of capillaries located in the subepicardial layer of the developing heart (see Tomanek, 1996; for a review). In contrast, several studies have demonstrated that the proximal segments of the coronary arteries develop via endothelial ingrowth from the peritruncal ring of coronary arterial vasculature into the newly formed aorta (Bogers et al., 1989; Waldo et al., 1990; Martire et al., 1998; Velkey and Bernanke, 2001; Ando et al., 2004). During the onset, multiple endothelial strands penetrate the walls of the three aortic sinuses, subsequently, these strands decrease in number to form the definitive right and left coronary artery trunks (Hood and Rosenquist, 1992; Poelmann et al., 1993; Waldo et al., 1994; Velkey and Bernanke, 2001; Reese et al., 2002; Wada et al., 2003; Ando et al., 2004). The mechanism by which only two selected aortic connections usually persist is still unclear. The restricted association of parasympathetic ganglia with the endothelial strands that form the definitive coronary artery stems suggest that such ganglia may somehow support coronary artery development (Hood and Rosenquist, 1992; Waldo et al., 1994). Failure to form a tunica media has also been adduced as a possible cause of regression of most endothelial strands that primarily penetrate the aortic media (Poelmann et al., 1993). Apoptosis has also been implicated in this latter process (Velkey and Bernanke, 2001; Bernanke and Velkey, 2002). Fusion of the endothelial strands that penetrate the right and left aortic sinuses was recently proposed as a key factor in the establishment of the stems of the right and left coronary arteries (Ando et al., 2004).

Whatever the mechanism might be, it should be stressed that the existence of only two coronary ostia in the aorta is not the rule among mammals. The present observations, together with the data from the literature cited above, indicate that the existence of two coronary artery ostia in the aorta is the most frequent, but not the general condition. The occurrence of more than two coronary artery trunks arising from the aorta cannot be further seen as the product of a disorder in the normal coronariogenetic process. It remains unexplained, however, why two coronary ostia become normally established in most mammalian species, while three or more ostia often appear in some others.

One of the main purposes of the present study was to assess whether the incidence of accessory coronary ostia in anomalous coronary artery patterns significantly varies from that of the normal pattern. The results obtained substantiate that this is not the case with the Syrian hamster. In this regard, it should be emphasized that the coronary ostia that can be regarded as accessory ostia in the anomalous coronary artery patterns (Group II) are homologous to those occurring in the normal coronary artery pattern (Group I); indeed, they correspond to the septal and conal arteries. Moreover, the incidence of these ostia is quite similar in both groups. Thus, it can be concluded that the morphogenetic deviations leading to the anomalous coronary artery patterns reported in this study do not alter the connections of the septal and conal arteries to the wall of the aortic root.

In the Syrian hamster, the conal artery only supplies a more or less extensive area of the right ventricular outflow tract. The territory vascularized by the septal artery is much wider; it comprises the most part of the interventricular septum (Durán et al., 1992; Sans-Coma et al., 1993), a cardiac structure which includes a large portion of myocardium that plays an important role in the systolic performance of the left ventricle. The existence of a well-developed septal artery constitutes the most constant anatomical feature of the hamster coronary artery system (Durán et al., 1992). The vessel is always present, even in specimens revealing anomalous coronary artery patterns. These observations, together with the fact that it arises directly from the aorta in a considerable percentage of individuals, lead to the concept that in the Syrian hamster, the septal artery might be viewed as a third coronary artery. In this regard, it should be kept in mind that the presence of a septal artery similar to that of the hamster is closely related to the intramyocardial course of the coronary arteries (Durán et al., 1991b, 1992). In the mammals with subepicardial coronary arteries, a septal artery is sometimes present, but in such cases, the contribution of the vessel to the blood supply of the interventricular septum is of lesser magnitude (for review see Rodríguez et al., 1961; Christensen, 1962; and Ldinghausen and Ohmachi, 2001).

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References

Aikawa, E., and J. Kawano, 1985: Genetic basis of the ‘posterior' coronary artery in mice. London: XII International Anatomical Congress [Abstract no. 4].

Ando, K., Y. Nakajima, T. Yamagishi, S. Yamamoto, and H. Nakamura, 2004: Development of proximal coronary arteries in quail embryonic heart. Multiple capillaries penetrating the aortic sinus fuse to form main coronary trunk. Circ. Res. 94, 346-352.

Angelini, P., 1989: Normal and anomalous coronary arteries: definitions and classification. Am. Heart J., 117, 418-434.

Angelini, P., S. Villason, A. V. Chan Jr, and J. G. Diez, 1999: Normal and anomalous coronary arteries in humans. In: Coronary Artery Anomalies. A Comprehensive Approach (P. Angelini, ed.). Philadelphia: Lippincott Williams and Wilkins, pp. 27-79.

Angelini, P., J. A. Velasco, and S. Flamm, 2002: Coronary anomalies. Incidence, pathophysiology, and clinical relevance. Circulation 105, 2449-2454.

Basson, P. A., and R. M. McCully, 1969: Eland: aorta with three coronary ostia. J. S. Afr. Vet. Assoc. 40, 104.

Becker, A. E., 1981: Variations of the main coronary arteries. In: Paediatric Cardiology 3 (A. E. Becker, G. Losekoot, G. Marcelletti and R. H. Anderson, eds). Edinburgh: Churchill Livingstone, pp. 263-277.

Berg, R., 1962: Untersuchungen über das Verhalten der Koronargefäbe beim Hausschwein im Hinblick auf das Herztodproblem. Mheft Vet. Med. 17, 469-472.

Berg, R., 1964: Über den Entwicklungsgrad des Koronargefäbmusters beim Hausschwein (*Sus scrofa domesticus*). Anat. Anz. 115, 193-204.

Bernake, D. H., and J. M. Velkey, 2002: Development of the coronary blood supply: changing concepts and current ideas. Anat. Rec. B New Anat. 269, 198-208.

Bianchi, A., 1904: Morfologia delle arteriae coronariae cordis. Arch. Ital. Anat. Embriol. 3, 87-164.

Bishop, M. B., S. L. Free, J. N. P. Davies, and R. P. Albert, 1970: The coronary arterial pattern of deer in New York State with special reference to the third (posterior) coronary artery. Am. Heart J. 80, 785-790.

Bogers, A. J. J. C., A. C. Gittenberger-de Groot, R. E. Poelmann, B. M. Péault, and H. A. Huysmans, 1989: Development of the origin of the coronary arteries, a matter of ingrowth or outgrowth? Anat. Embryol. 180, 437-441.

Christensen, G. C., 1962: The blood supply to the interventricular septum of the heart: a comparative study. Am. J. Vet. Res. 23, 869-874.

Colborn, G. L., 1966: The gross morphology of the coronary arteries of the common squirrel monkey. Anat. Rec. 155, 353–367.

Crainicianu, A. L., 1922: Anatomische Studien bei der Coronararterien und experimentelle Untersuchungen über ihre Durchgängigkeit. Virchows Arch A Pathol Pathol Anat 238, 1-75.

Durán, A. C., V. Sans-Coma, J. M. Arqué, and M. Cardo, 1991a: Anomalías de las arterias coronarias en roedores de vida libre. Zool. Baetica 2, 7-16.

Durán, A. C., V. Sans-Coma, M. Cardo, and J. M. Arqué, 1991b: The blood supply to the interventricular septum of the heart in Soricoidea (Mammalia). Zool. Anz. 227, 279-285.

Durán, A. C., V. Sans-Coma, J. M. Arqué, M. Cardo, B. Fernández, and D. Franco, 1992: Blood supply to the interventricular septum of the heart in rodents with intramyocardial coronary arteries. Acta. Zool. 73, 223-229.

Fernández, B., M. C. Fernández, A. C. Durán, D. López, A. Martire, and V. Sans-Coma, 1998: Anatomy and formation of congenital bicuspid and quadricuspid pulmonary valves in Syrian hamsters. Anat. Rec. 250, 70-79.

Fernández, M. C., A. C. Durán, R. Real, D. López, B. Fernández, A. V. De Andrés, J. M. Arqué, A. Gallego, and V. Sans-Coma, 2000: Coronary artery anomalies and aortic valve morphology in the Syrian hamster. Lab. Anim. 34, 145-154.

Grant, R. T., and M. Regnier, 1926: The comparative anatomy of the cardiac coronary vessels. Heart 13, 285-317.

Hood, L. C., and T. H. Rosenquist, 1992: Coronary artery development in the chick: origin and deployment of smooth muscle cells, and the effects of neural crest ablation. Anat. Rec. 234, 291-300.

Lüdinghausen, M. von, and N. Ohmachi, 2001: Right superior septal artery with ‘normal' right coronary and ectopic ‘early' aortic origin: a contribution to the vascular supply of the interventricular septum of the human heart. Clin. Anat. 14, 312-319.

Martire, A., B. Fernández, D. López, A. C. Durán, and V. Sans-Coma, 1998: Embryonic development of normal and abnormal origin of the coronary arteries in the Syrian hamster. 6th Meeting of the Working Group on Developmental Anatomy and Pathology of the European Society of Cardiology, Málaga [Abstract no. 13].

Nikolic, V., G. Teofilovski-Parapid, G. Stankovic, B. Parapid, S. Malobabic, and V. Stojic, 2004: Third coronary artery in monkey heart. Acta Vet. Hung. 52, 253-257.

Petit, M., and J. Reig, 1993: Arterias Coronarias. Aspectos Anatomoclínicos. Barcelona: Masson y Salvat, Ediciones Científicas y Técnicas, S.A.

Poelmann, R. E., A. C. Gittenberger-de Groot, M. M. T. Meink, R. Bökenkamp, and B. Hogers, 1993: Development of the cardiovascular endothelium studied with anti-endothelial antibodies in chicken-quail chimeras. Circ. Res. 73, 559-568.

Reese, D. E., T. Mikawa, and D. M. Bader, 2002: Development of the coronary vessel system. Circ. Res. 91, 761–768.

Rodríguez, F. L., S. L. Robbins, and M. Banasiewicz, 1961: The descending septal artery in human, porcine, equine, ovine, bovine, and canine hearts. A postmortem angiographic study. Am. Heart J. 62, 247-259.

Rowlatt, U., 1967: Functional anatomy of the heart of the fruit-eating bat, *Eidolon hervum*, Kerr. J. Morphol. 123, 213-230.

Sans-Coma, V., J. M. Arqué, A. C. Durán, M. Cardo, B. Fernández, and D. Franco, 1993: The coronary arteries of the Syrian hamster, *Mesocricetus auratus* (Waterhouse, 1839). Ann. Anat. 175, 53-57.

Sans-Coma, V., M. Cardo, G. Thiene, B. Fernández, J. M. Arqué, and A. C. Durán, 1992: Bicuspid aortic and pulmonary valves in the Syrian hamster. Int. J. Cardiol. 34, 249-254.

Schlesinger, M. J., P. M. Zoll, and S. Wessler, 1949: The conus artery: a third coronary artery. Am. Heart J. 38, 823-836.

Teplitsky, I., M. Wurzel, R. Melamed, and M. Aygen, 1987: Anomalous origin of the coronary arteries. Angiology 38, 128-132.

Tomanek, R. J., 1996: Formation of the coronary vasculature: a brief review. Cardiovasc. Res. 31, E46-E51.

Velkey, J. M., and D. H. Bernanke, 2001: Apoptosis during coronary artery orifice development in the chick embryo. Anat. Rec. 262, 310-317.

Wada, A. M., S. G. Willet, and D. Bader, 2003: Coronary vessel development. A unique from of vasculogenesis. Arterioscler. Thromb. Vasc. Biol. 23, 2138-2145.

Waldo, K. L., W. Willner, and M. L. Kirby, 1990: Origin of the proximal coronary artery system and review of ventricular vascularization in the chick embryo. Am. J. Cardiol. 188, 109-120.

Waldo, K. L., D. H. Kumiski, and M. L. Kirby, 1994: Association of the cardiac neural crest with the development of the coronary arteries in the chick embryo. Anat. Rec. 239, 315-331.

Wallach, J. D., and T. Howcroft, 1969: Variable number of coronary os in the aorta of the Zululand wildebeeste. Vet. Med. Small Anim. Clin. January, 21-22.

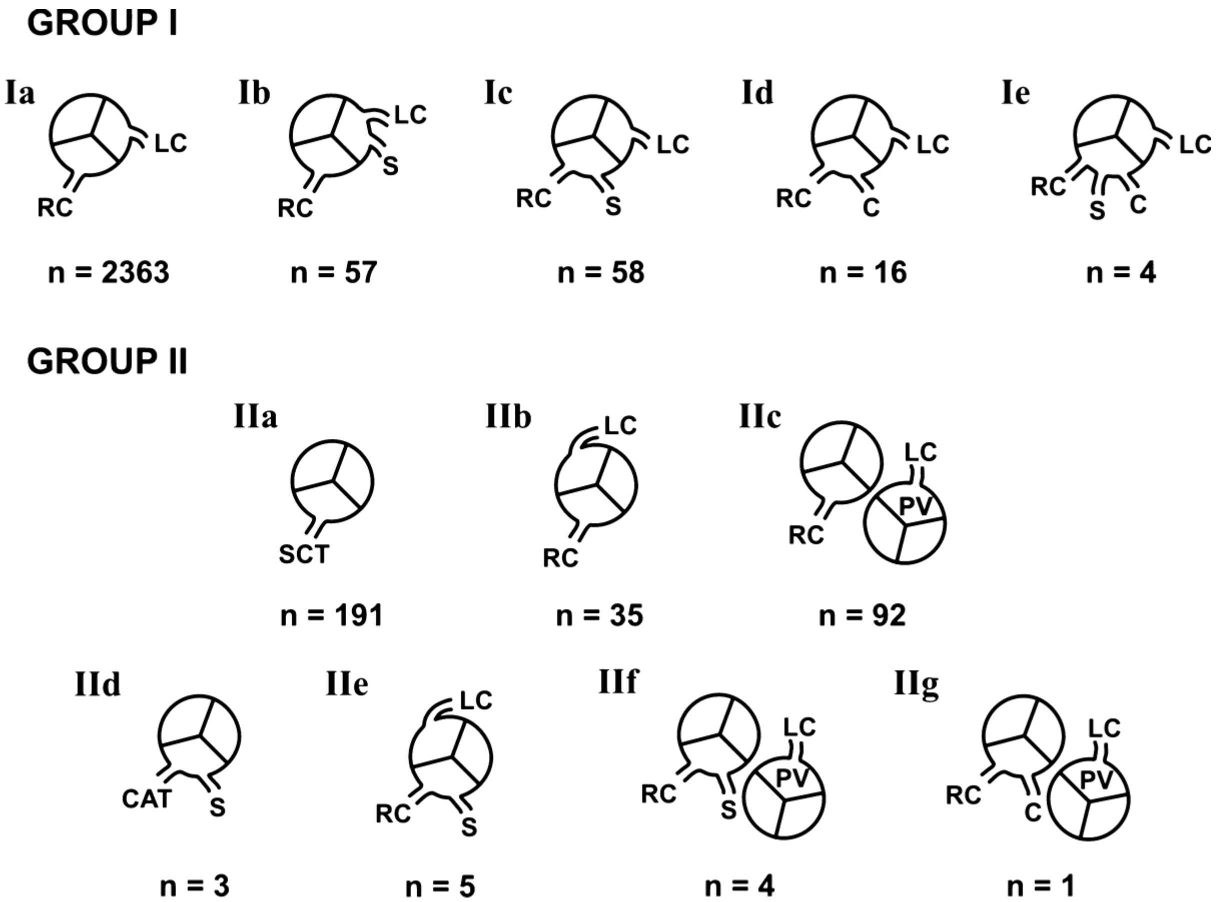

Fig. 1. Coronary artery ostia in Syrian hamsters with normal (Group I) and anomalous (Group II) coronary artery patterns. See text for further explanation. C, conal artery; CAT, coronary artery trunk that bifurcates into right and left coronary arteries; LC, left coronary artery; PV pulmonary valve, RC, right coronary artery; S, septal artery; SCT, single coronary artery trunk arising from the right aortic sinus.

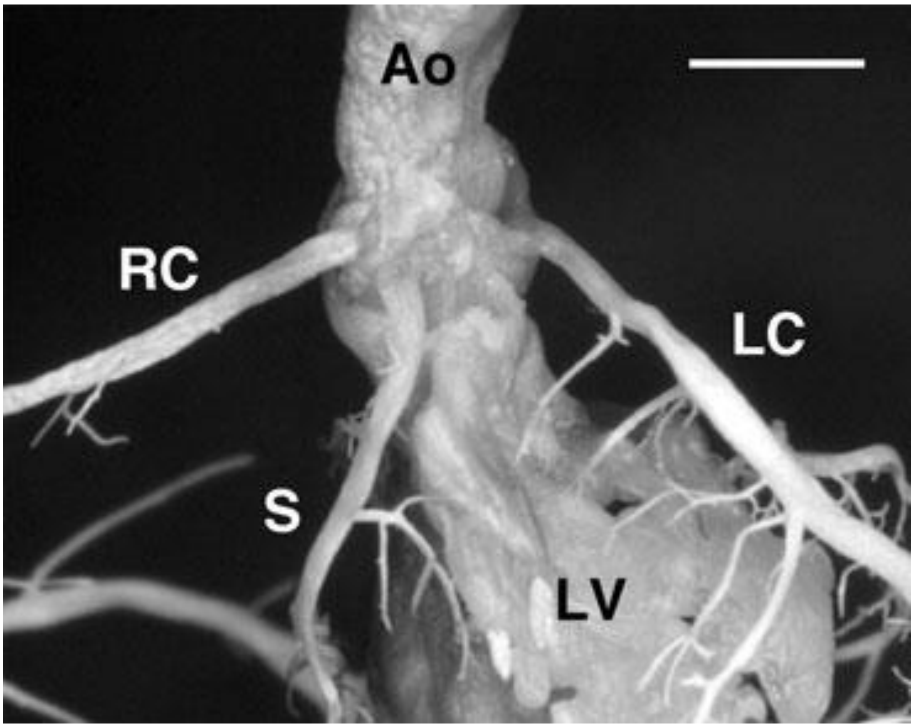

Fig. 2. Internal cast of the left ventricle (LV), aorta (Ao) and coronary arteries of an adult Syrian hamster. The septal artery (S) arises from an independent ostium located in the right aortic sinus. LC, left coronary artery; RC, right coronary artery. Bar = 500 lm.

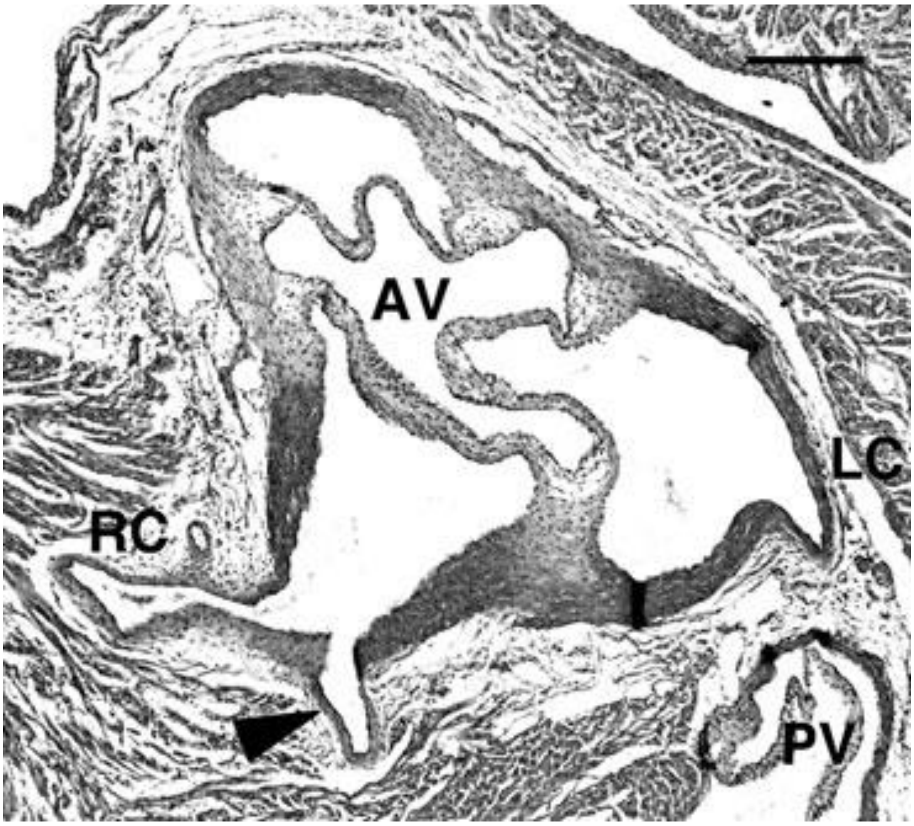

Fig. 3. Transverse section of the heart from an adult Syrian hamster, at the middle level of the aortic valve (AV). The septal artery (arrow) arises from an independent ostium located in the right aortic sinus. LC, left coronary artery; PV, pulmonary valve; RC, right coronary artery. Haematoxylin and eosin. Bar = 300 lm

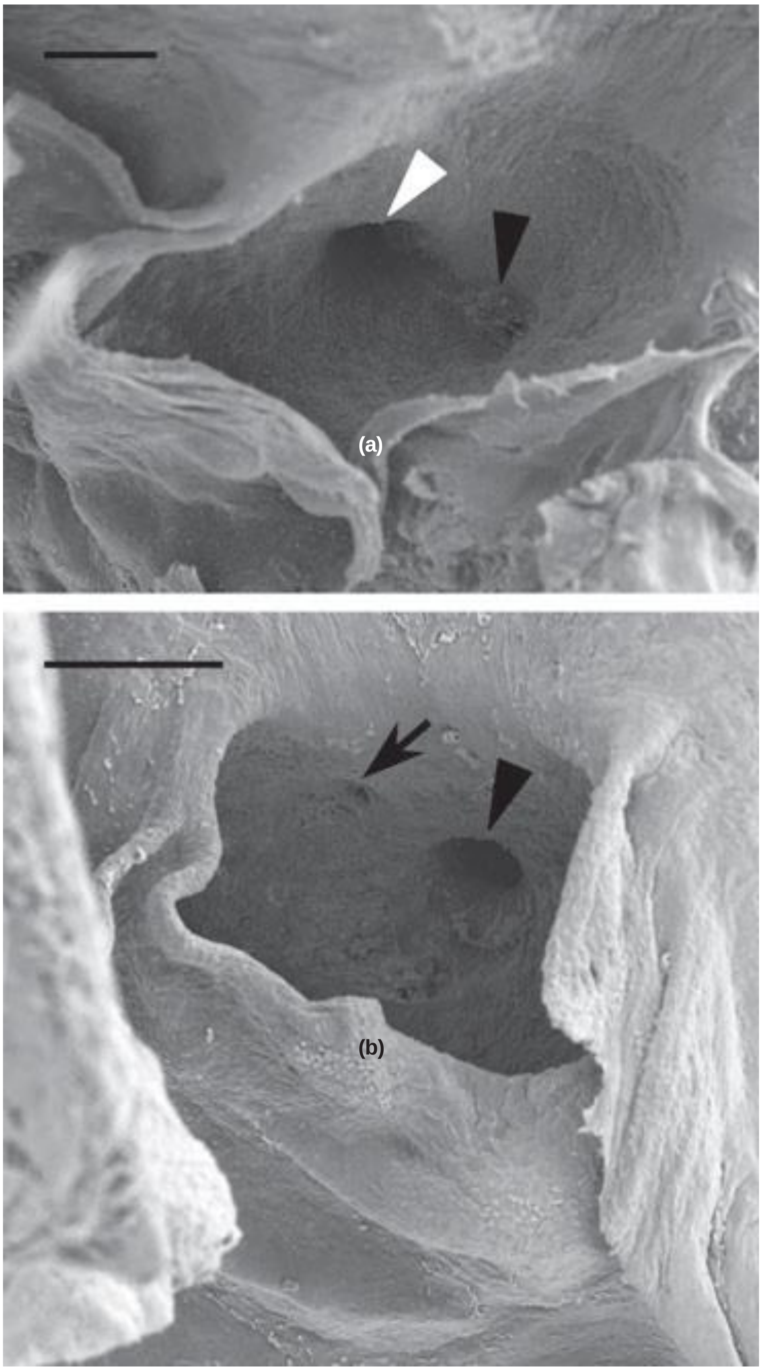

Fig. 4. Scanning electron photomicrographs of the right sinus and leaflet of the aortic valve from adult Syrian hamsters. Two coronary artery ostia are present in each specimen. The black arrowhead points to the ostium of the right coronary artery. In (a), the white arrowhead indicates the ostium of the septal artery which is somewhat wider than that of the right coronary artery. In (b), the arrow shows a relatively small ostium that leads to the conal artery. Bar = 200 lm