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Morphological characterization of the coronary sinus and its tributaries in short hair sheep. Comparative analysis with the veins in humans and pigs

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Abstract

To characterize morphologically the coronary sinus and its tributaries in short hair sheep, this descriptive cross-sectional study evaluated the coronary sinus and its tributaries in 62 hearts of short hair sheep. A semi-synthetic resin (Palatal GP40L 85%; styrene 15%) impregnated with mineral color blue was perfused through the coronary sinus. We evaluated the morphological characteristics and with a digital calibrator the biometrics of the coronary sinus and its tributaries. The length of the coronary sinus (± standard deviation) was 24.85 ± 4.94 mm. Proximal and distal calibers were 7.55 ± 1.54 mm, respectively. It was cylindrical in shape in 44 specimens (71%). The great cardiac vein originated at the apex in 44 hearts (71%), with the caliber of this vessel at the level of the paraconal interventricular sulcus being 2.55 ± 0.62 mm. The arteriovenous trigone was present in 50 specimens (80.6%) and presented a closed configuration at its lower and upper segments in 39 specimens (78%). The left marginal vein was present in 56 hearts (90.3%) and originated at the cardiac apex in 33 specimens (53.2%). The proximal and distal calibers of the middle cardiac vein were 1.74 ± 0.52 mm and 2.17 mm ± 0.71 mm respectively, and originated at the apex in 91.9% of the specimens. Due to the similitude of the features of the coronary sinus in short hair sheep with those of the human being, it is possible to propose this animal model for procedural and hemodynamic applied activities.

Key words

Sheep, heart, coronary sinus, arteriovenous trigone.

Introduction

The coronary sinus is located on the atrial surface of the heart; it drains into the right atrium, near the superior cava vein. The coronary sinus receives drainage from the great cardiac vein, the left marginal vein and - in sheep and pigs - the left azygos vein, whereas in humans the azygos vein drains into the superior vena cava (Nickel et al., 1981, 1987; Tipirdamaz, 1987; Tipirdamaz et al., 1993; Besoluk and Tipirdamaz, 2001; Aksoy et al., 2009), the middle cardiac vein also drains into the coronary sinus in the goat.

The length of the coronary sinus in adult sheep (2.5-2.8 cm) is similar to that of humans, pigs and goats (Hegazi, 1958, 1975; Getty, 1975; Besoluk and Tipirdamaz, 2001). The caliber of this venous structure in the pig is considerably larger than

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reported in humans (El-Maasarany et al., 2005; Lee et al., 2006; Ballesteros et al., 2010; Gomez et al., 2015b).

The great cardiac vein originates at the cardiac apex and anastomoses with branches of the middle cardiac vein in humans, sheep and pigs (Hegazi, 1958; May, 1964; Aksoy et al., 2009; El-Maasarany et al., 2005; Lee et al., 2006; Ballesteros et al., 2010; Gomez et al., 2015a). It ascends inside the paraconal interventricular sulcus, then crosses to the left until it reaches the left atrioventricular sulcus forming the base of the arteriovenous trigone of the heart together with the paraconal interventricular branch and the left circumflex branch of the left coronary artery. (McKibben and Christensen, 1964; Nickel et al., 1981; Besoluk and Tipirdamaz, 2001; Aksoy et al., 2009; El-Maasarany et al., 2005; Lee et al., 2006; Ballesteros et al., 2010; Gomez et al., 2015a). In the coronary sulcus, the great cardiac vein gives origin to the coronary sinus at the drainage point of the left azygos vein into the sinus (May 1964; Getty, 1975; Hassa, 1977; Aksoy et al., 2009). The configuration of the arteriovenous trigone of the heart has been based on whether the great cardiac vein crosses or not over the paraconal interventricular branch and the left circumflex branch, which determines closed trigones when the crossing exists or open trigones when the vein does not cross over these arterial branches. An arteriovenous trigone open at its lower segment and closed at its upper segment occurs in 50-73% of humans and pigs (Ortale et al., 2001; Kaczmarek and Czerwinski, 2007; Ballesteros et al., 2010; Gomez et al., 2015a).

The middle cardiac vein originates at the cardiac apex and ascends through the subsinusal interventricular sulcus together with the subsinusal interventricular branch of the left coronary artery, and ends in the coronary sinus (Hegazi, 1958; Getty, 1975; Dursun, 1994; Aksoy et al., 2009; Besoluk and Tipirdamaz, 2001). At the cardiac apex, this vessel anastomoses with the great cardiac vein (Hegazi, 1958) or with branches of the left marginal vein (Nickel et al., 1981). In humans and pigs, the middle cardiac vein also originates at the apex, and drains into the coronary sinus (Schaffler et al., 2000; Ortale et al., 2001; Gomez et al., 2015b).

The left marginal vein originates near the apex of the left ventricle, and runs toward the base of the heart along its caudal edge. When it reaches the coronary sulcus, the left marginal vein crosses over the left circumflex branch of the left coronary artery, and opens into the coronary sinus at the union of the left azygos vein with the coronary sinus (Nickel et al., 1981; Besoluk and Tipirdamaz, 2001; Aksoy et al., 2009). This vessel opens mostly into the coronary sinus in sheep and pigs, but into the great cardiac vein in humans and goats (Hegazi 1958; Yadm and Gad, 1992; Pejkovic and Bogdanovic, 1992; Ortale et al., 2001; Aksoy et al., 2009; Ballesteros et al., 2010; Gomez et al., 2015a).

The small cardiac vein drains myocardial blood from the sharp edge and the posterior wall of the right atrium, and ends at the pectineus muscles of the right atrium or into the coronary sinus (McKibben, 1964; Aksoy et al., 2009). It does not occur in sheep, but occurs in goats (Besoluk and Tipirdamaz, 2001).

The importance of characterizing the coronary sinus and its tributaries in short hair sheep resides in its contribution to comparative anatomy teaching and learning processes, and in the use of this species as an experimental model for cardiovascular surgery and hemodynamic pathophysiological applications. This research intends to improve our knowledge basis on the anatomical and morphometric characteristics of the coronary sinus and its tributaries through the evaluation of specimens of short hair sheep. At the same time, within a context of comparative anatomy of the coronary sinus in humans, pigs and short hair sheep, it intends to establish similarities and differences of this vascular structure.

Materials and methods

This descriptive cross-sectional study assessed the coronary sinus and its tributaries in 62 hearts of short hair sheep destined to slaughter with an average age of 5 months, obtained from the Frigorífico Caprinos Alvarez in Bucaramanga, Colombia. The organs were subjected to an exsanguination process in a water source for 6 hours. An arc-shaped fold with silk 2.0 was made around the orifice of the coronary sinus and a No. 14 catheter was inserted to perfuse the organ with a semisynthetic polyester resin consisting of a mixture of Palatal GP40L 85% and styrene 15% impregnated with mineral blue (Heliogen®, BASF, Ludwigshafen, Germany).

Subsequently, the hearts were subjected to a partial corrosion process with potassium hydroxide 15% to remove the subepicardial fat situated in the paraconal, subsinusal, and coronary sulci. Then the coronary sinus and its tributaries were dissected from their origin to their distal segments, recording their trajectories and anastomoses. An electronic caliper (Mitutoyo®) was used to measure the external diameter of these vessels at the middle segment and at 0.5 cm from their drainage points.

The shape of the coronary sinus was categorized as cylindrical when both proximal and distal calibers were similar, and funnel-like when the distal caliber was considerably larger than the proximal caliber. The caliber of the great cardiac vein was measured at its upper paraconal, interventricular and atrioventricular segments. The tributaries of the great cardiac vein were measured at their middle and distal segments, determining the presence of anastomoses of the great cardiac vein with other venous branches. The configuration of the arteriovenous trigone of the heart was determined by the relationship of the great cardiac vein with the branches of the left coronary artery, the paraconal interventricular branch and the left circumflex branch, and was categorized according to the criteria of Pejkovic and Bogdanovic (1992) as follows: open at its lower segment and closed at its upper segment; open at both lower and upper segments; closed at both its lower and upper segments; closed at its lower segment and open at its upper segment. We used the Nomina Anatomica Veterinaria of 2012 as a reference of the accepted international terminology.

The data were recorded in a physical matrix and were subsequently recorded in digital medium using an Excel table. All the specimens analyzed were photographed. The continuous variables were analyzed using Student´s t test, whereas the discrete variables were analyzed using Pearson's Chi^2 test. The results were evaluated using the statistical program "Epi - Info 3.5.4". The results are given as mean ± standard deviation; the level of significance was set at $p < 0.05$.

Results

Sixty-two hearts were evaluated, which had average weight of 187.1 ± 68.1 grams. The length of the coronary sinus was 24.85 ± 4.94 mm. The proximal and distal calibers were 7.55 ± 1.54 mm and 8.46 ± 2.3 mm, respectively. A cylindrical shape was found in 44 specimens (71%) and a funnel-like shape in 18 hearts (29%). All of the specimens lacked a valve at the orifice of the coronary sinus.

The great cardiac vein originated at the apex in 44 hearts (71%) and at the lower third of the paraconal interventricular sulcus in 18 specimens (29%). The caliber of the great cardiac vein at the paraconal interventricular sulcus was 2.55 ± 0.62 mm. and at the left atrioventricular sulcus it was 3.65 ± 0.85 mm. The great cardiac vein received on average the drainage of 2.6 anterior right ventricular branches and four posterior left ventricular branches. An anastomosis between the great cardiac vein and the middle cardiac vein was found in 44 specimens (71%). The left posterior veins had a caliber of 1.14 ± 0.47 mm, and in 22.6% of the cases they drained into the great cardiac vein, and in 77.4% into the coronary sinus.

The arteriovenous trigone was present in 50 specimens (80.6%) and had a closed configuration at its lower and upper segments in 39 specimens (78%); open at the lower segment and closed at the upper segment in 9 cases (18%); open at both lower and upper segments in 1 heart (2%) and closed at its bottom segment and open at its upper segment in 1 specimen (2%).

The left marginal vein was observed in 56 hearts (90.3%). It had its origin at the cardiac apex in 33 specimens (53.2%), at the lower third of the obtuse edge of the heart (33.9%; $p<0.05$ vs. origin at the apex), and at the middle third in 8 hearts

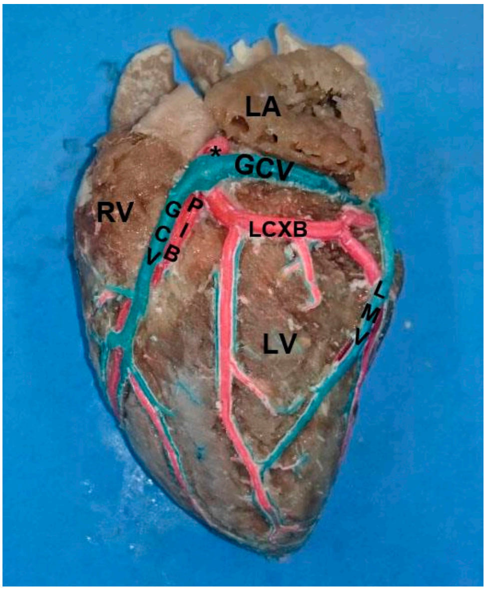

Figure 1. Left surface of the heart. LA: left atrium. LV: left ventricle. RV: right ventricle. GCV: great cardiac vein. PIB: paraconal interventricular branch. LCXB: left circumflex branch. LMV: left marginal vein. (*): arteriovenous triangle, closed at the lower end and top.

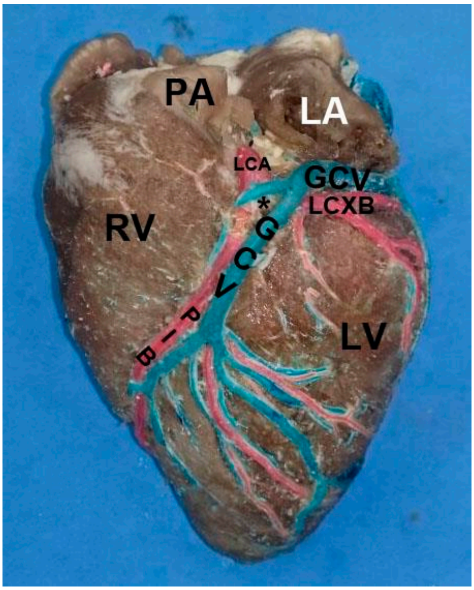

Figure 2. Left surface of the heart. LA: left atrium. LV: left ventricle. RV: right ventricle. PA: pulmonary artery. GCV: great cardiac vein. LCA: left coronary artery. PIB: paraconal interventricular branch. LCXB: left circumflex branch. (*): arteriovenous triangle, open at the lower end and closed at the top.

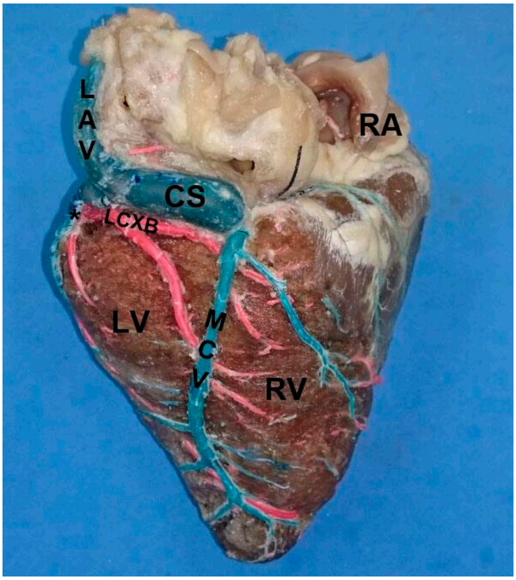

Figure 3. Right surface of the heart. RA: right atrium. RV: right ventricle. LV: left ventricule. LAV: left azygos vein. CS: cylindrical coronary sinus. MCV: middle cardiac vein. (*): left marginal vein. LCXB: left circumflex branch.

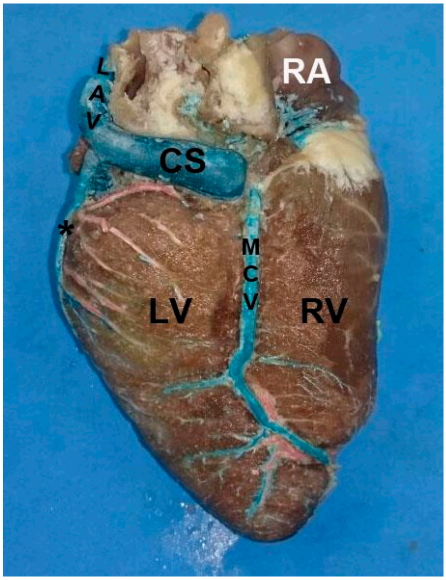

Figure 4. Right surface of the heart. RA: right atrium. RV: right ventricle. LV: left ventricule. LAV: left azygos vein. CS: funnel-like coronary sinus. MCV: middle cardiac vein. LMV: left marginal vein.

(12.9%). The left marginal vein drained into the distal segment of the great cardiac vein in 43 specimens (69.4%) and into the proximal segment of the coronary sinus (25.8%) in 16 hearts; in 3 cases, it drained into the mid surface of the coronary sinus (4.8%). The mean caliber of the left marginal vein was 1.91 ± 0.63 mm, and its distal caliber was of 2.29 ± 0.66 mm.

The middle cardiac vein originated at the apex in 91.9% of the specimens; its caliber at its proximal and distal segments was 1.74 ± 0.52 mm and 2.17 mm ± 0.71 mm, respectively. In all the specimens evaluated the middle cardiac vein drained into the posterior-inferior surface of the drain orifice of the coronary sinus into the right atrium. Anastomoses of the middle cardiac vein with different venous vessels were found in 44 specimens (71%), 28 (64%) of which were with the great cardiac vein and 16 (36%) with the great cardiac vein and the left marginal vein.

The small cardiac vein less had a caliber of 1.34 ± 0.08 mm. In 66.7% of the cases it drained into the coronary sinus and in 33.3% into the right atrium. The right marginal vein drained directly into the right atrium in 41 specimens (66.1%), whereas it gave origin to the great cardiac vein in 21 specimens (33.9%). The proximal and distal calibers of the to the right marginal vein were 0.97 ± 0.16 mm and 1.3 ± 0.69 mm, respectively. The left azygos vein had a caliber of 6.28 ± 1.43 mm at its drainage point into the coronary sinus.

Discussion

Previous reports of Besoluk and Tipirdamaz (2001) and Aksoy et al. (2009) from studies in sheep and goats point to the coronary sinus as a continuation of the left azygos vein, while Yadm and Gad (1992), in line with our findings, describe the coronary sinus as the cranial continuation of the great cardiac vein, an anatomical feature that has also been reported in pigs (Gomez et al., 2015b). In humans, the coronary sinus is considered as a continuation of the great cardiac vein because the azygos vein drains into the superior cava vein (Ortale et al., 2001; Ballesteros et al., 2010). The morphometric characteristics of the coronary sinus and its tributaries have not been described in sheep and goats; the studies that have addressed this issue have only made qualitative descriptions of these vascular structures. The length of the coronary sinus found in our study (24.8 mm) is slightly shorter than what has been described in humans and pigs, whereas the proximal and distal calibers (7.55 and 8.46 mm) are considerably smaller than what has been reported for humans and pigs (Schaffler et al., 2000; Ortale et al., 2001; Ballesteros et al., 2010; Gomez et al., 2015b). The cylindrical shape of the coronary sinus with similar proximal and distal calibers observed as the most common in our series coincides with what has been reported in humans and pigs (Ballesteros et al., 2010; Gomez et al., 2015b).

The great cardiac vein originating in most cases at the cardiac apex, as reported in humans and pigs, is consistent with our findings, but while the frequency in our series is of 71%, similar to what has been observed in pigs (76%), a range of 27-57.4% has been reported for humans (Schaffler et al., 2000; El-Maasarany et al., 2005; Christiaens et al., 2008; Ballesteros et al., 2010; Gomez et al., 2015a). The caliber of the great cardiac vein at the paraconal interventricular sulcus and its distal segment (2.55 and 3.65 mm, respectively) is substantially smaller than what has been reported for humans and pigs (Ortale et al., 2001; El-Maasarany et al., 2005; Ballesteros et al., 2010; Gomez et al., 2015).

The frequency of anastomoses between the great cardiac vein and the middle cardiac vein at the cardiac apex (71%) observed in the present study is substantially higher than what has been reported for humans (15-34%) and pigs (49%) (Pejkovic and Bogdanovic, 1992; Ortale et al., 2001; Ballesteros et al., 2010; Gomez et al., 2015a). Besoluk and Tipirdamaz (2001) have stated that the great cardiac vein is anastomosed with the middle cardiac vein in sheep and goats, but failed to state the frequency of occurrence. This anatomical expression is considered as protective in certain pathophysiological conditions because it allows to reduce the occurrence of cardiovascular disease by providing alternative routes of venous drainage (Ballesteros et al., 2010). The number of right ventricular branches (2.6) and left ventricular branches (4) that drain into the great cardiac vein observed in this series is lower than what has been reported for pigs (Gómez et al., 2015a). The great cardiac vein draining into the coronary sinus, as found in the present study, is consistent with most reports from studies on sheep and goats (Bhargava and Beaver, 1970;Dursun, 1994; Besoluk and Tipirdamaz, 2001; Aksoy et al., 2009). A similar situation has been reported for humans and pigs (Ballesteros et al., 2010; Gomez et al., 2015a). It should be noted that some studies report the great cardiac vein draining into the right atrium (Hegazi, 1958; May, 1964; Hassa 1977).

The frequency of drainage of the left posterior veins into the great cardiac vein (22.6%) is significantly lower to what has been reported for humans (28-35%) and pigs

(42%). The average caliber of these vessels observed in this series (1.14 mm) is smaller than what has been reported for humans and pigs (1.4-1.61 mm) (Pejkovic and Bogdanovic, 1992; Ortale et al., 2001; Liu et al., 2003; Gomez et al., 2015a). These small calibers could limit the use of intracoronary catheters to access the left ventricle intravenously in this animal species, because the diameter of the device is 1.1 mm. Interventional cardiologists consider that the minimum diameter of these vessels for a proper manipulation should be no less than 1.3 mm (Liu et al., 2003; Melo et al., 1998).

The presence of the arteriovenous trigone in 80.6% of the specimens in our research is consistent with some studies in humans reporting its presence between 59 and 80% of the cases (Pejkovic and Bogdanovic, 1992; Schaffler et al., 2000; Ortale et al., 2001; Kaczmarek and Czerwinski, 2007; Ballesteros et al., 2010) and this incidence is lower than what has been reported for pigs (97.5%: Gómez et al., 2015a). Additionally, our findings diverge from reports from studies with hearts of humans and pigs that point to an open aspect at the lower segment and a closed one at the upper segment as the most common for the arteriovenous trigone (Ortale et al., 2001; Kaczmarek and Czerwinski, 2007; Ballesteros et al., 2010; Gomez et al., 2015a). In our series, we observed the aspect closed at both upper and lower segments to have the highest incidence (78%).

The frequency and the caliber of the left marginal vein in our study (90.3% and 2.29 mm, respectively) are slightly lower than what has been reported in previous studies in humans and pigs (Pejkovic and Bogdanovic, 1992; Ortale et al., 2001; Christiaens et al., 2008; Ballesteros et al., 2010; Gomez et al., 2015b). In this work, we observed the left marginal vein originating mainly at the apex (53.2%), which is consistent with what was reported by Tipirdamaz and Besoluk (2001) for sheep, and by Gomez et al. (2015b) for pigs but with a smaller percentage of occurrence (46%). In humans, the origin of this vessel has been reported more frequently at the middle third of the obtuse edge of the heart (Ballesteros et al., 2010). The prevalent drainage of the left marginal vein into the great cardiac vein observed in this work is consistent with what has been reported in previous studies in sheep (Nickel et al., 1981; Besoluk and Tipirdamaz, 2001), but other authors dispute these findings and indicate that this vessel drains mainly into the great cardiac vein (Hegazi, 1958; Yadm and Gad, 1992; Aksoy et al., 2009). The frequency of the left marginal vein draining into the coronary sinus observed in this study was 30.6%, whereas it has been reported within a range of 5% to 19% in humans (Pejkovic and Bogdanovic, 1992; Ortale et al., 2001; Ballesteros et al., 2010) and 2.5% in pigs (Gomez et al., 2015b).

The highest incidence reported for humans concerning the origin of the middle cardiac vein was the cardiac apex (Schaffler et al., 2000; Mao et al., 2005), consistent with our findings (91.9%) and with what has been reported for pigs (Gomez et al., 2015b).

The middle cardiac vein draining at the posterior-inferior segment of the orifice of the coronary sinus in 100% of the specimens found in our research is consistent with the vast majority of the previous reports from studies in sheep (Bhargava and Beaver, 1970; Dursun, 1994; Besoluk and Tipirdamaz, 2001; Aksoy et al., 2009), pigs (Crick et al., 1998; Gomez et al., 2015b), and humans (Pejkovic and Bogdanovic, 1992; Nerantzis et al., 1998; Ballesteros et al., 2010). In sheep, some authors indicate that the middle cardiac vein drains directly into the right atrium (Hegazi, 1958; May, 1964; Hassa, 1977), while in humans this trait has been reported within a range of 15% to 20% (Pejkovic and Bogdanovic, 1992; Nerantzis et al., 1998). The anastomoses between the middle cardiac vein and the great cardiac vein or the left marginal vein at the cardiac apex observed in our series (71%), are considerably more common than those described in human (15-34%) and pig heart (63%) (Pejkovic and Bogdanovic, 1992; Ortale et al., 2001; Kaczmarek and Czerwinski, 2007; Ballesteros et al., 2010).

The occurrence of the small cardiac vein draining into the coronary sinus observed in this work in 66.7% of the cases is consistent with what has been reported for humans and pigs (Cendrowska-Pinkosz and Urbanowicz, 2000; Ballesteros et al., 2010; Gomez et al., 2015b), whereas previous studies in sheep have reported this vessel draining into the right atrium (Hegazi, 1958; May 1964; Besoluk, and Tipirdamaz, 2001). The left azygos vein is described in ruminants as draining into the coronary sinus, as occurs in pigs, but in humans this vessel drains into the superior vena cava (Nickel et al., 1981; Besoluk and Tipirdamaz, 2001; Ortale et al., 2001; Aksoy et al., 2009; Ballesteros et al., 2010; Gomez et al., 2015b). The caliber of the left azygos vein found in this study (6.28 mm) is smaller than what has been reported for pigs (Gomez et al., 2015b).

Previous studies in humans, sheep and pigs have characterized poorly the right marginal vein, with very fragmentary descriptions (Pejkovic and Bogdanovic, 1992; Crick et al., 1998; Besoluk and Tipirdamaz, 2001; Ortale et al., 2001; Ballesteros et al., 2010). Most studies with sheep indicate that this vessel drains into the coronary sinus (Nickel et al., 1981; Dursun, 1994; Besoluk and Tipirdamaz, 2001; Aksoy et al., 2009), while the researches conducted by Hegazi (1958), Ortale et al. (2001), Ballesteros et al. (2010) and Gomez et al. (2015b) in sheep, pigs and humans coincide with our research in assessing the right atrium as the most frequent site of drainage of the right marginal vein. The distal caliber (1.3 mm) of this vascular structure observed in our series is smaller than what has been reported for humans and pigs (Ortale et al., 2001; Ballesteros et al., 2010; Gomez et al., 2015b).

In humans, an adequate knowledge of the coronary sinus is necessary to meet the surgical and electrophysiological demands of cardiovascular diseases. Different procedures, such as retrograde perfusion through a cannula for myocardial preservation and the placement of electrical resynchronization and cardioversion devices with transvenous electrodes, require a rigorous training initially with animal models (El-Maasarany et al., 2005; Lee et al., 2006). Therefore, the morphological similarity between the coronary sinus and its tributaries in humans and short hair sheep allows us to propose this species as an experimental and procedural model for humans.

Conclusions

A higher frequency of anastomoses was observed at the cardiac apex between the middle cardiac vein and the great cardiac vein and the left marginal vein than described in studies conducted in humans and pigs.

The length and the predominantly cylindrical shape of the coronary sinus are consistent with previous studies conducted in humans and pigs, while its caliber is larger in pigs and sheep that in humans due to the drainage of the left azygos vein into the coronary sinus.

The qualitative and morphometric findings of the left marginal vein, the right marginal vein and the cardiac vein, not described in previous work, enrich the context of comparative anatomy.

Because of the similar morphological characteristics of the coronary sinus and its tributaries between short hair sheep and humans, this animal model is postulated for hemodynamic and procedural applications.

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