

Morphological expression of the pig coronary sinus and its tributaries: a comparative analysis with the human heart

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SUMMARY

The objective of this study was to determine the morphological expression of the coronary sinus and its tributary branches in pigs. This descriptive cross-over study evaluated continuous variables with t test, and discrete variables with the Pearson χ square test. A level of significance $p < 0.05$ was used. The coronary sinus (CS) and its tributaries were perfused with polyester resin (Palatal 85%, Styrene 15%), and then the hearts were subjected to KOH infusion to release subepicardial fat. The shape, trajectory and morphometry of the CS and its tributary veins were assessed. The CS was 26.9 ± 5.69 mm in length, with a proximal caliber of 10.8 ± 2.43 mm. It was cylindrical in shape in 69% of cases. The left marginal had a distal caliber of 2.6 ± 0.75 mm. The distal caliber of the middle cardiac vein (MCV) was 3.7 ± 1.04 mm. An anastomosis between the venous branches was observed in 63% of hearts. The caliber of the minor cardiac vein and the left azygous vein was 1.67 ± 0.49 mm and 8.47 ± 2.07 , mm respectively. The distal caliber of the right marginal vein was 1.54 ± 0.28 mm. Myocardial bridges over the MCV were found in 10 cases (8%). A greater frequency of anastomoses was observed at the level of the heart apex between the MCV and the great cardiac vein than described in human studies. Because

human and swine hearts exhibit similarity in the pattern of the CS and its tributaries, this animal model is suitable for performing procedural and hemodynamic applications.

Key words: Coronary sinus – Myocardial bridge – Middle cardiac vein – Pig

INTRODUCTION

The venous drainage of the heart in pigs is given for the most part by the coronary sinus (CS), which runs within the left atrioventricular sulcus. It is formed by the confluence of the great cardiac vein (GCV) and of the left azygous vein, it corresponds to the oblique vein of the left atrium in humans. As the CS runs around the mural flap of the mitral valve it receives the marginal vein, and then, at the level of the crux cordis, it receives the drainage of the middle cardiac vein (MCV), and the minor cardiac vein (MiCV) (which drains the blood from the posterior surface of the right ventricle). The various sizes of the left azygos somehow determine cylindrical or funnel-shaped CS. This arrangement is similar to the coronary venous drainage of the human heart, with the anterior veins of the right ventricle draining directly into the right atrium (Crick et al., 1998).

As in humans, the finalization site of the GCV and, at its turn, the beginning of the CS is determined by the presence of the internal valve, an incomplete closure valve. The origin of the CS may be also determined by the site of drainage of the

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oblique vein of the left atrium, or Marshall vein (Von Lüdinghausen, 1987; Gilard et al., 1998; Cendrowska-Pinkosz and Urbanowicz, 2000; El-Maasarany et al., 2005; Ballesteros et al., 2010). The shape of the CS is variable, and it may be cylindrical, flattened or funnel-like. This structure ends in the right atrium between the outlet of the caudal vena cava and the right atrial-ventricular orifice (Kato et al., 1987; Gilard et al., 1998; Mahmud et al., 2001; Lee et al., 2006).

The information existing on the tributaries of the CS in pigs is poor, and for this reason there is no substrate to carry out an anatomical comparison with the human heart. It has been said that, in humans, the GCV, the marginal veins of the left ventricle (MVLV), the MVC and the MiCV drain into the CS in the majority of the cases. When the right marginal vein (RMV) does not give origin to the MiCV, it does not drain into the CS but directly into the right atrium (Von Lüdinghausen, 1987; Gilard et al., 1998).

The importance of the characterization of the CS and its tributaries resides in the utilization of this species as an experimental model for cardiovascular surgery, hemodynamics, and teaching-learning processes in compared anatomy. This investigation intends to enrich the knowledge on the anatomic and morphometric characteristics of the CS through the evaluation of a sample of commercial pigs, and to establish similarities and differences of this vascular structure in a context of compared anatomy between human and pigs' hearts.

MATERIALS AND METHODS

This descriptive cross-over study evaluated the CS and tributaries of 120 hearts of commercial pigs (mixture of breeds Pietrain, Belgian Landrace, and Large White varieties) destined to the slaughterhouse with stunning method, with a mean age of 5 months, obtained from Frigorífico Vijagual of Bucaramanga - Colombia. The Bioethics Committee of the Cooperative University of Colombia supported this study. The organs were subjected to an exsanguination process in water source for 6 hours. An arciform plicature was made with silk 2.0 around the CS orifice and a number 14 catheter was installed, through which semisynthetic polyester resin was perfused, composed of a mixture of palatal GP40L 85% with styrene 15% and mineral blue dye.

Then, the hearts were subjected to a process of partial corrosion by immersion of the anatomical parts in a container with potassium hydroxide 15%, for five minutes, aiming to remove the subepicardial fat located in the ventricular and atrioventricular grooves. Consecutively, the CS and its tributary branches were dissected from its origin to its distal segment, recording its trajectories and presence of anastomosis. The external diameter of these tributary vessels of the CS was measured with an elec-

tronic calibrator (Mitutoyo®) in their middle segment and 0.5 cm away from their site of drainage, while the caliber of the CS was measured at the levels of the origin and drain in the right atrium. The shape of the CS was said to be cylindrical when the proximal and distal calibers were similar; and funnel-like when the distal caliber was considerably greater than the proximal caliber.

The data thus obtained were recorded in a physical matrix and were consigned in digital media using Excel tables. Photographs were taken of all of the pieces thus analyzed.

The continuous variables were analyzed with the t test, whereas the discrete variables were analyzed with Pearson's χ square test and Fisher's exact test. The results were assessed using the statistic software "Epi - Info 3.5.4". The level of significance utilized was $p < 0.05$.

RESULTS

One hundred and twenty hearts were assessed, 101 of which were from male pigs (84.2%) and 19 from female pigs (15.8%). The mean weight of the hearts was 375 ± 78.12 g, obtained from pigs with a mean weight of 90 kg. The length of the CS was 26.9 ± 5.69 mm, and its proximal and distal calibers were 10.8 ± 2.43 mm and 11.9 ± 2.37 mm, respectively. The CS was cylindrical in shape in 83 specimens (69%) (Fig. 1) and funnel-like in 37 hearts (31%) (Fig. 2). The CS orifice was 6.4 ± 0.77 mm high and 11.4 ± 1.11 mm wide. All specimens lack a valve at the level of the CS orifice.

The left marginal vein (LMV) was found in 117 hearts (97.5%), being more frequent in males with a significant difference ($p < 0.001$). The main site of its origin was the heart apex (46%), followed by

Table 1. Origin of the left marginal vein at the apex and lower, medium and upper thirds of the obtuse edge of the heart, by gender.

	Male	Female	Total sample	%
Apex	45 (44.5%)	9 (56.2%)	54	46
Lower third	13 (12.9%)	3 (18.8%)	16	14
Middle third	31(30.7%)	4 (25%)	35	30
Upper third	12 (11.9%)	-	12	10
Total	101	16	117	100

Table 2. Origin of the middle cardiac vein at the heart apex and at the lower and medium thirds of the sub-sinusal interventricular sulcus, by gender.

	Male	Female	Total sample	%
Apex	92 (91.1%)	17 (89.5%)	109	90.8
Lower third	7 (6.9%)	2 (10.5%)	9	7.5
Middle third	2 (2%)	-	2	1.7
Total	101	19	120	100

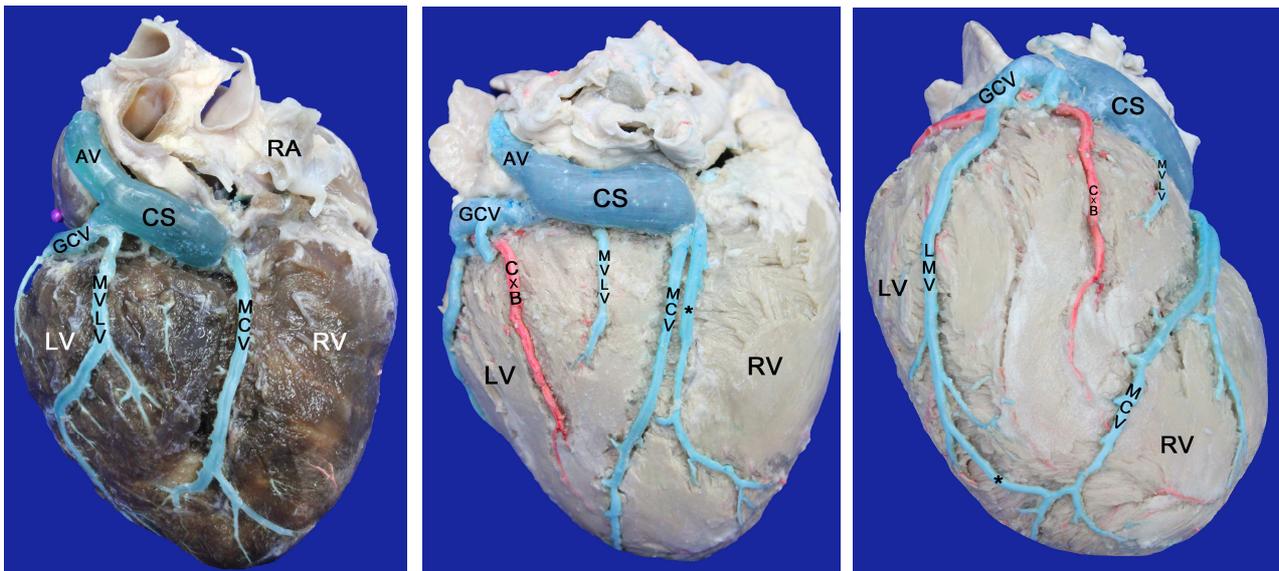


Fig. 1 (left). Right surface of the heart. Abbreviations: AV, Azygos vein; CS, cylindrical coronary sinus; GCV, great cardiac vein; LV, left ventricle; MCV, middle cardiac vein; MVLV, marginal veins of the left ventricle; PLCV, posterior left cardiac vein; RA, right atrium; RV, right ventricle.

Fig. 2 (middle). Right surface of the heart. Abbreviations: as in Figs. 1,2. Also, CxB, circumflex branch; (*), accessory middle cardiac vein.

Fig. 3 (right). Left border of the heart. Abbreviations: as in Fig. 1. Also LMV, left marginal vein; (*), cardiac apex.

the origin at the mid third of the obtuse edge of the heart ($p=0.68$) (Table 1). The caliber at the medium segment was 1.53 ± 0.51 mm and at the distal of 2.61 ± 0.75 mm. The LMV flowed into in the GCV in 116 specimens (97%) and with a lower frequency it adopted an oblique trajectory over the posterior surface of the left ventricle to flow into the proximal segment of the CS in 3 hearts (2.5%), and it ended into an anterior ventricular branch in one case (0.5%).

The proximal and distal calibers of the MVC were $2.59 \text{ mm} \pm 0.75 \text{ mm}$ and $3.70 \pm 1.04 \text{ mm}$, respectively. The MVC was originated at the apex in 91% of the specimens, but the difference between males and females was non-significant ($p = 0.82$) (Table 2). In 108 cases (90%) the MVC was located superficially and to the left side in relation to the subsinusal interventricular branch, whereas in 12 cases (10%) it was situated superficially and to the right side of the said vessel. In all of the hearts evaluated the MCV flowed into in the posterior-inferior surface of the orifice of drainage of the CS into the right atrium. In 76 hearts (63%) anastomoses were observed between the different venous branches, whereas in 44 cases (37%) this morphological expression was not observed ($p=0.29$). The anastomoses occurred between the MCV and the GCV in 38 specimens (50%); between MCV and LMV in 17 samples (22%) (Fig. 3) and in 21 cases (28%) there was a double anastomosis be-

tween the MCV, the GCV and the LMV.

The MiCV had a caliber of 1.67 ± 0.49 mm, and it ended in 50% of the cases into the CS and in the remaining 50% into the right atrium. The left azygos vein at the site of drainage to the CS had a caliber of 8.47 ± 2.07 mm.

The RMV was originated in 67% of the cases at the medium third of the acute edge of the heart; in 25% at the lower third, whereas in the 8% it was short and originated at the upper third. Its proximal and distal calibers were 1.14 ± 0.27 mm and 1.54 ± 0.28 mm, respectively. In 70 specimens the RMV ended (58%) directly into the right atrium and in 50 samples (42%) it gave origin to the MiCV.

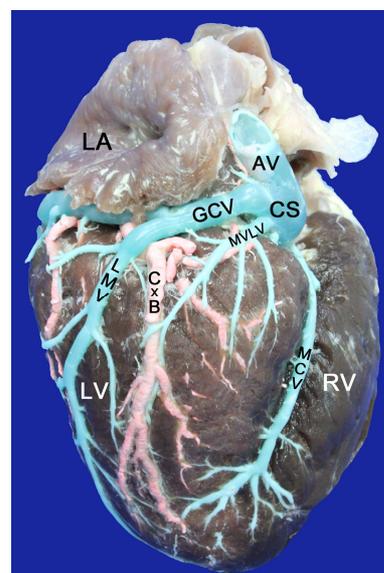


Fig. 4. Right surface of the heart. Abbreviations as in Figs. 1,2 and LA, left atrium; LMV, left marginal vein.

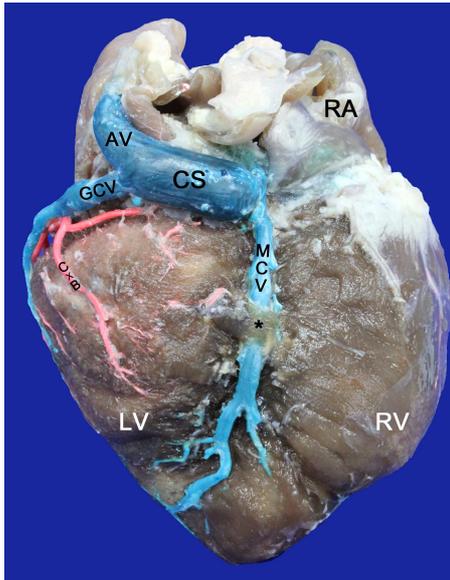


Fig. 5. Right surface of the heart. Abbreviations as in Figs. 1-3 and (*), myocardial bridge.

The MVLV distributed their drainage into the GCV in 58% of the cases, and into the CS in 42% (Fig. 4). They were 1.61 ± 0.61 mm in caliber. Ten myocardial bridges (MB) were found (8%) over the tributaries of the SC, 8 cases (80%) of which were situated at the medium segment of the MCV (Fig. 5) and in 2 specimens (20%) in the LMV. They were $11-23 \pm 5.67$ mm long and 1.13 ± 0.48 mm wide.

DISCUSSION

Prior studies on the CS in pigs had limited themselves to indicate qualitative characteristics, and data on the length and caliber of this structure are missing (Crick et al., 1998; Sousa-Rodrigues et al., 2005). The length of the CS observed in our study (26.8 mm) is similar to what has been reported in humans (Gilard et al., 1998; Schaffler et al., 2000; Ortale et al., 2001; Liu et al., 2003; Mao et al., 2005; de Oliveira et al., 2007; Ballesteros et al., 2010), whereas the proximal and distal calibers (10.76 mm and 11.89 mm) are considerably larger than those reported for the CS in humans (Kato et al., 1987; Piffer et al., 1990; Gilard et al., 1998; Schaffler et al., 2000; Liu et al., 2003; de Oliveira et al., 2007; Christiaens et al., 2008). The cause of this larger caliber in the porcine CS could be explained by the drainage of the left azygous vein, whose equivalent structure in the human drains in the distal segment of the superior vena cava. The incidence of the cylindrical shape of the CS, with similar proximal and distal calibers, observed in 69% of the specimens in our series, is consistent with reports in humans that have indicated it as the most frequent (Maros et al., 1983; Kato et al., 1987; Pejkoivic and Bogdanovic, 1992; Gilard et al., 1998; Ballesteros et al., 2010). The CS is an

important anatomic point of reference for imaging procedures in humans, but it is rarely seen in echocardiographic studies in healthy patients. It is often seen dilated and elongated in individuals with mitral valve insufficiency, left ventricular hypertrophy, and pulmonary hypertension (Kato et al., 1987; Schaffler et al., 2000).

In humans, the comprehension of the diverse morphological expression of the CS and its tributaries becomes imperative for the purpose of supplying surgical and electrophysiological concerns of the clinic. For this, depurated skills supported on the knowledge of the morphological expression of these structures are needed to perform different procedures, such as the placement of cardioversion or electric resynchronization devices with transvenous electrodes, retrograde perfusion in myocardial preservation techniques with cannulation and catheterization of the CS for radiofrequency ablation (Kato et al., 1987; Ballesteros et al., 2010). In this sense, the similarity of the venous drainage of the pig's heart is in excellent procedural model that allows the improvement of the mentioned techniques. Except for the drainage of the left azygos vein on the CS in the pig.

The frequency and caliber of the LMV reported in prior studies in humans (Mochizuki, 1933; Gilard et al., 1998; Schaffler et al., 2000; Christiaens et al., 2008) is consistent with our findings (97.5% and 2.61 mm, respectively). The drainage of this vascular structure into the GCV in the majority of the cases is consistent with reports in humans, but there is some controversy about the frequency of its drainage into the CS, which in our study was found in 2.5% of the specimens, whereas it has been reported within a range of 5-19% in humans (Mochizuki, 1933; Gilard et al., 1998; Christiaens et al., 2008). In the present work, we observed a predominance of the long LMV, originated with a greater frequency in the heart apex (46%), whereas the origin of this structure in humans has been reported more frequently at the medium third of the obtuse edge of the heart (Gilard et al., 1998).

There is controversy as to the origin of the MCV in humans, with the greater incidence corresponding to the heart apex (Mao et al., 2005; Christiaens et al., 2008), a characteristic that is consistent with our findings (91%). Similarly, it has been stated that the MCV in humans originates predominantly at the lower third of the posterior interventricular sulcus (Nerantzis et al., 1998) or even with similar incidences at the lower third of the said sulcus or at the heart apex (Gilard et al., 1998).

Consistent with the reports by Crick et al, 1998, we found that the MCV drained in all cases into the postero-inferior segment of the CS orifice (Crick et al., 1998), a morphological expression that is reported in the majority of studies carried out in human hearts (Mochizuki, 1933; Duda and Grzybiak, 1998; Gilard et al., 1998; Melo et al., 1998). However, the MCV has also been reported to directly

drain into the right atrium within a range of 15-20% (Mochizuki, 1933; Duda and Grzybiak, 1998; Melo et al., 1998). The distal caliber of the MCV measured near its outlet in our study (3.70 mm) is similar to what has been reported in humans (Gilard et al., 1998; Nerantzis et al., 1998; Kaczmarek and Czerwinski, 2007; Christiaens et al., 2008). The anastomosis between the MCV and the GCV or LMV at the heart apex observed in our series (63%), are considerably larger than those described in human hearts (15-34%). Anastomoses have been reported only between the MCV and the GCV in humans (Mochizuki, 1933; Gilard et al., 1998; Nerantzis et al., 1998; Schaffler et al., 2000; Christiaens et al., 2008; Kosiński et al., 2010).

The present study found that the MiCV drains in one half of the cases into the CS, whereas in humans this type of drainage has been reported within a range of 67-90% (Gilard et al., 1998; Melo et al., 1998; Cendrowska-Pinkosz and Urbanowicz, 2000). The trajectory, drained territory and caliber of the MiCV found in this work are consistent with prior studies conducted in humans (Gilard et al., 1998; Melo et al., 1998; Christiaens et al., 2008). The left azygous vein in the pig has been described qualitatively with the proviso that its confluence with the GCV gives origin to the CS (Crick et al., 1998), with the caliber observed in this series being a reference datum.

Prior studies conducted both in humans and in pigs have characterized poorly the RMV, with very fragmentary descriptions (Mochizuki, 1933; Crick et al., 1998; Gilard et al., 1998; Christiaens et al., 2008); the findings of the present series point towards its main origin at the middle third of the acute edge of the heart, its caliber of 1.54 mm in its distal segment, and its most frequent drainage into the right atrium.

The drainage of the MVLV into the GCV observed in our work in 58% of the specimens is not consistent with prior studies in humans, which have reported it as the main outlet of these veins into the CS within a range of 70-93% (Mochizuki, 1933; Maros et al., 1983; Pejkovic and Bogdanovic, 1992; Gilard et al., 1998; Schaffler et al., 2000; Christiaens et al., 2008). The caliber of the MVLV (1.61 mm) allows for procedural practices using the pig model to access these structures using catheters. This situation should be emphasized because the MVLV are used for the management of arrhythmias through the insertion of devices that give access to the left ventricle intravenously (Maros et al., 1983; Schaffler et al., 2000).

Few studies report on the presence of MB in pigs within a range much higher than our findings (24-86%), because they involve the presence of these muscle bands that cover both arteries as veins. The MB predominant location in the middle third of the MCV, their length and thickness observed in our series, are consistent with prior studies (Berg, 1963). A greater length and a predominant loca-

tion at the upper and medium thirds of the anterior interventricular branch have been described in humans. MB is generally considered a vascular heart variation due to their intermittent or enduring reducing of the arterial lumen, with a possible ischemic effect. Cardiac muscle ischemia may occur during the first 1/3 of diastole due to prolonged coronary artery lumen recovery following its systolic compression. This alters coronary flow speed and reserves, especially during enhanced heart rhythm during exercise and emotional stress (Ferreira et al, 1991; Aleksandrowicz et al., 1993; Loukas et al., 2006).

Anastomoses were observed more frequently at the heart apex between the MCV and the GCV and LMV than had been described in studies conducted in humans. The length and predominantly cylindrical shape of the CS are consistent with prior studies conducted in humans, whereas its caliber is greater due to the drainage of the left azygous vein into the CS.

The findings of the qualitative and morphometric characteristics of the LMV, RMV and MCV are new knowledge that had not been described previously in the literature.

Because human and swine have similarity in the pattern of the CS and its tributaries, this animal model is suitable for performing procedural and hemodynamic applications.

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