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Gross morphology and morphometry of coronary arteries in goat (*Capra hircus*)

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Abstract

Present study on the gross morphology and morphometry of coronary arteries in goat (*Capra hircus*) established that the left coronary artery (LCA) and right coronary artery (RCA) arose from left and right coronary sinuses. The oval and circular left and right coronary ostium respectively were located in the left posterior and right anterior coronary sinuses below the sinotubular junction. The mean diameters of the left and right coronary ostia were 0.46 ± 0.01 cm and 0.25 ± 0.01 cm respectively. The two main branches of LCA were left anterior descending (LAD) and circumflex branches (LCx). The branches of RCA were circumflex, conal, proximal and distal branches of right atrium, intermediate, proximal and distal branches of right ventricle and marginal branch. Several other sub- branches were given by LAD and LCx. The mean lengths of LCA and RCA were 1.11 ± 0.02 cm and 6.68 ± 0.13 cm respectively.

Keywords: left and right coronary arteries, coronary ostia, lad, LCx.

Introduction

Mammalian heart is supplied with blood which is about 15% of the total left ventricular output (Dyce *et al.*, 2010) [10]. Arteries undergo progressive changes from birth to death and it is difficult to say when the normal growth process ends and involution begins. Presently, coronary heart disease is leading health killer in the world. Animal models are required for translational research for better understanding of the underlying mechanism of high morbidity and mortality of coronary heart disease since the coronary arteries of animals are anatomically and histologically similar to humans (Liao *et al.*, 2016) [17]. Prospect of pig organ/s for human xeno-transplantation has become increasingly helpful due to advances in transgenic technology (Sahni *et al.*, 2008) [24]. Goats also show great promise in replacing calf and dog models for the study of mechanically assisted circulation (Lipovetsky *et al.*, 1983) [18]. Since goats are docile, easy to handle and readily available, require small amounts of space, and tolerate long periods of confinement.

Materials and Methods

The gross morphology of coronary arteries in goat was studied by corrosion cast method. The arteries were flushed with warm normal saline through aorta to clear the lumen. DPI-RR cold cure powder and solution was made in 1:2 ratio to which few drops of red color dye was mixed. This was injected into the coronary arteries before dissection. The vessels were clamped and kept at room temperature for effective polymerization for overnight. Subsequently, the specimens were immersed in a glass container containing 75% hydrochloric acid till the corrosion process was completed. The specimen was cleaned, dissected and vessels were exposed. Morphometry of the coronary arteries in terms of length were recorded by adopting thread and scale method and accordingly tabulated (George and Cochran 1994) [12].

Results and Discussion

Coronary arteries were the first vessels originated below sinotubular junction of aorta i.e. between the bulbous portion and ascending aorta. The aortic sinuses were right anterior coronary sinus (RACS), left posterior coronary sinus (LPCS) and right posterior or non-coronary sinuses (NCS). LCA and RCA arose from LPCS and RACS respectively. The left coronary ostium (LCO) was located in the LPCS present below the sinotubular junction and the sinotubular ridge was arched to accommodate the ostia within the sinus (Fig.1). Our findings are in concurrence with the findings of Muriago *et al.*, (1997) [22], Kalpana (2003) [14] and Subhash *et al.*, (2010) [25] who reported that human coronary arteries arose from aortic

sinuses which were named according to their positions as anterior, left posterior and right posterior aortic sinuses. They also reported that the LCA arose from left posterior aortic sinus while RCA from anterior coronary sinus. Further, they also reported that the aortic sinuses crossed the dorsal border of the cusp forming a circular sinotubular ridge.

The LCO in the goat was below the commissural line which is similar to the observations of Cavalcanti *et al.*, (2003)^[8] and Subhash *et al.*, (2010)^[25] in humans. It was oval in shape with a mean external diameter of 0.46 ± 0.01 cm (Table.1) which is in accordance with the reports of Kulkarni and Paranjpe (2015)^[15] who noted in humans that the shape of LCO was circular to oval in shape with a mean diameter of 2.8 ± 1.0 mm (range of 1-8 mm) and Lipovetsky *et al.*, (1983)^[18] stated that the diameter of LCO in goats at the origin ranged from 1.5 to 3.0 mm.

LCO was located at a mean distance of 0.78 ± 0.02 cm from left semi lunar leaflet while the distance was 0.75 ± 0.01 cm from the bottom of the left posterior aortic sinus (Table.1). The distance between the LCO and the RCO was 1.27 ± 0.04 cm. These observations are in accordance with the reports of Muriago *et al.*, (1997)^[22] who reported in humans that the distance of the left orifice in relation to the attachment of anterior and left posterior aortic leaflets at the sinotubular junction was 9.9 ± 3.01 mm with the range of 3–15 mm while Cavalcanti *et al.*, (2003)^[8] reported that mean diameter of the LCO in humans was 4.75 ± 0.93 mm and the mean distance from the LCO to the bottom of the corresponding sinus was 12.6 ± 2.61 mm.

LCA originated from LCO and traversed between the pulmonary trunk and left auricle. LCA was bifurcated into paraconal interventricular or left anterior descending (LAD) branch and left circumflex branch (LCx) (Fig.3) which is in accordance with the findings of Lipovetsky *et al.*, (1983)^[18] in goats, Machado *et al.*, (2002)^[20] in marsh deer, Atalar *et al.*, (2003)^[1] in porcupines, Vladova (2005)^[26] in adult male cats, Carla *et al.*, (2010)^[6] in dogs, Kupczynska *et al.*, (2015)^[16] in European bison where they reported that the LCA was divided between pulmonary trunk and left atrium into LAD and LCx. The mean length of LCA before its bifurcation into LAD and LCx was 1.11 ± 0.02 cm (Table.2). Present results could be correlated with the works of some of the researchers like Fox *et al.*, (1973)^[11] who mentioned that the length of LCA in humans before its bifurcation was greater than 10 mm in most of the cases. Such reports were also given by Waller *et al.*, (1992)^[27] who revealed that the length of LCA in humans ranged between 1-25 mm before it bifurcated into the left descending and left circumflex branches. According to Monfared *et al.*, (2013)^[21] the length of the LCA in Iranian native cats ranged from 0.3 to 0.9 cm, with a mean length of 0.63 cm, Muriago *et al.*, (1997)^[22] the mean length of the LCA in humans was 1 ± 0.23 cm with a range of 0.6–1.5 cm while Ballesteros and Ramirez (2008)^[3] reported that the average length of LCA in humans was 6.48 ± 2.57 mm with sexual variation as 6.53 mm in males and 6.37 mm in females. Similarly Carla *et al.*, (2010)^[6] and (2011)^[7] reported that length of LCA in dog ranged from 0.5 to 1.2 cm. According to Gomez and Ballesteros (2014)^[13] length of LCA in pigs was 3.51 ± 0.99 mm. These studies establish that the length vary in species, sex and coronary ability.

The mean length of LAD which was a continuation of LCA was 10.2 ± 0.19 cm (Table.2). It ran towards the paraconal interventricular groove (in the descending part), and entered the subsinuosal interventricular groove (in the ascending part)

(Fig.3) which is congruent with the observations of Yoldas *et al.*, (2010)^[28] in swiss albino mice and Kupczynska *et al.*, (2015)^[16] in European bison where they reported that the LCA continued as LAD and the ascending and descending portion ran towards subsinuosal and paraconal interventricular groove respectively. The mean length of LAD was in agreement with the reports given by Carla *et al.*, (2010)^[6] and (2011)^[7] in dog which ranged from 5.6 to 8.7 cm and Monfared *et al.*, (2013)^[21] in Iranian native cats ranged from 3.5 to 5.9 cm, with a mean of 4.7 cm.

The left conal branch (LCB) arose from the right side of the LAD and supplied to conus arteriosum (CA) (Fig.3). It ended at the right ventricular borders which is similar to the reports of Blair (1961)^[5] in dogs, Machado *et al.*, (2002)^[20] in marsh deer, Ozgel *et al.*, (2004)^[23] in donkeys, Yoldas *et al.*, (2010)^[28] in adult swiss albino mice and Kupczynska *et al.*, (2015)^[16] in European bison where they described that the LAD gave a branch to conus arteriosum. In the present study the septal branch (SB) vascularized the septum (Fig.2) which is in congruence with the observations made by Bertho and Gagnon (1964)^[4] in humans, porcine, and equine hearts, Lipovetsky *et al.*, (1983)^[18] in goats, Atalar *et al.*, (2003)^[1] in porcupine and Bahar *et al.*, (2007)^[2] in Angora rabbits where they mentioned that the anterior septal artery originated from the LAD and gave rise to collaterals to supply the interventricular septum.

The left diagonal branch (LDB) emerged from the left side of LAD and penetrated the myocardium (Fig.3). The terminal left branch (TLB) supplied the walls of the left ventricle close to the cardiac apex (Fig.3). The proximal and distal collateral branches of the right ventricle (PCRVB & DCRVB) supplied the right ventricular wall (Fig.3). The posterior ascending branch (PAB) was a direct extension of the LAD supplied the lateral walls of both ventricles and the interventricular septum (Fig.2). These observations are in agreement with the reports of Lipovetsky *et al.*, (1983)^[18] in goats where they reported that the LAD was branched into diagonal, posterior ascending, terminal branches and other small right and left branches. Similar such reports were also given by Craig and Learned (1954)^[9] in dogs and Kupczynska *et al.*, (2015)^[16] in European bison where they reported that LAD gave a branch to right ventricle distributing the upper part of right ventricle and also stated that the LAD was continued as ascending part beyond the apex of heart.

The left circumflex branch (LCx) was the second branch of the LCA with mean length of 9.16 ± 0.08 cm (Table.2) which is in agreement with the reports given by Carla *et al.*, (2010)^[6] and (2011)^[7] in dogs where the mean length of LCx ranged from 3.3 – 6.7 cm.

The anterior descending branch (ADB) was the first branch of LCx and supplied to the lateral wall of the left ventricle (Fig.4). This observation is in consonance with reports of Lipovetsky *et al.*, (1983)^[18] in goats who reported that the anterior ascending branch originated from the anterior portion of the LCx and terminated in the upper one- third of the anterior free wall of the left ventricle.

In the present study left marginal branch (LMB) in goat ended at half of its length while remaining half was within the myocardium (Fig.4). These findings are in agreement with the observations of Atalar *et al.*, (2003)^[1] in porcupine, Ozgel *et al.*, (2004)^[23] in donkeys, Bahar *et al.*, (2007)^[2] in Angora rabbits and Yoldas *et al.*, (2010)^[28] in Swiss albino mice wherein they mentioned that the ramus marginis ventriculi sinistri travelled along the margo ventricularis sinister and

supplied to this region and apex of the heart. An additional branch named as intermediate branch of the left ventricle (IBLV) was noticed which extended towards the ventricular border and terminated in the middle half of the ventricle (Fig.4). No comparison could be drawn due to paucity of literature available.

Distal branch of the left ventricle (DBLV) ended in the middle of the left ventricle. The distal branch of the left atrium (DBLA) supplied the left atrium along with proximal branch of the left atrium (Fig.6). LCx on reaching the right interventricular groove continued further as the subsinuosal interventricular artery (Fig.5 and 6). These observations are in agreement with the reports of Atalar *et al.*, (2003) [1] in porcupine, Ozgel *et al.*, (2004) [23] in donkeys, Bahar *et al.*, (2007) [2] in Angora rabbits, Yoldas *et al.*, (2010) [28] in Swiss albino mice and Kupczynska *et al.*, (2015) [16] in European bison wherein they mentioned that the ramus distalis ventriculi sinistri (DBLV) supplied the region between margo ventricularis sinister and sulcus interventricularis subsinuosal and ramus proximalis atria sinistri supplied the free margin of the left auricle. They also reported that the LCx was continued as subsinuosal interventricular branch.

The right coronary ostium (RCO) in goat was found in the right anterior coronary sinus below the sinotubular junction (Fig.1). These observations are in agreement with Blair (1961) [5] in dogs, Muriago *et al.*, (1997) [22], Kalpana (2003) [14] and Cavalcanti *et al.*, (2003) [8] in humans, Sahni *et al.*, (2008) [24] in pigs, Subhash *et al.*, (2010) [25] in humans and Kupczynska *et al.*, (2015) [16] in European bison where they reported that the RCO originated in the right coronary sinus below sino tubular junction (STJ).

It was circular in shape (Fig.1) with a mean external diameter of 0.25 ± 0.01 cm (Table.1) which is in confirmation with Kulkarni and Paranjpe (2015) [15] who noted in humans that the shape of RCO was oval to circular with a mean diameter of 2.5 ± 1.0 mm. In the present study the height at which the RCO was located from the bottom of the aortic sinus was 0.62 ± 0.008 cm. The mean distance of RCO from right semi lunar leaflet was 0.70 ± 0.02 cm (Table.1). The mean length of RCA was 6.68 ± 0.13 cm (Table.2). These observations are in acceptance with the findings of Muriago *et al.*, (1997) [22] who reported in humans that the mean distance of the right orifice in relation to the attachment of anterior and right posterior aortic leaflets at the sinotubular junction was 8.30 ± 2.58 mm and Cavalcanti *et al.*, (2003) [8] mentioned in humans that the mean distance from the RCO to the bottom of the corresponding aortic sinus was 13.2 ± 2.64 mm. Further, the mean length of RCA of present study are in confirmation with Monfared *et al.*, (2013) [21] who stated that the length of RCA in Iranian native cats ranged from 0.1 to 0.6 cm, with a mean of 0.38 cm while Carla *et al.*, (2010) [6] and (2011) [7] stated that the mean length of the RCA in dogs was 3.8 cm with a range of 1.0 – 7.2 cm.

The right conal branch (RCB) distributed to the conus arteriosum, proximal branch of the right atrium (PBRA) gave rise to curved ascending and descending branches (CAB & CDB) supplied the medial wall of the right atrium (Fig.5 and 7). Further the RCA gave anterior branch (AB) which supplied the wall of the right ventricular border. The posterior

branch (PB) supplied the lateral wall of the right ventricle. It gave small branches to the lateral wall of the right ventricle (Fig.7). The marginal branch of ventricular border (MBVB) vascularized a vast area of the right ventricle on the proximity of the right ventricular border (Fig.7). These observations are in agreement with the reports of Lipovetsky *et al.*, (1983) [18] in goats, Atalar *et al.*, (2003) [1] in porcupine, Kalpana (2003) [14] in humans, Bahar *et al.*, (2007) [2] in Angora rabbits, Loukas *et al.*, (2014) [19] in humans and Kupczynska *et al.*, (2015) [16] in European bison where they described the branches of RCA as right conal branch, the proximal branch of the right atrium, the proximal branch of the right ventricle, the branch of the right ventricular border, the intermediate branch of the right atrium, the distal branch of the right ventricle and the distal branch of the right atrium.

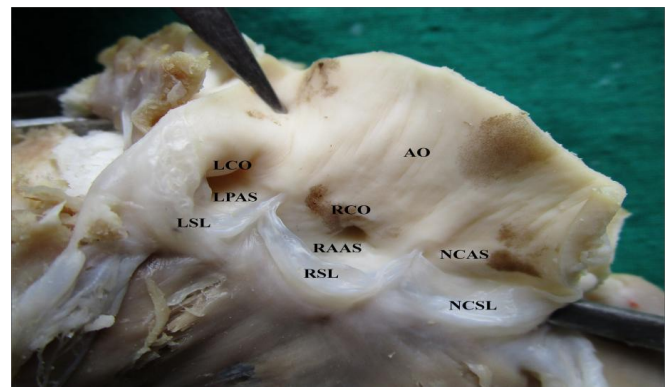


Fig 1: Photograph showing coronary ostium in goat: Left coronary ostium (LCO), Right coronary ostium(RCO), Left posterior coronary (LPCS), Right anterior coronary sinus (RACS), Non-coronary coronary sinus (NCS), Left semilunar leaflet (LSL), Right semilunar leaflet (RCL), Non-coronary semilunar leaflet (NCSL), Aorta (AO).

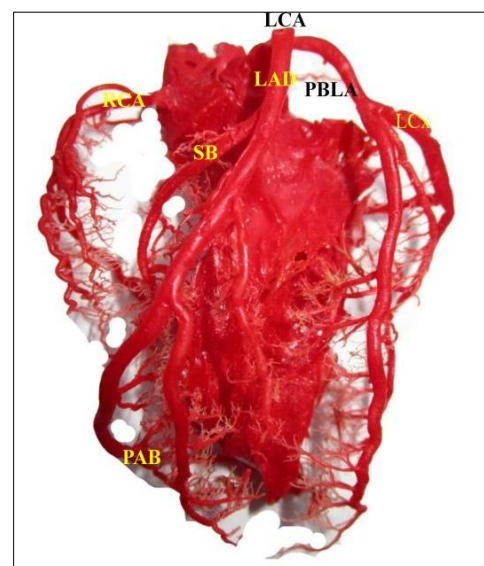


Fig 2: Photograph of complete coronary arterial cast in goat showing: Left coronary artery (LCA), Left anterior descending (LAD), Left circumflex branch (LCx), Posterior ascending branch (PAB), Septal branch (SB), Right coronary artery (RCA), Proximal branch of the left atrium (PBLA).

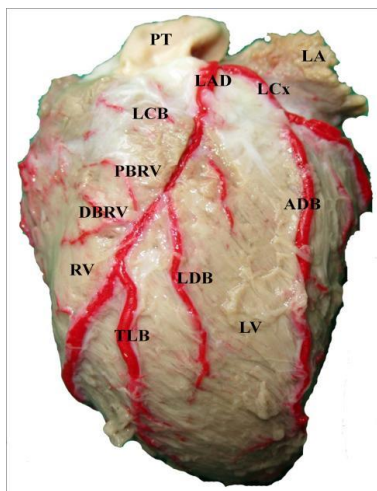


Fig 3: Photograph of coronary arterial cast showing branches of LAD & LCx in goat: Left anterior descending branch(LAD), Left conal branch (LCB), Left diagonal branch (LDB), Terminal left branch (TLB), Proximal and distal branches of the right ventricle (PBRV & DBRV), Left circumflex branch (LCx).

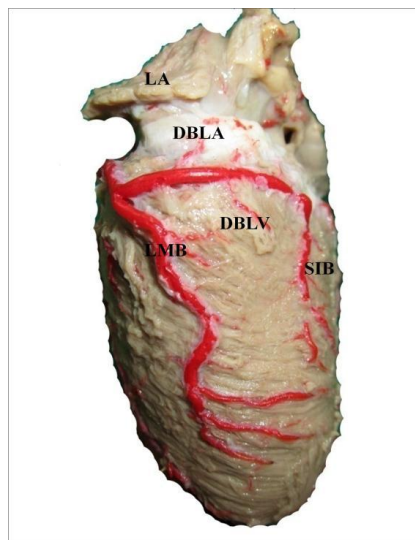


Fig 6: Photograph of coronary arterial cast showing branches of LCx on atrial surface of heart in goat: Anterior descending branch (ADB), Distal branch of the left atrium (DBLA), Distal branch of the left ventricle (DBLV), Subsinoasal interventricular branch (SIB).

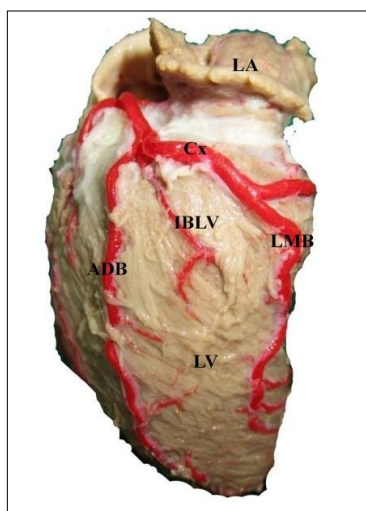


Fig 4: Photograph showing branches of LCx in goat: Left circumflex branch (LCx), Anterior descending branch (ADB), Intermediate branch of the left ventricle (IBLV), Left marginal branch (LMB), Left ventricle (LV).

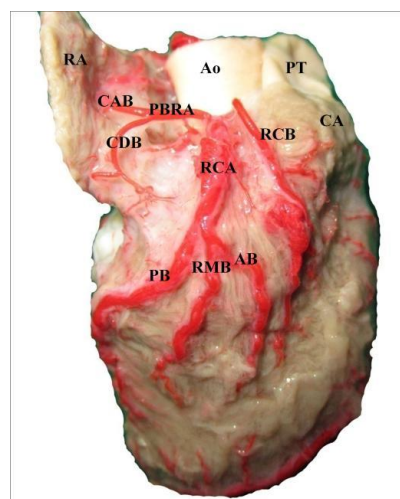


Fig 7: Photograph of coronary arterial cast showing branches of RCA in goat: Right coronary artery (RCA), Right conal branch (RCB), Proximal branch of the right atrium (PBRA), Anterior branch (AB), Right marginal branch (MB), Posterior branch (PB).

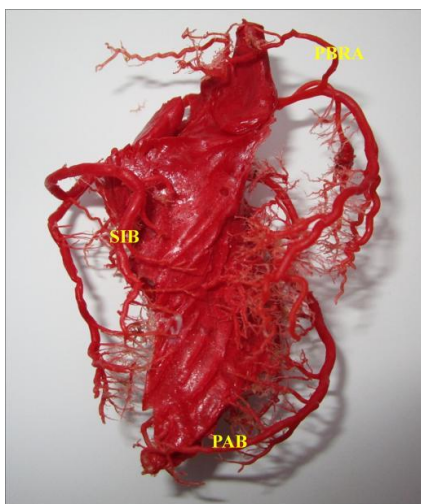


Fig 5: Photograph of complete coronary arterial cast in goat showing: Proximal branch of the left atrium (PBLA), Posterior ascending branch (PAB), Subsinoasal interventricular branch (SIB).

Table 1: Mean values of morphometric observations of external diameter of ostia (EDO), distance of ostium from leaflet (DOL) and height at which the ostium was located from the bottom of the sinus (HOS) in goat (centimeters).

	LCO		RCO	
	MEAN	SE	MEAN	SE
EDO	0.46	0.01	0.25	0.01
DOL	0.78	0.02	0.70	0.02
HOS	0.75	0.01	0.62	0.008

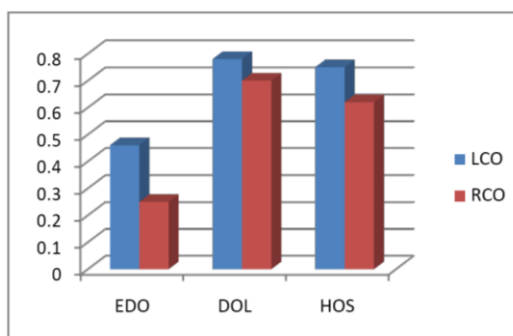
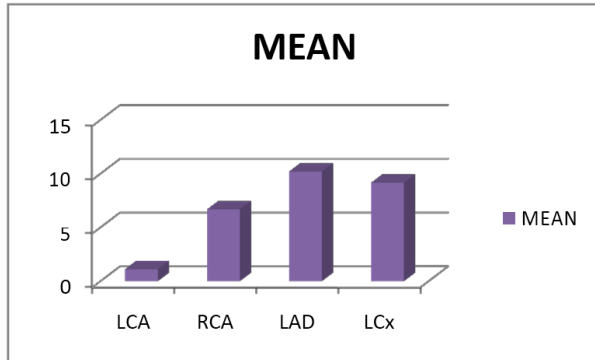


Table 2: Mean values of morphometric observations of length of LCA, RCA, LAD and LCx in goat (centimeters).

LENGTH	SHEEP	
	MEAN	SE
LCA	1.11	0.02
RCA	6.68	0.13
LAD	10.2	0.19
LCx	9.16	0.08



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