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Gross morphology and morphometry of coronary arteries in sheep (*Ovis aries*)

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Abstract
Present study on the gross morphology and morphometry of coronary arteries in sheep (*Ovis aries)* 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 sinutubular junction. The mean diameters of the left and right coronary ostia were 0.38 ± 0.02 cm and 0.25 ±0.02 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 1.16 ± 0.03 cm and 6.55 ± 0.11cm respectively.

Keywords: Left and right coronary arteries, coronary ostia, LAD, LCx

Introduction
Coronary arteries are the first vessels that normally originate below sinotubular junction of aorta i.e. between the bulbous portion and ascending aorta in humans (Reig 2003) [21]. These arteries are capable of auto regulation to maintain the coronary blood flow at levels appropriate to the needs of the myocardium (Sathapathy *et al*., 2015) [23]. The coronary heart disease is leading health killer of present day 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) [15]. The present investigation was undertaken to study the morphological features of the coronary arteries in sheep.

Materials and Methods
The gross morphology of coronary arteries in sheep 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) [10].

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) [19], Kalpana (2003) [12] and Subhash *et al*., (2010) [24] 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 sheep was below the commissural line which is similar to the observations of Cavalcanti *et al*., (2003) [7] and Subhash *et al*., (2010) [24] in humans. It was oval in shape with a mean external diameter of 0.38 ± 0.02 cm (Table.1) which is in accordance with the reports of Kulkarni and Paranjpe (2015) [13] 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) [16] 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 0.88 ± 0.03 cm from left semi lunar leaflet while the distance was 0.68 ± 0.03 cm from the bottom of the left posterior aortic sinus (Table.1). The distance between the LCO and the RCO was 1.35 ± 0.05 cm. These observations are in accordance with the reports of Muriago *et al.,* (1997) [19] 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 sinutubular junction was 9.9 ± 3.01 mm with the range of 3–15 mm while Cavalcanti *et al*., (2003) [7] 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.2) which is in accordance with the findings of Lipovetsky *et al*., (1983) [16] in goats, Atalar *et al*., (2003) [1] in porcupines, Vladova (2005) [25] in adult male cats, Carla *et al*., (2010) [6] in dogs, Kupczynska *et al*., (2015) [14] 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 1.16 ± 0.03 cm (Table.2). Present results could be correlated with the works of some of the researchers like Fox *et al*., (1973) [9] 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) [26] 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) [18] 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) [19] 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. Similiarly Carla *et al*., (2010) [6] reported that length of LCA in dog ranged from 0.5 to 1.2 cm. According to Gomez and Ballesteros (2014) [11] 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 9.81 ± 0.22 cm (Table2). It ran towards the paraconal interventricular groove (in the descending part), and entered the subsinuosal interventricular groove (in the ascending part) (Fig.2 and 4) which is congruent with the observations of Yoldas *et al*., (2010) [27] in swiss albino mice and Kupczynska *et al*., (2015) [14] in European bison where they reported that the LCA continued as LAD and the ascending and descending portion ran towards subsinousal and paraconal interventricular groove respectively. The mean length of LAD was in agreement with the reports given by Carla *et al*., (2010) [6] in dog which ranged from 5.6 to 8.7 cm and Monfared *et al*., (2013) [18] 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.2). It ended at the right ventricular borders which is similar to the reports of Blair (1961) [5] in dogs, Ozgel *et al*., (2004) [20] in donkeys, Yoldas *et al*., (2010) [27] in adult swiss albino mice and Kupczynska *et al*., (2015) [14] in European bison where they described that the LAD gave a branch to conus arteriosus. In the present study the septal branch (SB) vascularized the septum (Fig.4) which is in congruence with the observations made by Bertho and Gagnon (1964) [4] in humans, porcine, and equine hearts, Lipovetsky *et al*., (1983) [16] 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 proximal collateral left ventricular branch (PCLVB) emerged from the left side of LAD and penetrated the myocardium (Fig.2). The distal collateral left ventricular branch (DCLVB) supplied the walls of the left ventricle close to the cardiac apex (Fig.2). These observations are in agreement with the reports of Ozgel *et al*., (2004) [20] in donkeys, Yoldas *et al*., (2010) [27] in Swiss albino mice and Kupczynska *et al*., (2015) [14] in European bison who revealed that the PCLVB in European bison emerged from LAD and ran diagonally from the left ventricular wall and supplied the left ventricle while the DCLVB gave ramifications to the wall of the left ventricle at the apex of heart.

The proximal and distal collateral branches of the right ventricle (PCRVB & DCRVB) supplied the right ventricular wall (Fig.3). The ascending part (Ap) was a direct extension of the LAD supplied the lateral walls of both ventricles and the interventricular septum (Fig.4) which are similar to the reports of Craig and Learned (1954) [8] in dogs and Kupczynska *et al*., (2015) [14] 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 9.0 ± 0.12 cm (Table.2) which is in agreement with the reports given by Carla *et al*., (2010) [6] in dogs where the mean length of LCx ranged from 3.3 – 6.7 cm.

The proximal branch of the left ventricle (PBLV) was the first branch of LCx and supplied to the lateral wall of the left ventricle (Fig.5). This observation is in consonance with reports of Blair (1961) [5] in dogs, Lipovetsky *et al*., (1983) [16] described in goats, Atalar *et al*., (2003) [1] in porcupine, Ozgel *et al*., (2004) [20] in donkeys, Bahar *et al*., (2007) [2] in Angora rabbits and Kupczynska *et al*., (2015) [14] in European bison where they described that the PBLV distributed to the proximal part of the lateral surface of the left ventricle.

LCx gave branch of the ventricular border (BVB) and ended at half of its length while remaining half was within the myocardium (Fig.5). These findings are in agreement with the observations of Atalar *et al*., (2003) [1] in porcupine, Ozgel *et al*., (2004) [20] in donkeys, Bahar *et al*., (2007) [2] in Angora rabbits and Yoldas *et al*., (2010) [27] 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.

Distal branch of the left ventricle (DBLV) ended in the middle of the left ventricle (Fig.6). This is in agreement with the observations of Atalar *et al*., (2003) [1] in porcupine, Ozgel *et al*., (2004) [20] in donkeys, Bahar *et al*., (2007) [2] in Angora rabbits, Yoldas *et al*., (2010) [27] in Swiss albino mice and Kupczynska *et al*., (2015) [14] in European bison wherein they mentioned that the ramus distalis ventriculi sinistri (DBLV) supplied the region between margo ventricularis sinister and sulcus interventricularis subsinosus.

The distal branch of the left atrium (DBLA) supplied the left atrium along with proximal branch of the left atrium (Fig.5). This is similar to the reports of Atalar *et al*., (2003) [1] in porcupine, Ozgel *et al*., (2004) [20] in donkeys, Yoldas *et al*., (2010) [27] in Swiss albino mice and Kupczynska *et al*., (2015) [14] in European bison wherein they mentioned that the ramus proximalis atria sinistri supplied the free margin of the left auricle.

LCx on reaching the right interventricular groove continued further as the subsinuosal interventricular artery (Fig.6). Present findings are in partial confirmation with the reports of Atalar *et al*., (2003) [1] in porcupine and Kupczynska *et al*., (2015) [14] in European bison who described that the LCx was continued as subsinuosal interventricular branch.

The right coronary ostium (RCO) 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) [19], Kalpana (2003) [12] and Cavalcanti *et al*., (2003) [7] in humans, Sahni *et al*., (2008) [22] in pigs, Subhash *et al*., (2010) [24] in humans and Kupczynska *et al*., (2015) [14] 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 ± 0.02 cm (Table.1) which is in confirmation with Kulkarni and Paranjpe (2015) [13] 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 0.85 ± 0.0 cm. The mean distance of RCO from right semi lunar leaflet was 0.78 ± 0.03 cm (Table.1). The mean length of RCA was 6.55 ± 0.11cm (Table.2). These observations are in acceptance with the findings of Muriago *et al*., (1997) [19] 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 sinutubular junction was 8.30 ± 2.58 mm and Cavalcanti *et al*., (2003) [7] 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) [18] 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] stated that the mean length of the RCA in dogs was 3.8 cm with a range of 1.0 – 7.2 cm.

The first branch was the right circumflex (RCx) which was nothing but the continuation of the RCA (Fig.7) which is in confirmation with the studies of Blair (1961) [5] in dogs, Atalar *et al*., (2003) [1] in porcupine and Yoldas *et al*., (2010) [27] in Swiss albino mice where they reported that the RCA gave rise to right circumflex artery which terminated in a small branch just near the posterior longitudinal groove. In the present study the right conal branch (RCB) distributed to the conus arteriosum, proximal branch of the right atrium (PBRA) distributed to the right medial wall of the right auricle, and intermediate branch of the right atrium (IBRA) supplied the medial wall of the right atrium. Further, the RCA in the present study gave a small distal branch of the right atrium (DBRA) which supplied the lateral wall of the right atrium. The proximal branch of the right ventricle (PBRV) supplied the wall of the right ventricular border (Fig.7). The distal branch of right ventricle (DBRV) supplied the lateral wall of the right ventricle (Fig.7). It gave small branches to the lateral wall of the right ventricle. 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) [16] in goats, Atalar *et al*., (2003) [1] in porcupine, Kalpana (2003) [12] in humans, Bahar *et al*., (2007) [2] in Angora rabbits, Loukas *et al*., (2014) [17] in humans and Kupczynska *et al*., (2015) [14] 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.

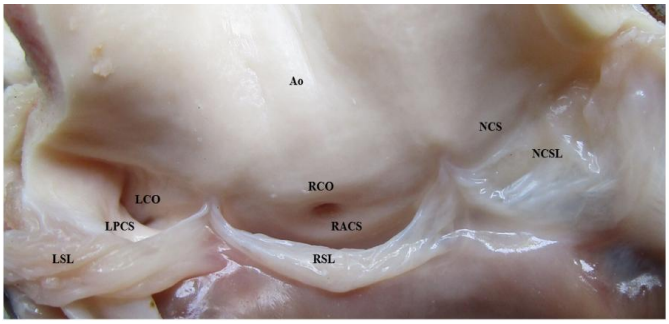


Fig 1: Photograph showing coronary ostium in sheep:Aorta(AO), Left coronary ostium (LCO), Left posterior coronary sinus (LPCS), Left semilunar leaflet (LSL), Right coronary ostium (RCO), Right anterior coronary sinus (RACS), Right semilunar leaflet (RSL), Non-coronary sinus (NCS), Non coronary semilunar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

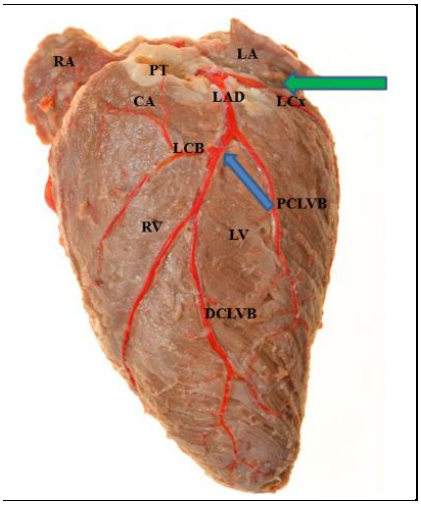


Fig 2: Photograph of coronary arterial cast in sheep showing LAD and LCX in paraconal interventricular groove (→) & subsinuosal interventricular groove (→) and branches of LAD.
Left conal branch (LCB), Conus arteriosum (CA), Proximal collateral left ventricular branch (PCLVB), Distal collateral left ventricular branch (DCLVB), Right ventricle (RV), Left ventricle (LV), Left circumflex artery (LCx).

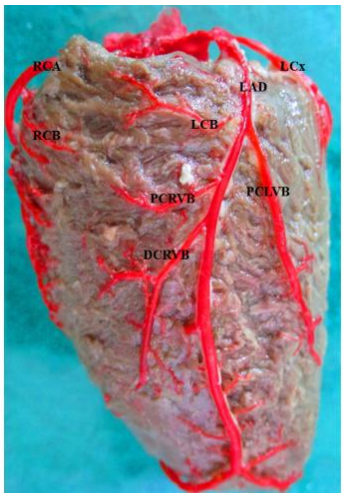


Fig 3: Photograph of coronary arterial cast showing right ventricular branches of LAD in sheep. Left anterior descending branch (LAD), Proximal and distal collateral branches of the right ventricle (PCRVB & DCRVB), Left circumflex artery (LCx), Proximal collateral left ventricular branch (PCLVB), Right coronary artery (RCA), Right conal branch (RCB),Left conal branch (LCB).

Fig 4: Photograph of complete coronary arterial cast in sheep showing: Left anterior descending artery (LAD), Septal branch (SB), Ascending part (Ap), Right coronary artery (RCA).

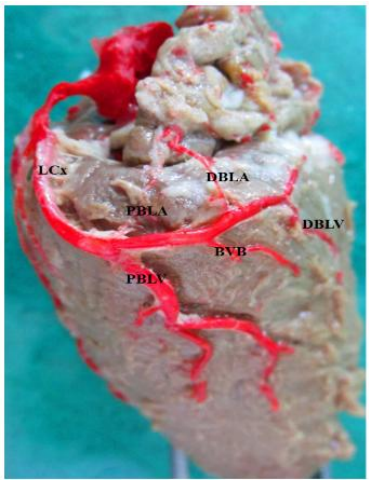


Fig 5: Photograph of coronary arterial cast showing branches of LCx in sheep: Left circumflex branch (LCx), Proximal branch of the left ventricle (PBLV), Proximal branch of the left atrium (PBLA), Branch of the ventricular border (BVB), Distal branch of the left ventricle (DBLV), Distal branch of the left atrium (DBLA).

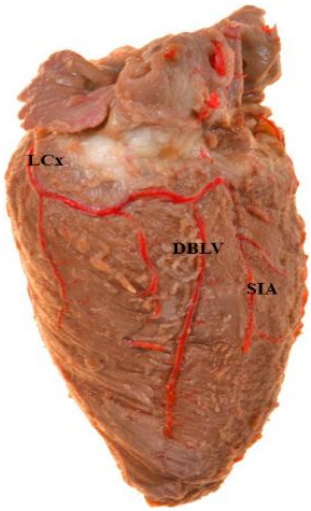


Fig 6: Photograph of coronary arterial cast of LCx branches on atrial surface in sheep: Left circumflex artery (LCx), Distal branch of the left ventricle (DBLV), Subsinuosal interventricular artery (SIA).

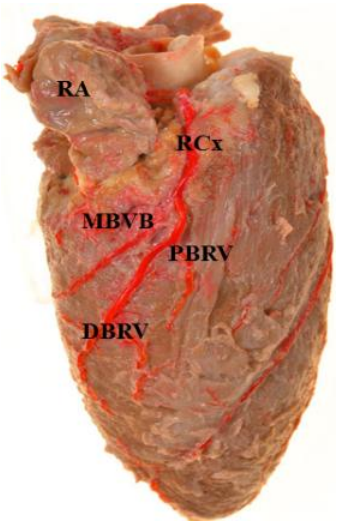


Fig 7: Photograph of coronary arterial cast showing ventricular branches of RCA: Proximal branch of the right ventricle (PBRV), Right circumflex artery (RCX) Distal branch of right ventricle (DBRV), Marginal branch of ventricular border (MBVB).

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 sheep (centimeters).

	LCO		RCO	
	MEAN	**SE**	**MEAN**	**SE**
EDO	0.38	0.02	0.25	0.02
DOL	0.88	0.03	0.78	0.03
HOS	0.68	0.03	0.85	0.05

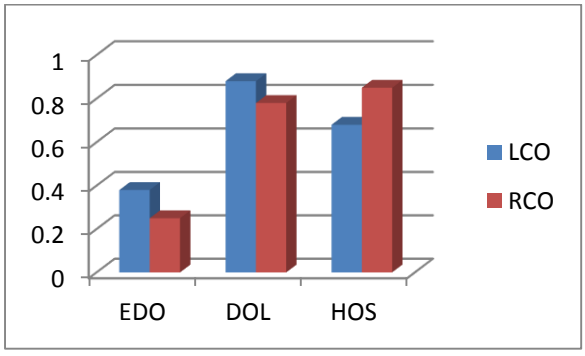
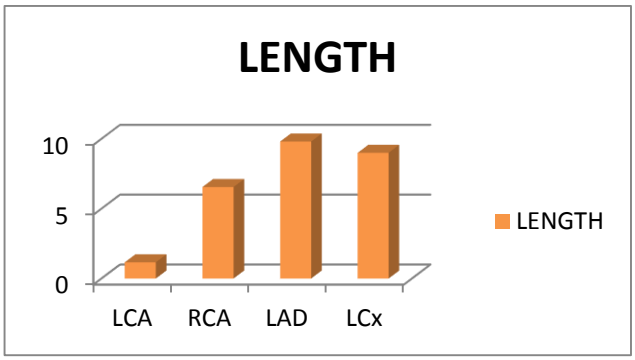


Table 2: Mean values of morphometric observations of length of LCA, RCA, LAD and LCx in sheep (centimeters).

	SHEEP	
LENGTH	**MEAN**	**SE**
LCA	1.16	0.03
RCA	6.55	0.11
LAD	9.81	0.22
LCx	9.0	0.12



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