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Anatomical Study of the Cardiac Veins and their Tributaries in Bovines (*Bos indicus*) in Comparison with Humans and Other Animal Species

Estudio Anatómico de las Venas Cardiacas y sus Tributarias en Bovinos (*Bos indicus*) en Comparación con Humanos y Otras Especies Animales

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SUMMARY: In bovines, anatomical observations of the coronary vascular tree describe qualitative characteristics. The objective of this study was to morphometrically characterize the coronary veins and their tributaries in cattle. An arcuate application with 2.0 silk was performed around the ostium of the coronary sinus of 28 bovine hearts and a number 14 catheter was placed, through which semi-synthetic polyester resin and mineral blue color was perfused. In 22 hearts (78.6 %) the great cardiac vein was originated at the cardiac apex. The configuration of the arteriovenous trigone was mainly closed inferior and superior types (50 %). The caliber of the great cardiac vein at the level of the atrioventricular sulcus was 6.7 +/- 1.2 mm. The origin of the left marginal vein was observed in the lower third of the left cardiac margin (53.6 %), its distal caliber was 4.1 +/- 0.8 mm and its drainage was at the level of the great cardiac vein. The middle cardiac vein originated from the cardiac apex in 78.6 % of the samples, emptied mainly into the coronary sinus (82.1 %) and its distal caliber was 4.7 +/- 0.9 mm. Anastomoses occurred in 28.6 % of the hearts, being found in most cases between the middle cardiac vein and the great cardiac vein (50 %), which was significant compared to other anastomoses ($p<0.001$). The length of the coronary sinus was 42.2 +/- 5.1 mm, its distal caliber was 13.8 +/- 2 mm, and its shape was cylindrical. Myocardial bridges were found in 3 hearts (10.7 %) mainly in the lower third of the middle cardiac vein (66.6 %). Most of the main coronary veins drained into the coronary sinus, with some cases with atypical outlets and the presence of a high percentage of anastomosis that serves to improve cardiac venous drainage in case of venous compression or obstruction.

KEY WORDS: Bovine; Coronary veins; Coronary sinus; Great cardiac vein; Arteriovenous trigone.

INTRODUCTION

Coronary circulation has been widely studied in humans and different animal species, but it has mainly focused on the study of the arteries of the heart. Few studies have characterized venous drainage in animals (Besoluk & Tipirdamaz, 2001; Aksoy *et al*., 2009; Gómez *et al*., 2015a; Gómez *et al*., 2018; Barszcz *et al*., 2020).

The coronary sinus (CS) empties into the right atrial surface of the heart between the orifice of the caudal vena cava (inferior vena cava in humans), the foramen ovale, and the right atrioventricular orifice. The coronary sinus receives drainage from the great cardiac vein (GCV), the left marginal vein (LMV) and, in sheep, goats and pigs, the left azygos vein, while in humans the azygos vein drains into the superior vena cava. The middle cardiac vein (mCV) also drains into the coronary sinus (Nickel *et al*., 1981; Tipirdamaz, 1987; Besoluk & Tipirdamaz, 2001; Ortale *et al*., 2001; Aksoy *et al*., 2009; Gómez *et al*., 2015a; Gómez *et al*., 2018).

In humans, the shape of the CS is described as cylindrical, flattened or funnel-shaped (Lee *et al*., 2006; Ballesteros *et al*., 2010). A cylindrical and funnel shape has been described in sheep (Genain *et al*., 2018; Gómez *et al*., 2018), as well as in pigs (Gómez *et al*., 2015a).

In the European bison, pigs, humans, sheep, and dogs, it has been described that the GCV originates in the cardiac apex and together with the paraconal interventricular branch

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(anterior in humans) and the left circumflex branch, they form the arteriovenous trigone (AVT). (Ballesteros *et al*., 2010; Gómez *et al*., 2015b; Genain *et al*., 2018; Gómez *et al*., 2018; Barszcz *et al*., 2020).

In sheep, the LMV originates in the cardiac apex and there is controversy between the termination of this vessel in the CS or in the distal end of the GCV (Besoluk & Tipirdamaz, 2001; Gómez *et al*., 2018). In the European bison and humans, LMV originates in the middle third of the left ventricular margin and empties into the GCV (Ballesteros *et al*., 2010; Barszcz *et al*., 2020). In pigs, this vessel originated at the cardiac apex and drained at the distal end of the GCV (Gómez *et al*., 2015b).

In humans and pigs, the mCV originates at the apex, ascends through the posterior interventricular sulcus (subsinus in animals) and empties into the CS (Ballesteros *et al*., 2010; Gómez *et al*., 2015a; Genain *et al*., 2018). In sheep and goats, it is debated which is the main site of origin of this vessel, between the apex and the lower third of the subsinus interventricular sulcus (SIS), but its drainage was always observed in the CS (Besoluk & Tipirdamaz, 2001; Aksoy *et al*., 2009; Genain *et al*., 2018; Gómez *et al*., 2018). In dogs, it has been described that the drainage of the mCV is in the CS (Genain *et al*., 2018).

The study aim was to describe the bovine cardiac venous system by injecting blood vessels with polyester resin, and indicating its morphology, morphometric description and the distribution of vascular patterns within a context of comparative anatomy and finally contrasting the findings with the descriptions of these veins in humans and other animal species.

MATERIAL AND METHOD

This is a cross-sectional descriptive study that evaluated the cardiac veins of 28 bovine hearts ethically obtained from animals destined for sacrifice at the Minerva Foods slaughterhouse in the city of Bucaramanga - Colombia, with an average age of 24 to 30 months and a weight between 450 and 500 kilos. The procedures were in accordance with the Ethics Committee of the Industrial University of Santander (N° 013-2023) and comply with Law 84 of 1989 of national scope, corresponding to Chapter VI of the "National Statute for the Protection of Animals", on the use of animals in experiments and research.

The hearts were frozen once they were received to maintain an excellent state of conservation. After performing the procedure, the hearts were left in a container with water for six hours to thaw and exsanguinate. Around the CS orifice, arcuate suture was performed with 2.0 silk and a number 14 catheter was installed to perfuse the semi-synthetic polyester resin, which was composed of a mixture of 85 % palatal GP40L with 15 % styrene and blue mineral color.

After obtaining the resin setting, 15 % Potassium Hydroxide (KOH) was injected into the subepicardial fat, to carry out a partial corrosion process of the fat.

The next process was to dissect the cardiac veins and their tributaries from their origin to their distal segments, recording their trajectories, shapes, calibers, anastomoses and presence of anatomical variations. The external diameter of these vessels was measured 0.5 cm from their respective origins and at their site of drainage with a digital caliper (Mitutoyo®).

To register the observations, digital photographs were taken of each cardiac specimen and the findings were saved in an Microsof® Excel® spreadsheet file.

The presence of myocardial bridges (MB) was evaluated in each cardiac vein and its tributaries. The evaluation of these MBs was adapted from the criteria described by Kosinski *et al.* (2010), for coronary arteries and were type I when they were in a single vein, type II when two MBs were observed in the same vein, and type III when they were found two or more MB in different veins.

Statistical analysis. Descriptive statistics and hypothesis testing were performed using SPSS 20 software (SPSS, Chicago, IL, USA) and Microsoft® Excel® 2013. The level of significance for the statistical test was $p<0.05$. Continuous variables were expressed as mean and 95 % confidence interval. Descriptive statistics were calculated for each morphometric parameter and the Kolmogorov-Smirnov normality test was performed for each sample. Data were expressed as mean and standard deviation (SD) for all measured lengths. The chi-square test was used to compare dichotomous qualitative variables, such as anastomosis and its variations. For quantitative variables, when comparing two independent groups, the Student test was used. In the case of quantitative variables that follow a normal distribution for different groups, the ANOVA test was used.

RESULTS

Twenty-eight bovine hearts weighing 1501.2 + 284.6 grams were evaluated. The CS had a length of 42.2 + 5.1 mm, its proximal and distal caliber were 12.5 + 2.2 mm and 13.8 + 2 mm respectively. This structure had a cylindrical shape in 16 hearts (57.1 %), a funnel shape in 9 samples

(32.1 %), and a flattened shape in 3 specimens (10.8 %). No heart had a valve in the exit orifice of the CS (Figs. 1 and 4b). The caliber of the left azygos vein was 10.3 + 1.7 mm and apparently the CS was the continuation of this vein in bovines (Fig. 1).

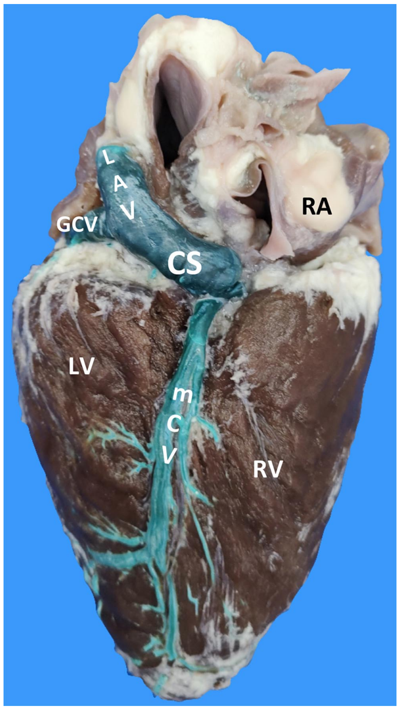

Fig. 1. Right surface of the heart. LAV: left azygos vein; CS: coronary sinus; mCV: middle cardiac vein; GCV: great cardiac vein; RA: right atrium; LV: left ventricle; RV: right ventricle.

We observed that the origin of the GCV was in the cardiac apex in 22 hearts (78.6 %) and in the lower third of the paraconal interventricular sulcus (PIS) in 6 samples (21.4 %). The caliber of this vessel in the PIS was 4 + 0.5 mm, in the left atrioventricular sulcus it was 6.7 + 1.2 mm and its distal caliber at the mouth site in the CS was 7.5 + 0.9 mm. The GCV received on average 4 right anterior ventricular tributaries, 6 left anterior ventricular tributaries, and 2 left posterior ventricular tributaries (Fig. 2).

We found the presence of the arteriovenous trigone (AVT) in 18 hearts (64.3 %). Its arrangement was closed at both upper and lower segments in 9 specimens (50 %) (Fig. 2a), open lower and closed upper in 5 samples (27.8 %) (Fig. 2b), open at both upper and lower segments in 2 hearts (11.1 %) (Fig. 3a) and open upper and closed lower in 2 specimens (11.1 %) (Fig. 3b).

LMV was observed in 26 hearts (92.9 %) and originated in the lower third of the left cardiac margin in 15 hearts (53.6 %), in the cardiac apex in 10 specimens (35.7 %) and in the middle third in 3 cases (10.7 %). This vessel had a large caliber, which in the middle third was 3.4 + 0.7 mm and in the upper third 4.1 + 0.8 mm. It drained into the distal end of the GCV in 20 hearts (76.9 %), at the beginning of the CS in 5 specimens (19.3 %), and into the CS in 1 specimen (3.8 %) (Fig. 4). There were no significant differences in the distal caliber of the LMV in each of the mouths of this vein (p=0.092).

The origin of the mCV was mainly observed in the cardiac apex in 22 hearts (78.6 %) and in 6 specimens (21.4 %) it originated in the lower third of the SIS. The proximal and distal caliber of this vein were 3.4 + 0.6 mm and 4.7 + 0.9 mm respectively. The mCV drained into the CS in 20 samples (82.1 %) and directly into the right atrium in 5 hearts (17.9 %) (Figs. 1 and 4b).

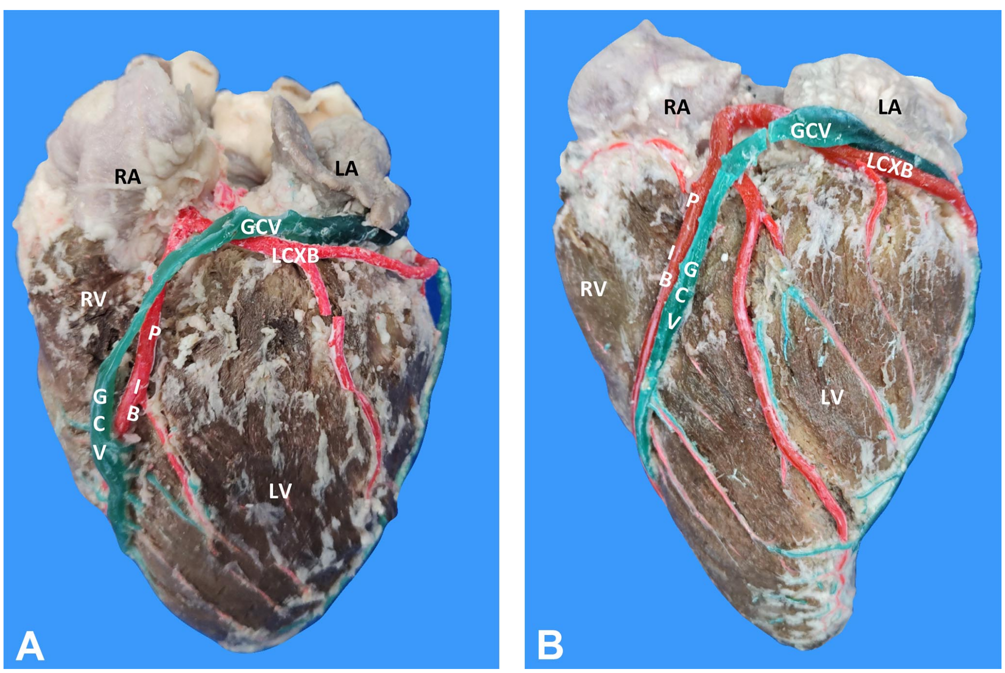

Fig. 2. Left surface of the heart. Closed configuration of the arteriovenous trigone in the upper and lower segments (A) and open in the lower segment and closed in the upper segment (B). GCV: great cardiac vein; PIB: paraconal interventricular branch; LCXB: left circumflex branch; RA: right atrium; LA: left atrium: RV: right ventricle; LV: left ventricle.

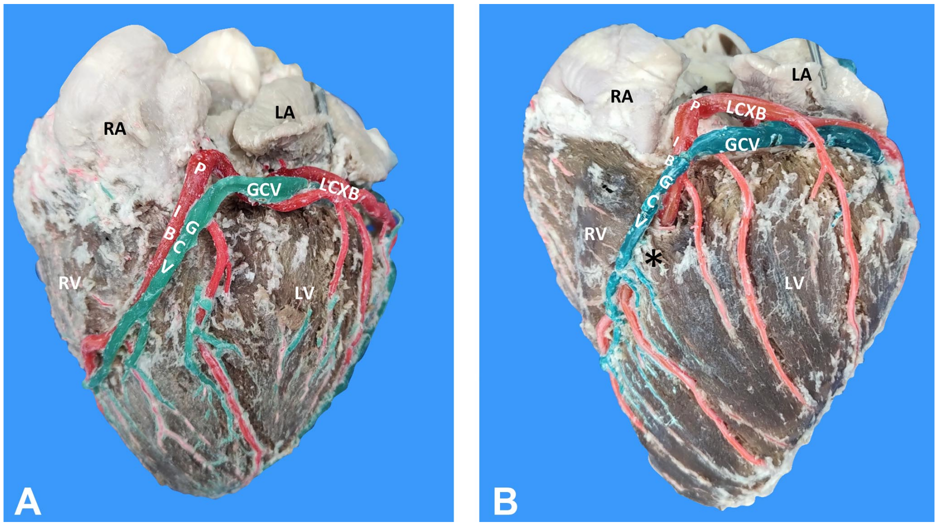

Fig. 3. Left surface of the heart. Open configuration of the arteriovenous trigone in the upper and lower segments (a) and closed in the lower segment and open in the upper segment (b). GCV: great cardiac vein; PIB: paraconal interventricular branch; LCXB: left circumflex branch; RA: right atrium; LA: left atrium: RV: right ventricle; LV: left ventricle. Note the presence of a myocardial bridge over the PIB (*).

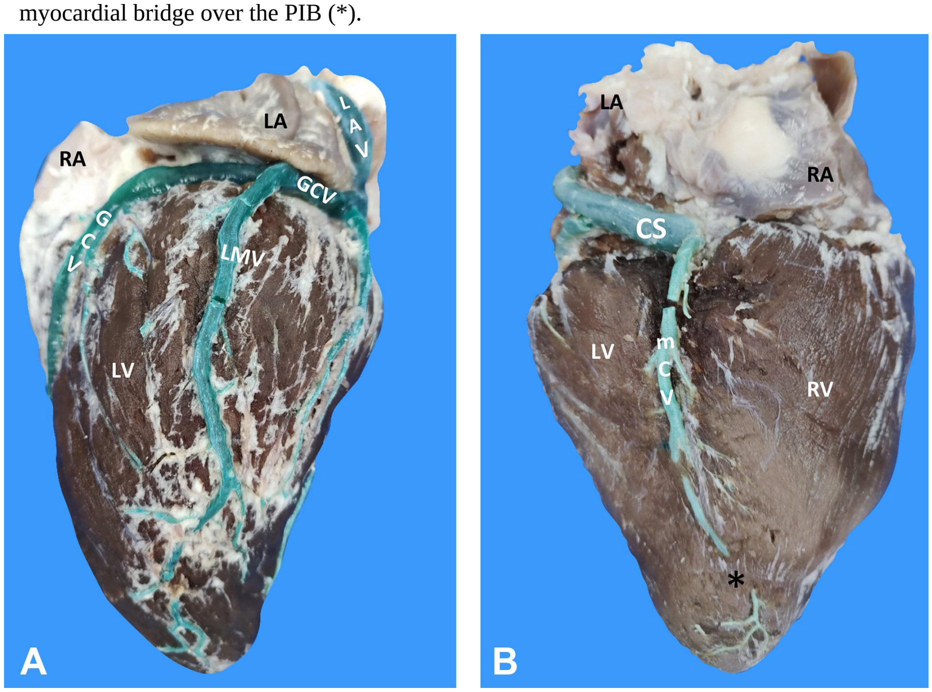

Fig. 4. Left lateral view of the heart (a) and right surface of the heart (b). Note in (b) the myocardial bridge (*) in the lower third of the middle cardiac vein (mCV). GCV: great cardiac vein; LMV: left marginal vein; LAV: left azygos vein; CS: coronary sinus; RA: right atrium; LA: left atrium: RV: right ventricle; LV: left ventricle.

The presence of MB was found in 3 hearts (10.7 %). In 2 specimens (66.7 %) it was observed over the lower third of the mCV (Fig. 5) and in 1 case (33.3 %) in the middle third of the LMV. The average length of these MB was 20.1 + 8.1 mm.

In 8 hearts (28.6 %), anastomosis was observed between the different cardiac veins. In all the anastomoses found, the mCV was involved. In 4 cases (50 %) the anastomosis was observed between the mCV and the GCV (Fig. 4b), in 2 hearts (25 %) between the mCV and the LMV, in 1 specimen (12.5 %) between the mCV and a right anterior ventricular tributary and lastly in one sample (12.5 %) there was a double anastomosis between the mCV, the GCV and the LMV.

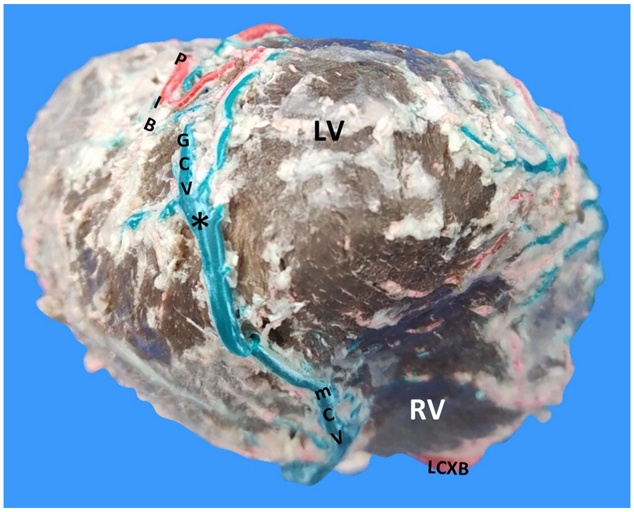

Fig. 5. Anastomosis between the tributaries of the middle cardiac vein (mCV) and the great cardiac vein (GCV) at the cardiac apex (*). PIB: paraconal interventricular branch; LCXB: left circumflex branch; RV: right ventricle; LV: left ventricle.

DISCUSSION

The study of cardiac veins in bovines allows the generation of new knowledge on the coronary irrigation of this animal species and considers it for use as an animal model in human medicine.

The cylindrical shape of the CS found mainly in our study coincides with what has been described in humans, sheep, pigs and dogs (Ballesteros *et al*., 2010; Gómez *et al*., 2015a; Genain *et al*., 2018; Gómez *et al*., 2018). The caliber of this structure at the level of the coronary ostium in this study and in previous reports from other species is recorded in Table I. Also the length of the CS (42.2 mm) in the bovines was greater in our study than reported in humans (25.9 mm), sheep (24.9 - 35.1 mm), pigs (26.9 - 42 mm) and dogs (32.1 mm) (Ballesteros *et al*., 2010; Gómez *et al*., 2015a; Genain *et al*., 2018; Gómez *et al*., 2018). In imaging procedures in humans, the CS is an important anatomical reference, but in healthy patients it is rarely observed in echocardiographic studies. In people with mitral insufficiency, pulmonary hypertension and left ventricular hypertrophy this structure is observed to be elongated and dilated (Kato *et al*., 1987; Schaffler *et al*., 2000). The study of the CS becomes important in these animal species to the extent of the training of different procedures such as electrical resynchronization with transvenous electrodes, catheterization of the CS and placement of cardioversion devices (Kato *et al*., 1987; Ballesteros *et al*., 2010). It has been described in different ungulates such as sheep and pigs that the left azygos vein is continuous with the CS (Aksoy *et al*., 2009; Gómez *et al*., 2015a; Gómez *et al*., 2018), which was also observed in our study and makes the CS of a much larger caliber in these animal species. In humans, the same does not happen since the equivalent structure drains into the distal segment of the superior vena cava (Ballesteros *et al*., 2010). In cardiac catheterization, serious errors of interpretation can be made due to the lack of recognition of the anomalies that affect the CS, as well as the associated hemodynamic alterations that can cause different types of iatrogenesis during cardiac surgery (Mantini *et al*., 1966).

The caliber of the GCV at the level of the PIS and the atrioventricular sulcus in previous studies in different species and in our research are recorded in Table I. It has been reported in humans and sheep that GCV can originate in the cardiac apex or in the lower third of the anterior interventricular sulcus (PIS in animals) (Besoluk & Tipirdamaz, 2001; Ortale *et al*., 2001; Aksoy *et al*., 2009; Ballesteros *et al*., 2010; Genain *et*

Table I. Comparison of the calibers of the cardiac veins in this study with different species.

Species	CS in coronary ostium (mm)	GCV in paraconal interventricular sulcus (mm)	GCV in atrioventricular sulcus (mm)	LMV at the drainage site (mm)	mCV (mm) at the drainage site	Author
Human	4-9	1.8	3.5-5.5	2.5	3.1-4	Gilard *et al*., 1998 Ortale *et al*., 2001 Ballesteros *et al*., 2010 Shah *et al*., 2012 Noheria *et al*., 2013 Genain *et al*., 2018
Sheep	7.4-8.5	2.6	3.7	2.3	2-2.2	Genain *et al*., 2018 Gómez *et al*., 2018
Pig	9.7-11.9	2.3-3.7	3.4-4.9	2.6	1.2-3.7	Gómez *et al*., 2015a Gómez *et al*., 2015b Genain *et al*., 2018
Dogs	5.5	1.5	2.4	-	1.1	Genain *et al*., 2018
Present study	13.8	4	6.7	4.1	4.7	Gómez *et al*., 2023

al., 2018; Gómez *et al*., 2018) and in pigs and European bison an origin in the cardiac apex has been described (Gómez *et al*., 2015b; Barszcz *et al*., 2020). In our study the origin from the cardiac apex coincides with what is observed in most species. In pigs it has been described that the caliber of the GCV at the drainage site within the CS was 5.3 mm (Gómez *et al*., 2015b), which is smaller than what was found in our research (7.5 mm).

In humans, the presence of AVT has been described in 58.8 - 89 % of cases (Ortale *et al*., 2001; Ballesteros *et al*., 2010), in pigs in 97.5 % of hearts (Gómez *et al*., 2015b) and in sheep in 80.6 % of the specimens (Gómez *et al*., 2018). In our series we observed the lowest presence of this arteriovenous configuration (64.3 %). In humans, it has been reported that the open configuration in the lower segment and closed in the upper segment (50 %) is the most common; in pigs, the same configuration as in humans occurs but in 65 % of the cases (Gómez *et al*., 2015b) and in sheep it presented a closed configuration in both segments (78 %) (Gómez *et al*., 2018), which is the same we found in this study but with a lower prevalence (50 %). The presence of the AVT is used as an anatomical reference point in the passage of electrodes during radiofrequency ablation procedures for the treatment of heart failure when cardiac arrhythmias are present and the lack of expression of this morphological characteristic can make the passage of electrodes difficult (Mochizuki, 1993; González-Suarez *et al*., 2022). In AVT when the GCV is located deep to the left circumflex branch of the left coronary artery and in the presence of occlusive disease of the coronary arterial branches, the vein can be compressed by the stiffness of the artery and worsen the disease by decreasing venous drainage. (Pejkovic & Bogdanovic, 1992).

It has been reported that LMV was present in humans between 94.1 - 100 % of hearts (Ortale *et al*., 2001; Ballesteros *et al*., 2010; Genain *et al*., 2018), in sheep it was present between 90.3 - 100 % of the cases (Genain *et al*., 2018; Gómez *et al*., 2018) and in pigs and dogs it was found in 100 % of the cases (Genain *et al*., 2018). In our series it was found in a similar way to the other reported species (92.9 %). This vessel originated in humans in the middle third of the obtuse surface of the heart (Ballesteros *et al*., 2010) and in sheep, goats, pigs and European bison it originates in the cardiac apex (Besoluk & Tipirdamaz, 2001; Aksoy *et al*., 2009; Gómez *et al*., 2015b; Gómez *et al*., 2018; Barszcz *et al*., 2020), unlike our study that originated in the lower third of the obtuse margin of the heart. Table I shows the comparison of the distal caliber of the LMV between the species in previous reports and in this study. In sheep and goats this vein drains between the GVC and the CS (Besoluk & Tipirdamaz, 2001; Aksoy *et al*., 2009; Gómez *et al*., 2018), in humans, pigs and European bison in the GCV (Ballesteros *et al*., 2010; Gómez *et al*., 2015b; Barszcz *et al*., 2020), as in the bovines of the present study.

In humans and the European bison, the mCV originated in the lower third of the posterior interventricular sulcus (SIS in animals) (Ballesteros *et al*., 2010; Barszcz *et al*., 2020) while in sheep, goats, and pigs it originates in the cardiac apex (Besoluk & Tipirdamaz, 2001; Aksoy *et al*., 2009; Gómez *et al*., 2015a; Gómez *et al*., 2018), as we observed in the present study. The distal caliber of the mCV between our study and previous reports from other species is observed in Table I. The drainage of the mCV in pigs, humans, sheep and European bison was in the distal part of the CS (Besoluk & Tipirdamaz, 2001; Ballesteros *et al*., 2010; Gómez *et al*., 2015a; Gómez *et al*., 2018; Barszcz *et al*., 2020), with an atypical drainage in the right atrium. In bovines we observed the same drainage pattern as described in previous studies.

Anastomosis were observed in humans in 58.8 % of hearts and only between the GCV and the mCV (Ballesteros *et al*., 2010), in pigs (63 %) and sheep (71 %) anastomosis were observed between the GCV and the mCV. mainly, although a double anastomosis could be visualized between the GCV, the mCV and the LMV (Gómez *et al*., 2015a; Gómez *et al*., 2018). In our study, as in the previously studied species, there were anastomoses (28.6 %) mainly between the GCV and the mCV, while the double anastomosis pattern described in other ungulates was also observed and in a high percentage of junctions between the mCV and the LMV. This anatomical variation in pathophysiological conditions is considered protective since it provides alternative routes of venous drainage, preventing the onset of cardiovascular diseases (Ballesteros *et al*., 2010).

In humans, the presence of MB on the cardiac veins has been indicated in 8.1 % of cases and mainly on the GCV at the level of the anterior interventricular sulcus (Ortale *et al*., 2001), differing from this study (10.7 %) which the presence of this variation was slightly higher and with a higher percentage on the mCV.

CONCLUSIONS

Most of the main coronary veins in bovines drain into the CS, with some cases with atypical drainages and with higher percentage of anastomosis that serves to improve cardiac venous drainage in case of venous compression or obstruction.

The presence of MB in the cardiac veins can generate obstructions in venous drainage that can worsen the heart disease from different etiologies.

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GÓMEZ-TORRES, F. A.; CORTÉS-MACHADO, L. S. & BALLESTEROS-ACUÑA, L. E. Estudio anatómico de las venas cardiacas y sus tributarias en bovinos (*Bos indicus*) en comparación con humanos y otras especies animales. *Int. J. Morphol., 42(1)*:52-58, 2023.

RESUMEN: En bovinos, las observaciones anatómicas de árbol vascular coronario describen características cualitativas. El objetivo de este estudio fue caracterizar morfométricamente las venas coronarias y sus tributarias en bovinos. Se realizó una aplicatura arciforme con seda 2.0 alrededor del ostium del seno coronario de 28 corazones de bovino y se colocó un catéter número 14, a través del cual se perfundió resina de poliéster semisintética y color azul mineral. La vena cardiaca magna se originó en 22 corazones (78,6 %) en el ápex cardiaco. La configuración del trígono arteriovenoso fue principalmente cerrado inferior y superior (50 %). El calibre de la vena cardiaca magna a nivel del surco atrioventricular fue 6,7 +/- 1,2 mm. El origen de la vena marginal izquierda se observó en el tercio inferior del margen izquierdo cardiaco (53,6 %), su calibre distal fue 4,1 +/- 0,8 mm y su desembocadura fue a nivel de la vena cardiaca magna. La vena cardiaca media se originó en el ápex cardiaco en el 78,6 % de las muestras, desembocó principalmente en el seno coronario (82.1 %) y su calibre distal fue 4,7 +/- 0,9 mm. Se presentó anastomosis en el 28,6 % de los corazones, encontrándose en la mayoría de los casos entre la vena cardiaca media y la vena cardiaca magna (50 %), lo cual fue significativo en comparación con otras anastomosis (p<0,001). La longitud del seno coronario fue 42,2 +/- 5,1 mm, su calibre distal fue 13,8 +/- 2 mm y su forma fue cilíndrica. Se encontró puentes miocárdicos en 3 corazones (10,7 %) y en el tercio inferior de la vena cardiaca media (66,6 %). La mayoría de las venas coronarias principales desembocan en el seno coronario, con algunos casos con desembocaduras atípicas y la presencia de un alto porcentaje de anastomosis que sirve para mejorar el drenaje venoso cardiaco en caso de compresión u obstrucción venosa.

PALABRAS CLAVE: Bovino; Venas coronarias; Seno coronario; Vena cardiaca magna; Trígono arteriovenoso.

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