

COMPARATIVE ANATOMICAL AND ECHOCARDIOGRAPHIC STUDIES ON HEART OF BUFFALO, SHEEP AND GOAT

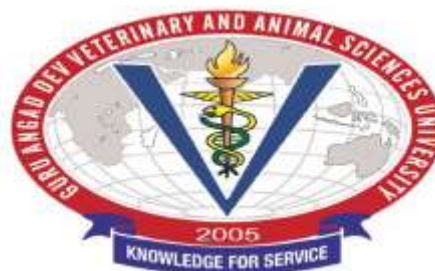
Thesis

**Submitted to Guru Angad Dev Veterinary and Animal Sciences University
in partial fulfillment of the requirements for the degree of**

**MASTER OF VETERINARY SCIENCE
in
VETERINARY ANATOMY
(Minor Subject: Veterinary Surgery and Radiology)**

By

**Dilmanpreet Sandhu
(L-2018-V-35-M)**



**Department of Veterinary Anatomy
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Ludhiana-141 004**

2020

CERTIFICATE I

This is to certify that the thesis entitled, “**COMPARATIVE ANATOMICAL AND ECHOCARDIOGRAPHIC STUDIES ON HEART OF BUFFALO, SHEEP AND GOAT**” submitted for the degree of **M.V.Sc.**, in the subject of **Veterinary Anatomy** (Minor subject: **Veterinary Surgery and Radiology**) of the Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, is a bonafide research work carried out by **Dilmanpreet Sandhu (L-2018-V-35-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis entitled, “**COMPARATIVE ANATOMICAL AND ECHOCARDIOGRAPHIC STUDIES ON HEART OF BUFFALO, SHEEP AND GOAT**” submitted by **Dilmanpreet Sandhu (L-2018-V-35-M)** to the Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.V.Sc.**, in the subject of **Veterinary Anatomy** (Minor subject: **Veterinary Surgery and Radiology**) has been approved by the Student’s Advisory Committee after an oral examination on the same, in collaboration with an external examiner.

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ABSTRACT

The present study was undertaken to elucidate gross anatomical, biometrical, echocardiographical and micrometrical studies on the heart of buffalo, sheep and goat. Heart as conical in shape with pointed apex and broad base in buffalo whereas triangular in shape with blunt apex in sheep and goat. In buffalo and sheep, the right moderator band was single and unbranched, but in goat, it was single and branched. The left moderator band was single and highly branched in buffalo, but there were three moderator bands (small, medium and large sized) present in the left ventricle of sheep and goat. The biometrical studies revealed that there was significant difference in weight, volume, length of anterior and posterior border, thickness of left atrial, right atrial, left and right ventricular wall and interventricular septum which was highest in buffalo followed by sheep and least in goat. The histological studies revealed that all four chambers were composed of three different layers i.e. endocardium, myocardium, and epicardium. Abundance of adipose tissue was seen in subendothelial layer in the atrium of buffalo, whereas it was present as isolated bundles in sheep and goat. Purkinje fibres had greater diameter than the cardiac myocytes and clustered in group. Myocardium was composed of bundles of cardiac muscle cells and Purkinje fibres. The bundles of cardiac muscles were comparatively larger in the ventricles as compared to the atrium in all the species studied. The myocytes were embedded in loose connective tissue that contained dense capillary network, lymph vessels and autonomic nerve fibres. Myocytes were elongated, branched and connected with each other. The cardiac muscle fibres showed different staining affinity, striations and intercalated discs. Right ventricle contained more amount of interstitial connective tissue as compared to left ventricle. Atrium was having thick layer of epicardium as compared to ventricle in buffalo, sheep and goat. The aorta and pulmonary arteries were consisted of three layers viz. tunica intima, tunica media, tunica adventitia. The echocardiographical values were more than biometrical and micrometrical values in buffalo, sheep and goat, but negligible difference was found between biometrical and micrometrical data.

Keywords: Anatomy, Buffalo, Echocardiography, Histology, Heart, Goat, Sheep

Signature of Major Advisor

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LIST OF ABBREVIATIONS

%	:	Percent
µm	:	Micrometer
AA	:	Ascending aorta
Ao	:	Aorta
CdVc	:	Caudal Venacava
Circ	:	Circumference
cm	:	centimetre
CrVc	:	Cranial Venacava
DA	:	Descending aorta
<i>et al</i>	:	et alia (and others)
Fig.	:	Figure
gm	:	Gram (s)
H & E	:	Hematoxylin and Eosin
IVS	:	Interventricular septum
LA	:	Left atrium
LAW	:	Left atrial wall
LV	:	Left ventricle
LVW	:	Left ventricle wall
MB	:	Moderator band
mg	:	milligram
mm	:	millimetre
ml	:	millilitre
NBF	:	Neutral buffered formalin
PA	:	Pulmonary artery
RA	:	Right atrium
RAW	:	Right atrial wall
RV	:	Right ventricle
RVW	:	Right ventricular wall
viz	:	that is

CHAPTER I

INTRODUCTION

Economy of rural India is dependent upon agriculture as well as animal husbandry. The buffalo plays a very important role in the Indian economy as it alone contributes 49.2% of the total milk produced in the country (Basic Animal Husbandry and Fisheries Statics 2017) and 12% of the world's milk production (Kumar and Pradhan 2014). Unfortunately, this species of animals did not receive the attention of researchers in accordance with its merits, which resulted in decline of buffalo population.

India is the seventh largest producer of the wool and accounts for nearly 2 to 3% of the total world wool production. The contribution of meat from sheep accounts for 7.68% of the total production (Indian Brand Equity Foundation 2012). The improvement of the production of sheep is essential for the upliftment of agrarian economy.

India is the world's largest producer of goat milk, with an annual production of over 5 million metric tons (India Livestock Census 2012). Unlike other animals, goats are easily manageable and have a heart size comparable with that of human being, which makes them an ideal species for developing of the animal models for human cardiovascular research.

In animal practice, cardiac diseases retain an unjustified mystique. The sophistication of cardiac diagnosis has improved remarkably over last few decades. Ultrasonography provides a good option for measuring and exploring most of the heart diseases. It is non-invasive, straight forward approach for bovine heart assessment (Hallowell *et al* 2007). It can be of great help for cardiovascular diseases management of bovine animals (Buczinski 2009).

Cardiac ultrasound examination is easy to perform in field conditions with high specificity and sensitivity (Braun 2009). Furthermore, echocardiography is important to create accurate and reliable reference values for each species in order to differentiate between normal subjects and the subjects suffering from cardiac disease (Boon *et al* 1983). Therefore, echocardiography is the most appropriate and practical tool to determine functional and structural heart changes (Dudas-Gyorki *et al* 2011).

Echocardiography with two dimensions (2D) and M-mode is used for evaluation of both normal and abnormal heart (Muzzi *et al* 2006). The 2-D display mode facilitates the evaluation of heart structure spatial relationships, while M-mode is ideal for measuring cardiac dimensions (Carlsten 1987).

Gross anatomical studies on the heart have been reported in goat (Malik *et al* 1978) sheep (Panditrao 2014) and buffalo (Anuradha *et al* 2013). Echocardiographic methods and normal values were recorded in dairy cattle (Hallowell *et al* 2007), horse (Gehlen *et al* 2007, Zucca *et al* 2008, Collins *et al* 2010), dog (Kobal and Petric 2007, Pereira *et al* 2009, Noviana *et al* 2011, Gugjoo *et al* 2014), dromedary camel (Tharwat *et al* 2012), sheep (Locatelli *et al* 2011, Poser *et al* 2013, Yadegari 2014, Acorda and Pajas 2015), donkey (Hassan and Torad 2015) and male and female buffaloes (Bhasin 2017). Echocardiographic values for normal heart of buffalo. Sheep and goat have not been compared except the preliminary work of Anuradha *et al* (2013).

The detailed comparative anatomical and echocardiographic studies on heart of buffalo, sheep and goat have not been reported till now which can form the baseline for diagnosing various heart diseases, so the present investigation was proposed with following objectives:

- 1) To compare gross anatomical, biometrical and histological studies on heart of buffalo, sheep and goat.
- 2) To study the echocardiography on heart of buffalo, sheep and goat.

CHAPTER II

REVIEW OF LITERATURE

2.1 GROSS ANATOMY

The heart lies between the lungs in the lower anterior portion of the body, extends to the left, and is enclosed in pericardium. The heart is a muscular organ, which regulates the circulatory system with four chambers (Shah *et al* 2010). It has specific input (veins) and output (arteries) channels (Pasquini *et al* 2007).

2.1.1 Atrium

Ghoshal (1971) noticed that ventral border of left auricle had several notches which were more distinct in left auricle of sheep and goat and both the auricles in ox. Evans (1993) reported in dog that the right and left atria located at the base of the heart and separated by interatrial septum. Dyce *et al* (1996) and Pasquini *et al* (2007) found that left atrium was seen on the left side of heart caudal to the pulmonary trunk where the veins opened.

Wang *et al* (1995) observed that the wall of right atrium was not uniformly thick because of presence of terminal crest and pectinate muscles on its internal surface. Crick *et al* (1998) reported that it was composed of sinus venarum and an auricle in pig. The latter was a conical diverticulum which curved around aorta and had five main openings in it. Ho *et al* (2002) observed small orifices of vena cordis parvae in the depressions between muscoli pectinati. They also reported that generally there was one inferior and one superior vena cava, but some mammals had two anterior venae cava. The site where the ostia of venae cava entered into the atrium varied among species. The ostia of the anterior and posterior venae cava entered at right angle in the large mammalian animal. The number of pulmonary veins entering the left atrium had two primary pulmonary vein ostia in pig (Crick *et al* 1998) and dog had five or six (Evans 1993).

Michaelsson and Ho (2000) studied the sinus venosus, valve of the inferior vena cava, valve of the coronary sinus, crista terminalis as well as atrial architecture in dogs, pigs, and sheep and concluded that these were principally same in all these species.

Kent and Carr (2001) stated that there was an earlike flap termed as an auricle or appendage in all large mammalian atria. It varied in size and shape between species. The junction between the left atrium and the left appendage were narrow whereas the junction between the right atrium and the right appendage was wide. In the right and left atrial appendages as well as on the lateral wall of the right atrium, multiple pectinate muscles were found. They also reported that the sinus venosus was incorporated into the right atrium and marked by the sinoatrial node in large mammals whereas it was a common separate structure in non-mammalian heart.

Ho *et al* (2002) observed small orifices of vena cordis parvae in the depressions between muscoli pectinate. The auricle was a conical diverticulum that had five main openings in it and was curved around aorta. They further found that within the large appendage, the right atrium was dominated by an extensive range of pectinate muscles, while the left atrium was comparatively smooth with a much smaller tubular appendage. They concluded that homogeneities were common in the normal heart in the gross structure.

Bhasin (2017) reported that the right atrium was located at the right anterior of the base of heart, and was composed of, the sinus venarum and auricle in male and female buffalo heart. Vena cava (anterior and posterior) and the coronary sinus opened up in the sinus venarum. The right auricle was characterized as the meshwork of pectinate muscles and a blind pocket of atria. Because the terminal crest and the pectinate muscles on its inner surface, the right atrial wall was not evenly thick. Small depression was found between the pectinate muscles and was called vena cordis parvae. In the rear of the auricle, the anterior venacava opened in the top, while at the bottom and back of the right auricle posterior venacava opened right in a straight line of the anterior venacava above the interventricular groove. Coronary sinus which delivered blood from heart itself opened ventral to posterior venacava opening while vena hemiazygous opened into coronary sinus.

2.1.2 Ventricle

Ventricular base was connected to right atrium through right atrio-ventricular orifice guarded by tricuspid valve but its left part projected higher and formed conus arteriosus, from which pulmonary artery arose whereas the left ventricle formed left

caudal part of ventricular mass and its wall was much thicker than right ventricle (Crick *et al* 1998).

Pasquini *et al* (2007) stated that right ventricle formed most of the right side of heart and wrapped around the cranial side of heart to continue as pulmonary trunk in domestic animals. It was connected to left atrium through left atrioventricular opening which was guarded by bicuspid valve. Bhasin (2017) found the triangular shape of the right ventricle with the base formed by the right atrio-ventricle orifice. Its left part was higher and continued into the pulmonary artery, called conus arteriosus. The anterior wall formed the heart's anterior border, and the interventricular septum formed its posterior wall.

Getty (1975) described that chordae tendinae were fewer but larger in left ventricle than that of right ventricle. Dyce *et al* (1996) also stated that within the left ventricle the chordae tendinae were less in number than the right ventricle but were longer and stronger. Bhasin (2017) reported that the chordae tendinae were the fine fibrous cord which attached the cusps to the wall of ventricle and each cusp received chordae tendinae from two papillary muscles

Jensen *et al* (1978) reported that band contained bundles of Purkinje fibers and nerve fibers which were separated by connective tissue in both species. The band originated much higher on the septal wall (Crick *et al* 1998) in pig, a muscular strand (branched or single) extended from the lumen of septal wall near, or from base of the anterior papillary muscle (Evans 1993) in dog.

Dyce *et al* (1996) reported that at the origin of an aorta the three semilunar cusps were connected to the aortic fibrous ring. Its base was connected into the right atrium by an atrio-ventricular, regulated by a tricuspid valve but it had a higher left part and formed a pulmonary artery, whereas the left caudal ventricular portion was a much larger than the right ventricle (Crick *et al* 1998).

The moderator band were two in number in left ventricle whereas in right ventricle, one or sometimes large muscular bands was found. In pigs, the moderator band was situated in a much higher position in right ventricle as compared to left one (Crick *et al* 1998). In both male and female buffalo, the moderator band had a myocardial cord crossing the lumen that connected the interventricular septum to a

midway wall between base and heart apex. In buffalo, the right moderator band present in right ventricle was thicker as compared to left one (Bhasin 2017).

Michaelsson and Ho (2000) found that papillary muscles on the ventricular wall supported the atrioventricular valves. In large mammalian heart, left ventricle had two and the right ventricle had three papillary muscles. Muscular bands were found in both ventricles which usually contained Purkinje fibers. In the right ventricle of most dogs, pigs, and ruminants, a band called as moderator band was present which varied in the composition, origin and insertion among different species.

Michaelsson and Ho (2000), and Kent and Carr (2001) found that the trabeculae carneae were present near the apex of both ventricles that strengthen the wall and increased the force exerted during contraction. Bhasin (2017) reported that in the ventricular wall, three types of trabeculae carneae were found. The first was attached across the entire length to the wall of the ventricle and known as the relief ridges. The second was attached at both ends and was free at the center called moderator band, whereas the third was known as papillary muscles. It was also reported that the left ventricle was conical, and the apex of the left ventricle was the heart's apex, and was present in male and female buffalo at the sixth intercostal area. The chordae tendinae were fewer in number and larger in left ventricle than right ventricle.

2.1.3 Arteries and Veins

2.1.3.1 Aorta

Dyce *et al* (1996) reported that aorta was a great artery leaving the left ventricle of heart and arching caudally. Oyama (2001) found that aorta arose at upper part of left ventricle after ascending for a short distance, arched backward and was divided into ascending and descending aorta at the upper left ventricle after climbing over a short distance.

Sakabe *et al* (2006) reported that at the union of ascending aorta with the aortic arch, the calibre of vessel was increased and termed as the bulb of aorta. Ascending aorta arose at upper part of base of left ventricle and at its origin it presented three small dilations called aortic sinuses (Pasquini *et al* 2007).

Bhasin (2017) reported that the opening of the aorta was guarded by three semilunar cusps i.e. anterior, right posterior and left posterior and arose from the base of left ventricle in buffalo. The valvular coronary arteries arose from the anterior and left posterior sinuses.

2.1.3.2 Pulmonary artery and vein

Dyce *et al* (1996) stated that the funnel formed outflow of right ventricle leading to the pulmonary trunk was the conus arteriosus. The three semilunar cusps attached to the aortic fibrous ring in the origin of aorta. Khan (2004) studied that pulmonary veins were four in number, destitute of valves and two from each lungs, supplied oxygenated blood to the left atrium of heart from the lungs. Holt *et al* (2005) noted that behind the right atrium, right pulmonary veins passed and superior vena cava the left in front of descending thoracic aorta. Motabagani (2006) found that it had a triangular orifice bordered by the free margins of three leaflets. Pasquini *et al* (2007) described that a pulmonary valve was present between conus of right ventricle and pulmonary trunk.

Bhasin (2017) studied that the pulmonary artery was the large trunk which carried blood from right ventricle to the lungs in buffalo. There were three semilunar cusps named as medial, lateral and posterior guarded the opening of right ventricle into pulmonary trunk. Pulmonary veins carried the oxygenated blood from lungs to the left atrium of the heart. They were four in number, two from each lung and devoid of valves.

2.2 BIOMETRY

2.2.1 Size and shape

Dyce *et al* (1996) reported that size of heart varied considerably among species and also among individuals. Some breeds of sheep and goat heart were relatively long and narrow and in others much wider and shorter. The general form of the heart was that of blunt cone with a base and an apex in human (Walmsely and Monkhouse 1988). Crick *et al* (1998) noticed that the human heart had trapezoidal and pig heart had classic valentine shape. Lima *et al* (2009) found globe-shaped heart in Western Grey kangaroo.

Archana *et al* (2010) found the triangular shape of heart in sheep with wide base which was directed upward, the apex directed downward and was bluntly pointed. Heart shape was like a cone and fat lined coronary grooves (Shah *et al* 2010). Similarly, Gupta *et al* (2012) observed that heart was cone shaped in buffalo. Its apex was conical and wide base extended from the third rib's cranial boundary to the 5th rib's caudal boundary.

Bhasin (2017) observed that the heart was conical with a pointed apex and a large base in buffalo. The heart base had been directed dorsally whereas the apex was lying above the last part of the sternum. The heart had one anterior and one posterior border as well as right and left surface. The right ventricle formed most of the right surface of the heart. The left ventricle formed a small part of the left surface while right ventricle formed more than one-third of it in both male and female buffalo.

2.2.2 Weight

Malik *et al* (1972) measured the mean weight of buffalo heart as 1175.75 ± 23.2 gm. Malik *et al* (1978) measured the mean weight of heart as 66.70 ± 1.43 gm in goat, whereas Chakravarthy and Sastry (1979) recorded that the mean heart weight was 107.8 gm (0.5% of body weight). Rajpal *et al* (1989) found that the weight of heart was 884.22 ± 0.003 gm in cattle. Where as Leinder (1996), Mohan and Prakash (1997) and Miglimo and Amorim (1998) observed that the average weight of heart ranged from 1800 to 2500 gm in ox.

Sathyamoorthy (2003) reported that heart weight / body weight ratio was 0.87% in day-old piglets and at three months of age it was 0.5% and then it gradually reduced to 0.26% in four year old pigs and concluded that heart weight / body weight ratio was found to be decreasing with increasing age.

Miller (2004) recorded the mean weight of heart of buffalo as 1175 ± 23 gm. Hussain *et al* (2006) measured the absolute weight of heart as 1606 ± 53.86 gm in young and 2561 ± 71.57 in adult buffaloes. Panhwar *et al* (2007) found the mean weight of buffalo heart in young male and female as 550.8 ± 2.03 gm and 540.6 ± 14.35 gm, respectively, whereas in adult male and female 1284.7 ± 59.62 gm and 954.5 ± 36.75 gm, respectively. The average heart weight in young male and female buffalo recorded by Shahida *et al* (2007) was 550.8 ± 12.03 and 540.6 ± 14.35 gm. It

was 1284.7 ± 59.62 and 954 ± 36.75 gm, respectively, for both adult male and female buffalo, the absolute heart weight in younger ones was 1606 ± 53.86 gm and 2561 ± 71.57 gm in Nili-Ravi Buffalo (Hussain and Qureshi, 2007).

Shah *et al* (2010) found that the mean absolute weight of goat heart was 94.47 ± 5.86 gm in goat. Sathapathy *et al* (2013) measured the average weight of young male and young female goat as 114 ± 6.28 gm and 126 ± 5.13 gm, respectively, while that of adult male and female as 138 ± 6.01 gm and 145 ± 4.67 gm, respectively. Gumansing (2015) observed that the weight of heart ranged between 83.50 gm - 122.50 gm with mean of 96.5 ± 5.661 gm in male goat. Similarly, weight of heart in female goat ranged between 77.00 gm - 107.50 gm with mean of 89.08 ± 4.723 gm.

Bhasin (2017) found the cardiac weight in male buffalo was between 2100 to 3850 gm with a mean of 3120 ± 155.97 gm. It ranged between 2800 gm and 4280 gm in female, with a mean of 3350 ± 145.51 gm. The heart weight was found higher in females than males.

Queiroz *et al* (2018) reported that cardiac weight of dogs weighing 20.1-24 kg was between 116 to 200 gm and the mean weight was 158.33 ± 42 gm, whereas dog weighing 28.1-32 kg was between 165 to 250 gm and the mean weight was 225.43 ± 49.34 gm.

2.2.3 Volume

The ventricular volume was found to be greater in left than in right chamber (Alvarez *et al* 1987). Shah *et al* (2010) recorded the mean heart volume as 89.23 ± 4.99 cm³ in goat.

Bhasin (2017) measured that the buffalo heart volume ranged between 420 ml to 785 ml in males, averaging 637.08 ± 41.37 ml, with parameters ranging from 5035 ml to 1055 ml and a mean of 705.83 ± 41.92 ml in females. The volume was more in females than male buffalo.

Queiroz *et al* (2018) reported that the volume of heart in dogs weighing 20.1-24 kg was between 120 to 200 cm³ and the mean volume was 158.33 ± 40.1 cm³, whereas the dogs weighing 28.1-32 kg was between 180 to 300 cm³ and the mean volume was 220 ± 54.16 cm³.

2.2.4 Borders

2.2.4.1 Anterior border

Malik *et al* (1972) measured the mean length of anterior border of heart in buffalo as 18.0 ± 1.00 cm whereas mean length of rostral border of caprine heart was recorded to be 8.32 ± 0.29 cm (Malik *et al* 1978).

The average length of anterior border base to apex of buffalo heart was found to be 18 cm (Mohan and Prakash 1997 and Miller 2004). Panhwar *et al* (2007) recorded the same parameter in heart of male and female buffaloes as 13.9 ± 0.22 cm and 13.3 ± 0.22 cm, respectively in young animals and 15.4 ± 0.02 cm and 15.8 ± 0.28 cm, respectively in adult buffaloes.

The length of anterior border ranged from base to apex from 7.60 to 8.80 cm with mean 8.28 ± 0.17 cm in sheep males. This ranged from 5.70 to 8.10 cm in females and mean was 6.98 ± 0.32 cm (Panditrao 2014). The difference of male heart was higher than female and indicated that the male heart was longer than the female.

Bhasin (2017) measured that the anterior border length in the buffalo was 12.2 cm to 15.2 cm with a mean of 13.55 ± 0.25 cm, while the same parameters in females ranged between 12.5 cm to 17.9 cm, with a mean of 14.38 ± 0.55 cm. The length of the anterior border was found to be more in the female buffalo than the male buffalo.

2.2.4.2 Posterior border

Malik *et al* (1972) found that right surface was mainly formed by right ventricle and small part by left, but left surface was formed more than one third by right and rest by left ventricle. He also reported that posterior border was shorter, thicker and slightly concave or nearly straight and was entirely formed by left ventricle in buffaloes. Malik *et al* (1972) measured the mean length of caudal border (base to apex) as 13.5 ± 0.70 cm and 13.5 cm, respectively in buffalo heart which was 6.40 ± 0.18 cm in goat (Malik *et al* 1978). The mean length of posterior border from base to apex of heart of young male and female buffaloes was measured as 12.1 ± 0.21 cm and 11.8 ± 0.28 cm, respectively (Panhwar *et al* 2007).

A comparison of length of anterior and posterior border of heart in adult buffalo showed that anterior border was larger than posterior one and mean ratio

between their length was $18.00 \pm 1.00:13.5 \pm 0.70$ cm in buffalo (Malik *et al* 1972) and $8.32:6.40$ cm in caprine heart (Malik *et al* 1978). Mohan and Prakash (1997) and Sharma *et al* (1998) reported the ratio between anterior and posterior borders as 13.9:11.8 in ox. Sathyamoorthy (2003) recorded that the ratio was 2.58:1.98 in day old piglets and 8.93:7.32 in 6 months-old pig that reached the maximum of 13.38:11.53 in four year-old pig. Panditrao (2014) observed that the length of the posterior border from base to apex ranged from 6.10 - 6.60 cm with a mean of 6.98 ± 0.32 cm in sheep males whereas it ranged from 4.80 - 6.20 cm in females with a mean of 5.60 ± 0.24 cm.

Bhasin (2017) found that the posterior border length in male buffalo was 9.8 cm to 12.5 cm with mean of 10.92 ± 0.19 cm, while the same parameters in female ranged from 10.3 to 12.6 cm with mean of 11.13 ± 0.19 cm. In male and female buffaloes, comparison of anterior and posterior border length of heart showed that anterior border was larger than that of the posterior border. The ratio between the length of posterior border was 14.38:11.13 in female and 13.5:10.92 in male buffaloes. The length of posterior border was more in female than the male buffalo.

2.2.5 Circumference of heart

The external surface of the buffalo and goat heart showed the demarcation of four grooves i.e. one transverse and three longitudinal (Malik *et al* 1972 and Malik *et al* 1978). Transverse / coronary groove was formed as a depression encircling the base of heart, except in conus.

2.2.5.1 Coronary Groove

The mean circumference of heart at the coronary groove (transverse groove) was found to be 38.75 ± 1.51 cm in buffalo (Malik *et al* 1972) and 13.83 ± 0.39 cm in goat (Malik *et al* 1978). Rajpal *et al* (1989) measured the circumference at the coronary groove was 30.77 ± 0.27 which decreased to 90% and 40% at the mid and lower fifth ventricular level, respectively. Mohan and Prakash (1997) measured the circumference within coronary grooves averaged 28.95 cm in buffaloes and 38.75 cm in cow; while Braun *et al* (1999) recorded 37 cm circumference in heart of cattle. Sathyamoorthy (2003) found that circumference of heart at the level of coronary groove was 6.5 cm in day-old, 25 cm in 6 months and 31.68 cm in 4 year-old pigs.

Hussain *et al* (2006) measured the circumference at base of heart as 30.87 ± 0.92 cm in young and 39.10 ± 0.79 cm in adult buffaloes.

The groove externally indicated the separation of atria and ventricles and contained coronary vessels (Pasquini *et al* 2007). Panhwar *et al* (2007) measured the mean circumference at coronary groove of heart in male and female buffaloes as 27.6 ± 0.41 and 26.0 ± 0.5 cm in young animals and 31.1 ± 0.48 and 33.5 ± 0.54 cm in adult animals.

Rehan and Qureshi (2007) observed that the mean circumference value for the camel heart at coronary groove level was 36.34 ± 0.57 cm. Shah *et al* (2010) found that the mean values for the goat heart circumference were 14.30 ± 0.34 cm.

Sathapathy *et al* (2013) measured that the circumference at coronary groove in young male and female goat as 5.69 ± 0.23 and 6.35 ± 0.15 cm while that in adult male and female as 5.78 ± 0.18 and 6.38 ± 0.16 cm.

Bhasin (2017) found that at the level of coronary groove, circumference of heart ranged of 30.2 to 37.6 cm with a mean 34.27 ± 0.69 cm for male buffalo, whereas same parameters for female buffalo ranged from 31.5 cm to 42.8 cm with a mean for 34.06 ± 1.29 cm.

2.2.5.1 Longitudinal Groove

Malik *et al* (1972) observed that all three longitudinal grooves (left, right and intermediate) passed downward, but right and left grooves curved toward each other and anastomosed at lower one third of the right surface a little above apex of buffalo heart. Malik *et al* (1978) recorded that right groove descended up to 3-4 cm above the apex of heart in goat. The right and left longitudinal grooves met each other at right side of anterior border and 4.54 ± 0.92 cm above the apex of buffalo heart; whereas in goat the point of merger was 1.86 ± 0.10 cm above the apex of heart. Mohan and Prakash (1997) observed that right and left longitudinal grooves met on the right side at 4.02 cm above the apex of heart in buffalo.

Braun *et al* (1999) found the distance between right and left coronary grooves to apex in cattle averaged to be 15.0 cm. Panhwar *et al* (2007) found the mean distance between right and left coronary grooves of heart in young male and female

buffalo was 13.9 ± 0.28 cm and 15.0 ± 0.25 cm, whereas similar parameter in adult male and female was 5.0 ± 0.25 cm and 15.7 ± 0.26 cm, respectively.

2.2.6. Thickness

2.2.6.1 Left atrial wall

Bhattacharya *et al* (1987) measured that the thickness of left atrial wall was 0.4 cm and 2.0 cm in one horned rhinoceros. Hussain *et al* (2006) measured the thickness of left atrium wall of heart as 1.74 ± 0.04 cm in young and 1.86 ± 0.04 cm in adult buffaloes. Rehan and Qureshi (2007) recorded that the mean thickness of left atrial wall of camel was 0.508 ± 0.03 cm and ranged from 0.29 to 0.95 cm.

Shah *et al* (2010) reported that the mean thickness of left atrial wall from auricle region were 0.25 ± 0.02 cm in goat. The thickness of left atrial wall ranged from 0.21 - 0.24 cm with average of 0.22 ± 0.009 cm in male goat. Similarly, the thickness of left atrial wall ranged from 0.21-0.28 cm and 0.24 ± 0.011 cm (Gumansing 2015) in female goat.

Bhasin (2017) studied that the left atrial wall thickness in male buffalo ranged from 0.6 cm to 1.5 cm with mean of 0.95 ± 0.07 cm, whereas the same parameter in female buffalo ranged from 0.8 cm to 1.5 cm with the mean of 1.1 ± 0.06 cm. The thickness of the left atrial wall was more in females than males.

Queiroz *et al* (2018) observed that thickness of left atrial wall in dogs weighing 20.1 - 24 kg was 0.2 to 0.3 cm and mean thickness was 0.23 ± 0.06 cm, while that of dogs weighing 28.1 - 32 kg was 0.2 to 0.4 cm and mean thickness was 0.28 ± 0.1 cm.

2.2.6.2 Right atrial wall

Bhattacharya *et al* (1987) recorded that the thickness of right atrial wall was 1.9 cm in one horned rhinoceros. Hussain *et al* (2006) measured the thickness of right atrium wall of heart as 1.33 ± 0.05 cm in young and 1.65 ± 0.03 cm in adult buffaloes. Rehan and Qureshi (2007) stated that the mean thickness of right atrial wall of camel was 0.597 ± 0.04 cm and ranged from 0.21 to 0.96 cm.

Shah *et al* (2010) found that the mean thickness of right wall from auricle region was 0.15 ± 0.01 cm in goat. The right atrial wall thickness of the male goat

ranged from 0.2 - 0.28 cm with mean of 0.25 ± 0.009 cm. Similarly, right atrial wall thickness of female goat ranged from 0.17 - 0.20 cm with average of 0.19 ± 0.002 cm (Gumansing 2015).

Bhasin (2017) observed that the right atrial wall thickness in male buffalo ranged from 0.5 cm to 1 cm with the mean of 0.75 ± 0.05 cm while same parameters in female buffaloes ranged from 0.7 cm to 1.2 cm with the mean of 0.93 ± 0.05 cm. He reported that the thickness of right atrial wall was more in female than in male buffalo.

Queiroz *et al* (2018) observed that thickness of right atrial wall in dog weighing 20.1 - 24 kg was 0.2 to 0.93 cm and mean thickness was 0.23 ± 0.06 cm, while that of dog weighing 28.1 - 32 kg was 0.2 to 0.3 cm and mean thickness was 0.25 ± 0.06 cm.

2.2.6.3 Left Ventricular wall

Malik *et al* (1972) recorded the mean thickness of left ventricular wall as 2.18 ± 0.19 cm in buffalo and 1.40 ± 0.06 cm in caprine heart. Bhattacharya *et al* (1987) measured the thickness of left ventricular wall as 1.6 cm in young and 5.5 cm in adult one horned rhinoceros. Rajpal *et al* (1989) observed that the left ventricular wall thickness was 2.83 ± 0.63 cm which revealed 1% and 43% decrease at mid and lower fifth ventricular levels respectively. Sathyamoorthy (2003) noticed that thickness of left ventricular wall was 0.50 cm in day old piglets which increased to 1.52 cm at 6 months of age. Hussain *et al* (2006) measured the thickness of left ventricle wall as 1.90 ± 0.03 cm in young and 3.17 ± 0.14 cm in adult buffaloes.

Archana *et al* (2010) reported that the thickness of left ventricular wall was 1.51 ± 0.07 cm in sheep. The mean thickness of left ventricular wall at the midpoint, between atrioventricular orifice and apex of heart, was recorded as 0.99 ± 0.05 cm in goat (Shah *et al* 2010). Gupta *et al* (2012) found the thickness of the ventricle of the heart as 1.70 ± 0.15 cm in buffalo. Panditrao (2014) observed that the thickness of left ventricular wall at upper region in male ranged between 1.31 - 1.80 cm with mean of 1.58 ± 0.08 cm and in female ranged between 1.22 - 1.90 cm with mean of 1.61 ± 0.10 cm. Thickness of left ventricular wall at middle region in male ranged between 1.35 - 2.00 cm with mean of 1.63 ± 0.10 cm while in female it ranged between 1.26 -

2.00 cm with mean of 1.68 ± 0.10 cm. Thickness of left ventricular wall of heart at lower region ranged between 1.30 - 1.80 cm with mean of 1.54 ± 0.07 cm in male but it was ranged between 1.24 - 1.95 cm with mean of 1.64 ± 0.10 cm in female. These observations were statistically highly significant between male and female sheep.

Bhasin (2017) studied that the left ventricular wall thickness in male buffalo ranged from 1.8 cm to 3.4 cm with the mean of 2.73 ± 0.13 cm while same parameters in female buffalo ranged from 1.8 cm to 3.8 cm with the mean of 2.70 ± 0.16 cm. He concluded that the left ventricular wall was thickest among all the chambers in male.

Queiroz *et al* (2018) observed that thickness of left ventricle wall in dog weighing 20.1 - 24 kg was 1.4 to 2.0 cm and mean thickness was 1.6 ± 0.35 cm, while that of dog weighing 28.1 - 32 kg was 1.1 to 2.2 cm and mean thickness was 1.75 ± 0.48 cm. Rehan and Qureshi (2007) recorded that the mean thickness of left ventricular wall of camel was 1.96 ± 0.082 cm and ranged from 0.97 to 2.45 cm.

2.2.6.4. Right Ventricular wall

Malik *et al* (1972) recorded the mean thickness of right ventricular walls in buffalo heart as 1.5 ± 0.29 cm. The same parameter was 0.74 ± 0.03 cm (Malik *et al* 1978) in caprine heart. Bhattacharya *et al* (1987) measured the thickness of right ventricular wall as 1.0 cm in young and 4.0 cm in adult one horned rhinoceros. Rajpal *et al* (1989) observed that the right ventricular wall was thinnest i.e. 1.52 ± 0.140 cm and showed 45% decrease in the middle of the ventricle.

Sathyamoorthy (2003) noticed that thickness of right ventricular wall was 0.25 cm in day old piglets which increased to 0.72 cm at 6 months of age. Hussain *et al* (2006) measured the thickness of right ventricle wall of heart as 1.49 ± 0.03 cm in young and 2.76 ± 0.12 cm in adult buffaloes. Gupta *et al* (2012) found right ventricular wall thickness as 0.79 ± 0.07 cm in buffalo. Rehan and Qureshi (2007) observed that the mean thickness of right ventricular wall of camel was 0.82 ± 0.047 cm and ranged from 0.41 to 1.66 cm.

Archana *et al* (2010) observed that the mean thickness of right ventricular wall was 0.68 ± 0.06 cm in sheep. The mean thickness of goat right ventricular wall at the midpoint, between atrioventricular orifice and apex of heart, was recorded as 0.39 ± 0.02 cm (Shah *et al* 2010). Panditrao (2014) stated that the thickness of right

ventricular wall of heart at upper region in male ranged between 0.60 - 0.90 cm with mean of 0.83 ± 0.05 cm and it was ranged between 0.60 - 0.90 cm with mean of 0.80 ± 0.04 cm in female. The thickness of right ventricular wall of heart in male at middle region ranged between 0.75 - 1.00 cm with mean of 0.92 ± 0.04 cm. while in female ranged between 0.65 - 0.95 cm with mean of 0.85 ± 0.05 cm. Thickness of right ventricular wall of heart at lower region in male ranged between 0.65 - 0.92 cm with mean of 0.85 ± 0.04 cm and it was ranged between 0.60 - 0.90 cm with mean of 0.78 ± 0.04 cm in female sheep.

Bhasin (2017) observed that the right ventricular wall thickness ranged from 1.1 cm to 1.8 cm with the mean of 1.45 ± 0.07 cm in buffalo male while same parameters in female ranged from 0.7 cm to 1.8 cm with the mean of 1.31 ± 0.09 cm. It was found that in males the right ventricular wall thickness was more than that of female buffalo.

Queiroz *et al* (2018) observed that thickness of right ventricle wall in dog weighing 20.1 - 24 kg was 0.5 to 0.90 cm and mean thickness was 0.7 ± 0.2 cm, while that of dog weighing 28.1 - 32 kg was 0.7 to 1 cm and mean thickness was 0.8 ± 0.14 cm.

2.2.6.5 Interventricular septal wall

Malik *et al* (1972) recorded the average thickness of interventricular septum in buffalo heart as 2.68 ± 0.21 cm. The thickness of interventricular septum was measured as 1.28 ± 0.04 cm (Malik *et al* 1978) in caprine heart. Sathyamoorthy (2003) noticed that thickness of interventricular septum was 0.60 cm in day old piglets which increased to 1.52 cm at 6 months of age.

Gupta *et al* (2012) found that the interventricular septal wall thickness of the heart was 2.11 ± 0.18 cm in buffalo. Panditrao (2014) observed that the thickness of interventricular septum of heart at upper region ranged between 1.21 - 1.31 cm with the mean of 1.26 ± 0.02 cm in male and it was ranged between 1.20 - 1.38 cm with mean of 1.28 ± 0.03 cm in female sheep. Thickness of interventricular septum of heart at middle region in male ranged between 1.26 - 1.33 cm with mean of 1.30 ± 0.01 cm and in female ranged between 1.28 - 1.40 cm with mean of 1.34 ± 0.02 cm. The thickness of interventricular septum of heart at lower region in male ranged

between 1.20 - 1.30 cm with mean of 1.26 ± 0.02 cm. Similarly the thickness of interventricular septum of heart at lower region in female ranged between 1.23 - 1.37 cm with mean of 1.29 ± 0.02 cm.

Bhasin (2017) observed that the interventricular wall thickness in male buffalo ranged from 1.4 cm to 3.0 cm with the mean of 2.29 ± 0.14 cm while same parameters in female buffalo ranged from 1.2 cm to 2.8 cm with the mean of 2.35 ± 0.14 cm. The interventricular wall thickness was more in female than that of male buffalo.

2.2.7 ARTERIES

2.2.7.1 Aorta

Archana *et al* (2010) observed that the aorta originated from the base of left ventricle and the wall of aorta was thicker than the wall of pulmonary artery. The thickness of the aorta wall at its origin was 0.34 ± 0.01 cm, whereas the circumference was 3.65 ± 0.29 cm in sheep.

Bhasin (2017) observed that the diameter of ascending aorta in males ranged from 1.2 cm to 2.35 cm with the mean of 1.96 ± 0.10 cm while same parameters in females ranged from 1.55 cm to 2.9 cm with the mean of 2.03 ± 0.10 . The diameter of descending aorta in males ranged between 2.2 cm to 2.9 cm with the mean of 2.62 ± 0.06 cm while same parameters in females ranged from 1.8 cm to 3.05 cm with the mean of 2.44 ± 0.09 cm. He also observed that the in female buffalo diameter of ascending aorta was more while the diameter of descending aorta was more in male buffalo than that of the ascending aorta.

2.2.7.2 Pulmonary artery

Bhattacharya *et al* (1987) measured the thickness of pulmonary artery as 0.1 cm in young and 0.8 cm in adult one horned rhinoceros. Archana *et al* (2010) stated that the pulmonary artery originated from base of right ventricle and the thickness of the pulmonary artery wall at its origin was 0.27 ± 0.02 cm, whereas the circumference was 3.45 ± 0.12 cm in sheep. Gupta *et al* (2012) measured the thickness of pulmonary artery at its origin as 0.27 ± 0.02 cm in buffalo. Sathapathy *et al* (2013) measured the diameter of pulmonary artery in young male and female goat as 1.24 ± 0.12 cm and 1.57 ± 0.24 cm, while in adult male and female as 1.45 ± 0.14 cm and 1.82 ± 0.16 cm, respectively.

The diameter of pulmonary artery in buffalo males ranged between 1.60 cm to 2.50 cm with the mean of 1.91 ± 0.09 cm while in females, the same parameters ranged between 1.35cm to 2.25 cm with the mean of 1.9 ± 0.07 cm. It was found that in male buffalo the diameter of pulmonary artery was more than that of female buffalo (Bhasin 2017).

2.3. HISTOMORPHOLOGY

Leeson *et al* (1985), Eurell and Frappier (1993) and Gumansing (2015) described that heart wall was consisted of three layers endocardium (inner layer), myocardium (middle layer) and epicardium (outer layer).

2.3.1. Endocardium

Leeson *et al* (1985) observed that endocardium was homologues, continued with tunica intima of blood vessels and covered all internal surfaces of the heart. Eurell and Frappier (1993) stated that endocardium lined all internal surfaces of the heart which consisted of innermost endothelium which continued with that of blood vessels entering and leaving the heart. It was composed of simple squamous epithelium. The middle layer was subendothelial layer consisted of narrow zone of loose connective tissue that was mainly composed of fine collagen, elastic and smooth muscle fibres toward the myocardium. The subendocardial layer was composed of connective tissue that contained blood vessels, nerves and branches of impulse-conducting system of the heart (Purkinje fibers). Dellman and Eurell (1998) described that endocardium consisted of three layers: a continuous endothelium and inner and outer subendothelial layers.

Nagpal (1977) reported that the endothelium layer on the wall of ventricles was supported by few longitudinally oriented elastic fibres and sparse quantity of collagen fibres in goat. In the deeper portion of this layer, purkinje fibres occurred in form of network whereas Ramstead and Anderson (1979) found that the subendocardium of the posterior wall of the left atrium at the junction with pulmonary veins consisted of smooth muscle cells in rat. Nagpal (1977) also found that the thickness of endocardium varied inversely with the thickness of myocardium and it also increased toward the origin of pulmonary artery in goat, while Sathyamoorthy

(2003) showed that the thickness of endocardium increased upto 2 years of age in pigs and then reduced.

Schummer *et al* (1981) noticed that the inner subendocardium of sheep and goat composed of small islets of adipose tissue, whereas outer subendocardial layer composed of loosely arranged collagen and elastic fibres. Adipose tissue was present along with blood vessels and conducting cells.

Bone (1982) reported that inner lining of the heart composed of squamous epithelium which was continuous with the endothelium of the vascular system. Bardosi *et al* (1990) and Fawcett (1994) found in human heart that the endocardium was lined by an endothelium of polygonal squamous cells which rest on the subendocardium made up of elastic fibres running parallel to endothelial layer. The elastic fibres were abundant in atrial wall and were arranged parallel to the endocardial surface (Dellman and Eurell 1998).

Terasaki *et al* (1993) in sheep found that it became continuous with smooth muscle layer within the tunica intima of pulmonary veins. In the right atrium smooth muscles were present overlying the sinu-atrial node.

The connective tissue was continuous with myocardium (Di Fiore 1989) while Sathyamoorthy (2003) reported in pigs that endocardium was attached to myocardium by a layer of elastic connective tissue. Inner subendocardial layer was composed of dense irregular connective tissue with collagen and elastic fibres. Gupta (2009) stated that the endocardium was thicker in atria as compared to ventricles in buffalo foetuses.

Ghonimi *et al* (2014) found that the endocardium consisted of three layers: a simple squamous epithelium i.e. endothelial layer, a subendothelial layer of loose connective tissue and a subendocardial layer that linked the endocardium to the myocardium and cardiomyocyte bundles of the purkinje fibres. Similarly, Bhasin (2017) reported that there were three layers of endocardium i.e. the innermost layer was formed by a continuous endocardium. The subendothelial layer situated beneath the endocardium was mainly composed of elastic fibres and loosely arranged collagen fibres. Gupta (2009) compared ventricles and atrium in buffalo foetuses and stated that the endocardium was thicker in atria than ventricles.

Bhasin (2017) stated that the endocardium lined the ventricles and atria completely and covered the cardiac valves and associated structures. The endocardium was consisted of three layers. The subendothelial layer located beneath the endocardium composed of dense irregular connective tissue and predominately composed of loosely arranged collagen and elastic fibres.

2.3.2 Myocardium

Leeson *et al* (1985) described myocardium corresponded of the tunica media which was composed of cardiac muscle. Its thickness varied in different part of the heart which was thinnest in the atria and thickest in left ventricle.

Myocardium formed the middle and thickest layer of the wall of different chambers of heart. It was thicker in ventricles as compared to atria and in the left than the right chamber. Myocardium of auricles formed of loosely arranged myocardial cells forming bundles and oriented in various directions (Banks 1993, Dellman and Eurell 1998). Sathyamoorthy (2003) in pigs and Sanchez – Quintana *et al* (2005) in human reported that myocardium of ventricular wall was arranged in three different layers – superficial (sub-epicardial), middle and deep layers. Superficial and deep layers were present in both ventricles whereas middle layer was found only in left ventricle, whereas Torrent – Guasp *et al* (2005) described that in left ventricular wall two groups of fibres could be distinguished as superficial and deep layers.

Nagpal (1977) found that myocardial cells were cylindrical with centrally located nucleus in goat. Dellman and Eurell (1998) described that the single nucleus of cardiac muscle cells was located in the centre of the cell with acidophilic cytoplasm. A network of fine reticular and collagenous fibres surrounded each cardiac muscle fibre. Nagpal (1977) reported that ventricular myocardium consisted of fibres which formed a more compact structure than that of atrium and its muscle bundles were comparatively larger and oriented in various directions viz. longitudinal, circular and oblique in goat. Collagen and elastic tissue were relatively inconspicuous in the ventricles as compared to auricles. Whereas Sathyamoorthy (2003) reported that muscle bundles were noticed as three layers viz. epimyocardium, endomyocardium and in between them, there was the thick middle layer in pig.

Terasaki *et al* (1993) noticed that the myocardial fibres of left ventricular papillary muscles were elongated and thinner at tips in human and animals, whereas Smolich (1995) described that left ventricular myocytes were larger than the right ventricular myocytes. Sommer and Johnson (1968) showed that individual cardiac myocytes were not only connected in longitudinal direction but also make lateral contacts in animals. In rats, intercalated discs appeared as prominent undulating membrane demarcating the border between two adjacent heart muscle cells. Fawcett (1994) and Zhang *et al* (1996) confirmed that cardiac muscles were joined by intercalated discs in human. Wang *et al* (1995) reported that atrial wall was consisted of circumferential and longitudinal muscle bundles, which were larger in the right atrium than left atrium.

Gumansing (2015) reported that the second layer of heart was myocardium which was composed of cardiac muscle fibres that run in different directions (complex-spiral) and usually inserted into the fibrous skeleton of the heart. It formed the main mass of the heart wall. It was the thickest layer in the heart wall which varied in different parts of the heart and thickest in the left ventricle. The myocardium was covered peripherally by the epicardium. It consisted of an inner subepicardial loose connective-tissue layer that formed protective sheaths around blood vessels and nerves. It was abundant around large subepicardial blood vessels.

Bhasin (2017) observed that the myocardium was the middle and thickest layer of the heart and was composed of bundles of cardiac muscle cells, branches of cardiac conduction fibres, an extensive capillary network and the cardiac skeleton. Bundles of cardiac muscle cells were embedded in loose connective tissue that contained dense capillary network, lymph vessels, and autonomic nerve fibres. The right ventricle contained more amount of interstitial connective tissue as compared to left ventricle. The cardiac cells of the atrium were smaller than the ventricle cardiac cells. A thin layer of fibroelastic tissue supported the mesothelium; this layer was connected to the myocardium by a broad layer of adipose tissue.

2.3.3 Epicardium

Leeson *et al* (1985) described epicardium was covered externally by single layer of mesothelial cells below which was a thin layer of connective tissue containing numerous elastic fibres.

The atrial epicardium was comparatively thicker than that of the ventricles and right atrium was covered by a more compact structure than left atrium. Its outer part was covered by a single layer of mesothelial cells supported by the fibro-elastic core (Nagpal 1977). Subepicardium was formed by compact bundles of collagenous fibers with few elastic fibers. Fawcett (1994) noticed that epicardium was lined by a single layer of fattened epithelial cells resting on a thin layer of fibro-elastic connective tissue. Dellman and Eurell (1998) found that epicardium was covered externally by the mesothelial cells. Under the epithelium was a loose connective tissue layer rich in elastic fibers that formed protective sheath around blood vessels, nerves and ganglia. Sathyamoorthy and Geetha (2008) found that epicardium was lined by flattened squamous cells.

Crick *et al* (1998) reported extensive ganglionated plexus in the epicardial tissue. Pauza *et al* (2000) noticed the high density of epicardiac ganglia near the heart hilum especially on the dorsal and dorsolateral surface of left atrium. Shimada *et al* (1985) reported in goat that capillaries of the working cardiac muscles were numerous, arranged mainly parallel to the large axis of the muscle cells and formed dense elongated networks.

Gumansing (2015) observed that the myocardium was covered peripherally by the epicardium. It consisted of an inner subepicardial loose connective-tissue layer that formed protective sheaths around blood vessels and nerves. The mesothelial cells of visceral pericardium formed the outer layer of epicardium. The epicardium continued with the parietal pericardium at the orifices of large blood vessels entering or leaving the heart. Pericardium consisted of an innermost mesothelial layer resting on a thin layer of loose connective tissue followed by thick resistant layer of collagen bundles and elastic fibres.

Bhasin (2017) stated that the myocardium was covered externally by the epicardium. Under this epithelium was present a loose connective tissue layer rich in elastic fibres that formed protective sheath around blood vessels and nerves. The epicardium reflected off the surface of the heart to form the parietal pericardium. The later was consisted of an innermost mesothelial cell layer resting on a thin layer of loose connective tissue which was fused with the fibrous pericardium, a thick layer of

collagen fibre bundles and elastic fibres. The atrium was having thick layer of epicardium as compared to the epicardium of ventricle.

2.3.4 Great vessels

2.3.4.1 Aorta

Banks (1993) described that aorta and its branches were distinguished by their great elasticity and made up of three layers from i.e. tunica intima, tunica media and tunica adventitia which were analogous to endo, myo and epicardium, respectively. Tunica intima had a large sub-endothelial layer which grew with age and its border was delineated by internal elastic membrane. Tunica media was thickest of three layers and smooth muscle cells were arranged in spiral around the long axis of the vessel. Tunica adventitia was relatively thin connective tissue layer with fibroblast, macrophages, collagen fibres and blood vessels were present in this layer. Amenta *et al* (1980) reported that the plexus of cholinergic nerve fibers consists of a superficial plexus localized in the adventitia – media transitional zone.

Al-Asadi (2017) found that the aorta consisted of three layers i.e. tunica intima, tunica media, tunica adventitia. The tunica intima contained simple squamous epithelium named as endothelium and sub endothelial layer consisted of loose connective tissue. Internal elastic lamina was located outside the tunica intima. The tunica media consisted of the smooth muscles fibres arranged in layer and occupied with the elastic as well as collagen fibres. External to tunica media was an external elastic lamina. The tunica adventitia had collagen and elastic fibre. Csibi *et al* (2017) reported that internal region of the tunica media possessed typical lamellar arrangement. The outer part of tunica media, the smooth muscle formed bundles of various sizes. Ogeng'o *et al* (2010) stated that the aortic wall consisted of tunica adventitia, media and tunica intima comprising endothelium, subendothelial zone and internal elastic lamina. Flat and round endotheliocytes comprised endothelium. Round cell population declined with the caudal growth of the internal elastic lamina. Tunica media comprised of two zones i.e. a luminal elastic and adventitial musculo-elastic zone, in which muscle islands interrupted some elastic lamellae. Sharanagouda *et al* (2016) reported that the thoracic aorta were elastic type, sub endothelial layer and indistinct internal elastic membrane and tunica intima consisted of a single layer of

flattened endothelial cells. Tunica media was thickest among the three layers and had well-defined elastic lamellae, they were separated by circularly arranged collagen fibres, smooth muscle and reticular fibres. Internal elastic membrane could not be differentiated from other elastic membranes, consisting of collagen fibres, elastic fibre, vasa vasorum and loose connective tissue fibroblasts, and tunica adventitia

2.3.4.2 Pulmonary artery

Qayyum *et al* (2001) reported that the wall of pulmonary arterial trunks in chicken and rat were made up of fibroblasts and smooth muscle surrounded by collagen and elastic fibers. Gomez *et al* (2005) further added that myocardial cells of external layer of truncus became fibroblastic and suggested that arterial valves had a dual origin: fibroblasts and mesenchymal tissue.

Castillo *et al* (2005) found that diameter of right pulmonary artery was wider than the left pulmonary artery while Szpinda *et al* (2005) noticed that a different tendency was observed for the internal diameter of both pulmonary arteries which were relatively decreased with increased foetal age. Ruano *et al* (2007) reported that mean diameter of main pulmonary artery, right pulmonary artery interspecies differences in quantity and arrangement of collagen, smooth muscle and elastic tissue in pulmonary trunk. The medial thickness of muscular pulmonary arteries was similar in man, goat, llama and monkey.

Emam and Abugherin (2019) observed in histological sections of heart from Egyptian bovines that the wall of right and left ventricles was tri-layered as endocardium, myocardium, and epicardium. The endocardium was lined with endothelium and filled with fibrous connective tissue. Purkinje fibres were present in the deep layer of the endocardium and in the myocardium and their size and the amount increased with advanced age. The hyper eosinophilic cardiac muscle cells were observed in the myocardium of ventricles suggesting hypercontraction during rigor mortis. An external layer (epicardium) was consisted of connective tissue and covered with mesothelium.

Mello de *et al* (2017) reported thickness of tunica intima was 4.03 μm , tunica media layer was 218.1 μm and tunica adventitia was 202.5 μm in the thoracic aorta of guinea pig, whereas, it was 2.68 μm , 202.5 μm and 57.9 μm in rats respectively and

tunica media was thickest among three layers. However, thickness of tunica intima was $19.64 \pm 0.39 \mu\text{m}$, tunica media was $954.80 \pm 59.15 \mu\text{m}$ and tunica adventitia was $115.3 \pm 12.00 \mu\text{m}$ in thoracic aorta of adult Deccani sheep, whereas, in adult Bidri goat it was $19.34 \pm 0.54 \mu\text{m}$, $905.67 \pm 31.73 \mu\text{m}$ and $109.75 \pm 16.34 \mu\text{m}$ respectively (Sharanagouda *et al* 2016). Bhasin (2017) stated that the left atrial wall thickness was $0.72 \pm 0.02 \mu\text{m}$ and right atrial wall thickness was $0.53 \pm 0.04 \mu\text{m}$ in male and female buffaloes. The wall thickness of the pulmonary artery was $0.45 \pm 0.02 \mu\text{m}$ and $0.49 \pm 0.02 \mu\text{m}$ and the ascending aorta wall thickness was $0.56 \pm 0.03 \text{ cm}$, and $0.62 \pm 0.02 \mu\text{m}$ in male and female buffaloes.

2.4 ECHOCARDIOGRAPHY

Allen (1982) described echocardiography as a research and clinical tool in veterinary medicine. Bonagura and Frank (1983) gave the principles of identification and interpretation of ultrasonic cardiac images. They showed that along with technical considerations, normal structures of heart can be studied by changing the angle or location of the transducer. Boon *et al* (1983) established normal values of canine echocardiogram in veterinary cardiology.

Bonagura and Frank (1983) diagnosed congenital heart defects by echocardiography and found it superior to other available non-invasive studies in the recognition and assessment of malformation of the heart. Jacobs and knight (1985) correlated echocardiographic parameters with body weight in non-anesthetized cat. A significant positive correlation to the body weight was found with aortic diameter, left atrial dimension, septal and left ventricular systolic and left ventricular diastolic wall thickness and right ventricular systolic internal dimensions.

Calvert and Brown (1986) reported that M-mode echocardiography provided a non-invasive method of evaluating cardiac chamber size, interventricular septum, left ventricular wall thickness, systolic and diastolic function.

Sisson and Schaeffer (1991) measured that left atrial, aortic, left and right ventricular internal dimensions, interventricular septal and left ventricular wall thickness increased in curvilinear fashion relative to increasing body weight. Crippa *et al* (1992) reported that the morpho-functional cardiac homogeneity was independent of size and age in Beagles aged around 28 weeks. Long *et al* (1992) found that there

was no significant difference between echocardiographic variables and body weight in national hunt horses.

Thomas *et al* (1993) recommended standardized imaging planes and displayed conventions for two-dimensional echocardiography in dog and cat. They concluded that two-dimensional echocardiographic, performed systematically using multiple imaging planes, allowed accurate detection and localization of cardiac and pericardial masses in dogs and was useful in predicting surgical accessibility of these lesions.

Rishniw and Erb (2000) evaluated 2-D echocardiographic methods of assessing left atrial size in dog. They found strong associations of left atrial dimensions with body weight ($r^2 = 0.76-0.88$).

Braun *et al* (2001) reported that poor quality image were due to the restlessness in the cattle and buffalo. Strattner *et al* (2002) observed that the quality of the image mainly dependent on the animal size.

Hansson *et al* (2002) measured left atrium (LA) and aorta (Ao) by two dimensional echocardiography (2-D) and compared it to M-mode method. The most important difference between the 2-D and the M-mode method was that 2-D measured the left atrium body rather than the left auricle or underestimated left atrium body dimensions. There was no difference between the two indices (LA/Ao-2-D and LA/Ao-M).

O'Leary *et al* (2003) reported that normal echocardiographic parameters varied between breeds with body size. They determined the range of various cardiac parameters using echocardiography in apparently normal, healthy English Bull Terriers. These dogs had greater left ventricular wall thickness and smaller aortic root diameters than those reported as normal for other breeds of comparable body size. Cornell *et al* (2004) found that the various variables that could influence echocardiographic evaluation of systolic function included age, sex, breed, weight and other co-morbid factors.

Oyama (2004) introduced the advancement in echocardiography and explained that echocardiography was highly operator dependent and relied on the proper acquisition and interpretation of results by an examiner who was familiar with the principles, capabilities, and limitations of ultrasound imaging. He reviewed the basics

of echocardiography, measurements of cardiac dimensions, and assessment of cardiac function and introduced emerging technologies that expanded the capabilities of the echocardiographic examination. Two dimensional echocardiography revealed thickening of the left ventricular free wall, interventricular septum, possibly right ventricular free wall in cases of hypertrophic cardiomyopathy in dogs.

Oyama and Sisson (2005) assessed cardiac chamber size using anatomical M-mode (AMM) and compared the results of the AMM and conventional M-mode (CMM) with 2-dimensional (2D) study via linear regression and calculation of coefficient of correlation. In healthy dogs, cardiac AMM measurements were associated with greater accuracy and less variability than CMM. It was concluded that AMM had potential to improve quantification of cardiac dimensions.

Synder *et al* (2005) evaluated healthy, non-exercising, awake Greyhounds to reveal substantial differences in left ventricular cavity dimensions, wall thickness, systolic time intervals and fractional shortening as compared to previously reported normal echocardiographic values obtained from mongrels and various other breeds. Muzzi *et al* (2006) found that adult German Shepherd dogs had larger ventricular dimensions and wall thickness than other small breeds. There was gender difference in right and left ventricular dimensions.

Borgarelli *et al* (2007) reported that fractional shortening was an important parameter to distinguish between hypertrophic and dilated cardiomyopathy. Yadav (2011) found a linear trend with body weight i.e. with increase in body weight; there was an increase in these parameters. Ultrasonography of the normal bovine heart had been described and used mainly as the method of choice for diagnosing traumatic pericarditis (Braun 2009).

El-Khodery *et al* (2010) observed ultrasonographic appearance and dimensions of the heart at 3-6 intercostal space on both sides of the thorax. On the right side, right and left ventricles were visualized in the caudal short axis. On the left side, right and left ventricles and the ventricular outflow could be imaged; however, the pulmonary artery was poorly visualized. During systole and diastole, size of the ventricles was significantly greater during diastole than systole ($P < 0.01$) and

dimensions of the left ventricle were greater than those of right ventricle. In systole, the dimensions of the interventricular septum and left ventricular free wall were greater than diastole ($P < 0.01$, respectively). The pulmonary artery diameter was greater in diastole than systole ($p < 0.01$). They concluded that ultrasonography could provide accurate reference values for cardiac dimensions in buffaloes and was a useful non-invasive technique.

Tharwat *et al* (2012) observed a caudal-long axis view of ventricles, atrium and interventricular septum on the right hand at 5th or 4th intercostal space (ICS) in camel and showed that it was possible to obtain good quality echocardiograms and normal cardiac dimensions.

Paslawska *et al* (2014) found that the left wall and internal ventricular diameter increased with increasing age and body weight in domestic swine. They observed a positive relation between body weight and fractional shortening, ejection fraction and body weight as well as between body weight, age and ratio of left ventricular internal diameter to its wall thickness as well as relative left atrial size.

The reference values of two dimensional, M-mode and Doppler derived echocardiographic parameters in sedated healthy female sheep (aged > 400 days) were established by Poser *et al* (2013). Hassan and Torad (2015) reported a weak linear correlation between the echocardiographic measurement and the body weight in left ventricular internal diameter in diastole and systole in healthy donkey.

Puri (2016) found significant differences except for the percentage thickening of interventricular septum, percentage thickening of left ventricular posterior wall in buffalo and cattle calves. Other parameters were significantly higher in healthy buffalo calves ($P < 0.05$) as compared to cattle calves.

Singh (2017) concluded that the most suitable windows for short axis as well as for long axis in two dimensional echocardiography in cattle and buffaloes were 3rd - 4th intercostal space on right side whereas 3rd - 5th intercostal space on the left side of hemi-thorax. M-mode echocardiography could be performed at a distance of 8- 12 cm above the olecranon in right parasternal long axis and short axis in cattle and buffalo from the 4th intercostal space.

2.4.1 Atrium

Yamaga and Too (1986) found the left atrial dimension as 56 mm in cow. Hallowell *et al* (2007) found the left atrial diameter in systole as 10.9 ± 0.5 cm in Jersey cow while 12 ± 1.2 cm in Holstein-Friesian cow. Tharwat *et al* (2012) found the left atrium diameter in systole as 5.6 cm and in diastole 7.6 cm in camel. Sabev (2014) found that the mean left atrial diameter in diastole as 11.8 ± 0.6 cm and at systole as 6.24 ± 0.3 cm in warm blooded horses. The mean right atrial diameter in diastole was 5.9 ± 1.9 cm and at systole was 6 ± 0.1 cm. Gugjoo *et al* (2014) found the mean left atrial diameter was 21.93 ± 0.37 mm in labrador retriever dogs.

Torad *et al* (2016) found the left atrial diameter in diastole as 4.02 ± 0.15 cm in small buffaloes and 4.81 ± 0.97 cm in large buffaloes. Singh *et al* (2017) found the left atrial diameter in systole as 24.36 ± 1.00 mm and in diastole as 21.76 ± 0.83 mm in goat. Whereas the left atrial posterior wall thickness at diastole was 11.04 ± 0.51 mm and at systole was 9.15 ± 0.51 mm.

Saini *et al* (2017) found the mean left atrial diameter as 2.69 ± 0.05 mm in Labrador Retriever dog. Bhasin (2017) observed that the thickness of the left atrium wall ranged from 0.51 cm to 1.37 cm with a mean of 0.96 ± 0.08 cm in buffalo males whereas the same parameters ranged from 0.72 cm to 1.35 cm with a mean of 1.10 ± 0.05 cm in female buffalo. Szalus-Jordanow *et al* (2017) found the mean left atrial diameter as 3.29 ± 0.41 cm in the adult dairy goat. Moura *et al* (2019) found that the mean left atrial diameter was 2.01 ± 0.2 cm in Peccaries.

Torad *et al* (2016) found the right atrial diameter in diastole as 2.1 ± 0.18 cm in small buffaloes and 2.79 ± 0.25 cm in large buffaloes. Bhasin (2017) found that thickness of the right atrium varied from 0.38 cm to 1.11 cm in buffalo males with a mean of 0.79 ± 0.06 cm, whereas the same parameters varied from 0.6 cm to 1.46 cm in buffalo females with a mean of 0.96 ± 0.07 cm. It was found that the thickness of the right atrial wall was greater in female than in male buffalo that was consistent with the biometric findings.

2.4.2 Ventricle

Yamaga and Too (1986) found the left ventricular wall thickness in diastole as 21 mm and in systole as 37 mm in normal cow. Hallowell *et al* (2007) found the left

ventricular diameter in diastole as 7.7 ± 0.7 cm in Jersey cow while 8.7 ± 1.0 cm in Holstein-Friesian cow while the same parameters in systole varied from 4.2 ± 0.53 cm in Jersey cow while 4.2 ± 0.8 cm in Holstein-Friesian cow. Tharwat *et al* (2012) found the left ventricle wall thickness in diastole as 2.8 cm and in systole as 1.9 cm in adult healthy camel.

Anuradha *et al* (2013) found the thickness of left ventricle wall as 1.57 mm in sheep, 1.42 mm in goat, 1.23 cm in pig and 1.85 cm in buffalo. Torad *et al* (2016) found the left ventricle wall thickness in diastole as 1.83 ± 0.21 cm in small buffaloes and 2.56 ± 0.19 cm in large buffaloes. Bhasin (2017) found that left ventricular wall thickness was 2.66 ± 0.11 cm during diastole and 3.13 ± 0.15 cm during systole in male buffalo, while the left ventricular wall thickness was found to be 2.63 ± 0.12 cm during diastole and 3.08 ± 0.12 cm during systole in female buffalo. It was concluded that the thickness of the left ventricular wall was higher in the female than in the male buffalo.

Yamaga and Too (1986) found the right ventricular wall thickness as 9 mm in normal cow. Hallowell *et al* (2007) found the right ventricular diameter in diastole as 2.45 ± 0.53 cm in Jersey cow while 2.27 ± 0.76 cm in Holstein-Friesian cow whereas the same parameters in systole varied from 1.32 ± 0.63 cm in Jersey cow while 1.14 ± 0.43 cm in Holstein-Friesian cow. Tharwat *et al* (2012) found the right ventricle wall thickness in diastole as 1.8 cm and in systole as 1.5 cm in camel.

Anuradha *et al* (2013) found the thickness of right ventricle wall as 0.65 mm in sheep, 0.64 mm in goat, 0.78 cm in pig and 0.54 cm in buffalo. Torad *et al* (2016) found the right ventricle wall thickness in diastole as 2.17 ± 0.24 cm in small buffaloes and 3.11 ± 0.35 cm in large buffaloes.

Bhasin (2017) recorded that right ventricular wall thickness as 1.98 ± 0.09 cm during diastole and 2.42 ± 0.08 cm during systole in male buffalo. Whereas the right ventricular wall thickness was found to be 1.85 ± 0.11 cm during diastole and 2.24 ± 0.13 cm during systole in female buffalo.

Yadegari (2014) found the mean left ventricle internal diameter at diastole as 2.94 ± 0.18 cm and at systole as 1.28 ± 0.11 cm in sheep. The mean right ventricle internal diameter at diastole as 1.44 ± 0.05 cm and at systole as 0.38 ± 0.05 cm.

Gugjoo *et al* (2014) found the mean left ventricle internal diameter at diastole as 37.58 ± 1.05 mm and at systole as 23.98 ± 0.97 mm in Labrador retriever dog. Sabev (2014) found the mean left ventricle internal diameter at diastole as 11.2 ± 0.9 cm and at systole as 7.4 ± 0.7 cm in horses.

Saini *et al* (2017) found the mean left ventricle internal diameter at diastole as 3.7 ± 0.06 cm and at systole as 2.5 ± 0.06 cm in Labrador retriever dog. The mean right ventricle internal diameter at diastole was 1.08 ± 0.05 cm in Labrador retriever dog.

Singh *et al* (2017) found the left ventricle diameter in systole as 19.20 ± 1.19 mm and left ventricle diameter in diastole as 29.54 ± 1.29 mm in goat. Szalus-Jordanow *et al* (2017) found that the mean left ventricle internal diameter at diastole was 4.17 ± 0.48 cm and at systole was 2.48 ± 0.38 cm in goat. The mean right ventricle internal diameter at diastole was 1.04 ± 0.36 cm.

Tejaswini *et al* (2018) found that the mean left ventricle internal diameter at diastole was 2.73 ± 0.07 cm and at systole was 1.66 ± 0.08 cm in the goat. The left ventricle posterior wall thickness at diastole was 8.75 ± 0.26 mm and at systole was 12.08 ± 0.4 mm.

Singh *et al* (2018) measured the left ventricle internal diameter in systole as 4.37 ± 0.12 (2.04-5.82) cm and left ventricle internal diameter in diastole as 7.35 ± 0.14 (4.82-9.23) cm in Holstein Friesian cow. The right ventricle internal diameter at diastole was 3.40 ± 0.06 (2.61-4.42) cm. Moura *et al* (2019) found the mean left ventricle internal diameter at diastole as 2.60 ± 0.6 cm and at systole as 1.92 ± 0.43 cm in Peccaries.

2.4.3 Interventricular septum

Yamaga and Too (1986) found the interventricular septal wall thickness as 21 mm in cow. Hallowell *et al* (2007) found the interventricular septal diameter in diastole as 2.0 ± 0.4 cm in Jersey cow and 2.2 ± 0.51 cm in Holstein-Friesian cow whereas the same parameters in systole varied from 3.6 ± 0.5 cm in Jersey cow and 3.4 ± 0.5 cm in Holstein-Friesian cow.

Tharwat *et al* (2012) found the interventricular septal wall thickness in diastole as 2.1 cm and in systole as 2.8 cm in camel. Anuradha *et al* (2013) found the

thickness of interventricular septal wall as 0.99 mm in sheep, 1.32 mm in goat, 1.27 cm in pig and 1.85 cm in buffalo. Torad *et al* (2016) found the interventricular septal wall thickness in diastole as 1.32 ± 0.17 cm in small buffalo and 1.86 ± 0.21 cm in large buffalo while the same parameters in systole varied from 2.0 ± 0.09 cm in small buffalo and 2.59 ± 0.24 cm in large buffalo.

Yadegari (2014) found the interventricular septum thickness in systole as 1.45 ± 0.16 cm and in diastole as 0.92 ± 0.11 cm in sheep. Gugjoo *et al* (2014) found the interventricular septum thickness in systole as 14.47 ± 0.64 mm and in diastole as 9.06 ± 0.37 mm in labrador retriever dog. Sabev (2014) found the interventricular septum thickness in systole as 3.8 ± 0.3 cm and in diastole as 2.9 ± 0.2 cm in horse.

Singh *et al* (2017) found the interventricular septum thickness in systole as 11.16 ± 0.39 mm and in diastole as 8.32 ± 0.26 mm in goat. Saini *et al* (2017) found the interventricular septum thickness in systole as 1.41 ± 0.05 cm and in diastole as 1.15 ± 0.03 cm in labrador retriever dog. Bhasin (2017) noted the interventricular septum thickness ranged from 1.25 cm to 2.87 cm with a mean of 2.36 ± 0.11 cm in male buffalo, while the same parameters varied from 1.08 cm to 3.21 cm in female buffalo with a mean of 2.41 ± 0.14 cm. It was found that in female buffalo the thickness of the interventricular septal wall was greater than male buffalo.

Szalus-Jordanow *et al* (2017) found the interventricular septum thickness in systole as $1.04 \pm 0.96 - 1.14$ cm and in diastole as 0.84 ± 0.14 cm in goat. Tejaswini *et al* (2018) found the interventricular septum thickness in systole as 1.07 ± 0.02 cm and in diastole as 0.80 ± 0.02 cm in goat. Singh *et al* (2018) found the interventricular septum thickness in systole as $2.72 + (1.77 - 3.81)$ cm and in diastole as 1.88 ± 0.06 (0.95 - 3.17) cm in Holstein Friesian cow. Moura *et al* (2019) found the interventricular septum thickness in systole as 0.94 ± 0.05 cm and in diastole as 0.49 ± 0.03 cm in Peccaries.

2.4.4 Arteries

2.4.4.1 Aorta

Yamaga and Too (1986) measured aortic root dimensions as 70 mm in cow. Hallowell *et al* (2007) measured the aortic diameter in diastole as 5.0 ± 0.26 cm in Jersey cow and 6.4 ± 0.62 cm in Holstein-Friesian cow. Tharwat *et al* (2012) found

the aortic diameter in diastole as 7.0 cm in camel. Torad *et al* (2016) found the aortic diameter at the level of valve leaflets as 3.11 ± 0.10 cm in small buffalo and 3.96 ± 0.31 cm in large buffalo while the aortic diameter at the level of sinus of valve was 3.37 ± 0.19 cm in small buffalo and 4.15 ± 0.29 cm in large buffalo.

Singh *et al* (2017) measured the aortic diameter in systole as 22.72 ± 0.86 mm and aortic diameter in diastole as 20.39 ± 0.81 mm in goat. Szalus-Jordanow *et al* (2018) reported the aortic diameter as 2.7 ± 0.27 cm in goat. Yadegari (2014) measured the aortic diameter as 2.03 ± 0.09 cm in sheep. Gugjoo *et al* (2014) measured the aortic diameter as 23.63 ± 0.40 cm in labrador retriever dogs. Sabev (2014) found the aortic diameter in systole as 8.1 ± 0.5 cm and aortic diameter in diastole as 7.8 ± 0.6 cm in horse. Moura *et al* (2019) measured the aortic diameter as 1.47 ± 0.13 cm in Peccaries.

Saini *et al* (2017) found the aortic diameter as 2.22 ± 0.04 in labrador retriever dog. Bhasin (2017) reported that the wall thickness of the ascending aorta ranged from 0.56 cm to 0.94 cm with a mean of 0.65 ± 0.03 cm in male buffalo, while the same parameters ranged from 0.39 cm to 1.33 cm with a mean of 0.78 ± 0.07 cm in female buffalo. The wall thickness of the descending aorta ranged from 0.64 cm to 1.19 cm with a mean of 0.84 ± 0.04 cm in male buffalo, while the same parameters ranged from 0.67 cm to 1.49 cm with a mean of 0.89 ± 0.06 cm in female buffalo.

2.4.4.2 Pulmonary artery

Hallowell *et al* (2007) measured the pulmonary artery diameter in diastole as 4.2 ± 0.27 cm in Jersey cow and 5.5 ± 0.8 cm in Holstein-Friesian cow. Hallowell *et al* (2012) recorded the pulmonary artery diameter as 2.38 ± 0.21 cm in sheep.

Bhasin (2017) found that pulmonary artery wall thickness varied from 0.41 cm to 0.76 cm with a mean of 0.55 ± 0.03 cm in male buffalo, whereas the same parameters varied from 0.40 cm to 0.86 cm with an average of 0.60 ± 0.04 cm in female buffalo. It was concluded that pulmonary artery wall thickness was more in female than male buffalo.

CHAPTER III

MATERIALS AND METHODS

3.1 Collection of samples

The gross morphological, biometrical, micrometrical and ultrasonographic studies were conducted on heart of buffalo, sheep and goat (n=12 each) collected from slaughter house. The ultrasonographic studies were also done on buffaloes presented to the teaching Veterinary hospital, GADVASU, Ludhiana for elective surgeries like castration, supra-numerary teats, medial patellar desmotomy and post fracture repair follow up etc. Echocardiography of sheep and goat heart was done on animals from Department of Livestock Production and Management, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana

3.2 Gross morphological observations

The gross anatomical studies were conducted on external and internal structures of all the four chambers of heart in buffalo, sheep and goat. Immediately after slaughtering, the heart were collected by opening the thoracic cavity and study were conducted on external and internal structures of all the four chambers of heart of buffalo, sheep and goat.

3.3 Biometrical observations

After gross anatomical studies, the hearts were subjected to biometrical analysis. The weight of heart samples were measured by weighing balance, volume by water displacement method, circumference at base, length of anterior and posterior border by calibrated scale and inelastic thread, and thickness of right and left ventricular wall and interventricular septum by digital vernier calipers.

3.4 Fixation and processing

After biometrical observations, the small pieces of 0.5 cm thickness were collected from following locations for histological and micrometrical observations:

- i) Left and right atrial wall
- ii) Left and right ventricular wall
- iii) Interventricular septum
- iv) Aorta and Pulmonary artery

The tissue samples collected from above mentioned locations in buffalo, sheep and goat heart were fixed in 10% neutral buffered formalin (NBF). Once the fixation was achieved, the tissues were processed for paraffin block preparation by acetone-benzene schedule (Luna 1968). The blocks were prepared and sections of 5-7 μm thickness were cut and obtained on clean glass slides with rotary microtome. The paraffin sections were stained with hematoxylin and eosin stains to study the histomorphology and micrometry.

3.5 Histomorphological studies

The histomorphological parameters related to comparison of endocardium, myocardium and epicardium were recorded in atrium and ventricle of buffalo, sheep and goat. The histoarchitecture of Purkinje fibres was observed in the different animals studied. The histology of interventricular septum, aorta and pulmonary artery was also studied in different animals. The observations were recorded and necessary photomicrographs were taken under digital microscope Nikon 80 i.

3.6 Micrometrical studies

Micrometrical observations were recorded on hematoxylin and eosin stained sections with the help of image analysis system loaded in digital microscope micrometer. The thickness of wall of aorta and pulmonary artery were measured.

3.7 Echocardiographic studies

The echocardiographic studies were conducted on the heart of buffalo, sheep and goat (12 each). Echocardiographic examination of heart was done on buffalo in standing position from left side and right side (2nd to 8th intercostal space) and in sheep and goat in right and left parasternal recumbency (2nd to 8th intercostal space) by using 3.5-MHz convex transducers and care was taken to keep the animals as still as possible with manual restraint. The hair were clipped and shaved on both sides from the 1st to 9th intercostal space and the area was scrubbed with alcohol to remove excess oil and coupling gel was applied. In the cardiac area, the heart was thoroughly imaged. The thickness of wall and diameter of left and right atrium, thickness of wall and diameter of left and right ventricles and thickness of interventricular septum was measured. The thickness of wall and diameter of aorta and pulmonary artery was also

measured. The echocardiographical data was compared with biometrical, and micrometrical values.

3.8 Statistical analysis

All the biometrical, micrometrical and echocardiographical parameters were statistically evaluated using Microsoft Excel version 2007 and SPSS software having inbuilt function for statistical analysis. Mean and standard error for morphometric measurements were computed and statistically analyzed for their significance (Snedecor and Cochran 1994).

CHAPTER IV

RESULTS AND DISCUSSION

The present study was undertaken to elucidate gross anatomical, biometrical, echocardiographical and micrometrical studies in the heart of buffalo, sheep and goat.

4.1 GROSS ANATOMICAL STUDIES

Heart was located in lower ventral part of mediastinal space between lungs from 3rd to 6th intercostal space in all the three species studied. The heart was conical in shape with pointed apex and broad base in buffalo (Fig 1A), triangular in shape with blunt apex in sheep (Fig 2A) and goat (Fig 3A). The base of the heart was directed dorsally whereas the apex lied above the last segment of the sternum in buffalo, sheep and goat. Similar findings have been reported in sheep (Panditrao 2014), goat (Gumansing 2015) and buffalo (Bhasin 2017).

The heart had two borders (anterior and posterior) and two surfaces (right and left) (Figs 1A and B, 2A and B, 3A and B). The right surface was formed mainly by the right ventricle (Figs 1B, 2B and 3B). A small part of it was formed by left ventricle whereas the left surface was formed by more than one-third by right ventricle and rest by left ventricle in buffalo, sheep and goat (Figs 1A, 2A and 3A). The anterior border was convex and curved ventrally and was present parallel to the sternum. The posterior border was vertical in all the hearts studied and laid with anterior border of 6th rib in buffalo, sheep and goat. Similar findings have been reported in buffalo (Malik *et al* 1972 and Bhasin 2017), sheep (Panditrao 2014) and goat (Gumansing 2015).

The divisions of heart into four chambers were indicated on surface by grooves. There were one transverse and three longitudinal grooves on external surface of the heart in buffalo, sheep and goat. These grooves were occupied by coronary vessels and fat. The amount of fat was highest in buffalo (Figs 1A and B) followed by goat (Figs 3A and B) and lowest in sheep (Figs 2 A and B). The coronary transverse groove encircled the heart except conus arteriosus and indicated the separation of atria from ventricles and was occupied by the coronary vessels. Similar findings have been reported by Malik *et al* (1978) in caprine heart, Schummer *et al* (1981) in ox, Panditrao (2014) in sheep and Bhasin (2017) in buffalo.

All the three longitudinal grooves (left, right and intermediate) were seen on external surface of ventricles. The right longitudinal groove was on the right surface and was posterior in position. It began at coronary groove below the termination of posterior vena cava and moved downward towards apex and joined the left longitudinal groove almost in centre of anterior border in buffalo, sheep and goat (Figs 1B, 2B and 3B). The left longitudinal groove was more prominent than the right longitudinal groove (Figs 1A, 2A and 3A). The short and shallow intermediate groove extended from coronary groove down the left side of posterior border up to middle of ventricle. This was in agreement with findings of Ghoshal (1971) in ox, Dyce *et al* (1996) in dog and Pasquini *et al* (2007) in domestic animals.

4.1.1 Right Atrium

The right atrium was situated at right anterior part of the base of the heart and was having two parts: sinus venarum and auricle in all animals studied (Figs 1A and B, 2A and B, 3A and B). The anterior and posterior venacava and coronary sinus opened in the sinus venarum. The right auricle was blind pocket of aorta and was characterized as meshwork of pectinate muscles. Similar finding have been reported earlier by Getty (1975) in domestic animals and Crick *et al* (1998) in pigs.

The wall of right atrium was not uniformly thick because of presence of terminal crest and pectinate muscles on its internal surface. In between the pectinate muscles small depression were found and was named as vena cordis parva (Figs 1C and D, Figs 2C and D, Figs 3C and D). In the posterior part of auricle anterior venacava opened at upper and back part whereas posterior venacava opened at lower and back part of right auricle just above the interventricular groove in straight line with anterior venacava. Coronary sinus which delivered blood from heart itself opened ventral to posterior venacava opening and vena hemiazygos opened into coronary sinus in all the heart studied. The opening into the right ventricle was right atrio-ventricular opening (Figs 1C and D, Figs 2C and D, Figs 3C and D). The present findings are in accordance with the Schummer *et al* (1981) in ox, Panditrao (2014) in sheep and Bhasin (2017) in buffalo.

4.1.2 Left Atrium

It was situated at the posterior part of base of heart, behind and to the left of the right atrium in buffalo, sheep and goat. It lied behind the pulmonary artery and aorta and above the left ventricle in all the three species studied (Figs 1A, 2A and 3A). Similarly, Dyce *et al* (1996) and Pasquini *et al* (2007) reported that left atrium was seen on the left side of heart caudal to the pulmonary trunk where the pulmonary veins opened.

The ventral border of left atrium had several notches (Figs 1A, 2A and 3A). Similarly, Bhasin (2017) noticed several notches which were more distinct in left auricle of buffalo. On contrary to this indistinct notching in horse and smooth ventral border of left auricle was observed in dog (Schummer *et al* 1981).

Seven to eight pulmonary veins opened into the atrium behind and on the right side. The pointed blind end of the auricle was behind the origin of pulmonary artery. The left atrio-ventricular opening was triangular. (Figs 1C and D, 2C and D and 3C and D) This was in agreement with findings of Ghoshal (1971) in ox, Dyce *et al* (1996) in dog and Pasquini *et al* (2007) in domestic animals.

4.1.3 Right Ventricle

The right ventricle was triangular in shape with the base formed by right atrio-ventricle orifice. Its left part was projected higher and continued into root of pulmonary artery and was known as conus arteriosus (Figs 1A and D, 2A and D, 3 A and D). Similarly, Bhasin (2017) reported that right ventricle formed most of the right side of heart and wrapped around the cranial side of heart to continue as pulmonary trunk in buffalo.

The anterior wall of right ventricle formed the anterior border of the heart while its posterior wall was formed by the interventricular septum (Figs 1C, 2C, 3C). In the transverse section it was crecentric in shape and had tri-cuspid valve which were made of short cylindrical curtain of fibrous tissue which projected into ventricle formed margin of atrio-ventricle orifice (Figs 1E and F, 2E and F, 3 E and F). The bases of valve touched one another and were named as infundibulum, marginal and septal depending on their position. Similar findings have been reported in male and female buffalo by Bhasin (2017).

The chordae tendinae were the fine fibrous cord which attached the cusps to the papillary muscles projecting from the ventricle wall (Figs 1C and D, 2C and D and 3C and D). Each cusp received chordae tendinae from two papillary muscles and vice-versa in all the heart studied. These findings were in close proximity with the observations of Motabagani (2006) in human and mammalian species and Bhasin (2017) in buffalo heart.

Three type of trabeculae carneae were found in the ventricular wall. First one was attached to the wall of ventricle in the whole length and were known as ridges of relief. Second one were attached at both ends and were free in middle called moderator band while third one known as papillary muscles. Similarly, Sathyamoorthy (2003) in pig found that right ventricle had three papillary muscles namely musculi papillaris magnus, musculi papillaris parvi and musculi papillaris sub arteriosus, and Motabagani (2006) reported that musculi papillaris was on the free wall while other two were on the inter-ventricular septum in human and some mammalian species.

The moderator band was a cord of myocardium crossing the lumen connecting the interventriculum septum to the opposite wall present midway between base and apex of heart. In buffalo and sheep, the right moderator band in the right ventricle was single and unbranched, but in goat, it was single and branched. Similarly, Crick *et al* (1998) in pigs and Sathyamoorthy (2003) in pig reported that moderator band extended from the anterior side of the base of musculi papillaris magnus in the base of musculi papillaris sub-arteriosus.

4.1.4 Left Ventricle

The left ventricle was conical in shape having base above and apex of left ventricle formed the apex of heart and was present approximately at sixth intercostal space in buffalo, sheep and goat heart (Fig 1C and D, 2C and D and 3C and D). The left ventricle formed left caudal part of ventricular mass and its wall was much thicker than right ventricle (Crick *et al* 1998).

The chordae tendinae were larger than right ventricle but were fewer in all the three animals studied. The trabeculae carneae resembled that of right ventricle while it had only two bundles of papillary muscles instead of three bundles as in right

ventricle. On contrary to present findings Ramsheyi *et al* (1996) classified the papillary muscles of left ventricle into four types based on the way that they related to the leaflets via chordae. Moderator band was comparatively thinner than right ventricle. The moderator band of left ventricle was single and highly branched in buffalo, but there was three moderator bands (small, medium and large sized) present in the left ventricle of sheep and goat. Similar findings have been reported by Hareeswaraiah *et al* (2019).

Interventricular septum was concave towards the left ventricle, so the transverse section of the cavity was nearly circular. The greater part of it had approximately same thickness as the left ventricular wall (Fig 1F, 2F and 3F) and was muscular in nature whereas the small portion of upper part was membranous and thin and lied between pulmonary and aortic orifices. Dyce *et al* (1996) stated the three semilunar cusps attached to the aortic fibrous ring in the origin of aorta.

4.1.5 Aorta

Aorta arose from the base of left ventricle (Fig. 1C, 2C and 3C) and its opening was guarded by three semilunar cusps (anterior, right posterior and left posterior). From the anterior and left posterior sinuses of valvular coronary arteries arose. Sakabe *et al* (2006) found that at the union of ascending aorta with the aortic arch, the calibre of vessel was increased and termed as the bulb of aorta. These findings were in close proximity with the observations of Bhasin (2017) in male and female buffalo.

4.1.6 Pulmonary artery

Pulmonary artery was large trunk which carried blood from right ventricle to the lungs. The opening of right ventricle into pulmonary trunk was guarded by three semilunar cusps (medial, lateral and posterior) (Figs 1E, 2E and 3E) in all the three types of animals studied.

4.1.7 Pulmonary vein

Pulmonary veins returned blood from the lungs to the left atrium of heart. There are 6-7 pulmonary veins present in buffalo whereas these were three in sheep and goat. Similar findings have been reported by Hareeswaraiah *et al* (2019) in domestic animals.

4.2 BIOMETRY

4.2.1 Size and shape

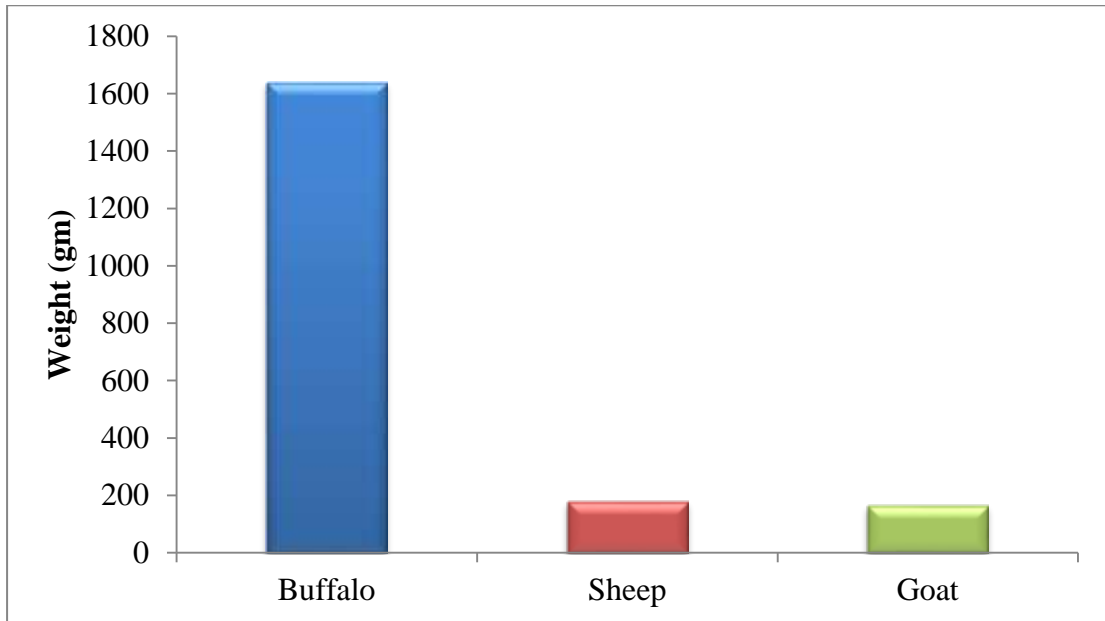
The heart was like a blunt cone with broad base and pointed apex in buffalo and triangular in sheep and goat. Bhasin (2017) reported that the heart was like a blunt cone with broad base and pointed apex in males whereas in females the base of heart was wider as compared to males. Getty (1975) stated that size and form of the heart varied according to the degree of its contraction and relaxation. Dyce *et al* (1996) reported that size of heart varied considerably among species and also among individuals. Some breeds of sheep and goat heart were relatively long and narrow and in others much wider and shorter. However (Crick *et al* 1998) stated that the human heart had trapezoidal and pig heart had classic valentine shape.

4.2.2 Weight

The heart weight varied from 1150 gm to 2205 gm (Table 1 and Graph 1) with the mean of 1638.66 ± 69.29 gm in buffalo. Similar findings have been reported in cattle (Rajpal *et al* 1989, Leinder 1996, Mohan and Prakash 1997 and Miglimo and Amorim 1998) and buffalo (Malik *et al* 1972, Miller 2004, Hussain *et al* 2006, Panhwar *et al* 2007, Shahida *et al* 2007, Hussain and Qureshi, 2007). However, Bhasin (2017) found the heart weight in male buffalo as 3120 ± 155.97 gm and in female as 3350 ± 145.51 gm.

The weight of heart varied from 159.72 gm to 199.73 gm (Table 1 and Graph 1) with the mean of 178.45 ± 3.54 gm in sheep, whereas in goat it varied from 112.73 gm to 228.88 gm (Table 1 and Graph 1) with the mean of 165.10 ± 10.91 gm. Similar findings have been reported by Chakravarthy and Sastry (1979), Shah *et al* (2010) Sathapathy *et al* (2013) Gumansing (2015) in goat. Whereas Malik *et al* (1978) measured the mean weight of heart as 66.70 ± 1.43 gm in goat,

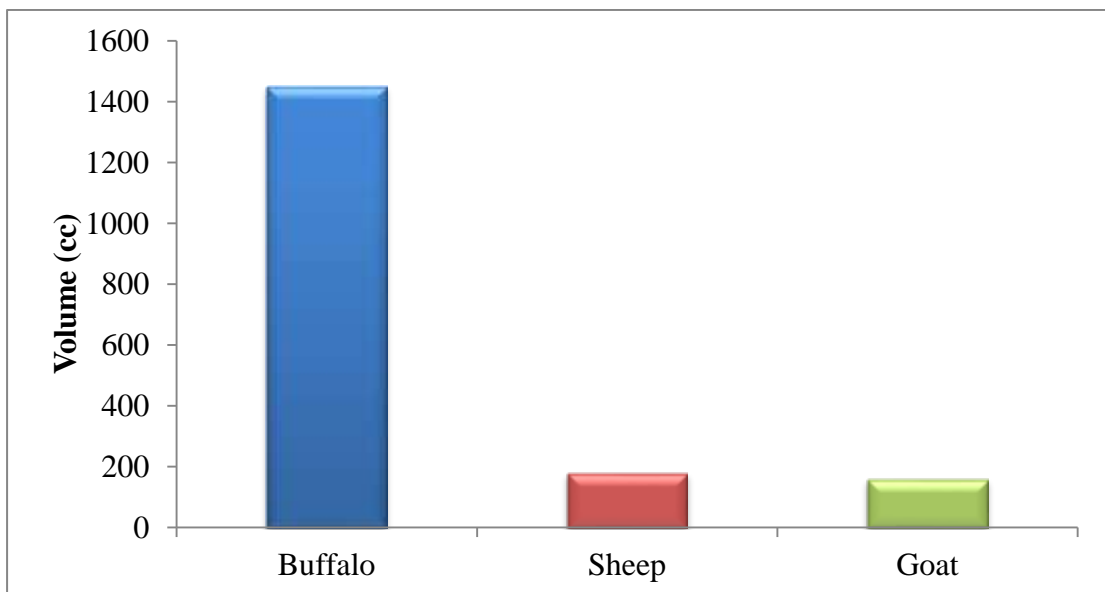
There was significant difference in weight at $p \leq 0.05$ level of significance in buffalo (1638.66 ± 69.29 gm) as compared to sheep (178.45 ± 3.54 gm) and goat (165.13 ± 10.91 gm), but no significant difference was observed between the right of heart of sheep and goat. This may be due to the variation in size of heart and body weight of animal.



Graph 1: Weight of heart in buffalo, sheep and goat

4.2.3 Volume

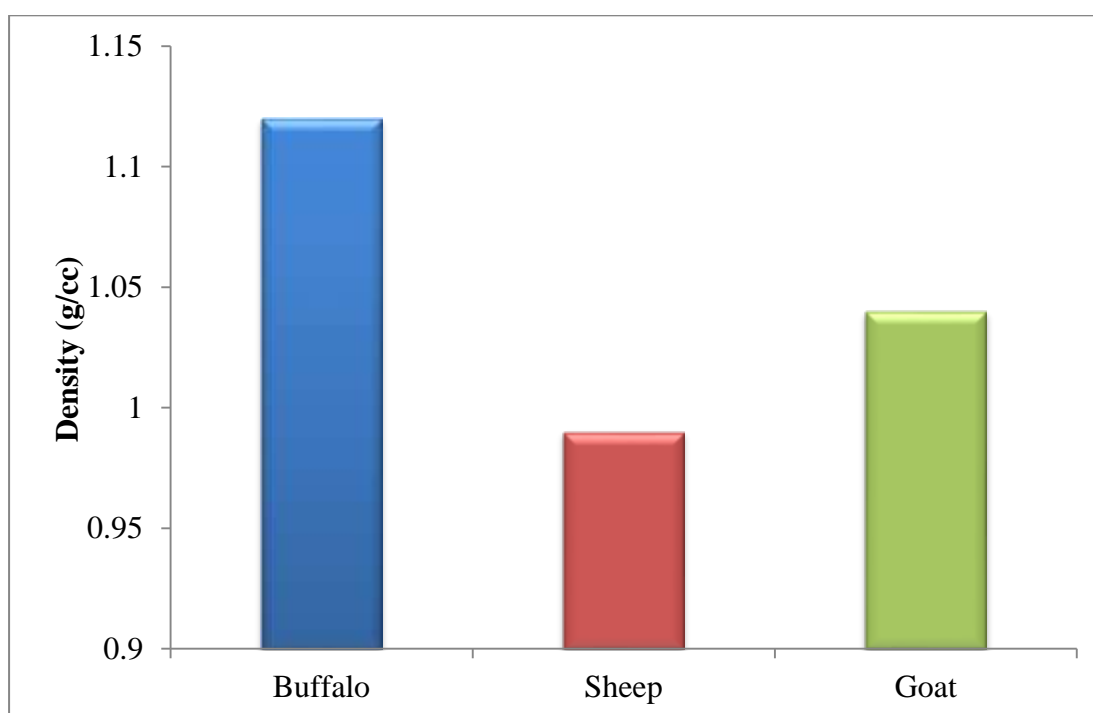
The volume of heart varied from 1050 cc to 1930 cc in buffalo (Table 1 and Graph 2) with the mean of 1450.0 ± 58.29 cc, in sheep it varied from 160 cc to 200 cc (Table 1 and Graph 2) with the mean of 180 ± 4.43 cc, whereas in goat it varied from 100 cc to 220 cc (Table 1 and Graph) with the mean of 158.91 ± 11.59 cc. Similar findings have been reported in buffalo (Bhasin 2017) and goat (Alvarez *et al* 1987 and Shah *et al* 2010)



Graph 2: Volume of heart in buffalo, sheep and goat

There was significant difference in volume at $p \leq 0.05$ level of significance in buffalo (1450.5 ± 58.29 cc) as compared to sheep (180 ± 4.43 cc) and goat (158.91 ± 11.59). However there was no significant difference observed between sheep and goat.

The density of the heart varied from 1.10 g/cc to 1.15 g/cc in buffalo (Table 1 and Graph 3) with the mean of 1.12 ± 0.01 g/cc, in sheep it varied from 0.86 g/cc to 1.12 g/cc (Table 1 and Graph 3) with the mean of 0.99 ± 0.02 g/cc, whereas in goat it varied from 0.92 g/cc to 1.14 g/cc (Table 1 and Graph 3) with the mean of 1.04 ± 0.01 g/cc. There was significant difference in density at $p \leq 0.05$ level of significance between buffalo (1.12 ± 0.004 g/cc), sheep (1.05 ± 0.016 g/cc) and goat (0.99 ± 0.017 g/cc). Highest density of heart was observed in buffalo followed by goat and least in sheep.



Graph 3: Density of heart in buffalo, sheep and goat

4.2.4 Borders

4.2.4.1 Anterior border

The length of anterior border varied from 17.1 cm to 26.5 cm in buffalo (Table 1 and Graph 4) with the mean of 23.28 ± 0.73 cm. Similar findings have been reported in buffalo (Mohan and Prakash 1997, Miller 2004 and Panhwar *et al* 2007)

Whereas, Bhasin (2017) reported that the length of anterior border was 13.55 ± 0.25 cm in males and 14.38 ± 0.55 cm in females.

The length of anterior border in sheep varied from 10.90 cm to 12.20 cm (Table 1 and Graph 4) with the mean of 11.5 ± 0.09 cm. Panditrao (2014) mentioned the length of anterior border was 8.28 ± 0.17 cm in male and 6.98 ± 0.32 cm in female sheep.

In goat, length of anterior border varied from 8.50 cm to 12.40 cm (Table 1 and Graph 4) with the mean of 10.35 ± 0.39 cm. Similar findings have been reported by Malik *et al* (1978).

There was significant difference in length of anterior border at $p \leq 0.05$ level of significance in buffalo (23.28 ± 0.73 cm) as compared to sheep (11.54 ± 0.09 cm) and goat (10.35 ± 0.39 cm), but there was no significant difference observed between sheep and goat. The difference in anterior border of heart of buffalo, sheep and goat indicated that the buffalo heart was largest followed by sheep and least in goat.

4.2.4.2 Posterior border

The length of posterior border varied from 15.6 cm to 18.5 cm in buffalo (Table 1 and Graph 4) with the mean of 16.64 ± 0.26 cm. Similar findings have been reported in buffalo (Malik *et al* 1972, Panhwar *et al* 2007 and Bhasin 2017) and ox (Mohan and Prakash 1997 and Sharma *et al* 1998).

The length of posterior border varied from 8.30 cm to 9.30 cm (Table 1 and Graph 4) with the mean of 8.67 ± 0.08 cm in sheep. Panditrao (2014) observed that the length of the posterior border from base to apex was 6.98 ± 0.32 cm in male and 5.60 ± 0.24 cm in female sheep. In goat it varied from 7.20 cm to 8.70 cm (Table 1 and Graph 4) with the mean of 8.00 ± 0.13 cm. Similar findings have been reported by Malik *et al* (1978). There was significant difference in length of posterior border at $p \leq 0.05$ level of significance in buffalo (16.64 ± 0.26 cm) as compared to sheep (8.67 ± 0.08 cm) and goat (8.00 ± 0.13 cm). Highest length of posterior border was observed in buffalo followed by sheep and least in goat.

The data indicated posterior border was shorter, thicker and slightly concave or nearly straight and was entirely formed by left ventricle in buffalo, sheep and goat.

Table 1: Biometrical data on different parameters (Mean \pm S.E) of heart in buffalo, sheep and goat

Parameter	Buffalo		Sheep		Goat	
	Mean \pm S.E	Range	Mean \pm S.E	Range	Mean \pm S.E	Range
Weight (gm)	1638.66 \pm 69.29 ^b	1150-2205	178.45 \pm 3.54 ^a	159.72-199.73	165.1 \pm 10.91 ^a	112.73-228.88
Volume (cc)	1450.00 \pm 58.29 ^b	1050-1930	180 \pm 4.43 ^a	160-200	158.91 \pm 11.59 ^a	100-220
Density (g/cc)	1.12 \pm 0.01 ^c	1.10-1.15	0.99 \pm 0.02 ^a	0.86-1.12	1.04 \pm 0.01 ^b	0.92-1.14
Length of anterior border (cm)	23.28 \pm 0.73 ^b	17.10-26.50	11.54 \pm 0.09 ^a	10.90-12.20	10.35 \pm 0.39 ^a	8.50-12.40
Length of posterior border (cm)	16.64 \pm 0.26 ^b	15.60-18.50	8.67 \pm 0.08 ^a	8.30-9.30	8.00 \pm 0.13 ^a	7.20-8.70
Circumference at base (cm)	45.05 \pm 0.74 ^b	41.20-51.0	19.75 \pm 0.19 ^a	18.50-20.90	18.80 \pm 0.34 ^a	16.50-21.40

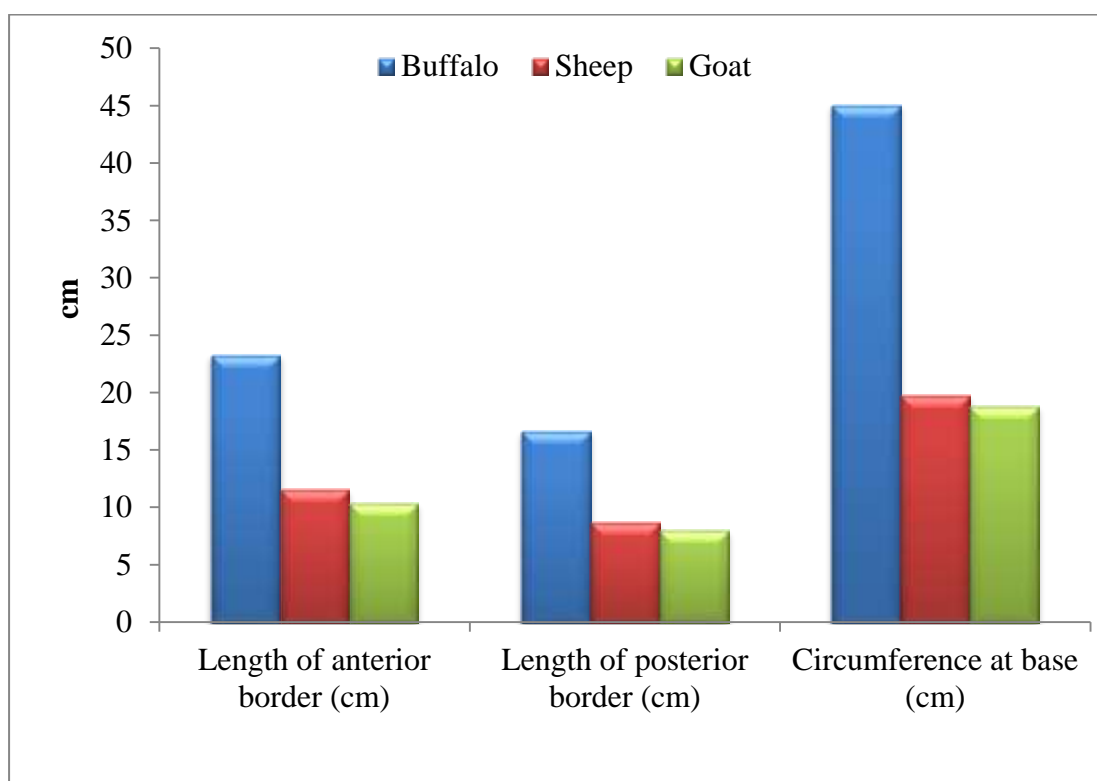
Mean \pm S.E, with different small letter superscript in a row differ significantly ($p \leq 0.05$)

4.2.5 Circumference of heart

The circumference at the level of coronary groove of the heart varied from 41.2 cm to 51.0 cm in buffalo (Table 1 and Graph 4) with the mean of 45.08 ± 0.74 . Whereas Bhasin (2017) measured circumference at the level of coronary groove of the heart as 34.27 ± 0.69 cm in males and 34.06 ± 1.29 cm in female buffalo.

In sheep, circumference at the level of coronary groove of the heart varied from 18.50 cm to 20.90 cm (Table 1 and Graph 4) with the mean of 19.75 ± 0.19 cm, whereas in goat it varied from 16.50 cm to 21.40 cm (Table 1 and Graph 4) with the mean of 18.80 ± 0.34 cm. Similar findings have been reported in goat (Malik *et al* 1978) and sheep (Panditrao 2014).

There was significant difference in circumference of heart at $p \leq 0.05$ level of significance in buffalo (45.08 ± 0.74 cm) as compared to sheep (19.75 ± 0.19 cm) and goat (18.80 ± 0.34 cm). Highest circumference of heart was observed in buffalo followed by sheep and least in goat.



Graph 4: Length of anterior border, posterior border and circumference at base of heart in buffalo, sheep and goat

4.2.6 Thickness

4.2.6.1 Left atrial wall

The thickness of left atrial wall of heart varied from 0.39 cm to 0.57 cm in buffalo (Table 2 and Graph 5) with the mean of 0.50 ± 0.19 cm. Similarly, Bhasin (2017) reported that the thickness of left atrial wall of heart varied was 0.95 ± 0.07 cm in male and 1.1 ± 0.06 cm in female buffalo. Bhattacharya *et al* (1987) measured that the thickness of left atrial wall was 0.4 cm in one horned rhinoceros. Hussain *et al* (2006) measured the thickness of left atrium wall of heart as 1.74 ± 0.04 cm in young and 1.86 ± 0.04 cm in adult buffaloes. Rehan and Qureshi (2007) reported that the mean thickness of left atrial wall of camel was 0.508 ± 0.03 cm.

In sheep, it varied from 0.10 cm to 0.51 cm (Table 2 and Graph 5) with the mean of 0.26 ± 0.03 cm, whereas in goat it varied from 0.20 cm to 0.31 cm (Table 2 and Graph 5) with the mean of 0.24 ± 0.01 cm. Shah *et al* (2010) reported that the mean thickness of left atrial wall was 0.25 ± 0.02 cm in goat. Similar findings have been reported by Gumansing (2015).

There was significant difference in the thickness of left atrial wall at $p \leq 0.05$ level of significance in buffalo (0.50 ± 0.19 cm) as compared to sheep (0.26 ± 0.03 cm) and goat (0.24 ± 0.01 cm). Highest left atrial wall was observed in buffalo followed by sheep and least in goat.

4.2.6.2. Right atrial wall

The thickness of right atrial wall of heart varied from 0.17 cm to 0.49 cm (Table 2 and Graph 5) with the mean of 0.40 ± 0.02 cm in buffalo. Bhasin (2017) found the right atrial wall thickness of heart as 0.75 ± 0.05 cm in male and 0.93 ± 0.05 cm in female buffalo. Bhattacharya *et al* (1987) recorded that the thickness of right atrial wall was 1.9 cm in one horned rhinoceros. Whereas Hussain *et al* (2006) measured the thickness of right atrium wall of heart as 1.33 ± 0.05 cm in young and 1.65 ± 0.03 cm in adult buffaloes. However, Rehan and Qureshi (2007) stated that the mean thickness of right atrial wall of camel was 0.597 ± 0.04 cm.

In sheep, right atrial wall thickness varied from 0.11 cm to 0.43 cm (Table 2 and Graph 5) with the mean of 0.21 ± 0.02 cm, whereas it varied from 0.11 cm to 0.23 cm (Table 2 and Graph 5) with the mean of 0.15 ± 0.01 cm in goat. Shah *et al* (2010)

Table 2: Biometrical data on thickness (Mean \pm S.E) of atrial, ventricular and interventricular wall in buffalo, sheep and goat

Parameter	Buffalo		Sheep		Goat	
	Mean \pm S.E	Range	Mean \pm S.E	Range	Mean \pm S.E	Range
Left atrial wall (cm)	0.50 \pm 0.19 ^b	0.39-0.57	0.26 \pm 0.03 ^a	0.10-0.51	0.24 \pm 0.01 ^a	0.20-0.31
Right atrial wall (cm)	0.40 \pm 0.02 ^b	0.17-0.49	0.21 \pm 0.02 ^a	0.11-0.43	0.15 \pm 0.01 ^a	0.11-.23
Left ventricular wall (cm)	2.71 \pm 0.9 ^b	2.30-3.40	1.50 \pm 0.05 ^a	1.30-1.91	1.43 \pm 0.04 ^a	1.20-1.70
Right ventricular wall (cm)	1.74 \pm 0.12 ^b	1.10-2.40	0.75 \pm 0.02 ^a	0.63-0.91	0.73 \pm 0.05 ^a	0.43-1.16
Interventricular septum (cm)	2.34 \pm 0.09 ^b	1.90-3.10	1.71 \pm 0.05 ^a	1.40-1.96	1.62 \pm 0.01 ^a	1.48-1.71

Mean \pm S.E, with different small letter superscript in a row differ significantly ($p \leq 0.05$)

Found the same parameter as 0.15 ± 0.01 cm in goat. The right atrial wall thickness was 0.25 ± 0.009 cm in male and 0.19 ± 0.002 cm in female goat (Gumansing 2015).

There was significant difference in right atrial wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.2.6.3 Left ventricular wall

The left ventricular wall thickness varied from 2.30 cm to 3.40 cm (Table 2 and Graph 5) with the mean of 2.71 ± 0.9 cm in buffalo. Hussain *et al* (2006) measured the thickness of left ventricle wall as 1.90 ± 0.03 cm in young and 3.17 ± 0.14 cm in adult buffaloes. Gupta *et al* (2012) found the thickness of the ventricle of the heart as 1.70 ± 0.15 cm in buffalo. Bhasin (2017) measured the left ventricular wall thickness as 2.73 ± 0.13 cm in male and 2.70 ± 0.16 cm in female buffalo. Similar findings have been reported in buffalo (Malik *et al* 1972) one horned rhinoceros (Bhattacharya *et al* 1987) and pig (Sathyamoorthy 2003)

The left ventricular wall thickness varied from 1.30 cm to 1.91 cm (Table 2 and Graph 5) with the mean of 1.50 ± 0.05 cm in sheep, Archana *et al* (2010) reported that the thickness of left ventricular wall was 1.51 ± 0.07 cm in sheep.

It varied from 1.20 cm to 1.70 cm (Table 2 and Graph 5) with the mean of 1.43 ± 0.04 cm in goat. The mean thickness of left ventricular wall at the midpoint, between atrioventricular orifice and apex of heart, was recorded as 0.99 ± 0.05 cm in goat (Shah *et al* 2010). Panditrao (2014) observed that the thickness of left ventricular wall was 1.58 ± 0.08 cm in male and 1.61 ± 0.10 cm in female sheep.

There was significant difference in left ventricle wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.2.6.4 Right ventricular wall

The right ventricular wall thickness varied from 1.10 cm to 2.40 cm in buffalo (Table 2 and Graph 5) with the mean of 1.74 ± 0.12 cm. Malik *et al* (1972) recorded the mean thickness of right ventricular walls in buffalo heart as 1.5 ± 0.29 cm. Hussain *et al* (2006) measured the thickness of right ventricle wall of heart as $1.49 \pm$

0.03 cm in young and 2.76 ± 0.12 cm in adult buffaloes. Gupta *et al* (2012) found right ventricular wall thickness as 0.79 ± 0.07 cm in buffalo. However, Bhasin (2017) measured the right ventricular wall thickness as 1.45 ± 0.07 cm in male and 1.31 ± 0.09 cm in female buffalo.

In sheep it varied from 0.63 cm to 0.91 cm (Table 2 and Graph 5) with the mean of 0.75 ± 0.02 cm. Similarly, Archana *et al* (2010) and Panditrao (2014) observed that the mean thickness of right ventricular wall was 0.68 ± 0.06 cm and 0.83 ± 0.05 cm respectively in sheep. Whereas in goat it varied from 0.43 cm to 1.16 cm (Table 2 and Graph 5) with the mean of 0.73 ± 0.05 cm. Similar findings have been reported by Malik *et al* (1978) in caprine heart, Bhattacharya *et al* (1987) in one horned rhinoceros and Sathyamoorthy (2003) in pig.

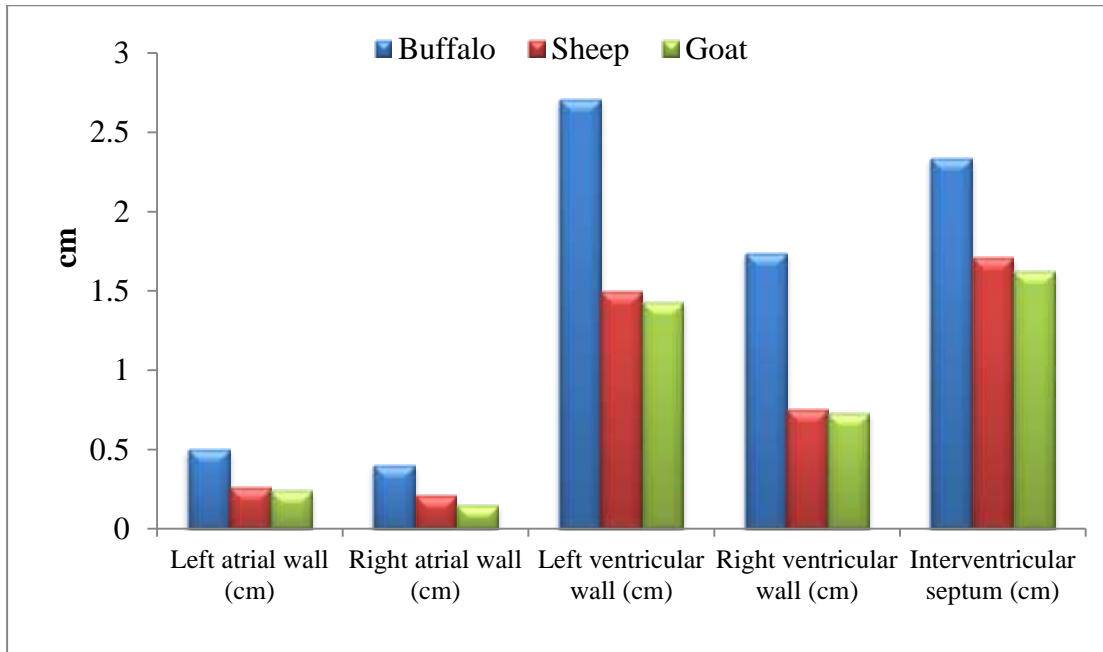
There was significant difference in right ventricle wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.2.6.5 Interventricular Septal wall

The interventricular wall thickness varied from 1.90 cm to 3.10 cm in buffalo (Table 2 and Graph 5) with the mean of 2.34 ± 0.09 cm. Similar findings have been reported by Malik *et al* (1972) and Gupta *et al* (2012) in buffalo. Bhasin (2017) found the interventricular wall thickness as 2.29 ± 0.14 cm in male and 2.35 ± 0.14 cm in female buffalo.

It varied from 1.40 cm to 1.96 cm (Table 2 and Graph 5) with the mean of 1.71 ± 0.05 cm. Similar findings have been reported by Panditrao (2014) in sheep. The interventricular wall thickness varied from 1.48 cm to 1.71 cm (Table 2 and Graph 5) with the mean of 1.62 ± 0.01 cm in goat. Similar findings have been reported by Malik *et al* (1978) in caprine heart.

There was significant difference in interventricular septum wall thickness at $p \leq 0.05$ level of significance in buffalo (2.34 ± 0.09 cm) as compared to sheep (1.71 ± 0.05 cm) and goat (1.62 ± 0.01 cm). Highest interventricular septum wall thickness was observed in buffalo followed by sheep and least in goat.



Graph 5: Wall thickness of left atrium, right atrium, left ventricle, right ventricle and interventricular septum in buffalo, sheep and goat

4.2.7 Arteries

4.2.7.1 Aorta

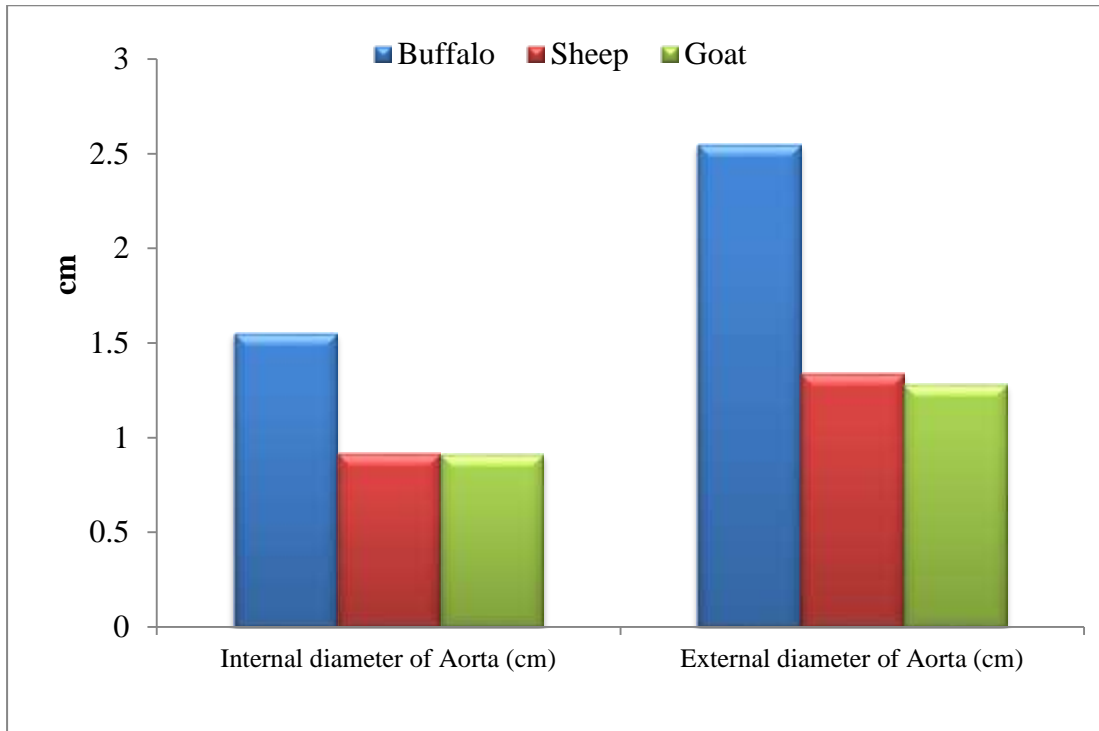
The diameter of aorta varied from 2.25 cm to 3.25 cm (external) and 1.25 cm to 1.85 cm (internal) in buffalo (Table 3 and Graph 6) with the mean of 2.55 ± 0.07 (external) and 1.55 ± 0.06 (internal), in sheep it varied from 1.0 cm to 1.70 cm (external) and 0.60 cm to 1.20 cm (internal) (Table 3 and Graph 6) with the mean of 1.34 ± 0.05 cm (external) and 0.92 ± 0.04 cm (internal) whereas in goat it varied from 1.0 cm to 1.50 cm (external) and 0.80 cm to 1.10cm (internal) (Table 3 and Graph 6) with the mean of 1.28 ± 0.03 cm (external) and 0.91 ± 0.03 (internal).

There was significant difference in external diameter of aorta at $p \leq 0.05$ level of significance in buffalo (2.55 ± 0.07 cm) as compared to sheep (1.34 ± 0.05 cm) and goat (1.28 ± 0.03 cm), but there was no significant difference observed between sheep and goat. There was significant difference in internal diameter of aorta at $p \leq 0.05$ level of significance in buffalo (1.55 ± 0.06 cm) as compared to sheep (0.92 ± 0.04 cm) and goat (0.91 ± 0.03 cm), but there was no significant difference observed between sheep and goat.

Table 3: Biometrical data on internal and external diameter (Mean \pm S.E) of pulmonary artery and aorta in buffalo, sheep and goat

Species	Internal diameter of Pulmonary artery (cm)		External diameter of Pulmonary artery (cm)		Internal diameter of Aorta (cm)		External diameter of Aorta (cm)	
	Mean \pm S.E	Range	Mean \pm S.E	Range	Mean \pm S.E	Range	Mean \pm S.E	Range
Buffalo	2.13 \pm 0.16 ^b	1.4-3.05	2.80 \pm 0.14 ^b	2.3-3.85	1.55 \pm 0.06 ^b	1.25-1.85	2.55 \pm 0.07 ^b	2.25-3.25
Sheep	1.04 \pm 0.03 ^a	0.80-1.15	1.4 ^a \pm 0.04 ^a	1.20-1.65	0.92 \pm 0.04 ^a	0.60-1.20	1.34 \pm 0.05 ^a	1.0-1.70
Goat	1.03 \pm 0.03 ^a	0.90-1.20	1.32 \pm 0.03 ^a	1.10-1.55	0.91 \pm 0.03 ^a	0.80-1.10	1.28 \pm 0.03 ^a	1.0-1.50

Mean \pm S.E, with different small letter superscript in a column differ significantly ($p \leq 0.05$)



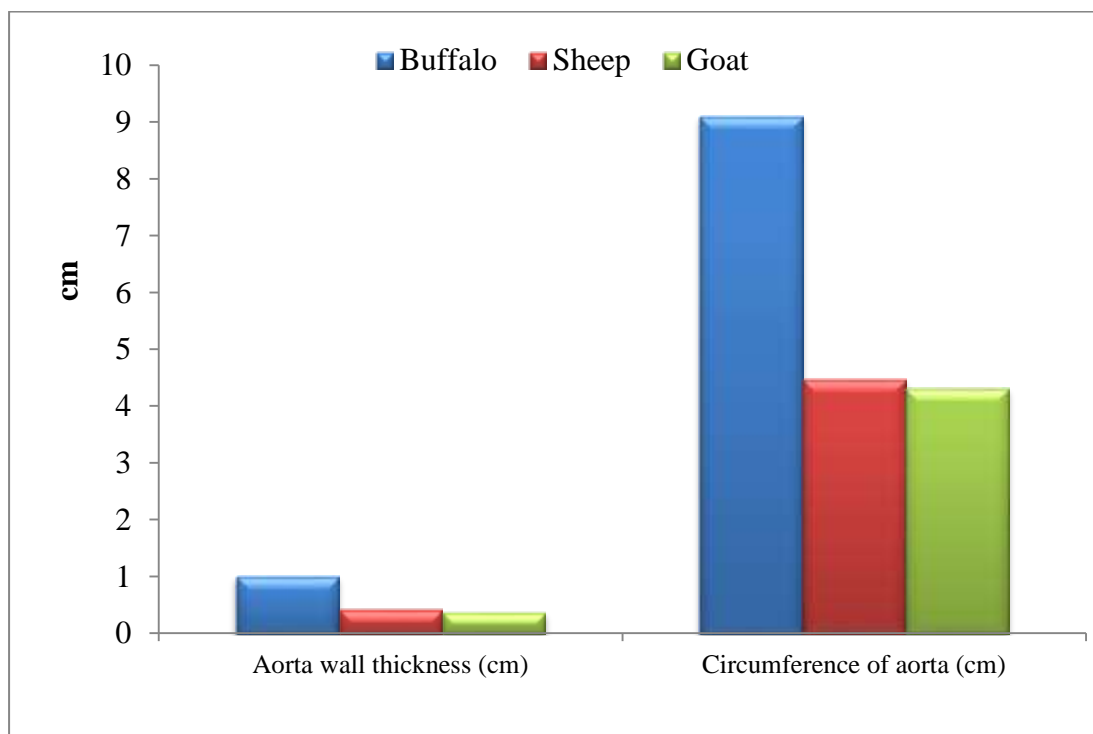
Graph 6: Internal and external diameter of aorta in buffalo, sheep and goat

The aorta wall thickness varied from 0.60 cm to 1.40 cm in buffalo (Table 4 and Graph 7) with the mean of 1.00 ± 0.06 cm, in sheep it varied from 0.25 cm to 0.55 cm (Table 4 and Graph 7) with the mean of 0.42 ± 0.02 cm and in goat it varied from 0.15 cm to 0.60 cm (Table 4 and Graph 7) with the mean of 0.37 ± 0.03 cm. Bhasin (2017) reported that the diameter of ascending aorta was 1.96 ± 0.10 cm in males and 2.03 ± 0.10 cm in female buffalo. Archana *et al* (2010) observed that thickness of the aorta wall at its origin was 0.34 ± 0.01 cm and circumference was 3.65 ± 0.29 cm in sheep.

There was significant difference in aorta wall thickness at $p \leq 0.05$ level of significance in buffalo (1.00 ± 0.06 cm) as compared to sheep (0.42 ± 0.02 cm) and goat (0.37 ± 0.03 cm), but there was no significant difference observed between sheep and goat.

The circumference of aorta varied from 8.0 cm to 10.80 cm (Table 4 and Graph 7) with the mean of 9.10 ± 0.22 cm in buffalo, in sheep it varied from 3.30 cm to 5.40 cm (Table 4 and Graph 7) with the mean of $4.48 \text{ cm} \pm 0.18$ cm, whereas in goat it varied from 3.80 cm to 4.70 cm (Table 4 and Graph 7) with the mean of $4.31 \pm$

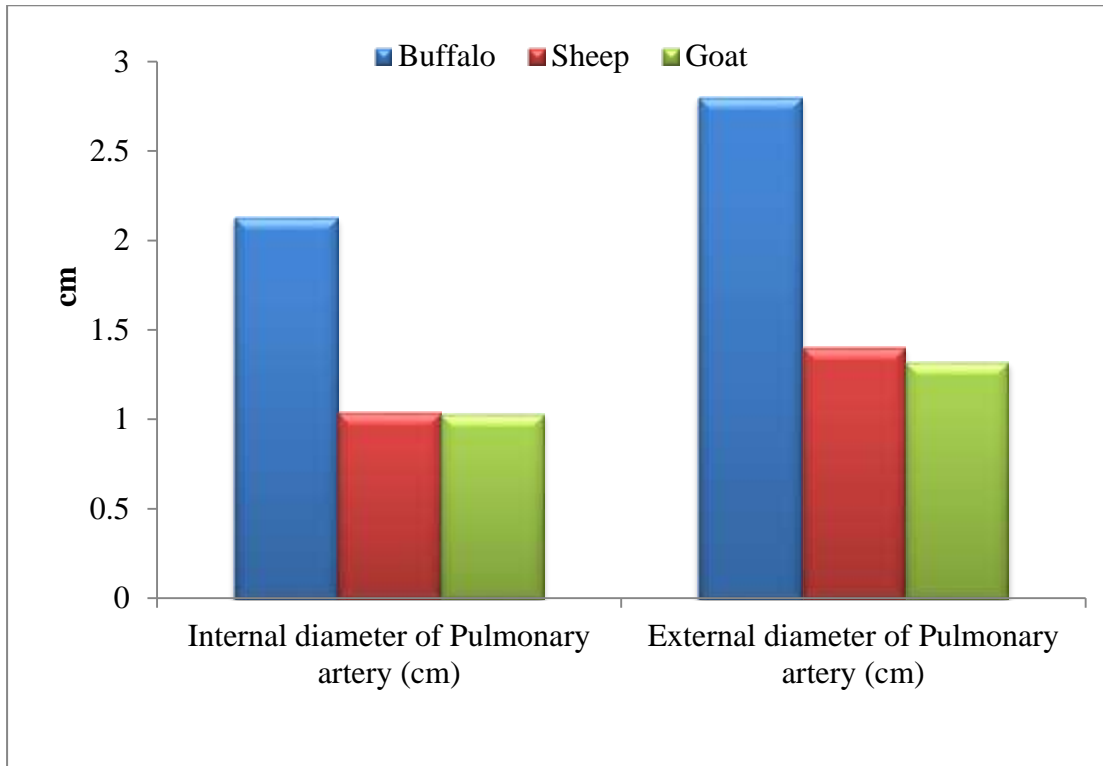
0.07 cm. There was significant difference in circumference of aorta at $p \leq 0.05$ level of significance in buffalo (9.10 ± 0.22 cm) as compared to sheep ($4.48 \text{ cm} \pm 0.18$ cm) and goat (4.31 ± 0.07 cm), but there was no significant difference observed between sheep and goat.



Graph 7: Wall thickness and circumference of aorta in buffalo, sheep and goat

4.2.7.2 Pulmonary artery

The diameter of pulmonary artery varied from 2.30 cm to 3.85 cm (external) and 1.40 cm to 3.05 cm (internal) in buffalo (Table 3 and Graph 8) with the mean of 2.80 ± 0.14 cm (external) and 2.13 ± 0.16 cm (internal), in sheep it varied from 1.20 cm to 1.65 cm (external) and 0.80 cm to 1.15 cm (internal) (Table 3 and Graph 8) with the mean of 1.41 ± 0.04 cm (external) and 1.04 ± 0.03 cm (internal), whereas in goat it varied from 1.10 cm to 1.55 cm (external) and 0.90 cm to 1.20 cm (internal) (Table 3 and Graph 8) with the mean of 1.32 ± 0.03 cm (external) and 1.03 ± 0.03 cm (internal). The diameter of pulmonary artery in buffalo males was 1.91 ± 0.09 cm while in females was 1.9 ± 0.07 cm (Bhasin 2017). Sathapathy *et al* (2013) measured the diameter of pulmonary artery as 1.45 ± 0.14 cm and 1.82 ± 0.16 cm, respectively in male and female goat.



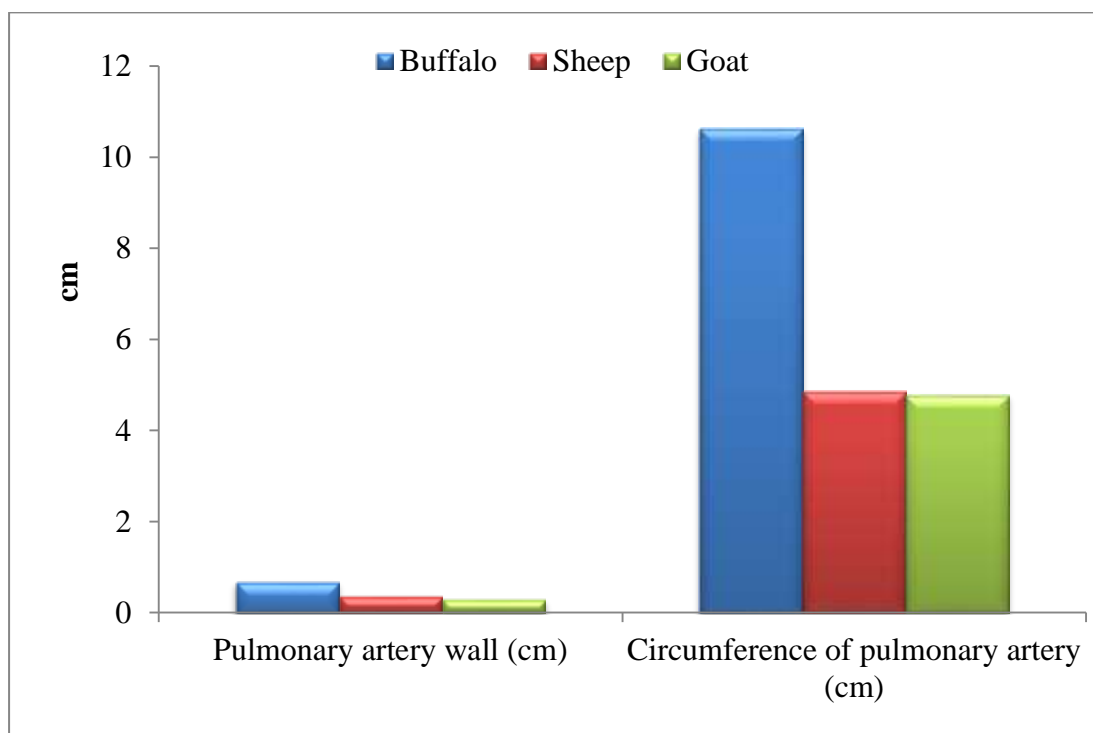
Graph 8: Internal and external diameter of pulmonary artery in buffalo, sheep and goat

There was significant difference in external diameter of pulmonary artery wall at $p \leq 0.05$ level of significance in buffalo (2.80 ± 0.14 cm) as compared to sheep (1.41 ± 0.04 cm) and goat (1.32 ± 0.03 cm), but there was no significant difference observed between sheep and goat. There was significant difference in internal diameter of pulmonary artery at $p \leq 0.05$ level of significance in buffalo (2.13 ± 0.16 cm) as compared to sheep (1.04 ± 0.03 cm) and goat (1.03 ± 0.03 cm), but there was no significant difference observed between sheep and goat.

The pulmonary artery wall thickness varied from 0.35 cm to 0.95 cm in buffalo (Table 4 and Graph 9) with the mean of 0.67 ± 0.06 cm, in sheep it varied from 0.20 cm to 0.45 cm (Table 4 and Graph 9) with the mean of 0.37 ± 0.02 cm and in goat it varied from 0.15 cm to 0.52 cm (Table 4 and Graph 9) with the mean of 0.29 ± 0.02 cm. Similarly, Archana *et al* (2010) found that thickness of the pulmonary artery wall at its origin was 0.27 ± 0.02 cm, whereas the circumference was 3.45 ± 0.12 cm in sheep.

There was significant difference in pulmonary artery wall thickness at $p \leq 0.05$ level of significance in buffalo (0.67 ± 0.06 cm) as compared to sheep (0.37 ± 0.02

cm) and goat (0.29 ± 0.02 cm), but there was no significant difference observed between sheep and goat.



Graph 9: Wall thickness and circumference of pulmonary artery in buffalo, sheep and goat

The circumference of pulmonary artery varied from 9.80 cm to 12.80 cm (Table 4 and Graph 9) with the mean of 10.63 ± 0.25 cm in buffalo, in sheep it varied from 4.0 cm to 5.20 cm (Table 4 and Graph 9) with the mean of 4.85 ± 0.12 cm, whereas in goat it varied from 4.10 cm to 5.30 cm (Table 4 and Graph 9) with the mean of 4.78 ± 0.11 cm. There was significant difference in circumference of pulmonary artery at $p \leq 0.05$ level of significance in buffalo (10.63 ± 0.25 cm) as compared to sheep (4.85 ± 0.12 cm) and goat (4.78 ± 0.11 cm), but there was no significant difference observed between sheep and goat.

The biometrical thickness of left atrial wall, right atrial wall, left ventricle wall, right ventricle wall, interventricular septum was significantly different ($p \leq 0.05$) in buffalo as compare to sheep and goat, but there was no significant difference between sheep and goat. Higher value of these compartments was found in buffalo than in sheep and least in goat. This may be due to the larger size of heart in large ruminants (buffalo) as compare to the small ruminants (sheep and goat).

Table 4: Biometrical data on thickness and circumference (Mean \pm S.E) of pulmonary artery and aorta in buffalo, sheep and goat

Parameter	Pulmonary artery wall (cm)		Aorta wall (cm)		Circumference of pulmonary artery (cm)		Circumference of aorta (cm)	
	Mean \pm S.E	Range	Mean \pm S.E	Range	Mean \pm S.E	Range	Mean \pm S.E	Range
Buffalo	0.67 \pm 0.06 ^b	0.35-0.95	1.00 \pm 0.06 ^b	0.60-1.40	10.63 \pm 0.25 ^b	9.80-12.80	9.1 \pm 0.22 ^b	8.0-10.80
Sheep	0.37 \pm 0.02 ^a	0.20-0.45	0.42 \pm 0.02 ^a	0.25-0.55	4.85 \pm 0.12 ^a	4.0-5.20	4.48 \pm 0.18 ^a	3.30-5.40
Goat	0.29 \pm 0.02 ^a	0.15-0.52	0.37 \pm 0.03 ^a	0.15-0.60	4.78 \pm 0.11 ^a	4.10-5.30	4.31 \pm 0.07 ^a	3.80-4.70

Mean \pm S.E, with different small letter superscript in a column differ significantly ($p \leq 0.05$)

4.3 HISTOMORPHOLOGY

The histological sections from the heart of buffalo, sheep and goat revealed that all four chambers were composed of three different layers i.e. endocardium, myocardium and epicardium (Figs 4A, 7A, 8A).

4.3.1 Endocardium

Endocardium was the innermost layer lining the atria and ventricles and covered the cardiac valves and associated structures. The endocardium was subdivided into three layers i.e. endothelium, subendothelium and subendocardium layers in buffalo (Figs 4B, 4C), sheep (Fig 7B) and goat. Similar findings have been reported by Ghonimi *et al* (2014) in camel and Emam and Abugherin (2019) in Egyptian Bovine. The endothelial layer was composed of simple squamous epithelium resting on the thin basement membrane in the atria and ventricles of buffalo (Fig 4C), sheep (Fig 7F) and goat. The subendothelial layer was the second layer of endocardium and was relatively thicker than endothelium and subendocardium. It contained dense irregular connective tissue with loosely arranged collagen and elastic fibres and few smooth muscle cells in the atrium, whereas the Purkinje fibres were seen in this layer in the ventricles of all the species studied. Adipose tissue was also present along with blood vessels and conducting cells in the ventricles of all the species under study (Figs 5E, 7E). Abundance of adipose tissue was also seen this layer in the atrium of buffalo (Fig 4B), whereas it was present as isolated bundles in sheep and goat. Schummer *et al* (1981) also noticed that the inner subendocardium of sheep and goat composed of small islets of adipose tissue.

The subendocardium layer was the deepest layer of endocardium that connected the endocardium with myocardium and was composed of loosely arranged collagen, elastic fibres, adipose tissue, blood and lymph vessels and Purkinje fibres at certain locations (Fig 5A). Purkinje fibres were varying in size large than myocytes. Its cytoplasm was pale as contained few fibrils. It had single central large nucleus and sometimes binucleated (Figs 5B, 5C, 5D, 10F). At the same time some of them appeared non nucleated. Similar findings have been reported by Ghomini *et al* (2014) in camel.

4.3.2 Myocardium

Myocardium was the middle and thickest layer of the heart. The ventricular myocardium was characterized by housing massive, large numerous cardiac myocytes because of relatively high pressure and overload on ventricles (Fig 5F). It was composed of bundles of cardiac muscle cells and Purkinje fibres. The cardiac myocytes were embedded in loose connective tissue that contained dense capillary network, lymph vessels and autonomic nerve fibres (Figs 6A, 6B). Similar arrangements of cardiac myocytes and Purkinje fibres were seen in the ventricles and interventricular septum in sheep (Figs 7B, 10E) and goat (Figs 9E, 10 A). The bundles of cardiac muscles were comparatively larger in the ventricles as compared to the atrium in all the species studied (Figs 4E, 4F, 6E, 6F). These cardiac muscles were arranged in sheath in a complex and spiral manner and were oriented in various directions viz. longitudinal, circular and oblique (Figs 4E, 8C and 9C). However in the interventricular septum, cardiac myocytes were arranged in circular and longitudinal directions (Figs 9C and D).

These bundles of cardiac muscle cells were laterally separated from each other by a considerable amount of loose connective tissue that was rich with dense capillary network, lymph vessels and ganglionic plexuses (Figs 4D, 6A and 7E). The intercellular connective tissue was few in ventricles where cardiac myocytes were numerous and much close to each other and appeared overcrowded. Most of these cells were elongated, branched and connected with each other (Figs 6C, 7D, 9F). In cross section cardiac myocytes appeared irregular polygonal cells of different sizes with large round, centrally placed, single nucleus and sometimes binucleated (Figs 4C, 5D, 6D). The cardiac muscle fibres showed different staining affinity i.e. some had darkly stained cytoplasm and others had lighter cytoplasm. The darkly stained muscle fibres were termed as hyper eosinophilic (Figs 5F, 6F, 7D) as reported by Ghomini *et al* (2014) in camel and Emam and Abugherin (2019) in Egyptian Bovines. This characteristic feature was also noticed in the myocardium of sheep and goat. The cardiac muscle fibres showed striations and intercalated discs in all the species studied (Figs 6F, 7C, 7D, 10 B).

Purkinje fibres were present in the subendocardium, between the myocardial bundles and as intramural fibres among the cardiac myocytes (Fig 9A, 9B). These fibres were large specialized cardiac muscle fibres and had greater diameter than the cardiac myocytes and cluster as group. Each cell had only one or two centrally placed nuclei. The cytoplasm of Purkinje fibres was lightly stained because of large amount of glycogen (Figs 8D, 8E, 10C, 10D). Fine connective tissue was also observed between the cardiac myocytes along with blood vessels and nerve fibres. The right ventricle contained more amount of interstitial connective tissue as compared to left ventricle. The cardiac cells of the atrium were smaller than the ventricle cardiac cells (Figs 8B, 8C, 8F). A thin layer of fibroelastic tissue supported the mesothelium; this layer was connected to the myocardium by a broad layer of adipose tissue. Similarly, Nagpal (1977) reported in goat that ventricular myocardium consisted of fibres which formed a more compact structure than that of atrium and its muscle bundles were comparatively larger and oriented in various directions viz. longitudinal, circular and oblique. Collagen and elastic tissue were relatively inconspicuous in the ventricles as compared to auricles. Whereas Sathyamoorthy and Geeta (2008) reported in pigs that muscle bundles were noticed as three layers viz. epimyocardium, endomyocardium and in between them, there was the thick middle layer.

Individual cardiac myocytes were not only connected in longitudinal direction but also made lateral contacts in buffalo, sheep and goat. Intercalated discs appeared as prominent undulating membrane demarcating the border between two adjacent heart muscle cells (Figs 5F, 6D). Terasaki *et al* (1993) noticed that the myocardial fibers of left ventricular papillary muscles were elongated and thinner at tips in human and animals whereas Smolich (1995) described that left ventricular myocytes were larger than the right ventricular myocytes in mammalian heart. Wang *et al* (1995) reported that atrial wall consisted of circumferential and longitudinal muscle bundles and were larger in the right atrium than left atrium in humans.

4.3.3 Epicardium

The myocardium of heart was covered externally by epicardium (Fig 8A). This layer was thin as compared to myocardium. It was composed of mesothelium (simple squamous epithelium) and subepicardial layer (Fig 9B). The later was made

of loose connective tissue along with veins, nerves and adipose tissue. The atrium was having thick layer of epicardium as compared to that of ventricle in buffalo, sheep and goat. Similarly (Nagpal 1977) found that atrial epicardium was comparatively thicker than that of the ventricles and right atrium was covered by a more compact structure than left atrium. Its outer part was covered by a single layer of mesothelial cells supported by the fibro-elastic core. Fawcett (1994) noticed that epicardium was lined by a single layer of fattened epithelial cells resting on a thin layer of fibro-elastic connective tissue. Dellman and Eurell (1998) found that epicardium was covered externally by the mesothelial cells. Under the epithelium was a loose connective tissue layer rich in elastic fibers that formed protective sheath around blood vessels, nerves and ganglia. Sathyamoorthy and Geetha (2008) in pig found that epicardium was lined by flattened squamous cells.

4.3.4 Aorta

The study revealed that the aorta was consisted of three layers viz. tunica intima, tunica media, tunica adventitia in buffalo, sheep and goat (Figs 11 A, 13 A and 14 A). Tunica intima was comprised of endothelium with squamous and round endotheliocytes, a subendothelial zone and internal elastic lamina. The endothelium was lined by a simple squamous epithelium resting on a thin basement membrane and their nuclei bulged into the lumen of the vessel (Fig 11B, 11C, 13B, 14B). Subendothelium was comprised of fibroblasts, few smooth muscle fibres, collagen and numerous, fine, longitudinally oriented elastic fibres. No capillaries were seen as this layer received nutrition through diffusion and transendothelial transport. The internal elastic lamina was not readily distinguishable from the elastic lamellae of the tunica media.

The tunica media of aorta was thickest of three layers and consisted primarily of concentrically arranged, fenestrated elastic lamellae. Smooth muscle fibres were attached to elastic laminae by collagen and elastic fibres. Smooth muscle fibres were differently arranged in the internal and the external halves of tunica media. These were fewer in internal half and did not have the tendency to form bundles. Smooth muscle fibres were abundant were visible in the external part of tunica media and formed muscle bundles (Figs 11B, 11E). The nuclei of smooth muscle cells were

clearly evident. The intercellular substance was more basophilic than ordinary connective tissue because it contained greater amount of sulphated glycosaminoglycan. The inner quarters of tunica media exhibited concentrically arranged elastic lamellae.

The outermost coat of the aorta, the tunica adventitia, was composed of longitudinally arranged bundles of collagenous and elastic fibres interspersed with connective tissue cells and blood vessels, the vasa vasorum (Figs 11 D, 11E, 11F, 13 C). Similarly, Banks (1993) described that aorta and its branches were distinguished by their great elasticity and made up of three layers from i.e. tunica intima, tunica media and tunica adventitia which were analogous to endocardium, myocardium and epicardium, respectively. Tunica intima had a large sub-endothelial layer which grew with age and its border was delineated by internal elastic membrane. Tunica media was thickest of three layers and smooth muscle cells were arranged in spiral around the long axis of the vessel. Tunica adventitia was relatively thin connective tissue layer with fibroblast, macrophages, collagen fibres and blood vessels were present in this layer.

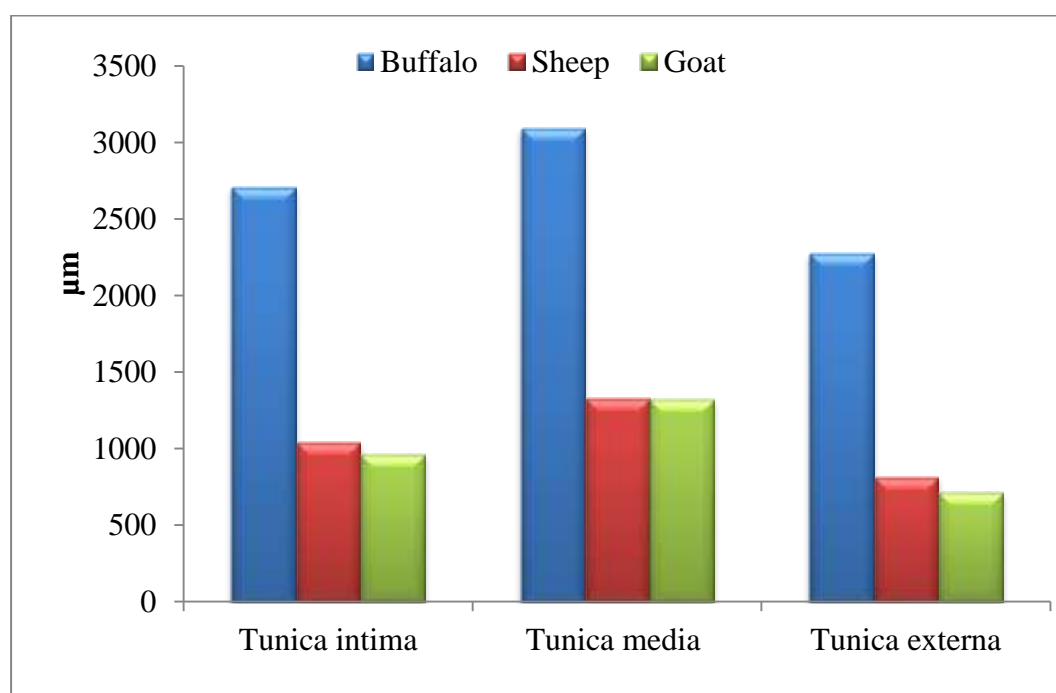
Micrometrical observations revealed that the thickness of tunica intima of aorta in buffalo varied from 1644.70 to 3658.97 μm (Table 5 and Graph 10) with the mean of $2712.40 \pm 160.38 \mu\text{m}$, it varied from 784.06 to 1246.15 μm (Table 5 and Graph 10) with the mean of $1041.72 \pm 49.48 \mu\text{m}$ in sheep, however in goat it varied from 630.94 to 1246.18 μm (Table 5 and Graph 10) with the mean of $960.83 \pm 54.88 \mu\text{m}$. The thickness of tunica media of aorta of buffalo varied from 1861.05 to 4012.13 μm (Table 5 and Graph 10) with the mean of $3019.58 \pm 175.35 \mu\text{m}$, it varied from 962.78 to 1596.46 μm (Table 5 and Graph 10) with the mean of $1327.44 \pm 58.34 \mu\text{m}$ in sheep, however in goat it varied from 729.18 to 1646.18 μm (Table 5 and Graph 10) with the mean of $1323.12 \pm 86.60 \mu\text{m}$. The thickness of tunica externa of aorta of buffalo varied from 1455.69 to 3111.78 μm (Table 5 and Graph 10) with the mean $2275.03 \pm 132.45 \mu\text{m}$, it varied from 593.87 to 998.18 μm (Table 5 and Graph 10) with the mean of $816.44 \pm 42.11 \mu\text{m}$ in sheep, whereas in goat it varied from 555.60 to 959.52 μm (Table 5 and Graph 10) with the mean of $714.68 \pm 38.09 \mu\text{m}$. Mello *et al* (2017) reported thickness of tunica intima 4.03 μm , tunica media layer 218.1 μm

and tunica adventitia 202.5 μm in the thoracic aorta of guinea pig, whereas, it was 2.68 μm , 202.5 μm and 57.9 μm in rats respectively and tunica media was thickest among three layers. However, thickness of tunica intima was $19.64 \pm 0.39 \mu\text{m}$, tunica media was $954.80 \pm 59.15 \mu\text{m}$ and tunica adventitia was $115.3 \pm 12.00 \mu\text{m}$ in thoracic aorta of adult Deccani sheep, whereas, in adult Bidri goat it was $19.34 \pm 0.54 \mu\text{m}$, $905.67 \pm 31.73 \mu\text{m}$ and $109.75 \pm 16.34 \mu\text{m}$ respectively (Sharanagouda *et al* 2016). Similarly, Banks (1993) described that aorta and its branches were distinguished by their great elasticity and made up of three layers from i.e. tunica intima, tunica media and tunica adventitia which were analogous to endocardium, myocardium and epicardium, respectively.

Table 5: Micrometrical data on aorta (Mean \pm S.E) in buffalo, sheep and goat

Species	Aorta(μm)			
	Tunica intima	Tunica media	Tunica externa	Total thickness
Buffalo	2712.40 \pm 160.38 ^b	3091.58 \pm 175.35 ^b	2275.03 \pm 132.45 ^b	8079.01 \pm 463.82 ^b
Sheep	1041.72 \pm 49.48 ^a	1327.44 \pm 58.34 ^a	816.44 \pm 42.11 ^a	3185.60 \pm 130.04 ^a
Goat	960.83 \pm 54.88 ^a	1323.12 \pm 86.60 ^a	714.68 \pm 38.09 ^a	2998.62 \pm 168.69 ^a

Mean \pm S.E, with different small letter superscript in a column differ significantly



Graph 10: Wall thickness of aorta in buffalo, sheep and goat

4.3.5 Pulmonary artery

Pulmonary artery had three layers viz. tunica intima, tunica media and tunica adventitia from inside to outside in buffalo (Fig 12A), sheep (Fig 13 D) and goat (Fig 14 C). Tunica intima was made up of an epithelium, which was a single layer of squamous epithelial cells, together with a supporting layer of elastin rich collagen (Figs 12B, 12C, 13E, 14D, 14 E). Tunica media was broad and elastic with concentric fenestrated sheets of elastin, and collagen and only relatively few smooth muscle fibres (Figs 12B, 12D, 14D). Tunica adventitia was the outer layer and had small 'vasa vasorum' (Figs 12E, 12 F, 13C, 13 F, 14 F). Similarly, Castillo *et al* (2005) found that diameter of right pulmonary artery was wider than the left pulmonary artery while Szpinda *et al* (2005) noticed that a different tendency was observed for the internal diameter of both pulmonary arteries which were relatively decreased with increased foetal age. Ruano *et al* (2007) in human foetuses reported that mean diameter of main pulmonary artery, right pulmonary artery interspecies differences in quantity and arrangement of collagen, smooth muscle and elastic tissue in pulmonary trunk. The medial thickness of muscular pulmonary arteries were similar in man, goat, llama and monkey.

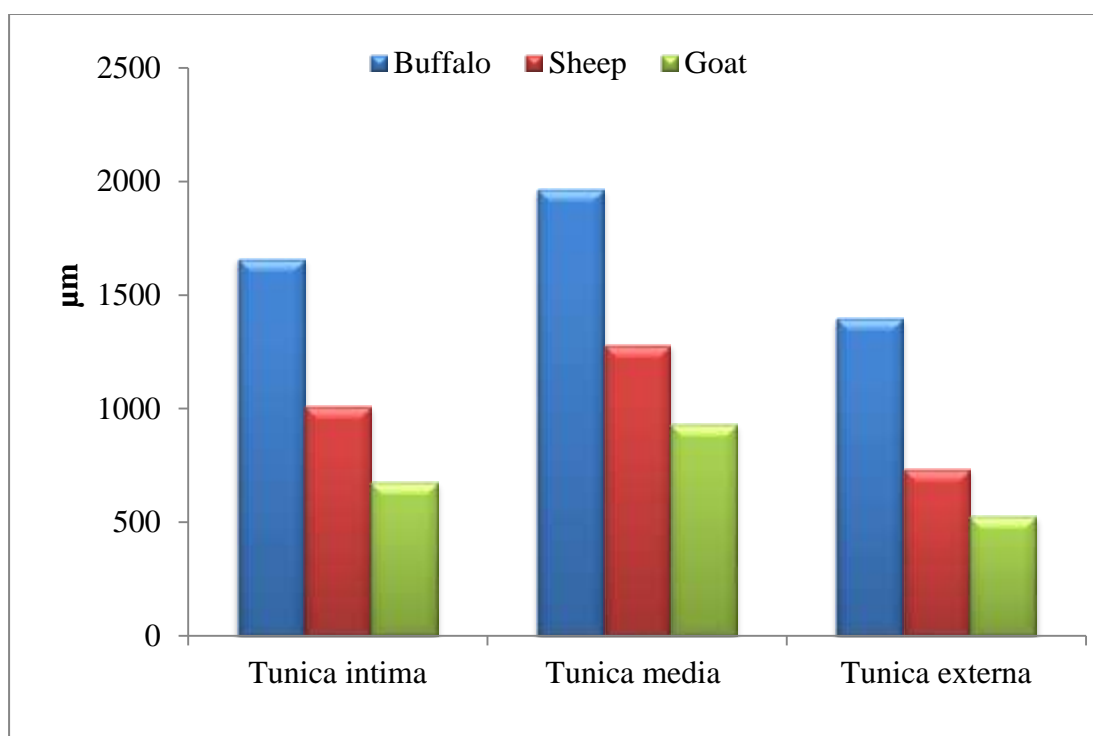
Micrometrical observations showed that the thickness of tunica intima of pulmonary artery varied from 906.73 to 2319.47 μm (Table 6 and Graph 11) with the mean of $1658.91 \pm 135.61 \mu\text{m}$ in the buffalo, in sheep it varied from 399.60 to 1479.43 μm (Table 6 and Graph 11) with the mean of $1007.70 \pm 83.97 \mu\text{m}$, whereas in goat it varied from 199.62 to 1008.19 μm (Table 6 and Graph 11) with the mean of $674.89 \pm 63.56 \mu\text{m}$. The thickness of tunica media of pulmonary artery varied from 1045.08 to 2533.41 μm (Table 6 and Graph 11) with the mean $1965.34 \pm 121.23 \mu\text{m}$ in buffalo. In sheep, it varied from 541.62 to 1744.15 μm (Table 6 and Graph 11) with the mean of $1279.12 \pm 106.59 \mu\text{m}$, whereas in goat it varied from 328.89 to 1379.49 μm (Table 6 and Graph 11) with the mean of $928.38 \pm 92.32 \mu\text{m}$. The thickness of tunica externa of pulmonary artery varied from 806.46 to 1887.42 μm with the mean $1395.14 \pm 106.50 \mu\text{m}$ (Table 6 and Graph 11) in the buffalo, in sheep it varied from 293.68 to 1139.56 μm with the mean of $733.37 \pm 61.11 \mu\text{m}$ (Table 6 and Graph 11),

whereas in goat it varied from 201.73 to 819.41 μm with the mean of 524.89 ± 54.81 μm (Table 6 and Graph 11). Bhasin (2017) reported that thickness of the wall of pulmonary artery was 0.45 ± 0.02 μm and 0.49 ± 0.02 μm in males and females respectively.

Table 6: Micrometrical data on pulmonary artery (Mean \pm S.E) in buffalo, sheep and goat

Species	Pulmonary artery(μm)			
	Tunica intima	Tunica media	Tunica externa	Total thickness
Buffalo	1658.91 \pm 135.61 ^b	1965.34 \pm 121.23 ^b	1395.14 \pm 106.50 ^b	5019.38 \pm 352.25 ^b
Sheep	1007.70 \pm 83.97 ^a	1279.12 \pm 106.59 ^a	733.37 \pm 61.11 ^a	3020.18 \pm 251.40 ^a
Goat	674.89 \pm 63.56 ^a	928.38 \pm 92.32 ^a	524.89 \pm 54.18 ^a	2128.16 \pm 204.34 ^a

Mean \pm S.E, with different small letter superscript in a column differ significantly ($p \leq 0.05$)



Graph 11: Wall thickness of pulmonary artery in buffalo, sheep and goat

4.4 ECHOCARDIOGRAPHY

4.4.1 Atrium

4.4.1.1 Left Atrium

4.4.1.1.1 Internal diameter

The systolic internal diameter of left atrium varied from 4.33 to 5.63 cm with the mean of 4.92 ± 0.10 cm (Table 7, Fig 15A and Graph 12) in the buffalo, it varied from 1.86 to 2.85 cm with the mean of 2.23 ± 0.07 cm (Table 7, Fig 16B and Graph 12) in sheep, whereas in goat it varied from 1.65 to 2.85 cm with the mean of 2.10 ± 0.08 cm (Table 7 and Graph 12). The diastolic internal diameter of left atrium varied from 6.00 to 8.96 with the mean of 7.24 ± 0.28 cm (Table 7, Fig 15B and Graph 12) in the buffalo, it varied from 2.50 to 2.98 cm with the mean of 2.75 ± 0.05 cm (Table 7, Fig 16C and Graph 12) in sheep, whereas in goat it varied from 1.99 to 3.41 cm with the mean of 2.60 ± 0.03 cm (Table 7 and Graph 12). There was significant difference in systolic and diastolic internal diameter of left atrium at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

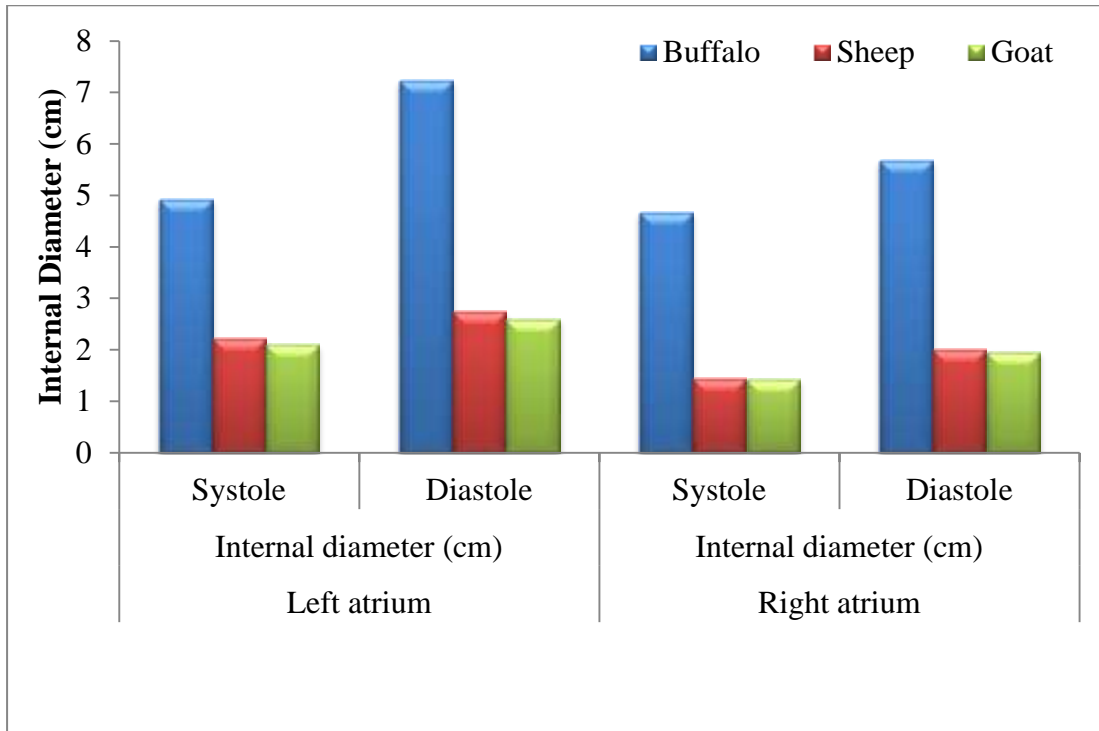
4.4.1.1.2 Wall thickness

The systolic wall thickness of left atrium varied from 0.91 to 1.28 cm with the mean of 1.05 ± 0.03 cm (Table 8, Fig 15C and Graph 14) in the buffalo, it varied from 0.59 to 0.69 cm with the mean of 0.64 ± 0.01 cm (Table 8, Fig 16A and Graph 14) in sheep, whereas in goat it varied from 0.32 to 0.65 cm with the mean of 0.53 ± 0.02 cm (Table 8, Fig 17A and Graph 14). The diastolic wall thickness of left atrium varied from 0.63 to 0.95 cm with the mean of 0.75 ± 0.03 cm (Table 8, Fig 15D and Graph 14) in the buffalo, it varied from 0.47 to 0.57 cm with the mean of 0.52 ± 0.01 cm (table 8 and Graph 14) in sheep, whereas in goat it varied from 0.28 to 0.57 cm with the mean of 0.45 ± 0.02 cm (Table 8, Fig 17B and Graph 14). There was significant difference in systolic and diastolic left atrium wall at $p \leq 0.05$ level of significance in buffalo as compared, sheep and goat. Highest left atrial wall was observed in buffalo followed by sheep and least in goat. Bhasin (2017) reported that the wall thickness of left atrium varied from 0.51 cm to 1.37 cm with the mean of 0.96 ± 0.08 cm in male buffalos, whereas same parameters varied from 0.72 cm to 1.35 cm with the mean of 1.10 ± 0.05 cm in female buffalo.

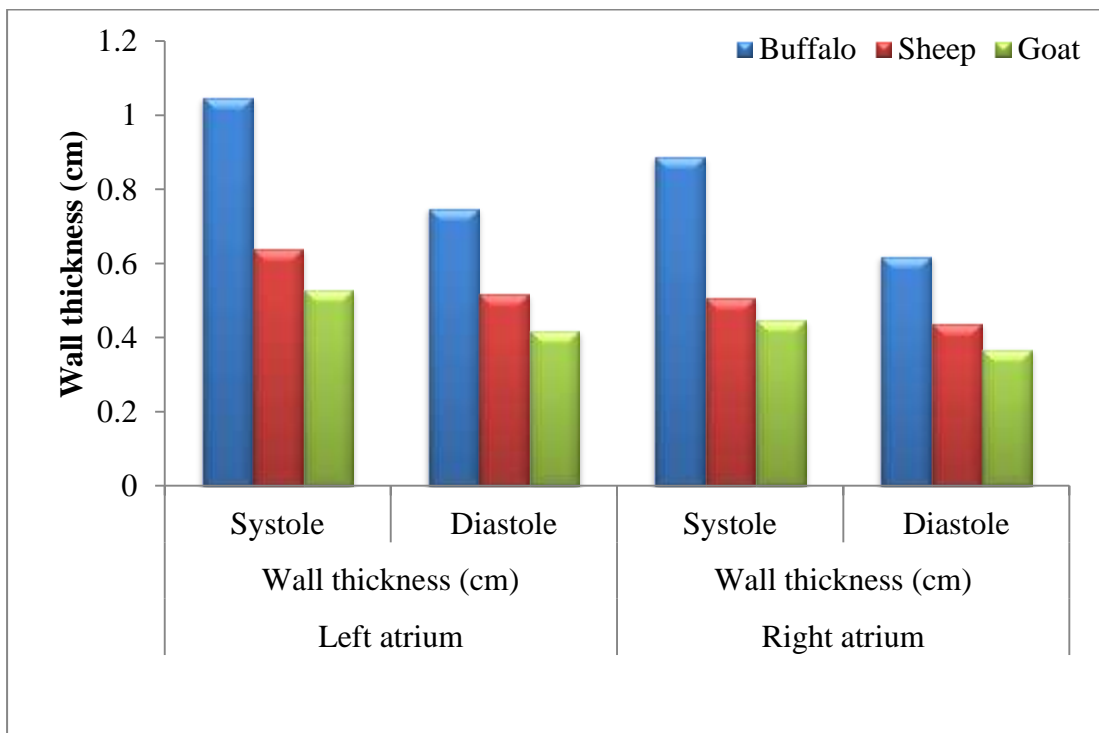
Table 7: Echocardiographic data on internal diameter (Mean \pm S.E) of atrium and ventricle in buffalo, sheep and goat

Species	Left atrium		Right atrium		Left ventricle		Right ventricle	
	Internal diameter (cm)		Internal diameter (cm)		Internal diameter (cm)		Internal diameter (cm)	
	Systole	Diastole	Systole	Diastole	Systole	Diastole	Systole	Diastole
Buffalo	4.92 \pm 0.10 ^b	7.24 \pm 0.28 ^b	4.67 \pm 0.32 ^b	5.68 \pm 0.33 ^b	3.32 \pm 0.19 ^b	9.22 \pm 0.23 ^b	2.51 \pm 0.25 ^b	6.50 \pm 0.32 ^b
Sheep	2.23 \pm 0.07 ^a	2.75 \pm 0.05 ^a	1.44 \pm 0.08 ^a	2.01 \pm 0.05 ^a	1.76 \pm 0.04 ^a	3.11 \pm 0.13 ^a	1.53 \pm 0.03 ^a	2.04 \pm 0.05 ^a
Goat	2.10 \pm 0.08 ^a	2.60 \pm 0.3 ^a	1.42 \pm 0.07 ^a	1.96 \pm 0.09 ^a	1.68 \pm 0.06 ^a	3.07 \pm 0.05 ^a	1.42 \pm 0.05 ^a	1.94 \pm 0.06 ^a

Mean \pm S.E, with different small letter superscript in a column differ significantly ($p \leq 0.05$)



Graph 12: Internal diameter of left and right atrium of heart in buffalo, sheep and goat



Graph 14: Left and right atrial wall thickness in buffalo, sheep and goat

4.4.1.2 Right Atrium

4.4.1.2.1 Internal diameter

The systolic internal diameter of right atrium varied from 3.27 to 6.64 cm with the mean of 4.67 ± 0.32 cm (Table 7, Fig 18A and Graph 12) in the buffalo, it varied from 1.11 to 1.83 cm with the mean of 1.44 ± 0.08 cm (Table 7, Fig 19C and Graph 12) in sheep, whereas in goat it varied from 0.94 to 1.76 cm with the mean of 1.42 ± 0.07 cm (Table 7, Fig 20 B and Graph 12). The diastolic internal diameter of right atrium varied from 4.10 to 7.48 cm with the mean of 5.68 ± 0.33 cm (Table 7, Fig 18B and Graph 12) in the buffalo, it varied from 1.72 to 2.33 cm with the mean of 2.01 ± 0.05 cm (Table 7, Fig 19D and Graph 12) in sheep, whereas in goat it varied from 1.23 to 2.33 cm with the mean of 1.96 ± 0.09 cm (Table 7, Fig 20C and Graph 12). There was significant difference in systolic and diastolic internal diameter of right atrium at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.4.1.2.2 Wall thickness

The systolic wall thickness of right atrium varied from 0.74 to 1.05 cm with the mean of 0.89 ± 0.02 cm (Table 8 and Graph 14) in the buffalo, it varied from 0.42 to 0.63 cm with the mean of 0.51 ± 0.04 cm (Table 8, Fig 19A and Graph 14) in sheep, whereas in goat it varied from 0.29 to 0.57 cm with the mean of 0.45 ± 0.02 cm (Table 8, Fig 20A and Graph 14). The diastolic wall thickness of right atrium varied from 0.39 to 0.82 cm with the mean of 0.62 ± 0.03 cm (Table 8 and Graph 14) in the buffalo, it varied from 0.33 to 0.59 cm with the mean of 0.44 ± 0.03 cm (Table 8, Fig 19B and Graph 14) in sheep, whereas in goat it varied from 0.27 to 0.55 cm with the mean of 0.37 ± 0.02 cm (Table 8 and Graph 14). There was significant difference in systolic and diastolic right atrial wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat. Highest right atrial wall was observed in buffalo followed by sheep and least in goat. Bhasin (2017) stated that the wall thickness of right atrium varied from 0.38 cm to 1.11 cm with the mean of 0.79 ± 0.06 cm in male buffalos, whereas same parameters varied from 0.6 cm to 1.46 cm with the mean of 0.96 ± 0.07 cm in female buffalos.

Table 8: Echocardiographic data on thickness (Mean \pm S.E) of atrium, ventricle and interventricular wall in buffalo, sheep and goat

Species	Left atrium		Right atrium		Left ventricle		Right ventricle		Interventricular septum	
	Wall thickness (cm)		Wall thickness (cm)		Wall thickness (cm)		Wall thickness (cm)		Wall thickness (cm)	
	Systole	Diastole	Systole	Diastole	Systole	Diastole	Systole	Diastole	Systole	Diastole
Buffalo	1.05 \pm 0.03 ^b	0.75 \pm 0.03 ^b	0.89 \pm 0.02 ^b	0.62 \pm 0.03 ^b	3.55 \pm 0.03 ^b	2.07 \pm 0.09 ^b	2.27 \pm 0.13 ^b	1.86 \pm 0.12 ^b	2.96 \pm 0.09 ^b	1.86 \pm 0.06 ^b
Sheep	0.64 \pm 0.01 ^a	0.52 \pm 0.01 ^a	0.51 \pm 0.04 ^a	0.44 \pm 0.03 ^a	2.00 \pm 0.10 ^a	1.16 \pm 0.06 ^a	0.88 \pm 0.02 ^a	0.69 \pm 0.02 ^a	2.09 \pm 0.10 ^a	1.43 \pm 0.06 ^a
Goat	0.53 \pm 0.02 ^a	0.42 \pm 0.02 ^a	0.45 \pm 0.02 ^a	0.37 \pm 0.02 ^a	2.01 \pm 0.14 ^a	0.99 \pm 0.06 ^a	0.86 \pm 0.03 ^a	0.64 \pm 0.03 ^a	1.91 \pm 0.08 ^a	1.38 \pm 0.08 ^a

Mean \pm S.E, with different small letter superscript in a column differ significantly ($p \leq 0.05$)

4.4.2 Ventricle

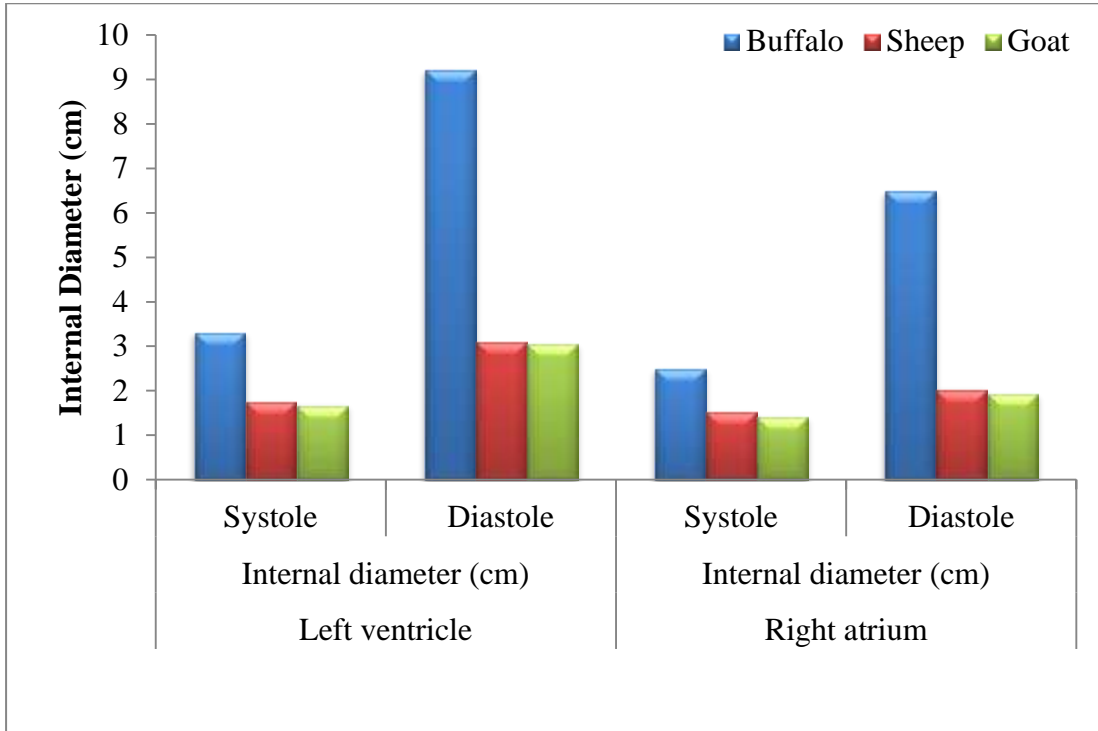
4.4.2.1 Left Ventricular

4.4.2.1.1 Internal diameter

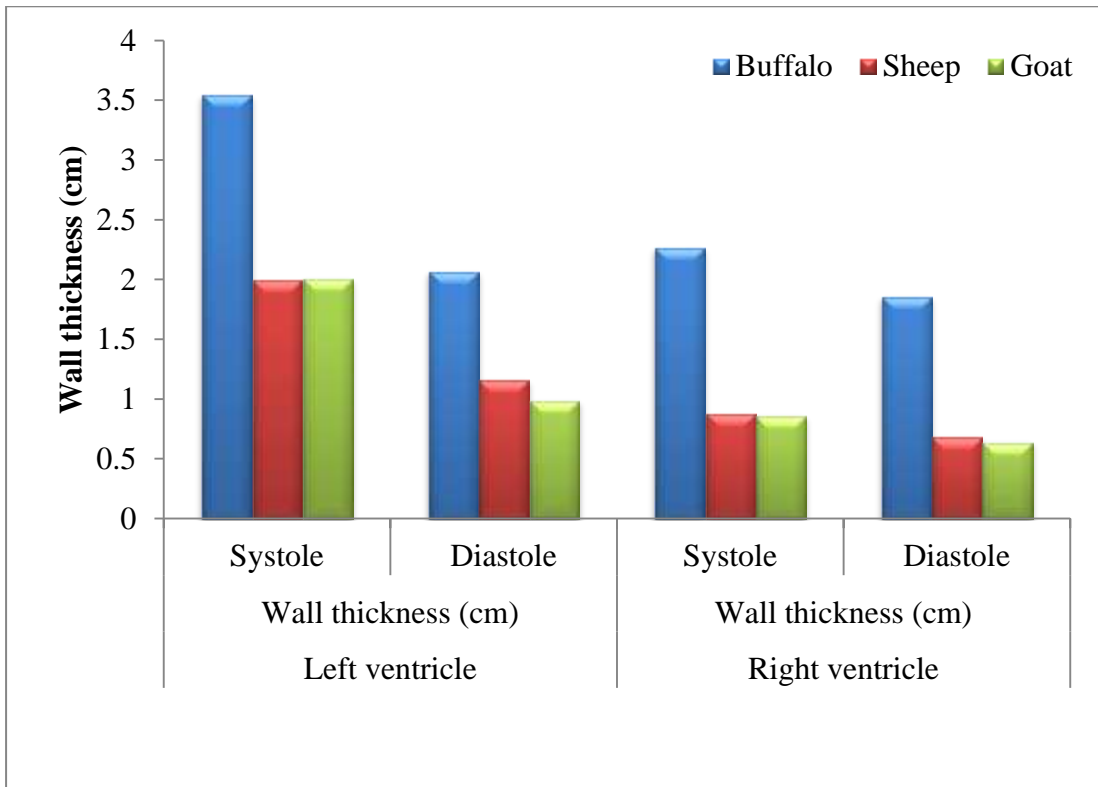
The systolic internal diameter of left ventricle varied from 2.46 to 4.05 cm with the mean of 3.32 ± 0.19 cm (Table 7, Fig 21A and Graph 13) in the buffalo, in sheep it varied from 1.55 to 2.11 cm with the mean of 1.76 ± 0.04 cm (Table 7, Fig 22A and Graph 13), whereas in goat it varied from 1.07 to 1.98 cm with the mean of 1.68 ± 0.06 cm (Table 7, Fig 23C and Graph 13). The diastolic internal diameter of left ventricle varied from 7.99 to 10.61 cm with the mean of 9.22 ± 0.23 cm (Table 7, Fig 21B and Graph 13) in the buffalo, in sheep it varied from 2.62 to 4.12 cm with the mean of 3.11 ± 0.13 cm (Table 7, Fig 22A and Graph 13), whereas in goat it varied from 2.55 to 3.28 cm with the mean of 3.07 ± 0.05 cm (Table 7, Fig 23D and Graph 13). There was significant difference in systolic and diastolic internal diameter of left ventricle at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.4.2.1.2 Wall thickness

The systolic wall thickness of left ventricle varied from 3.34 to 3.74 cm with the mean of 3.55 ± 0.03 cm (Table 8, Fig 21C and Graph 15) in the buffalo, in sheep it varied from 1.13 to 2.37 cm with mean of 2.00 ± 0.10 cm (Table 8, Fig 22A and Graph 15), whereas in goat it varied from 1.29 to 2.92 cm with mean of 2.01 ± 0.14 cm (Table 8, Fig 23A and Graph 15). The diastolic wall thickness of left ventricle varied from 1.21 to 2.46 cm with the mean of 2.07 ± 0.09 cm (Table 8 and Graph 15) in the buffalo, in sheep it varied from 0.77 to 1.47 cm with mean of 1.16 ± 0.06 cm (Table 8, Fig 22A and Graph 15), whereas in goat it varied from 0.57 to 1.31 cm with mean of 0.99 ± 0.06 cm (Table 8, Fig 23B and Graph 15). There was significant difference in systolic and diastolic left ventricle wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat. Bhasin (2017) observed that the thickness of left ventricular wall varied from 1.79 cm to 4.06 cm with the mean of 2.76 ± 0.11 cm in male buffalos, whereas same parameters varied from 1.80 cm to 3.85 cm with the mean of 2.77 ± 0.17 cm in female buffalos.



Graph 13: Internal diameter of left and right ventricle of heart in buffalo, sheep and goat



Graph 15: Left and right ventricular wall thickness in buffalo, sheep and goat

4.4.2.2 Right Ventricle

4.4.2.2.1 Internal diameter

The systolic internal diameter of right ventricle varied from 1.43 to 3.42 cm with the mean of 2.51 ± 0.25 cm (Table 7 and Graph 13) in the buffalo, in sheep it varied from 1.36 to 1.76 cm with the mean of 1.53 ± 0.03 cm (Table 7, Fig 25C and Graph 13), whereas in goat it varied from 1.13 to 1.67 cm with the mean of 1.42 ± 0.05 cm (Table 7, Fig 26C and Graph 13).

The diastolic internal diameter of right ventricle varied from 4.03 to 7.59 cm with the mean of 6.50 ± 0.32 cm (Table 7, Fig 24A and Graph 13) in the buffalo, in sheep it varied from 1.86 to 2.41 cm with the mean of 2.04 ± 0.05 cm (Table 7, Fig 25 D and Graph 13), whereas in goat it varied from 1.61 to 2.39 cm with the mean of 1.94 ± 0.06 cm (Table 7, Fig 26D and Graph 13). There was significant difference in systolic and diastolic internal diameter of right ventricle at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.4.2.2.2 Wall thickness

The systolic wall thickness of right ventricle varied from 1.00 to 2.62 cm with the mean of 2.27 ± 0.13 cm (Table 8 and Graph 15) in the buffalo, in sheep it varied from 0.67 to 0.99 cm with mean of 0.88 ± 0.02 cm (Table 8, Fig 25A and Graph 15), whereas in goat it varied from 0.58 to 0.97 cm with the mean of 0.86 ± 0.03 cm (Table 8, Fig 26A and Graph 15). The diastolic wall thickness of right ventricle varied from 0.85 to 2.18 cm with the mean of 1.86 ± 0.12 cm (Table 8, Fig 24B and Graph 15) in the buffalo, in sheep it varied from 0.49 to 0.79 cm with mean of 0.69 ± 0.02 cm (Table 8, Fig 25B and Graph 15), whereas in goat it varied from 0.45 to 0.79 cm with the mean of 0.64 ± 0.03 cm (Table 8, Fig 26B and Graph 15). There was significant difference in systolic and diastolic right ventricle wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat. Bhasin (2017) observed that the thickness of right ventricular wall varied from 0.95 cm to 2.28 cm with the mean of 1.49 ± 0.12 cm in male buffalos whereas same parameters varied from 0.97 cm to 1.92 cm with the mean of 1.33 ± 0.08 cm in female buffalos.

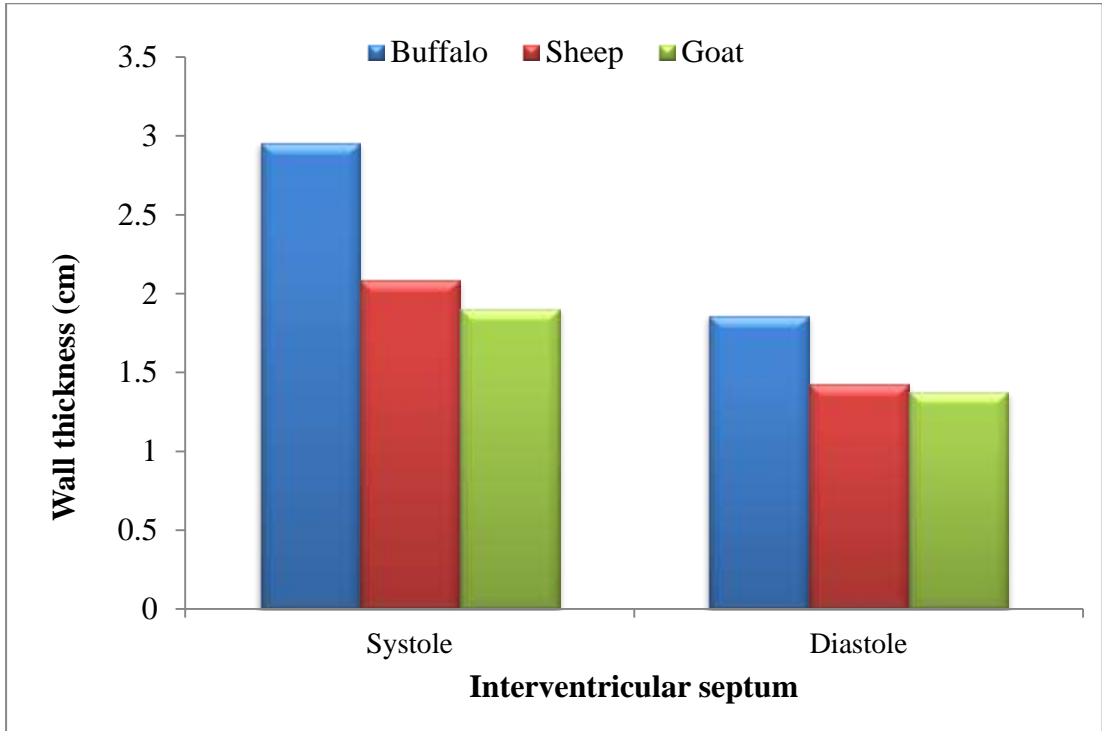
4.4.3 Interventricular Septum

The systolic wall thickness of interventricular septum varied from 2.42 to 3.35 cm with the mean of 2.96 ± 0.09 cm (Table 8, Fig 27A and Graph 16) in the buffalo, in sheep it varied from 1.42 to 2.53 cm with the mean of 2.09 ± 0.10 cm (Table 8, Fig 22B and Graph 16), whereas in goat it varied from 1.21 to 2.16 cm with the mean of 1.91 ± 0.08 cm (Table 8, Fig 28A and Graph 16). The diastolic wall thickness of interventricular septum varied from 1.47 to 2.11 cm with the mean of 1.86 ± 0.06 cm (Table 8, Fig 27B and Graph 16) in the buffalo, in sheep it varied from 1.42 to 2.53 cm with the mean of 2.09 ± 0.10 cm (Table 8, Fig 22B and Graph 16), whereas in goat it varied from 1.21 to 2.16 cm with the mean of 1.91 ± 0.08 cm (Table 8, Fig 28B and Graph 16). There was significant difference in systolic and diastolic interventricular septum wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat. Bhasin (2017) recorded that the thickness of interventricular septal wall varied from 1.25 cm to 2.87 cm with the mean of 2.36 ± 0.11 cm in male buffalos, whereas same parameters varied from 1.08 cm to 3.21 cm with the mean of 2.41 ± 0.14 cm in female buffalos.

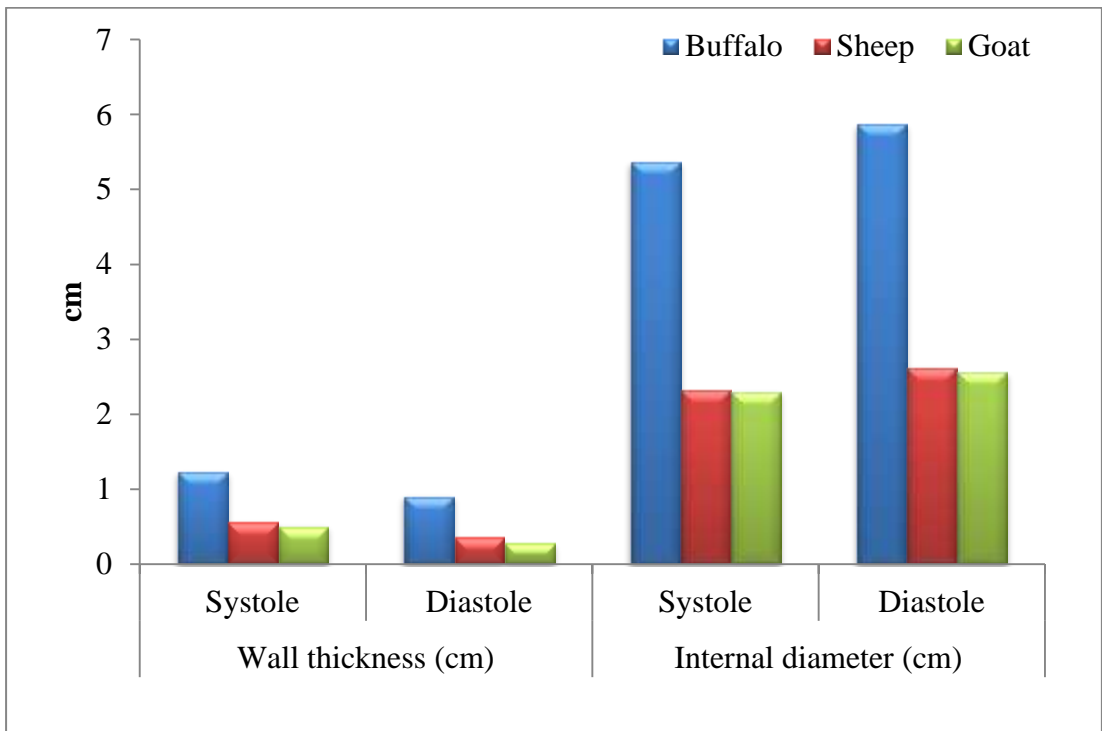
4.4.4 Aorta

4.4.4.1 Internal diameter

The systolic internal diameter of aorta varied from 5.09 to 5.75 cm with the mean of 5.37 ± 0.06 cm (Table 9, Fig 29A and Graph 17) in the buffalo, in sheep it varied from 2.11 to 2.63 cm with the mean of 2.33 ± 0.12 cm (Table 9, Fig 30B and Graph 17), whereas in goat it varied from 2.22 to 2.37 cm with the mean of 2.31 ± 0.05 cm (Table 9, Fig 31B and Graph 17). The diastolic internal diameter of aorta varied from 5.60 to 6.25 cm with the mean of 5.88 ± 0.06 cm (Table 9, Fig 29B and Graph 17) in the buffalo, in sheep it varied from 2.52 to 3.03 cm with the mean of 2.63 ± 0.03 cm (Table 9, Fig 30C and Graph 17), whereas in goat it varied from 2.40 to 2.72 cm with the mean of 2.57 ± 0.02 cm (Table 9 and Graph 17). There was significant difference in systolic and diastolic internal diameter of aorta at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.



Graph 16: Wall thickness of interventricular septum in buffalo, sheep and goat



Graph 17: Wall thickness and internal diameter of aorta in buffalo, sheep and goat

4.4.4.2 Wall thickness

The systolic wall thickness of aorta varied from 0.83 to 1.63 cm with the mean of 1.24 ± 0.08 cm (Table 9 and Graph 17) in the buffalo, in sheep it varied from 0.41 to 0.71 cm with the mean of 0.57 ± 0.01 cm (Table 9 and Graph 17), whereas in goat it varied from 0.37 to 0.63 cm with the mean of 0.51 ± 0.02 cm (Table 9, Fig 31A and Graph 17). The diastolic wall thickness of aorta varied from 0.60 to 1.26 cm with the mean of 0.91 ± 0.06 cm (table 9, Fig 29C and Graph 17) in the buffalo, in sheep it varied from 0.27 to 0.44 cm with the mean of 0.37 ± 0.01 cm (Table 9, Fig 30A and Graph 17), whereas in goat it varied from 0.23 to 0.38 cm with the mean of 0.29 ± 0.01 cm (Table 9 and Graph 17). There was significant difference in systolic and diastolic aorta wall at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.4.5 Pulmonary Artery

4.4.5.1 Internal diameter

The systolic internal diameter of pulmonary artery varied from 3.31 to 6.18 cm with the mean of 5.21 ± 0.23 cm (Table 9, Fig 32A and Graph 18) in the buffalo, in sheep it varied from 1.17 to 1.89 cm with the mean of 1.53 ± 0.09 cm (Table 9 and Graph 18), whereas in goat it varied from 1.05 to 1.89 cm with the mean of 1.39 ± 0.06 cm (Table 9, Fig 34B and Graph 18). The diastolic internal diameter of pulmonary artery varied from 5.10 to 6.74 cm with the mean of 6.04 ± 0.17 cm (Table 9 and Graph 18) in the buffalo, in sheep it varied from 1.42 to 2.39 cm with the mean of 1.77 ± 0.07 cm (Table 9 and Graph 18), whereas in goat it varied from 1.27 to 2.12 cm with the mean of 1.74 ± 0.07 cm (Table 9 and Graph 18). There was significant difference in systolic and diastolic internal diameter of pulmonary artery at $p \leq 0.05$ level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

4.4.5.2 Wall thickness

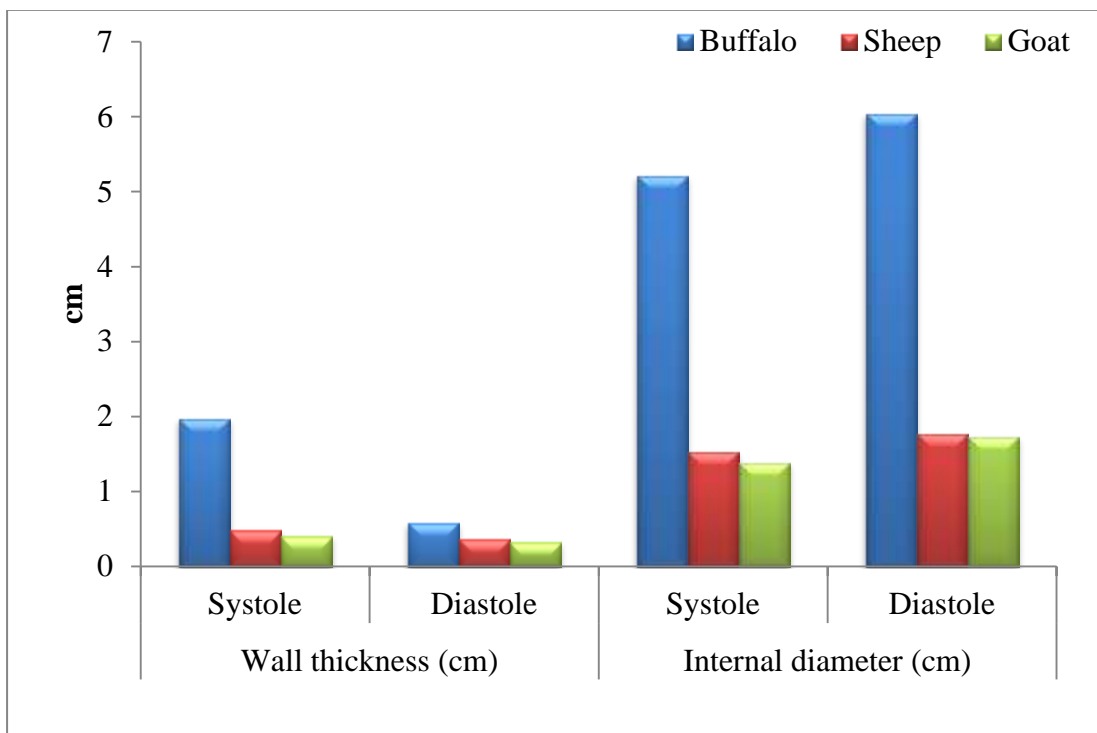
The systolic wall thickness of pulmonary artery varied from 1.71 to 3.31 cm with the mean of 1.97 ± 0.12 cm (Table 9 and Graph 18) in the buffalo, in sheep it varied from 0.32 to 0.66 cm with the mean of 0.49 ± 0.03 cm (Table 9, Fig 33A and

Table 9: Echocardiographic data on thickness and internal diameter (Mean \pm S.E) of pulmonary artery and aorta in buffalo, sheep and goat

Species	Pulmonary artery		Aorta		Pulmonary artery		Aorta	
	Wall thickness (cm)		Wall thickness (cm)		Internal diameter (cm)		Internal diameter (cm)	
	Systole	Diastole	Systole	Diastole	Systole	Diastole	Systole	Diastole
Buffalo	1.97 \pm 0.12 ^b	0.59 \pm 0.05 ^b	1.24 \pm 0.08 ^b	0.91 \pm 0.06 ^b	5.21 \pm 0.23 ^b	6.04 \pm 0.17 ^b	5.37 \pm 0.06 ^b	5.88 \pm 0.06 ^b
Sheep	0.49 \pm 0.03 ^a	0.37 \pm 0.03 ^a	0.57 \pm 0.01 ^a	0.37 \pm 0.01 ^a	1.53 \pm 0.09 ^a	1.77 \pm 0.07 ^a	2.33 \pm 0.12 ^a	2.63 \pm 0.03 ^a
Goat	0.41 \pm 0.02 ^a	0.33 \pm 0.02 ^a	0.51 \pm 0.02 ^a	0.29 \pm 0.01 ^a	1.39 \pm 0.06 ^a	1.74 \pm 0.07 ^a	2.31 \pm 0.05 ^a	2.57 \pm 0.02 ^a

Mean \pm S.E, with different small letter superscript in column differ significantly ($p \leq 0.05$)

Graph 18), whereas in goat it varied from 0.32 to 0.56 cm with the mean of 0.41 ± 0.02 cm (Table 9, Fig 34A and Graph 18). The diastolic wall thickness of pulmonary artery varied from 0.35 to 1.01 cm with the mean of 0.59 ± 0.05 cm (Table 9, Fig 32B and Graph 18) in the buffalo, in sheep it varied from 0.23 to 0.54 cm with the mean of 0.37 ± 0.03 cm (Table 9, Fig 33B and Graph 18), whereas in goat it varied from 0.25 to 0.46 cm with the mean of 0.33 ± 0.02 cm (Table 9 and Graph 18). There was significant difference in systolic and diastolic pulmonary artery wall at ($p \leq 0.05$) level of significance in buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.



Graph 18: Wall thickness and internal diameter of pulmonary artery in buffalo, sheep and goat

The echocardiographical thickness of left atrial wall, right atrial wall, left ventricle wall, right ventricle wall, interventricular septum was significantly different ($p \leq 0.05$) in buffalo as compare to sheep and goat, but there was no significant difference between sheep and goat. Higher value of these parameters was found in buffalo than sheep and least in goat. This may be due to the larger size of heart in large ruminants (buffalo) as compare to the small ruminants (sheep and goat).

The comparative observations on biometrical and echocardiographical values on the thickness of left atrial wall, right atrial wall, left ventricle wall, right ventricle wall, interventricular septum (Table 10) in buffalo, sheep and goat was analysed by using Paired t – test (Snedecor and Cochran, 1994).

The comparative biometrical and echocardiographic studies depicted that the echocardiographical observations were significantly higher as compared to the biometrical observations. This may be due to accuracy in the measurements by ultrasound machine as compared to the manual measurements (Vernier calliper and inelastic thread method) of formalin fixed heart. Difference in the echocardiographical and biometrical values may also be due to the measurements on the different components of heart on live animal (echocardiographical) and slaughtered animal (Biometrical).

The comparative observations on biometrical, echocardiographical and micrometrical aspects on the thickness of pulmonary artery and aorta (Table 11) of buffalo or sheep or goat was analysed by two – way anova method.

The echocardiographical values of aorta and pulmonary artery were significantly different $p \leq 0.05$ from biometrical and micrometrical values in buffalo, sheep and goat, but there was no significant difference between biometrical and micrometrical data was found.

It may be depicted from the present study that the thickness of aorta and pulmonary artery was significantly higher echocardiographical followed by biometrical and least micrometrical observations in buffalo, sheep and goat. The higher echocardiographical observation on the thickness of aorta and pulmonary artery in different animals studied may be due to the accuracy in measurement by ultrasound machine as compare to manual measurement. The least value by micrometrical method may be due to the shrinkage of tissue sample (pulmonary artery and aorta) during processing and paraffin sectioning for histological studies.

Table 10: Comparative biometrical and echocardiographical observation on thickness of various compartments of heart in buffalo, sheep and goat

Parameter	Biometrical			Echocardiographical		
	Wall thickness(cm)			Wall thickness systole(cm)		
	Buffalo	Sheep	Goat	Buffalo	Sheep	Goat
Left atrial wall (cm)	0.50 ± 0.19 ^a	0.26 ± 0.03 ^a	0.24 ± 0.01 ^a	1.05 ± 0.03 ^b	0.64 ± 0.01 ^b	0.53 ± 0.02 ^b
Right atrial wall (cm)	0.40 ± 0.02 ^a	0.21 ± 0.02 ^a	0.15 ± 0.01 ^a	0.89 ± 0.02 ^b	0.51 ± 0.02 ^b	0.43 ± 0.02 ^b
Left ventricular wall (cm)	2.71 ± 0.9 ^a	1.50 ± 0.05 ^a	1.43 ± 0.04 ^a	3.55 ± 0.03 ^b	2.00 ± 0.10 ^b	2.01 ± 0.14 ^b
Right ventricular wall (cm)	1.74 ± 0.12 ^a	0.75 ± 0.02 ^a	0.73 ± 0.05 ^a	2.27 ± 0.13 ^b	0.88 ± 0.02 ^b	0.86 ± 0.03 ^b
Interventricular septum (cm)	2.34 ± 0.09 ^a	1.71 ± 0.05 ^a	1.62 ± 0.01 ^a	2.96 ± 0.09 ^b	2.09 ± 0.10 ^b	1.91 ± 0.08 ^b

Mean ± S.E, with different small letter superscript in differ significantly $p \leq 0.05$

Table 11: Comparative biometrical, echocardiographical and micrometrical observations on thickness of pulmonary artery and aorta of heart in buffalo, sheep and goat

Species	Biometrical		Echocardiographical		Micrometrical	
	Wall thickness (cm)		Wall thickness systole (cm)		Wall thickness (cm)	
	Pulmonary artery	Aorta	Pulmonary artery	Aorta	Pulmonary artery	Aorta
Buffalo	0.67 ± 0.06^a	1.00 ± 0.06^a	1.97 ± 0.12^b	1.24 ± 0.08^b	0.50 ± 0.03^a	0.81 ± 0.04^a
Sheep	0.37 ± 0.02^a	0.42 ± 0.02^a	0.49 ± 0.03^b	0.57 ± 0.01^b	0.30 ± 0.01^a	0.32 ± 0.01^a
Goat	0.29 ± 0.02^a	0.37 ± 0.03^a	0.41 ± 0.02^b	0.51 ± 0.02^b	0.21 ± 0.01^a	0.30 ± 0.01^a

Mean \pm S.E, with different small letter superscript differ significantly $p \leq 0.05$

FIGURE 1

- A. Left view of heart of buffalo showing left atrium (LA), pulmonary artery (PA), aorta (A), left ventricle (LV), right ventricle (RV) and ascending aorta (AA).
- B. Right view of heart of buffalo showing aorta (A), right atrium (RA), right ventricle (RV), left ventricle (LV) and ascending aorta (AA).
- C. Longitudinal section of heart of buffalo showing left atrium (LA), aorta (A), left ventricle (LV), right ventricle (RV) and interventricular septum (IVS).
- D. Longitudinal section of heart of buffalo showing left ventricle (LV), right ventricle (RV), interventricular septum (IVS), aorta (A) and right atrium (RA).
- E. Transverse section of buffalo heart at the base showing right atrioventricular valve (RAV), left atrioventricular valve (LAV), pulmonary valve in pulmonary artery (PA), aortic valve in aorta (A).
- F. Transverse section of buffalo heart at the middle of ventricles showing circular left ventricle (LV) and crescent right ventricle (RV).

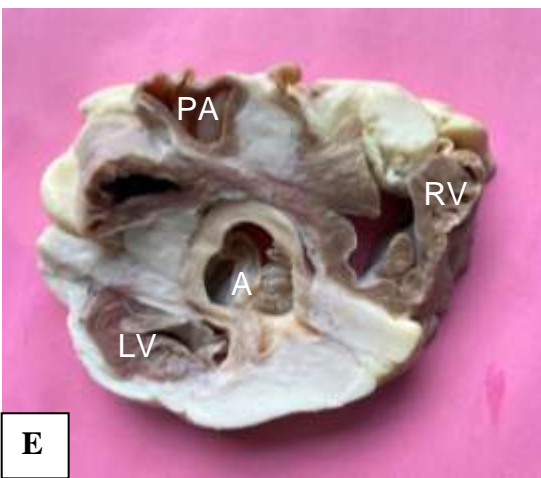
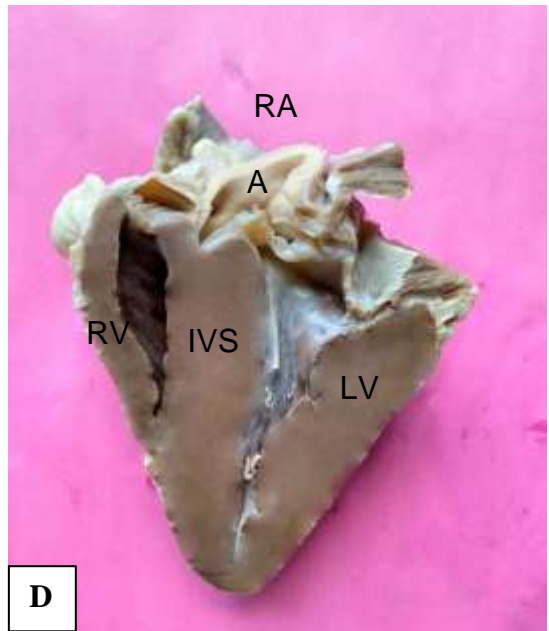
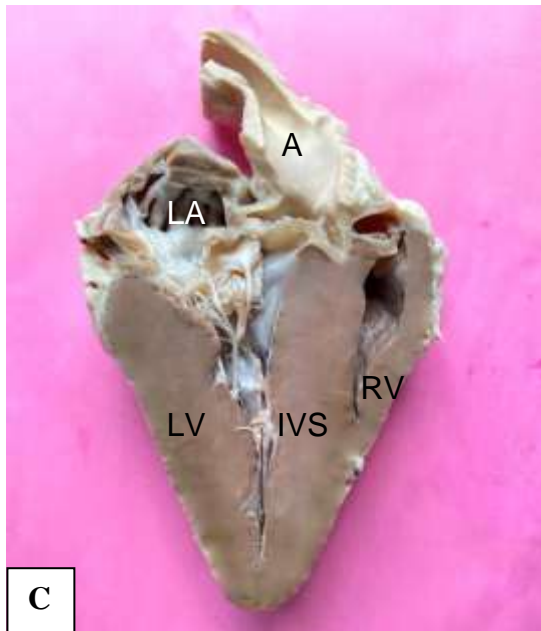
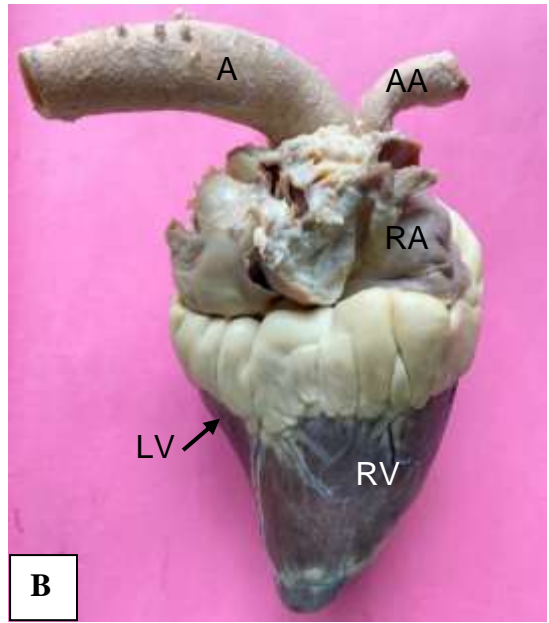
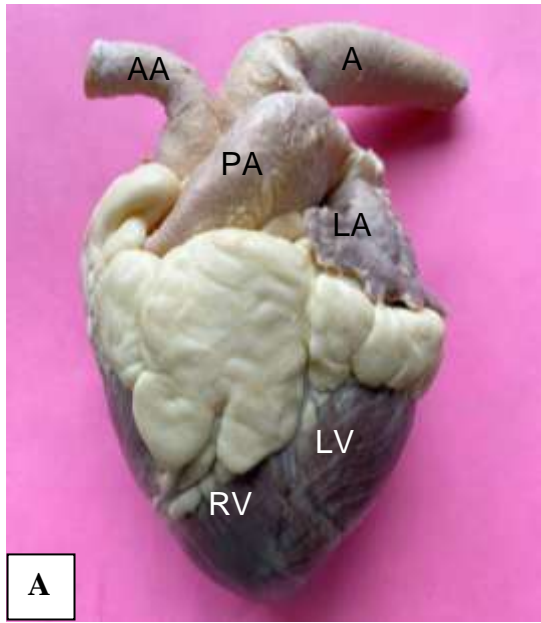


Figure 1

FIGURE 2

- A. Left view of heart of sheep showing left atrium (LA), pulmonary artery (PA), aorta (A), left ventricle (LV), right ventricle (RV), right atrium (RA) and ascending aorta (AA).
- B. Right view of heart of sheep showing aorta (A), right atrium (RA), right ventricle (RV), left ventricle (LV), pulmonary artery (PA) and ascending aorta (AA).
- C. Longitudinal section of heart of sheep showing aorta (A), left ventricle (LV), right ventricle (RV), right atrium (RA), ascending aorta (AA) and interventricular septum (IVS).
- D. Longitudinal section of heart of sheep showing left ventricle (LV), left atrium (LA), right ventricle (RV), interventricular septum (IVS) and aorta (A).
- E. Transverse section of sheep heart at the base showing right atrioventricular valve (RAV), left atrioventricular valve (LAV), pulmonary valve in pulmonary artery (PA), aortic valve in aorta (A).
- F. Transverse section of sheep heart at the middle of ventricles showing circular left ventricle (LV), interventricular septum (IVS) and crescent right ventricle (RV).

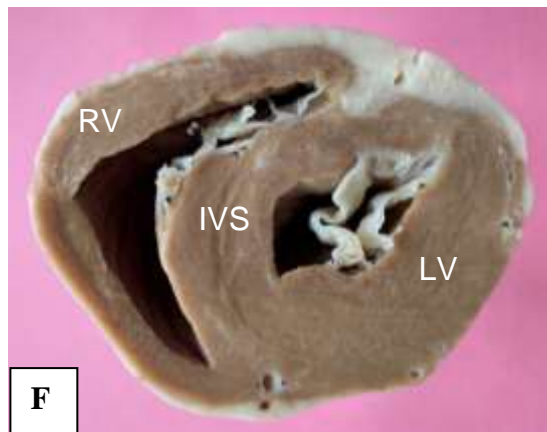
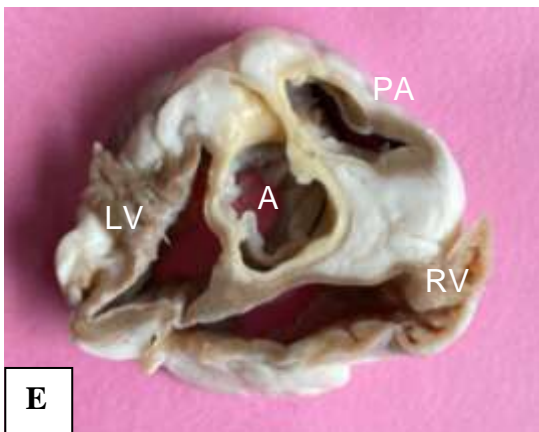
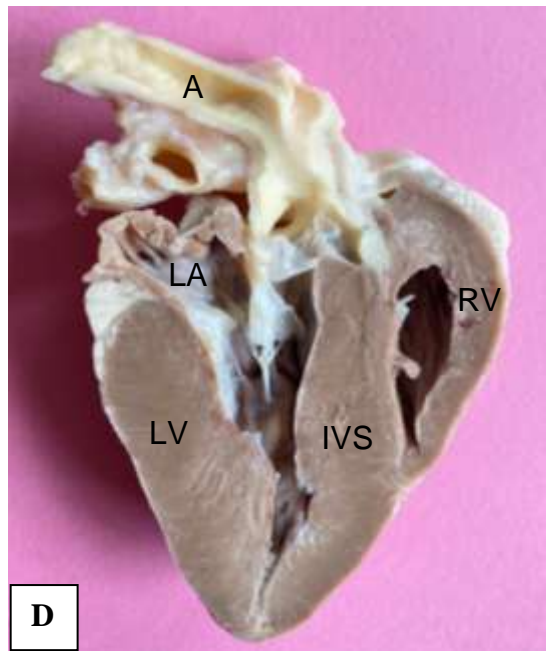
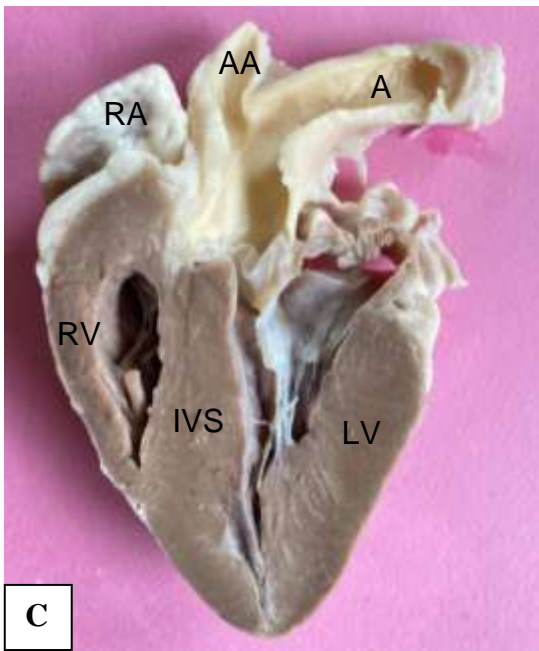
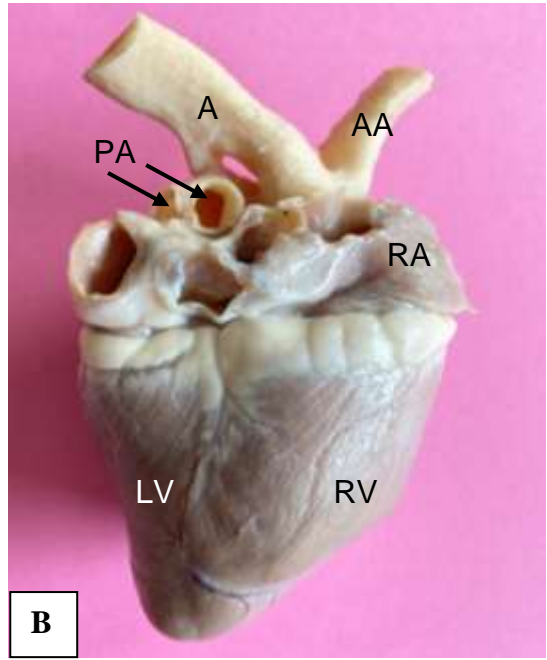
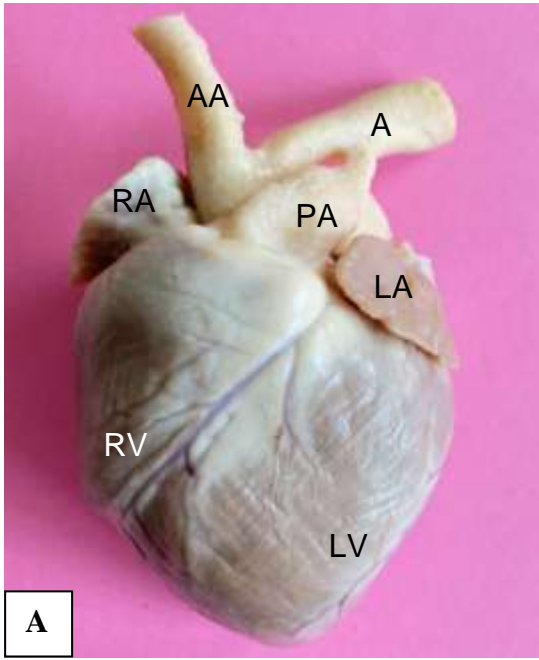


Figure 2

FIGURE 3

- A. Left view of heart of goat showing left atrium (LA), pulmonary artery (PA), right ventricle (RV), left ventricle (LV), right atrium (RA), aorta (A) and ascending aorta (AA).
- B. Right view of heart of goat showing aorta (A), right atrium (RA), right ventricle (RV), left ventricle (LV), ascending aorta (AA) and left atrium (LA).
- C. Longitudinal section of heart of goat showing left atrium (LA), left ventricle (LV), right ventricle (RV), interventricular septum (IVS), right atrium (RA), ascending aorta (AA) and aorta (A).
- D. Longitudinal section of heart of goat showing left ventricle (LV), left atrium (LA), right ventricle (RV), interventricular septum (IVS) and aorta (A).
- E. Transverse section of goat heart at the base showing right atrioventricular valve (RAV), left atrioventricular valve (LAV), pulmonary valve in pulmonary artery (PA), aortic valve in aorta (A).
- F. Transverse section of goat heart at the middle of ventricles showing circular left ventricle (LV), interventricular septum (IVS) and crescent right ventricle (RV).

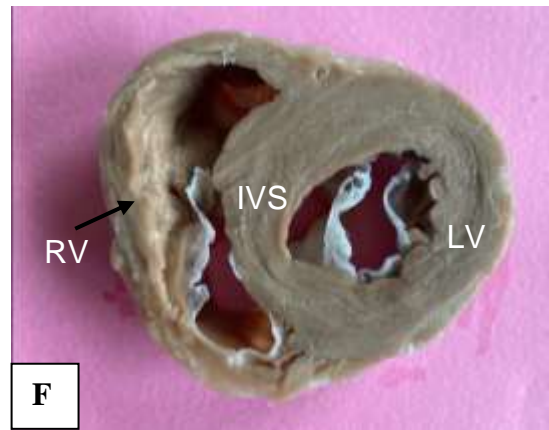
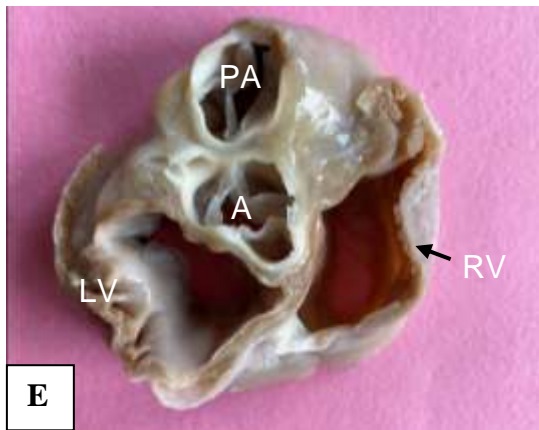
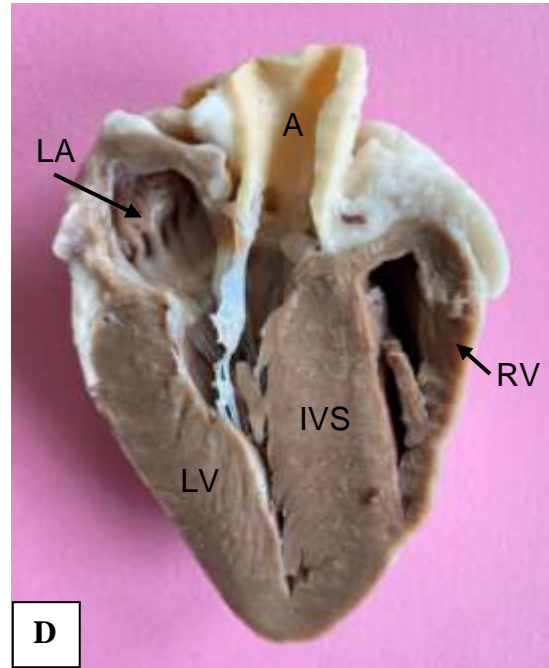
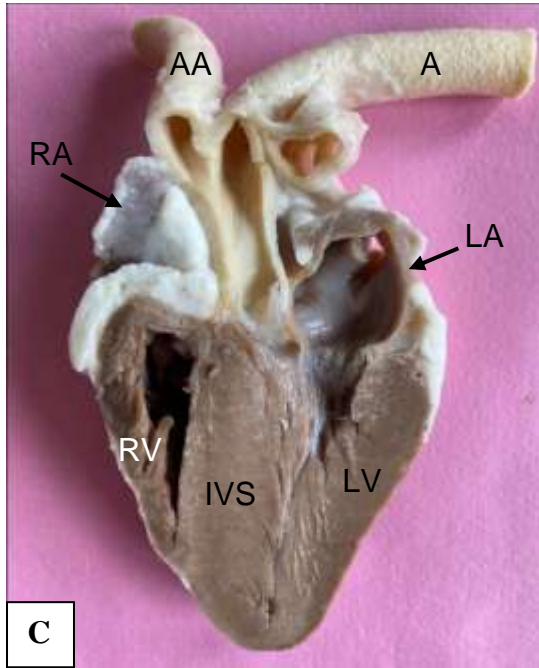
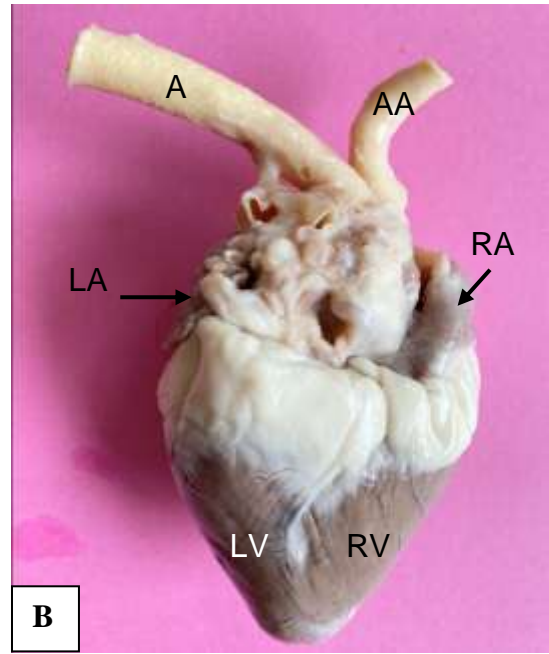
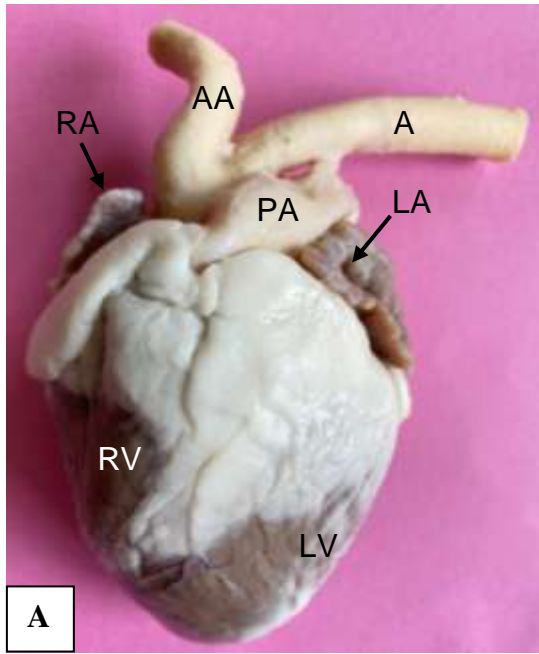
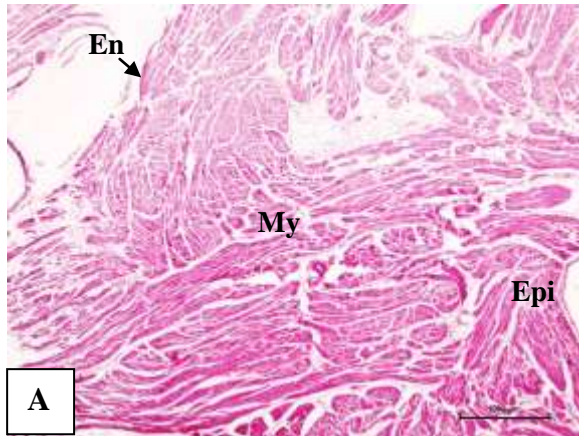


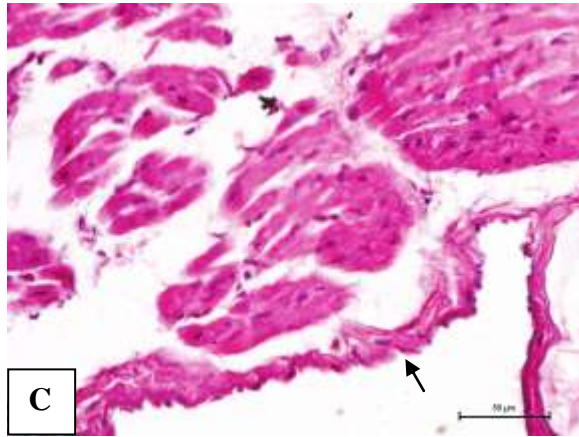
Figure 3



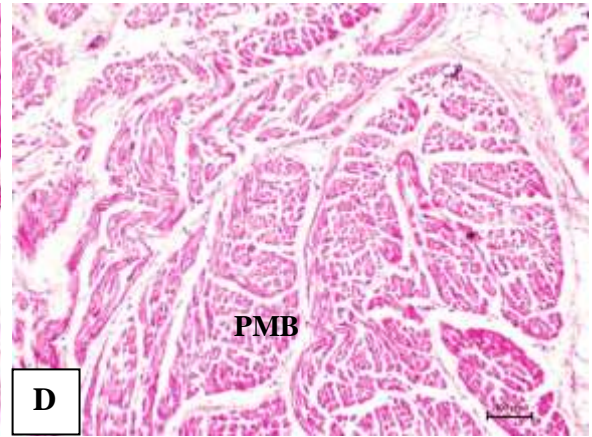
A
 Photomicrograph of right atrium of buffalo showing endocardium (En), myocardium (My) and epicardium (Epi). Hematoxylin & Eosin X 20.



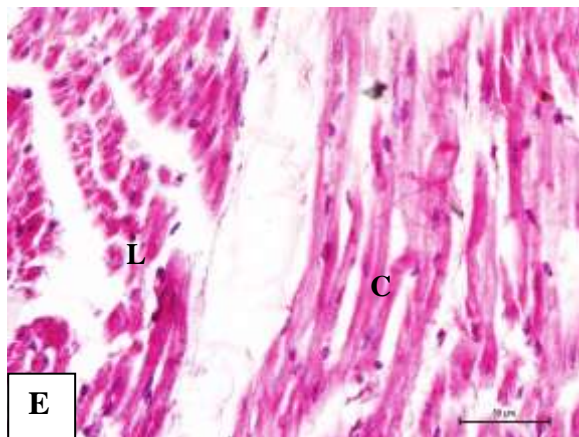
B
 Higher magnification of Fig. A showing endocardium (En), sub endocardium (SbEn) and pectinate muscle bundles (PMB). Hematoxylin & Eosin X 100.



C
 Higher magnification of Fig. B showing simple squamous endothelium. Hematoxylin & Eosin X 400.



D
 Photomicrograph of right atrium of buffalo showing pectinate muscle bundles (PMB) in myocardium. Hematoxylin & Eosin X 100.

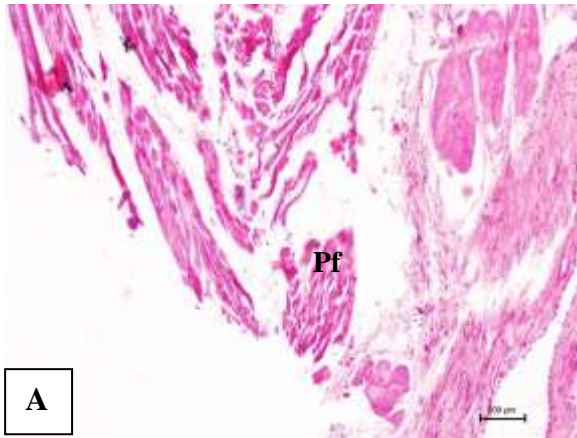


E
 Higher magnification of Fig. D showing longitudinal (L) and circular (C) arranged cardiac muscles. Hematoxylin & Eosin X 400.



F
 Higher magnification of Fig. A showing loosely arranged connective tissue in epicardium (Epi). Hematoxylin & Eosin X 100.

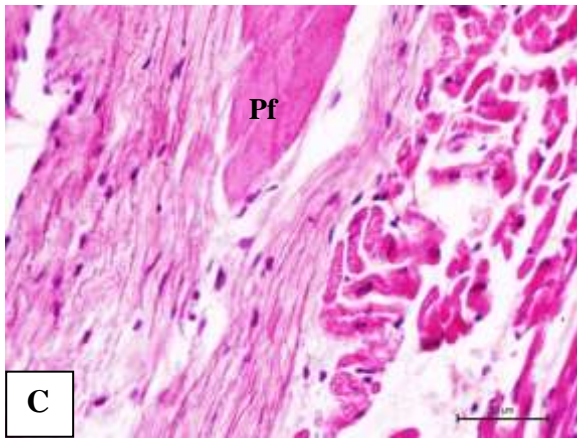
Figure 4



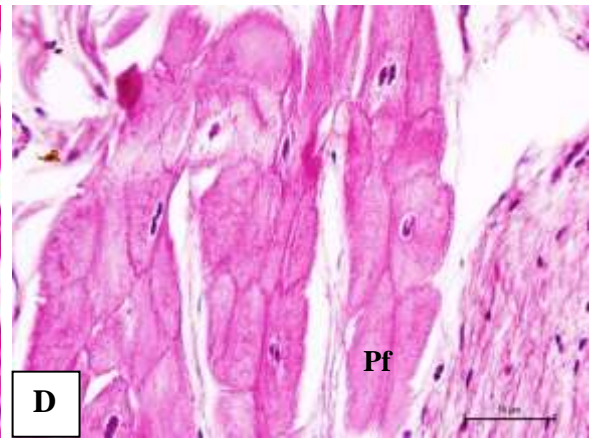
A
 Photomicrograph of left ventricle of buffalo showing Purkinje fibres (Pf) in sub endocardium, papillary muscles. Hematoxylin & Eosin X 100.



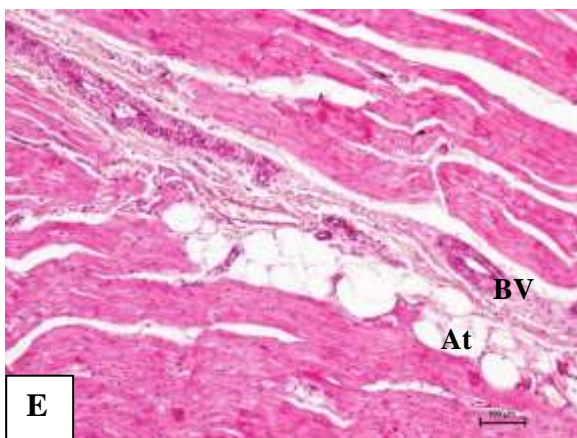
B
 Higher magnification of Fig. A showing Purkinje fibres (Pf), circularly (C) and longitudinally (L) arranged papillary muscles. Hematoxylin & Eosin X 400.



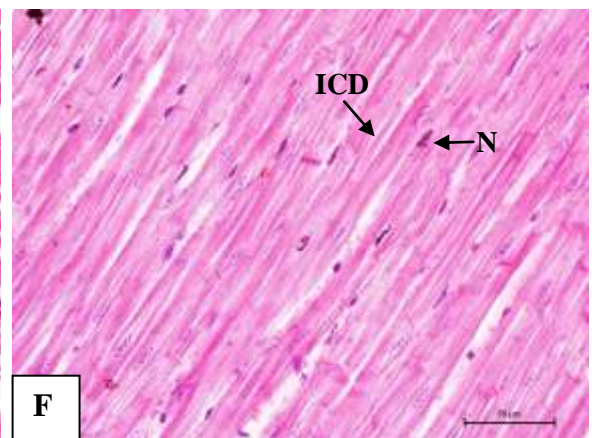
C
 Higher magnification of Fig. A showing simple squamous epithelium in endocardium and purkinje fibres (Pf) in sub endocardium. Hematoxylin & Eosin X 400.



D
 Photomicrograph of left ventricle of buffalo showing Purkinje fibres (Pf). Hematoxylin & Eosin X 400.

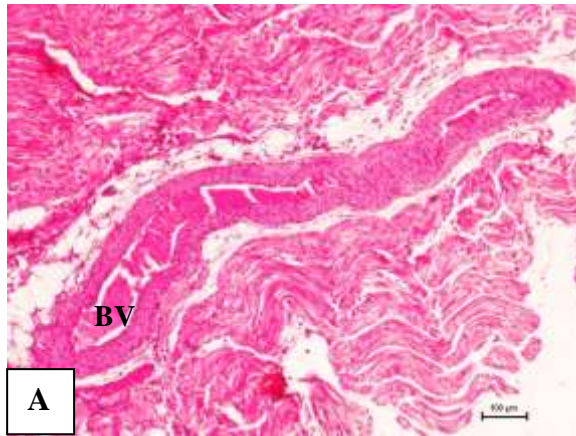


E
 Photomicrograph showing blood vessels (BV) and adipose tissue (At) in right ventricle of buffalo. Hematoxylin & Eosin X 100.

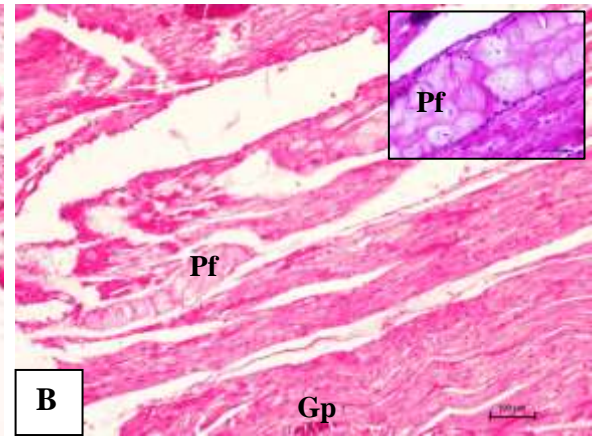


F
 Photomicrograph of right ventricle of buffalo showing intercalated disc (ICD) and perrinucleated (N) myocytes. Hematoxylin & Eosin X 400.

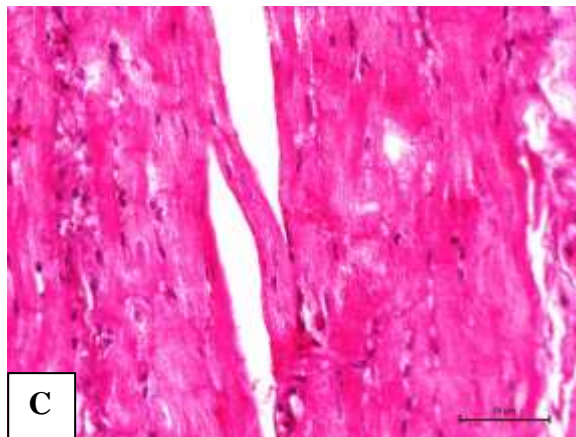
Figure 5



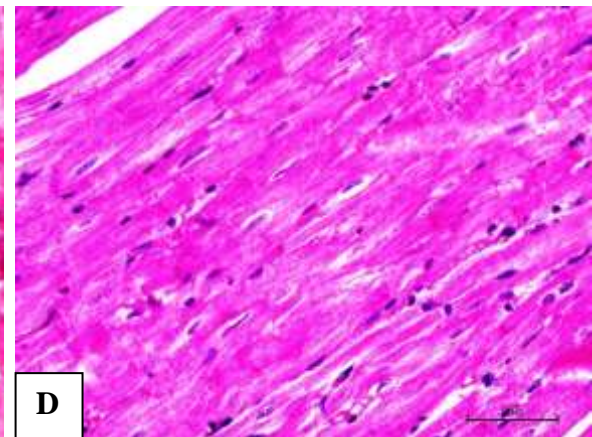
A
Photomicrograph of left ventricle of sheep showing large blood vessel (BV) surrounded by adipose tissue in myocardium. Hematoxylin & Eosin X 100.



B
Photomicrograph of left ventricle of sheep showing bundles of Purkinje fibers (Pf) and ganglionic plexus (Gp) in myocardium. Hematoxylin & Eosin X 100. Inset showing Purkinje fibers (PF) X 400.



C
Photomicrograph of left ventricle of sheep showing branching myofibers, intercalated discs and striations. Hematoxylin & Eosin X 400.



D
Photomicrograph of left ventricle of sheep showing intercalated discs and striations in myocardium. Hematoxylin & Eosin X 400.



E
Photomicrograph of right atrium of sheep showing endocardium (En), myocardium (My) and epicardium (Ep). Hematoxylin & Eosin X 40.

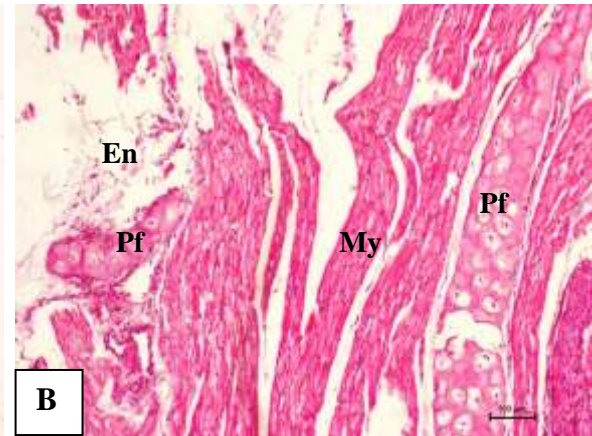


F
Higher magnification of Fig. E showing squamous epithelium of endocardium (En) and loosely arranged myocardium (My). Hematoxylin & Eosin X 400.

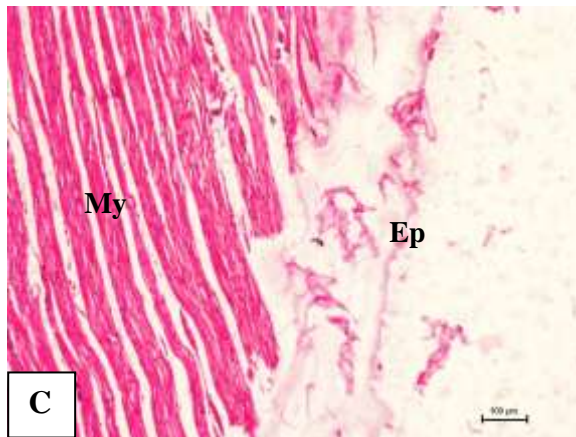
Figure 6



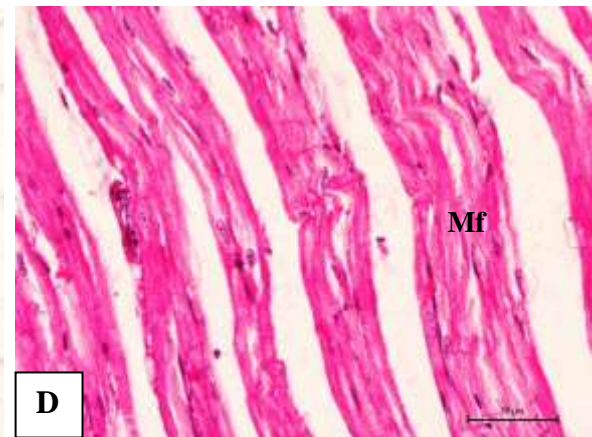
A
Photomicrograph of right ventricle of sheep showing epicardium (Ep), myocardium (My) and endocardium (En). Hematoxylin & Eosin X 20.



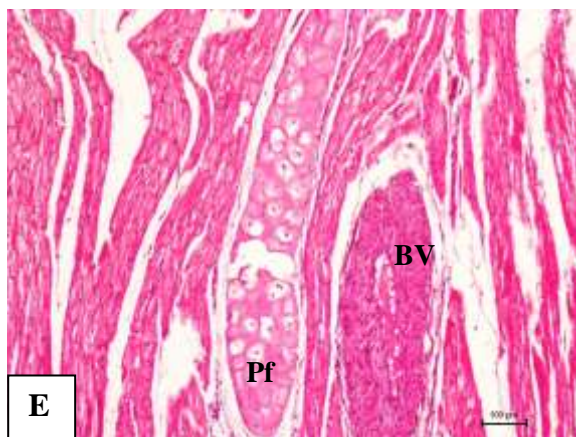
B
Higher magnification of Fig. A showing Purkinje fiber (Pf) in sub endocardium (En) and myocardium (My). Hematoxylin & Eosin X 100.



C
Higher magnification of Fig. A showing epicardium (Ep) and myocardium (My). Hematoxylin & Eosin X 100.



D
Higher magnification of Fig. C showing loosely arranged myofibrils (Mf). Hematoxylin & Eosin X 400.

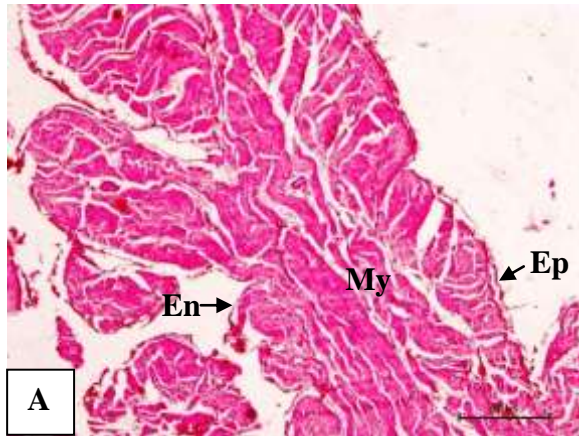


E
Higher magnification of Fig. A showing large blood vessels (BV) and Purkinje fibers (Pf) in myocardium. Hematoxylin & Eosin X 100.

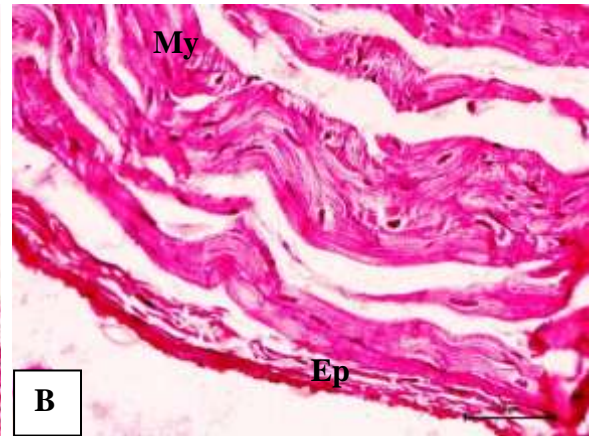


F
Higher magnification of Fig. E showing Purkinje fiber (Pf). Hematoxylin & Eosin X 400.

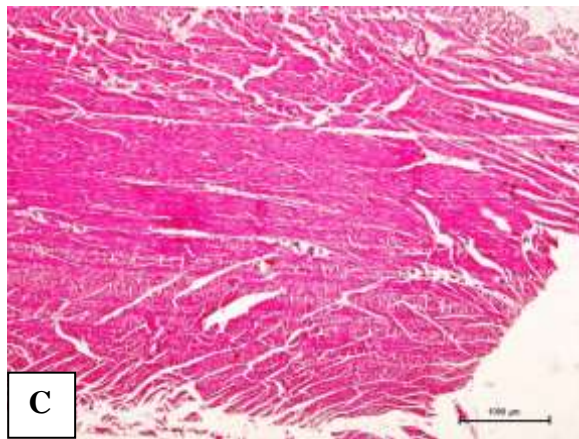
Figure 7



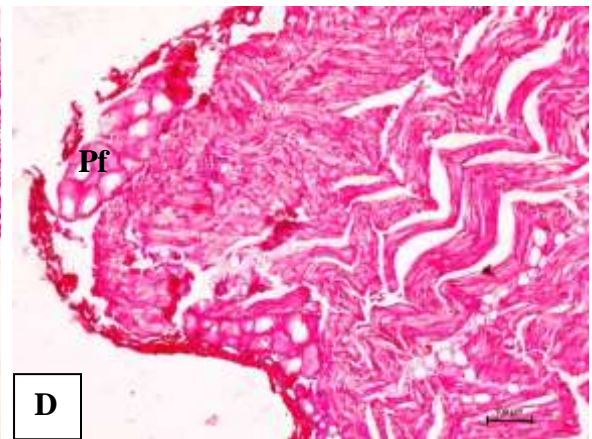
A
Photomicrograph of left atrium of goat showing epicardium (Ep), myocardium (My) and endocardium (En). Hematoxylin & Eosin X 40.



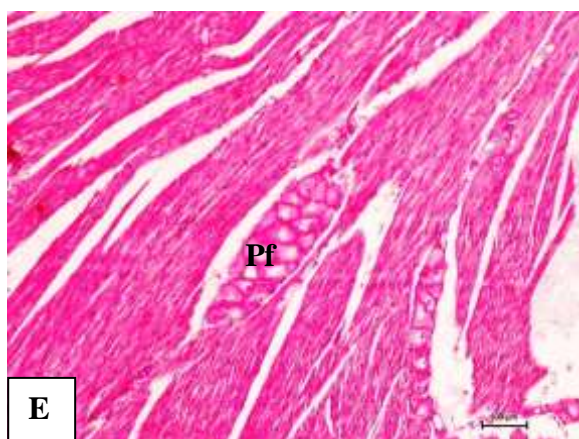
B
Higher magnification of Fig. A showing epicardium (Ep) and myocardium (My). Hematoxylin & Eosin X 400.



C
Photomicrograph of left ventricle of goat showing different orientations of cardiac muscle fibers. Hematoxylin & Eosin X 20.



D
Higher magnification of Fig. C showing Purkinje fibers (Pf) in sub endocardium. Hematoxylin & Eosin X 100.

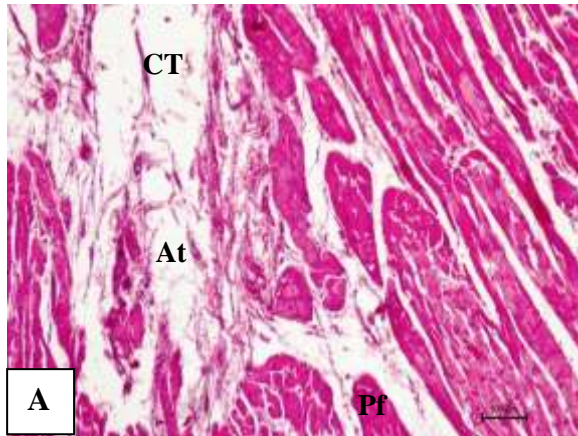


E
Higher magnification of Fig. C showing bundles of Purkinje fibers (Pf) in myocardium. Hematoxylin & Eosin X 100.

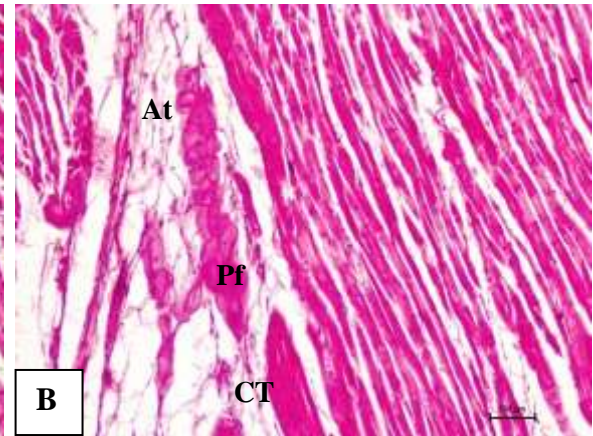


F
Photomicrograph of right ventricle of goat showing loosely arranged muscle fibers (Mf). Hematoxylin & Eosin X 100.

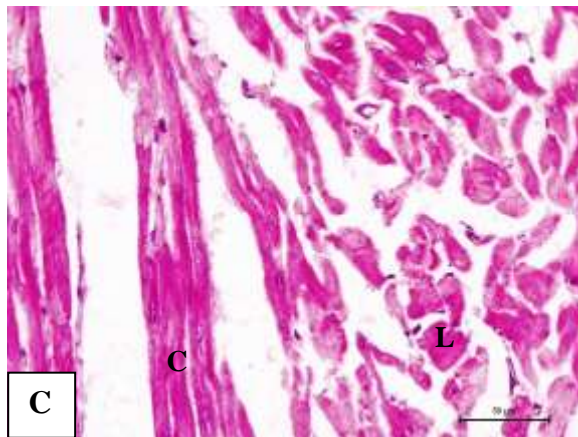
Figure 8



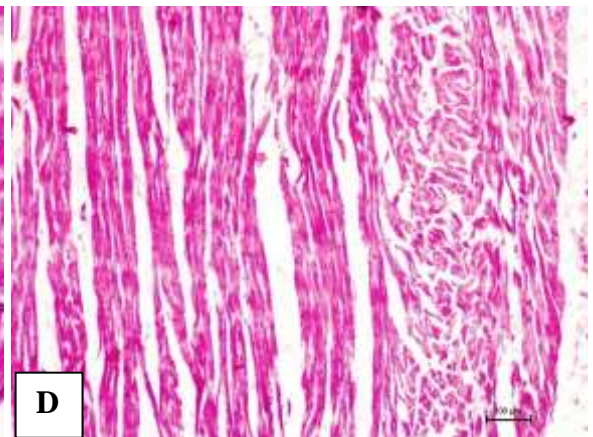
Photomicrograph of interventricular septum of buffalo showing purkinje fibres (Pf), adipose tissue (At) and loosely arranged connective tissue (CT) in myocardium. Hematoxylin & Eosin X 100.



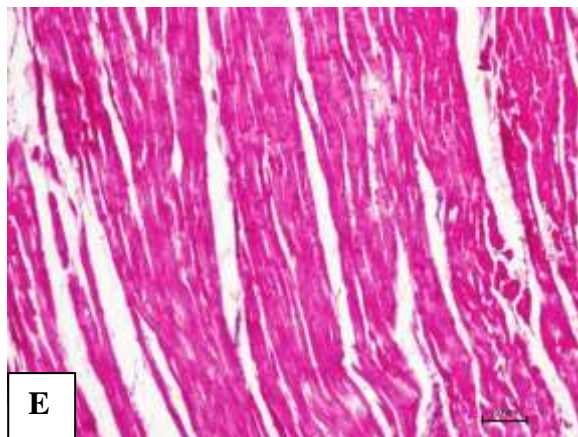
Photomicrograph of interventricular septum of buffalo showing purkinje fibres (Pf) and adipose tissue (At) and loosely arranged connective tissue (CT) in myocardium. Hematoxylin & Eosin X 100.



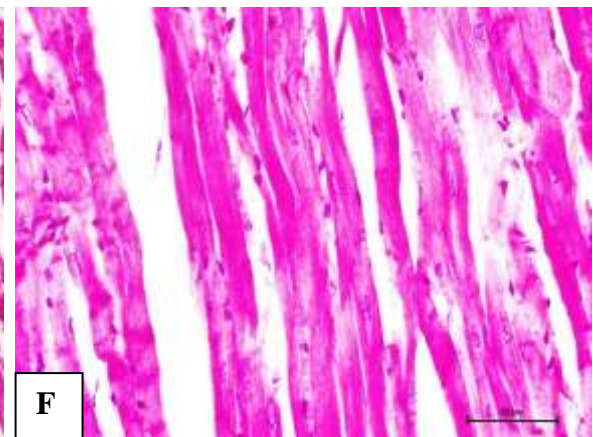
Photomicrograph of interventricular septum of buffalo showing circularly (C) and longitudinally (L) arranged cardiac myocytes. Hematoxylin & Eosin X 100.



Higher magnification of Fig. C. Hematoxylin & Eosin X 400.

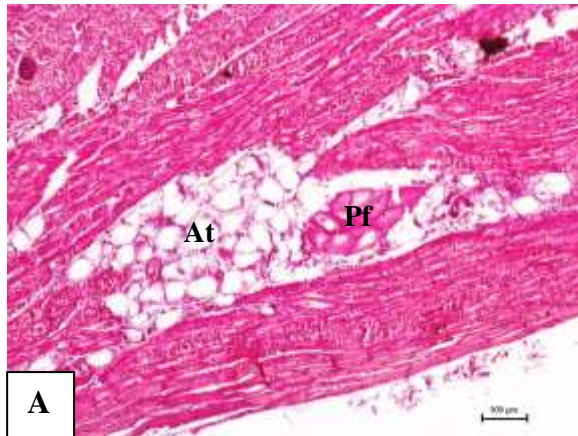


Photomicrograph of interventricular septum of buffalo showing branching pattern of cardiac fibres. Hematoxylin & Eosin X 100.

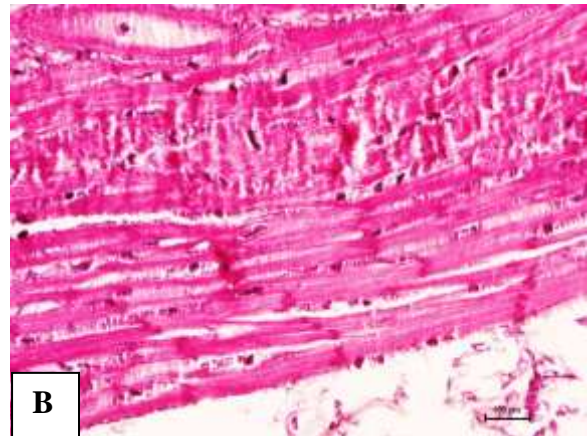


Higher magnification of Fig. E. Hematoxylin & Eosin X 400.

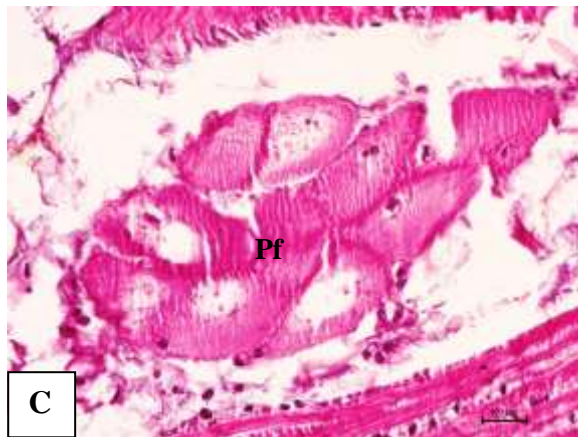
Figure 9



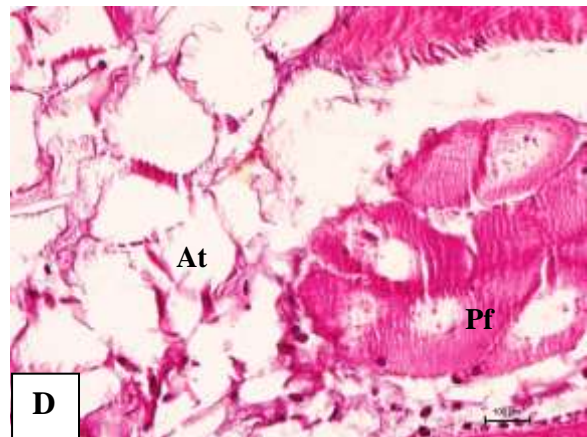
A
Photomicrograph of interventricular septum of goat showing Purkinje fibers (Pf), adipose tissue (At) and ganglionic plexus (Gp) in between cardiac muscle bundles. Hematoxylin & Eosin X 100.



B
Photomicrograph of interventricular septum of goat showing intercalated discs, striations and branching pattern of cardiac muscle fibers. Hematoxylin & Eosin X 400.



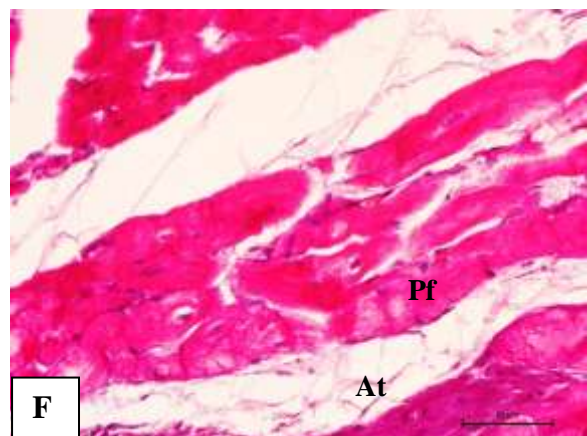
C
Higher magnification of Fig. A showing Purkinje fibers (Pf). Hematoxylin & Eosin X 400.



D
Higher magnification of Fig. A showing adipose tissue (At) surrounding Purkinje fibers (Pf). Hematoxylin & Eosin X 400.

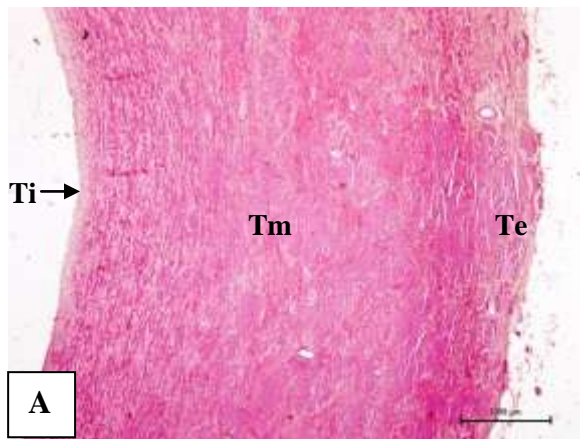


E
Photomicrograph of interventricular septum of sheep showing Purkinje fibers (Pf) and ganglionic plexus (Gp). Hematoxylin & Eosin X 100.

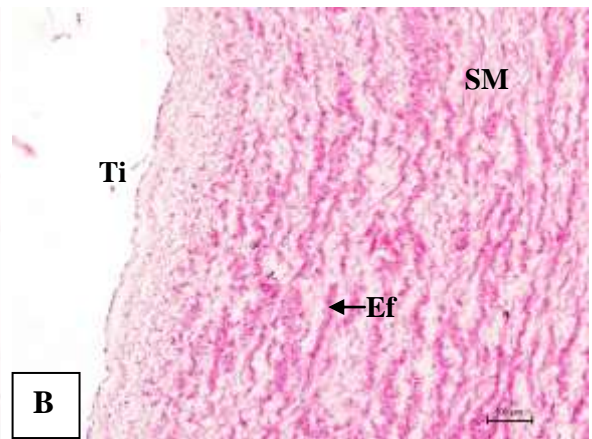


F
Higher magnification of Fig. E showing Purkinje fibers (Pf) surrounded by adipose tissue (At). Hematoxylin & Eosin X 400.

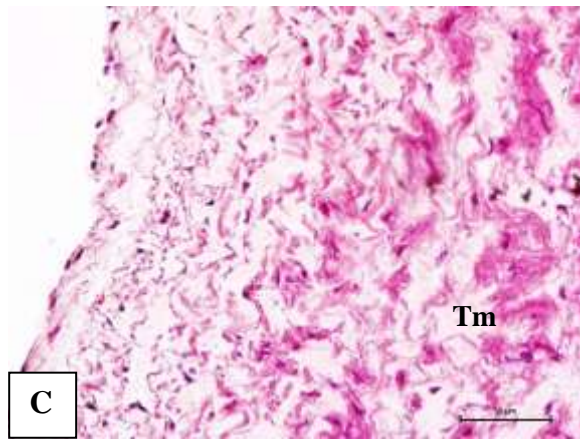
Figure 10



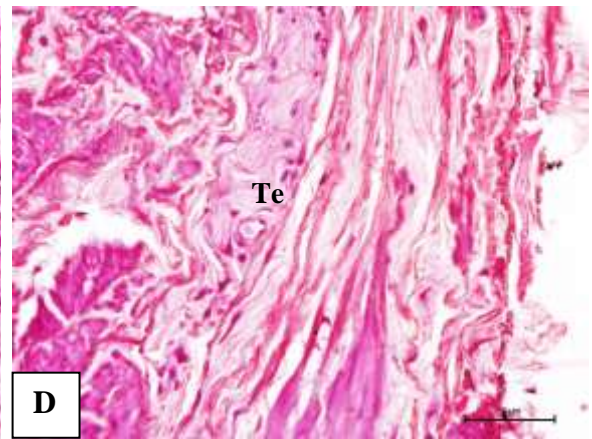
A
 Photomicrograph of aorta of buffalo showing tunica intima (Ti), tunica media (Tm) and tunica externa (Te). Hematoxylin & Eosin X 20.



B
 Higher magnification of Fig. A showing endothelial lining of tunica intima (Ti) and elastic fibres (Ef) intermingled between smooth muscle fibres (SM) of tunica media. Hematoxylin & Eosin X 100.



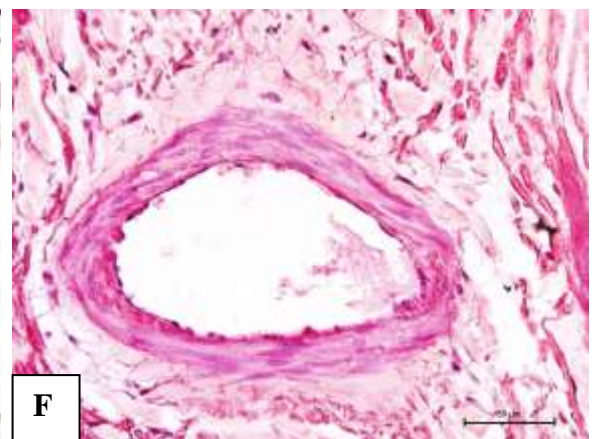
C
 Higher magnification of Fig. B showing endothelial lining and sub endothelial layer surrounded by tunica media (Tm). Hematoxylin & Eosin X 400.



D
 Higher magnification of Fig. A showing loosely arranged connective tissue in tunica externa (Te). Hematoxylin & Eosin X 400.

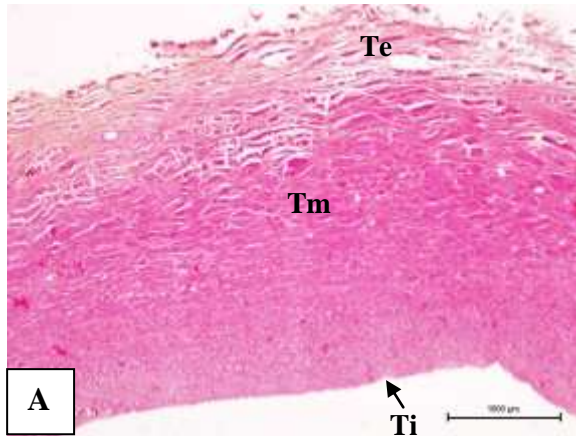


E
 Higher magnification of Fig. A showing vasavasorum in tunica externa (Te). Hematoxylin & Eosin X 100.

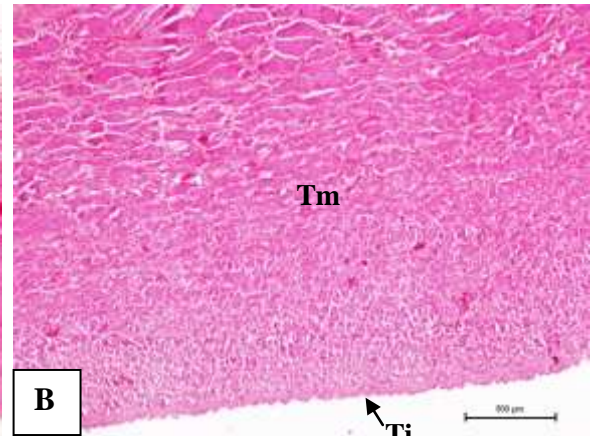


F
 Higher magnification of Fig. E. Hematoxylin & Eosin X 400.

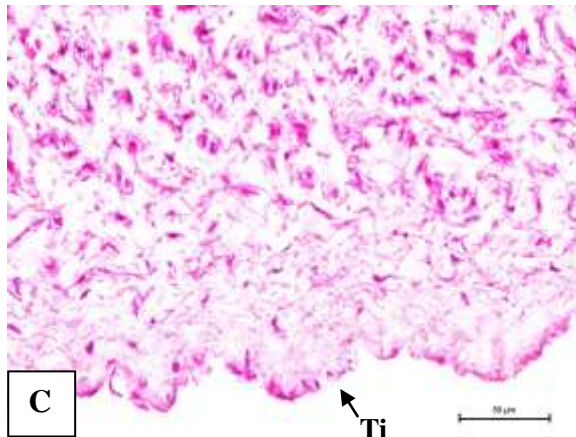
Figure 11



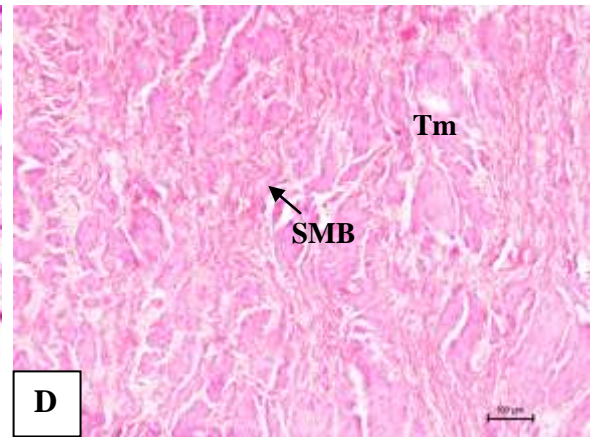
A
Photomicrograph of pulmonary artery of buffalo showing tunica intima (Ti), tunica media (Tm), tunica externa (Te). Hematoxylin & Eosin X 20.



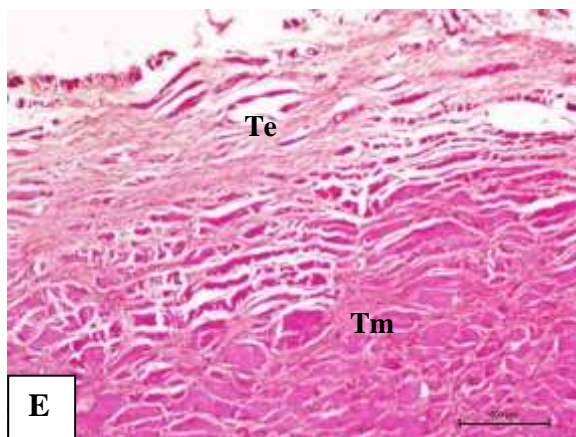
B
Higher magnification of Fig. A showing folded tunica intima (Ti) and smooth muscle fibres in tunica media (Tm). Hematoxylin & Eosin X 40.



C
Higher magnification of Fig. B showing endothelial lining of tunica intima (Ti). Hematoxylin & Eosin X 400.



D
Higher magnification of Fig. A showing smooth muscle bundle (SMB) in tunica media (Tm). Hematoxylin & Eosin X 100.

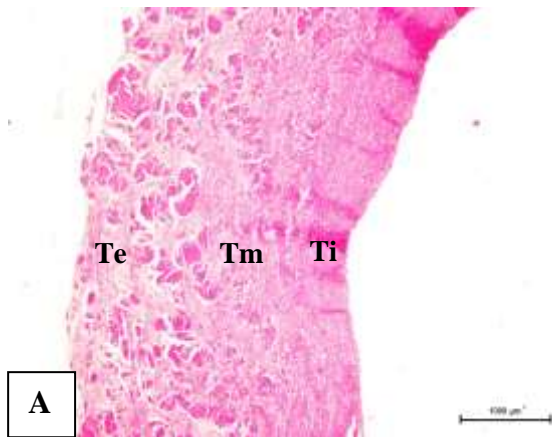


E
Photomicrograph of pulmonary artery showing tunica externa (Te) and tunica media (Tm). Hematoxylin & Eosin X 40.

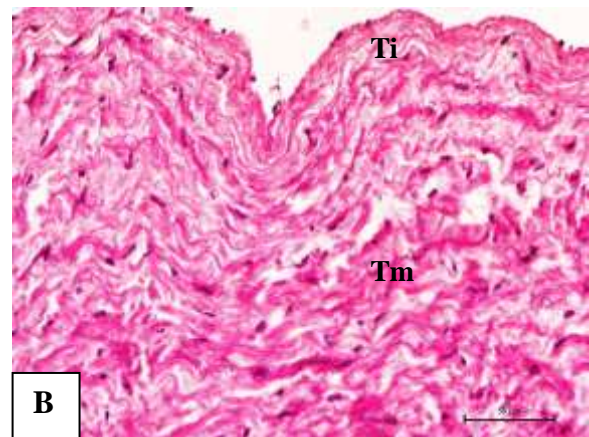


F
Higher magnification of Fig. E showing vasavasorum in tunica externa (Te). Hematoxylin & Eosin X 100. Inset of Fig. F Hematoxylin & Eosin X 400.

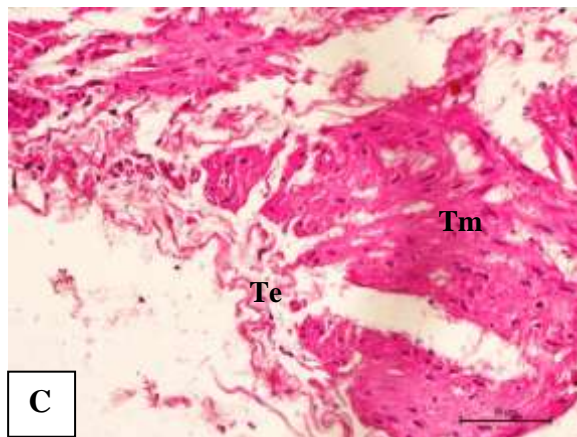
Figure 12



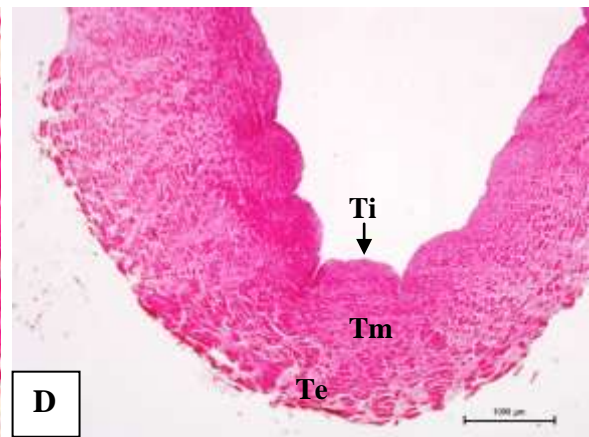
A
Photomicrograph of aorta of sheep showing tunica intima (Ti), tunica media (Tm) and tunica externa (Te). Hematoxylin & Eosin X 20.



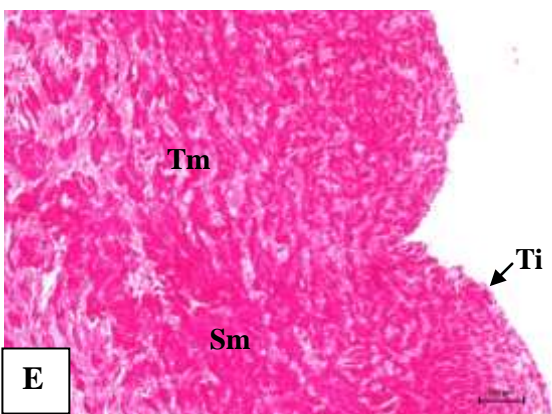
B
Higher magnification of Fig. A showing endothelial lining in tunica intima (Ti) and smooth muscle fibres along with connective tissue in tunica media (Tm). Hematoxylin & Eosin X 400.



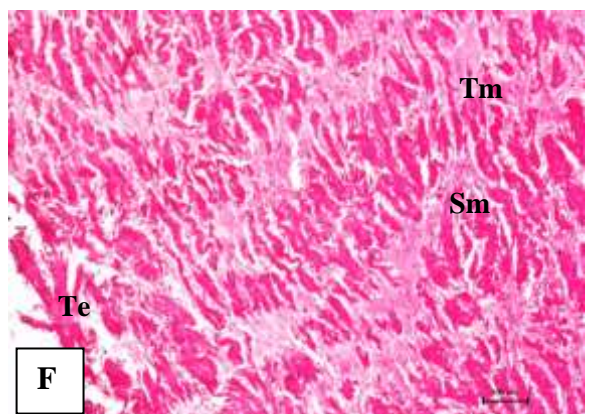
C
Higher magnification of Fig. A showing tunica externa (Te), tunica media (Tm). Hematoxylin & Eosin X 400.



D
Pulmonary artery of sheep showing folded tunica intima (Ti), tunica media (Tm) and tunica externa (Te). Hematoxylin & Eosin X 20.



E
Higher magnification of Fig. D showing simple squamous epithelium in tunica intima (Ti) and smooth muscle fibres (Sm) in tunica media (Tm). Hematoxylin & Eosin X 100.

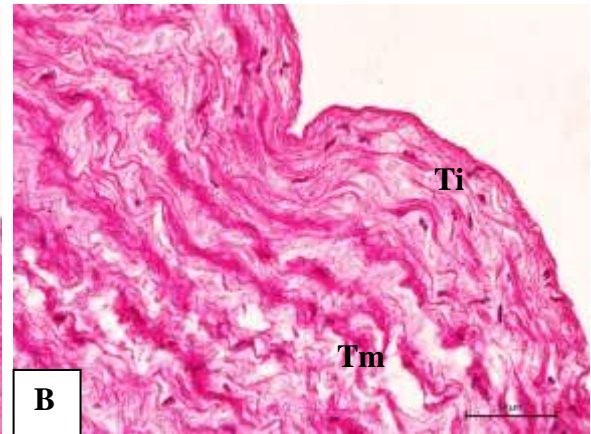


F
Higher magnification of Fig. D showing loosely arranged smooth muscle fibres (Sm) in tunica media (Tm) and connective tissue in tunica externa (Te). Hematoxylin & Eosin X 100.

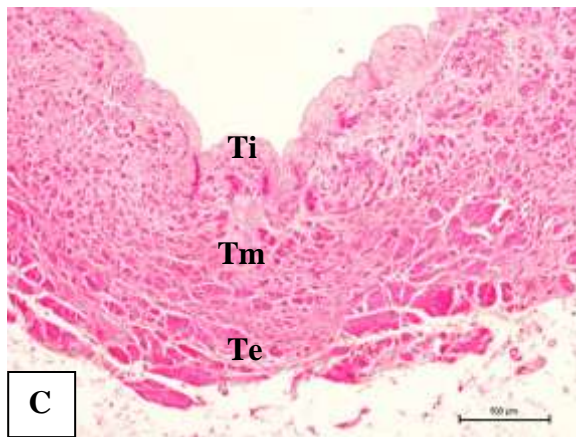
Figure 13



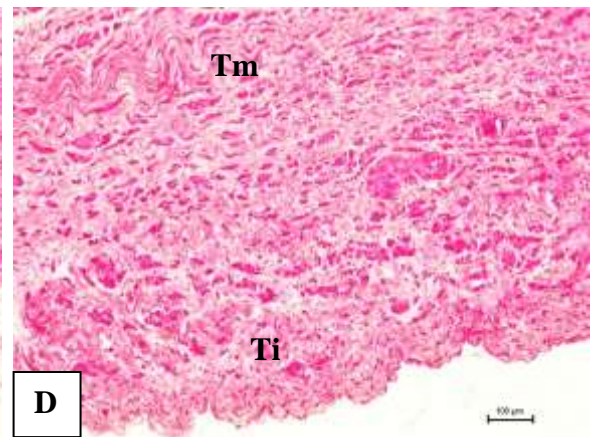
Photomicrograph of aorta of goat showing tunica intima (Ti), tunica media (Tm) and tunica externa (Te). Hematoxylin & Eosin X 40.



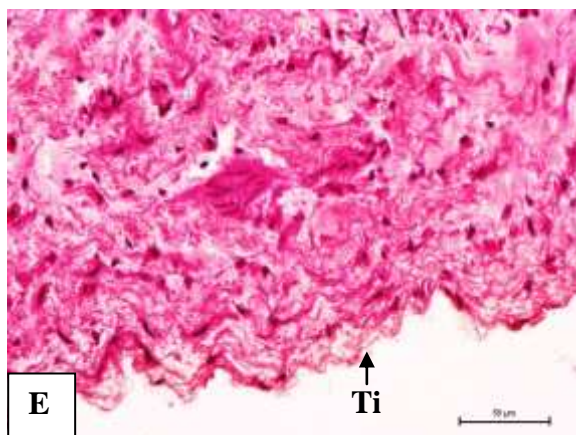
Higher magnification of Fig. A showing endothelial lining in tunica intima (Ti) and smooth muscle fibers along with connective tissue in tunica media (Tm). Hematoxylin & Eosin X 400.



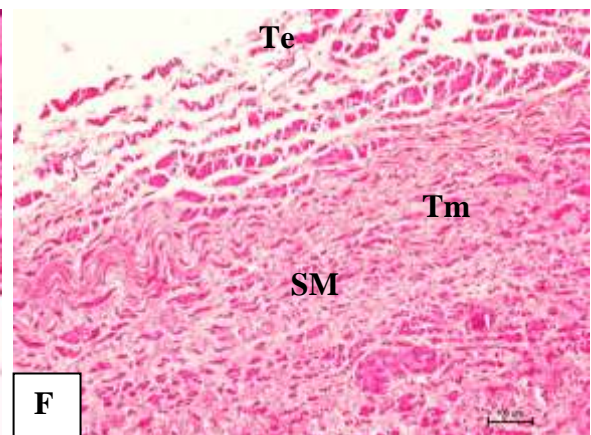
Photomicrograph of pulmonary artery showing tunica intima (Ti), tunica media (Tm) and tunica externa (Te). Hematoxylin & Eosin X 40.



Higher magnification of Fig. C showing tunica intima (Ti) and tunica media (Tm). Hematoxylin & Eosin X 100.



Higher magnification of Fig. D showing simple squamous epithelium in tunica intima (Ti). Hematoxylin & Eosin X 400.



Higher magnification of Fig. C showing loose connective tissue in tunica externa (Te) and smooth muscle fibers (SM) in tunica media (Tm). Hematoxylin & Eosin X 100.

Figure 14



Echocardiogram showing the internal diameter of left atrium at systole in buffalo



(B) Echocardiogram showing the internal diameter of left atrium at diastole in buffalo



Echocardiogram showing the thickness of left atrium wall at systole in buffalo



Echocardiogram showing the thickness of left atrium wall at diastole in buffalo

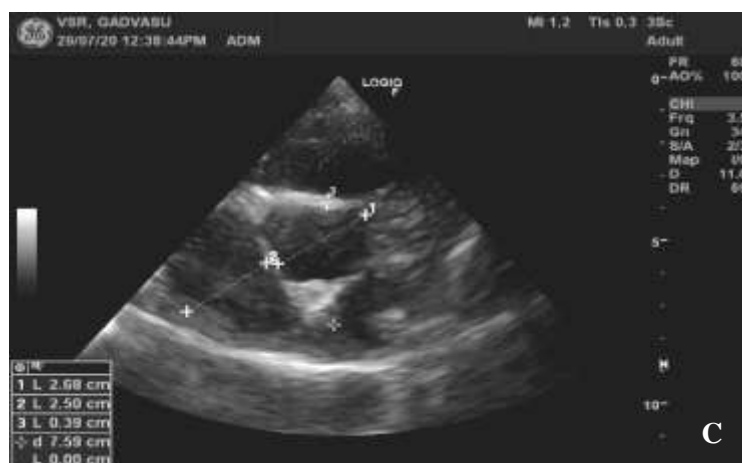
Figure 15



Echocardiogram showing the thickness of left atrium wall at systole in sheep



Echocardiogram showing the internal diameter of left atrium at systole in sheep

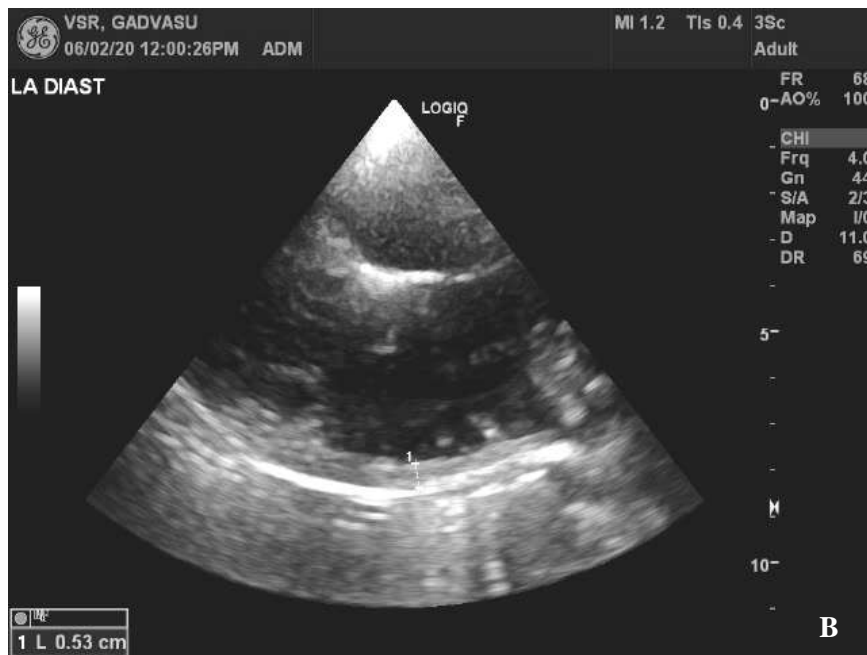


Echocardiogram showing the internal diameter of left atrium at diastole in sheep

Figure 16



Echocardiogram showing left atrium wall thickness at systole in goat.



Echocardiogram showing left atrium wall thickness at diastole in goat.

Figure 17



Echocardiogram showing the internal diameter of right atrium at systole in buffalo



Echocardiogram showing the internal diameter of right atrium at diastole in buffalo

Figure 18



Echocardiogram showing the wall thickness of right atrium at systole in sheep.



Echocardiogram showing the wall thickness of right atrium at diastole in sheep.



Echocardiogram showing the internal diameter of right atrium at systole in sheep.



Echocardiogram showing the internal diameter of right atrium at diastole in sheep.

Figure 19



Echocardiogram showing right atrium wall thickness at systole in goat.



Echocardiogram showing the internal diameter of right atrium at systole in goat.



Echocardiogram showing the internal diameter of right atrium at diastole in goat.

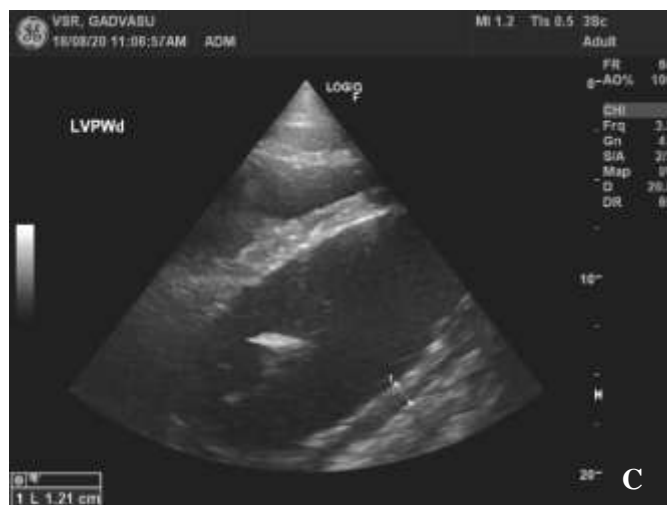
Figure 20



Echocardiogram showing the internal diameter of left ventricle at systole in buffalo

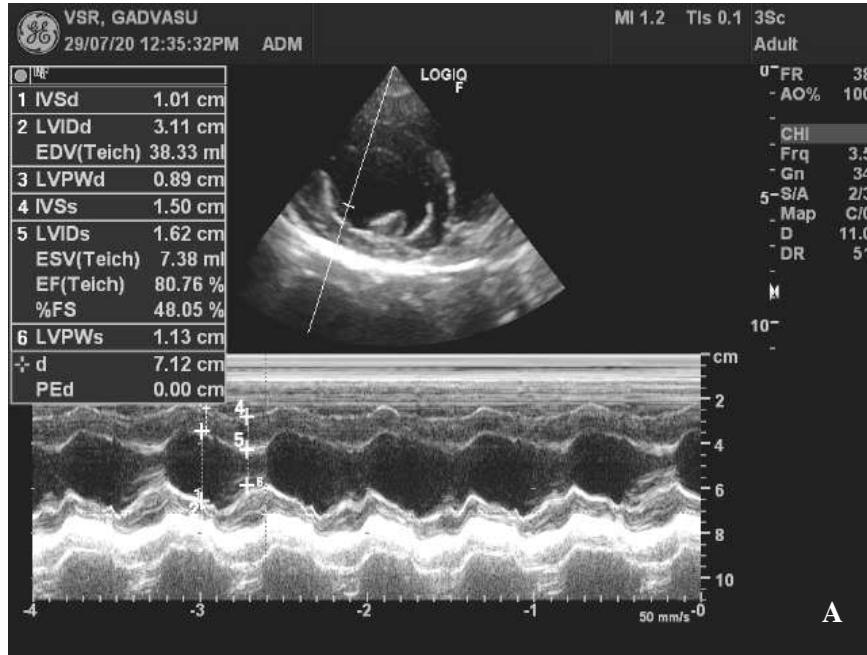


Echocardiogram showing the internal diameter of left ventricle at diastole in buffalo

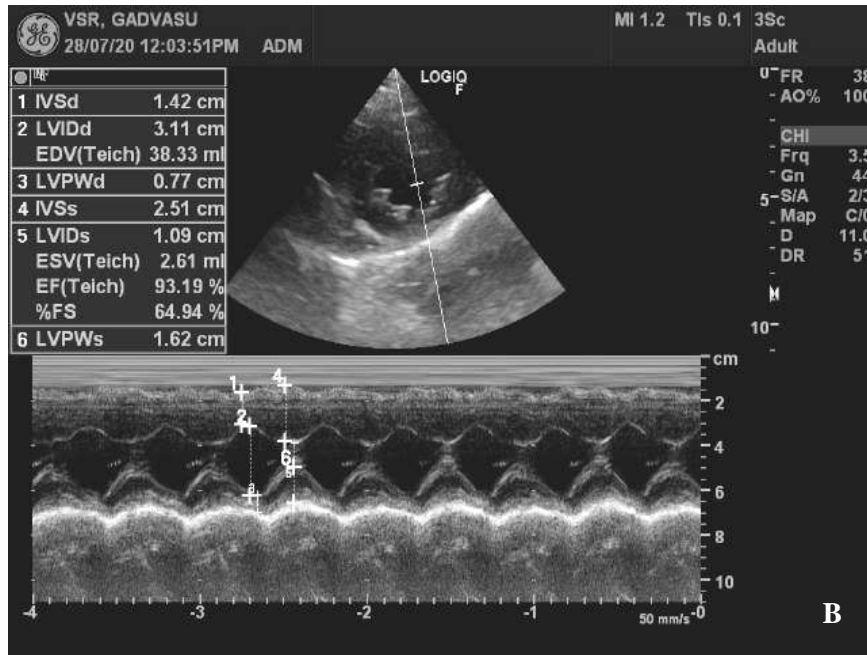


Echocardiogram showing left ventricle wall thickness at systole in buffalo

Figure 21

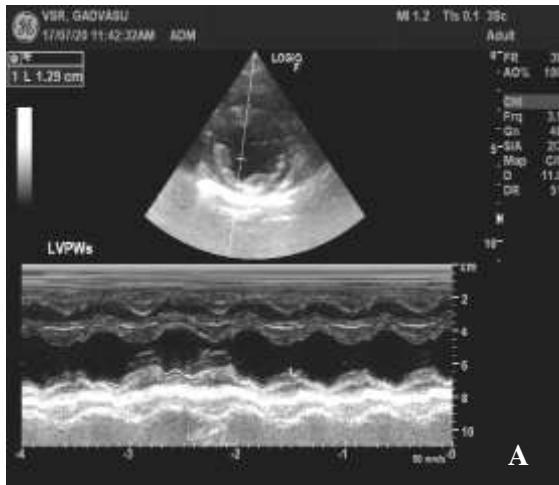


Echocardiogram showing the wall thickness and internal diameter of left ventricle at systole and diastole in sheep.

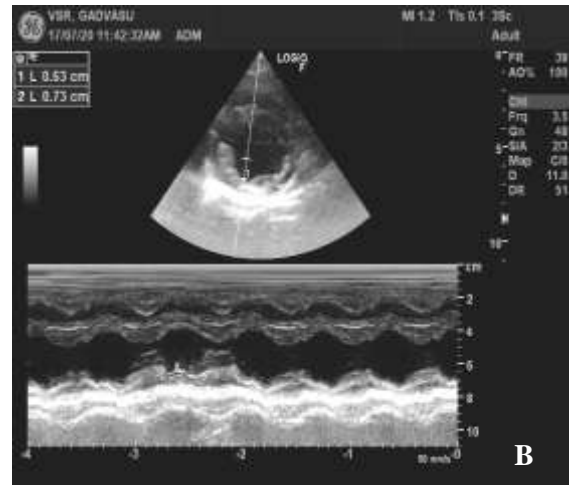


Echocardiogram showing the wall thickness of interventricular septum at systole and diastole in sheep.

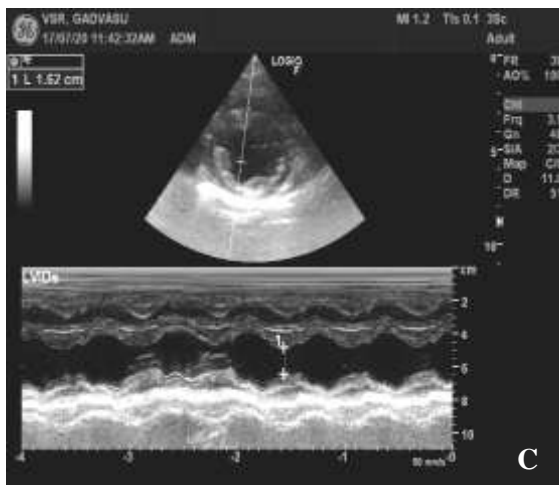
Figure 22



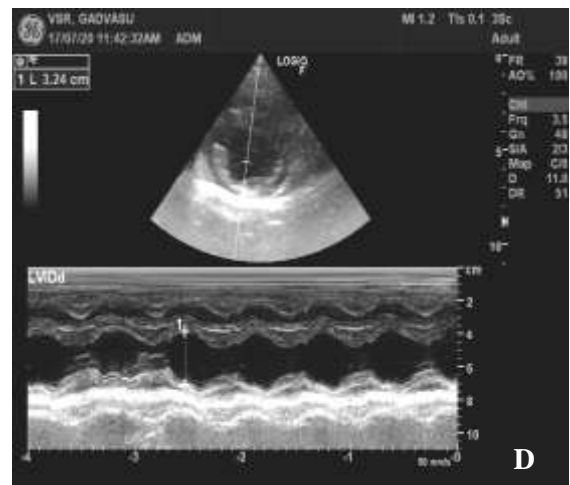
Echocardiogram showing the left ventricle wall thickness at systole in goat



Echocardiogram showing left ventricle wall thickness at diastole in goat



Echocardiogram showing the internal diameter of left ventricle at systole in goat.



Echocardiogram showing the internal diameter of left ventricle at diastole in goat.

Figure 23



Echocardiogram showing the internal diameter of right ventricle at diastole in buffalo



Echocardiogram showing right ventricle wall thickness at diastole in buffalo

Figure 24



Echocardiogram showing the right ventricle wall thickness at systole in sheep.



Echocardiogram showing the right ventricle wall thickness at diastole in sheep.



Echocardiogram showing the internal diameter of right ventricle at systole in sheep.



Echocardiogram showing the internal diameter of right ventricle at diastole in sheep.

Figure 25



Echocardiogram showing the right ventricle wall thickness at systole in goat



Echocardiogram showing the right ventricle wall thickness at diastole in goat



Echocardiogram showing the internal diameter of right ventricle at systole in goat.

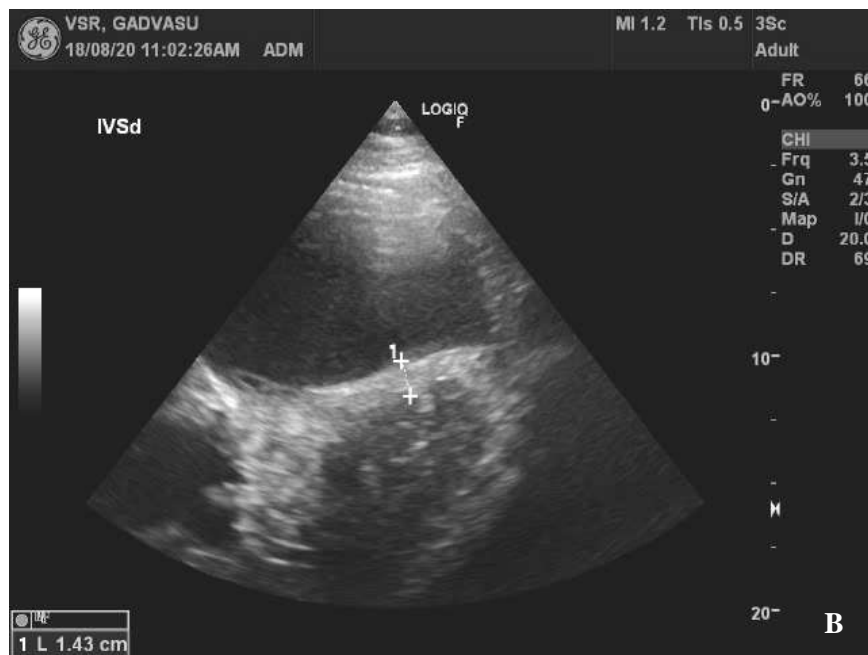


Echocardiogram showing the internal diameter of right ventricle at diastole in goat.

Figure 26

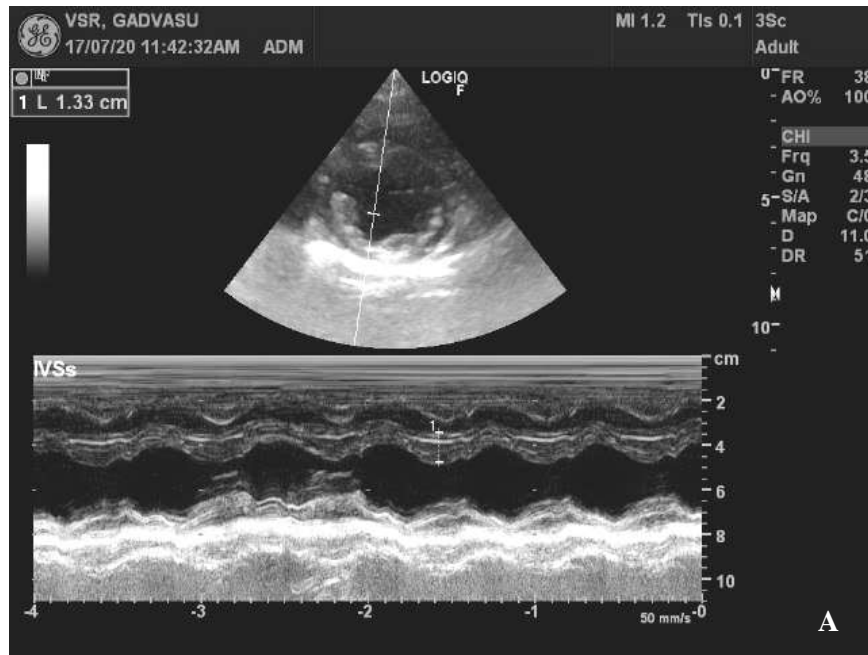


Echocardiogram showing the thickness of interventricular septum at systole in buffalo

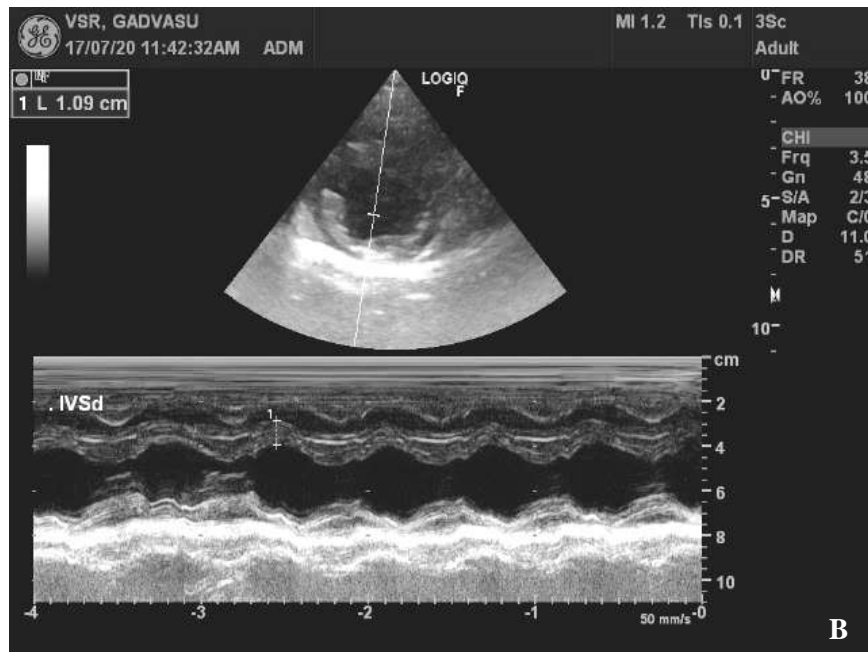


Echocardiogram showing the thickness of interventricular septum at diastole in buffalo

Figure 27

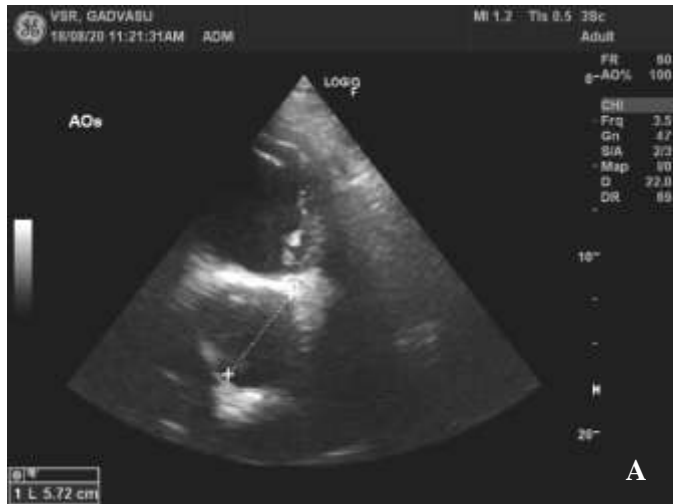


Echocardiogram showing the wall thickness of interventricular septum at systole in goat.



Echocardiogram showing the wall thickness of interventricular septum at diastole in goat.

Figure 28



Echocardiogram showing the internal diameter of aorta at systole in buffalo



Echocardiogram showing the internal diameter of aorta at diastole in buffalo



Echocardiogram showing the wall thickness of aorta at diastole in buffalo

Figure 29



Echocardiogram showing the wall thickness of aorta at diastole in sheep

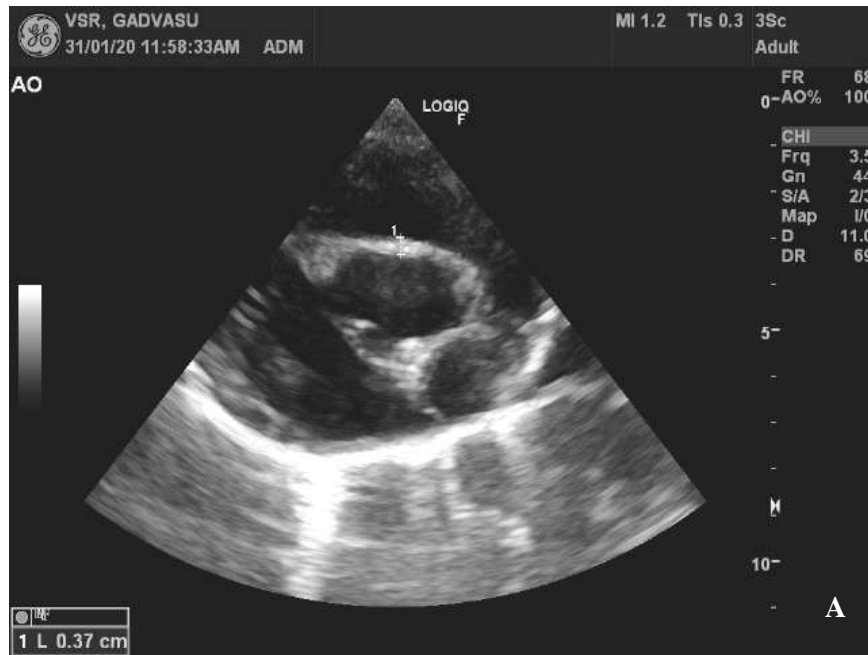


Echocardiogram showing the internal diameter of aorta at systole in sheep

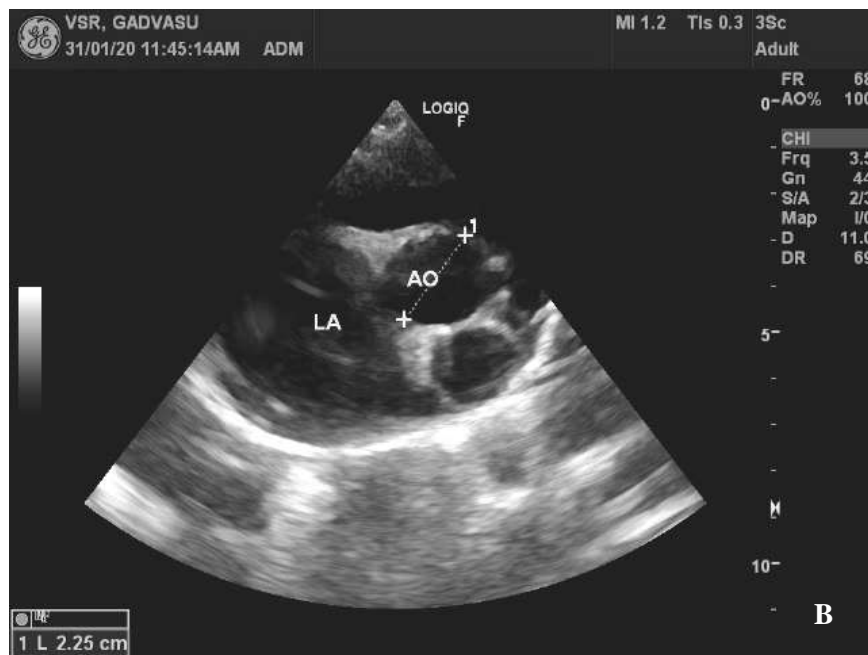


Echocardiogram showing the internal diameter of aorta at diastole in sheep

Figure 30



Echocardiogram showing the wall thickness of aorta at systole in goat.



Echocardiogram showing the internal diameter of aorta at systole in goat.

Figure 31



Echocardiogram showing the internal diameter of pulmonary artery at systole in buffalo



Echocardiogram showing the wall thickness of pulmonary artery at diastole in buffalo

Figure 32



Echocardiogram showing the wall thickness of pulmonary artery at systole in sheep.



Echocardiogram showing the wall thickness of pulmonary artery at diastole in sheep.

Figure 33



Echocardiogram showing the wall thickness of pulmonary artery at systole in goat



Echocardiogram showing the internal diameter of pulmonary artery at systole in goat.

Figure 34

CHAPTER V

SUMMARY AND CONCLUSIONS

The present study was undertaken to elucidate gross anatomical, biometrical, echocardiography and micrometrical studies on the heart of buffalo, sheep and goat.

Heart was located in lower ventral part of mediastinal space between lungs from 3rd to 6th intercostal space in all the three species studied. The heart was conical in shape with pointed apex and broad base in buffalo, triangular in shape with blunt apex in sheep and goat. The heart had two borders (anterior and posterior) and two surfaces (right and left). The right surface was formed mainly by the right ventricle. A small part of it was formed by left ventricle whereas the left surface was formed by more than one-third by right ventricle and rest by left ventricle in buffalo, sheep and goat. The anterior border was convex and curved ventrally and was present parallel to the sternum. The posterior border was vertical in all the hearts studied and laid with anterior border of 6th rib in buffalo, sheep and goat.

The divisions of heart into four chambers were indicated on surface by grooves. There were one transverse and three longitudinal grooves on external surface of the heart in buffalo, sheep and goat. These grooves were occupied by coronary vessels and fat. The amount of fat was highest in buffalo followed by goat and lowest in sheep. The coronary transverse groove encircled the heart except conus arteriosus and indicated the separation of atria from ventricles and was occupied by the coronary vessels.

All the three longitudinal grooves (left, right and intermediate) were seen on external surface of ventricles. The right longitudinal groove was on the right surface and was posterior in position. It began at coronary groove below the termination of posterior vena cava and moved downward towards apex and joined the left longitudinal groove almost in centre of anterior border in buffalo, sheep and goat. The left longitudinal groove was more prominent than the right longitudinal groove. The short and shallow intermediate groove extended from coronary groove down the left side of posterior border up to middle of ventricle.

The right atrium was situated at right anterior part of the base of the heart and was having two parts: viz sinus venarum and auricle in all animals studied. The

anterior and posterior venacava and coronary sinus opened in the sinus venarum. The right auricle was blind pocket of aorta and was characterized as meshwork of pectinate muscles.

The wall of right atrium was not uniformly thick because of presence of terminal crest and pectinate muscles on its internal surface. In between the pectinate muscles small depression were found and was named as vena cordis parva. In the posterior part of auricle anterior venacava opened at upper and back part whereas posterior venacava opened at lower and back part of right auricle just above the interventricular groove in straight line with anterior venacava. Coronary sinus which delivered blood from heart itself opened ventral to posterior venacava opening and vena hemiazygos opened into coronary sinus. The opening into the right ventricle was right atrio-ventricular opening.

Left atrium was situated at the back of base of heart, behind and to the left of the right atrium in buffalo, sheep and goat. It lied behind the pulmonary artery and aorta and above the left ventricle in all the three species studied. The ventral border of left atrium had several notches. Seven to eight pulmonary veins opened into the atrium behind and on the right side. The pointed blind end of the auricle was behind the origin of pulmonary artery. The left atrio-ventricular opening was triangular.

The right ventricle was triangular in shape with the base formed by right atrio-ventricle orifice. Its left part was projected higher and continued into root of pulmonary artery and was known as conus arteriosus. The anterior wall of right ventricle formed the anterior border of the heart while its posterior wall was formed by the interventricular septum. In the transverse section it was crescentic in shape and had tri-cuspid valve which were made of short cylindrical curtain of fibrous tissue which projected into ventricle formed margin of atrio-ventricle. The chordae tendinae were the fine fibrous cord which attached the cusps to the papillary muscles projecting from the ventricle wall. Each cusp received chordae tendinae from two papillary muscles and vice-versa in all the heart studied. Three type of trabeculae carneae were found in the ventricular wall. First one was attached to the wall of ventricle in the whole length and was known as ridges of relief. Second one were attached at both ends and were free in middle called moderator band while third one known as papillary muscles.

The moderator band was a cord of myocardium crossing the lumen connecting the interventriculum septum to the opposite wall present midway between base and apex of heart. In buffalo and sheep, the right moderator band was single and unbranched, but in goat, it was single and branched.

The left ventricle was conical in shape having base above and apex of left ventricle formed the apex of heart and was present approximately at sixth intercostal space in buffalo, sheep and goat heart. The chordae tendinae were larger than right ventricle but were fewer in all the three animals studied. The trabeculae carneae resembled that of right ventricle while it had only two bundles of papillary muscles instead of three bundles as in right ventricle. Moderator band was comparatively thinner than right ventricle. The left moderator band was single and highly branched in buffalo, but there was three moderator bands (small, medium and large sized) present in the left ventricle of sheep and goat

Interventricular septum was concave towards the left ventricle, so the transverse section of the cavity was nearly circular. The greater part of it had approximately same thickness as the left ventricular wall and was muscular in nature whereas the small portion of upper part was membranous and thin and lied between pulmonary and aortic orifices.

Aorta arose from the base of left ventricle and its opening was guarded by three semilunar cusps (anterior, right posterior and left posterior). From the anterior and left posterior sinuses of valvular coronary arteries arose. Pulmonary artery was large trunk which carried blood from right ventricle to the lungs. The opening of right ventricle into pulmonary trunk was guarded by three semilunar cusps (medial, lateral and posterior) in all the animals studied.

Biometrical observations revealed that there was significant difference in weight, volume, length of anterior border, posterior border and circumference of buffalo as compared to sheep and goat but no significant difference was found between sheep and goat. All the parameters were highest in buffalo followed by sheep and least in goat.

Highest left and right atrial wall thickness, left and right ventricle wall and interventricular septum was observed in buffalo followed by sheep and least in goat. There was significant difference in internal and external diameter, wall thickness and

circumference of aorta and pulmonary artery of buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.

The histological studies revealed that all four chambers were composed of three different layers i.e. endocardium, myocardium, and epicardium.

Endocardium was the innermost layer lining the atria and ventricles and covered the cardiac valves and associated structures. The endocardium was subdivided into three layers i.e. endothelium, subendothelium and subendocardium layers in buffalo, sheep and goat. The endothelial layer was composed of simple squamous epithelium resting on the thin basement membrane in the atria and ventricles of buffalo, sheep and goat. The subendothelial layer was the second layer of endocardium and was relatively thicker than endothelium and subendocardium. It contained dense irregular connective tissue with loosely arranged collagen and elastic fibres and few smooth muscle cells in the atrium, whereas the Purkinje fibres were seen in this layer in the ventricles of all the species studied. Abundance of adipose tissue was also seen this layer in the atrium of buffalo, whereas it was present as isolated bundles in sheep and goat.

The subendocardium layer was the deepest layer of endocardium that connected the endocardium with myocardium and was composed of loosely arranged collagen, elastic fibres, adipose tissue, blood and lymph vessels and Purkinje fibres at certain locations.

The ventricular myocardium was composed of large numerous cardiac myocytes because of relatively high pressure and overload on ventricles. It was composed of bundles of cardiac muscle cells and Purkinje fibres. The cardiac myocytes were embedded in loose connective tissue that contained dense capillary network, lymph vessels and autonomic nerve fibres. The bundles of cardiac muscles were comparatively larger in the ventricles as compared to the atrium in all the species studied. These cardiac muscles were arranged in sheath in a complex and spiral manner and were oriented in various directions viz. longitudinal, circular and oblique. These bundles of cardiac muscle cells were laterally separated from each other by a considerable amount of loose connective tissue that was rich with dense capillary network, lymph vessels and ganglionic plexuses.

In cross section cardiac myocytes appeared irregular polygonal cells of different sizes with large round, centrally placed, single nucleus and sometimes binucleated. The cardiac muscle fibres showed different staining affinity i.e. some had darkly stained cytoplasm and others had lighter cytoplasm. The darkly stained muscle fibres were termed as hyper-eosinophilic. The cardiac muscle fibres showed striations and intercalated discs.

Purkinje fibres were present in the subendocardium, between the myocardial bundles and as intramural fibres among the cardiac myocytes. These fibres were large specialized cardiac muscle fibres and had greater diameter than the cardiac myocytes and cluster as group. Each cell had only one or two centrally placed nuclei. The cytoplasm of Purkinje fibres was lightly stained because of large amount of glycogen. Fine connective tissue was also observed between the cardiac myocytes along with blood vessels and nerve fibres. The right ventricle contained more amount of interstitial connective tissue as compared to left ventricle. The cardiac cells of the atrium were smaller than the ventricle cardiac cells. A thin layer of fibroelastic tissue supported the mesothelium; this layer was connected to the myocardium by a broad layer of adipose tissue. Collagen and elastic tissue were relatively inconspicuous in the ventricles as compared to auricles. Individual cardiac myocytes were not only connected in longitudinal direction but also made lateral contacts in buffalo, sheep and goat.

The myocardium of heart was covered externally by epicardium. This layer was thin as compared to myocardium. It was composed was made of loose connective tissue along with veins, nerves and adipose tissue. The atrium was having thick layer of epicardium as compared to the epicardium of ventricle in buffalo, sheep and goat. Its outer part was covered by a single layer of mesothelial cells supported by the fibro-elastic core.

The aorta was consisted of three layers viz. tunica intima, tunica media, tunica adventitia. Tunica intima was comprised of endothelium with squamous and round endotheliocytes, a subendothelial zone, and internal elastic lamina. The endothelium was lined by a simple squamous epithelium resting on a thin basement membrane and their nuclei bulge into the lumen of the vessel. Subendothelium was comprised of fibroblasts, few smooth muscle fibres, collagen and numerous, fine, longitudinally

oriented elastic fibres. No capillaries were seen as this layer received nutrition through diffusion and transendothelial transport. The internal elastic lamina was not readily distinguishable from the elastic lamellae of the tunica media.

The tunica media of aorta was thickest of three layers and consisted primarily of concentrically arranged, fenestrated elastic lamellae. Smooth muscle fibres were attached to elastic laminae by collagen and elastic fibres. Smooth muscle fibres were differently arranged in the internal and the external halves of tunica media. These were fewer in internal half and did not have the tendency to form bundles. Smooth muscle fibres were abundant were visible in the external part of tunica media and formed muscle bundles. The nuclei of smooth muscle cells were clearly evident. The intercellular substance was spaces were more basophilic than ordinary connective tissue because it contained greater amount of sulphated glycosaminoglycan. The inner quarters of tunica media exhibited concentrically arranged elastic lamellae.

The outermost coat of the aorta, the tunica adventitia, was composed of longitudinally arranged bundles of collagenous and elastic fibres interspersed with connective tissue cells and blood vessels, the vasa vasorum.

Pulmonary artery had three layers viz. tunica intima, tunica media and tunica adventitia in buffalo, sheep and goat. Tunica intima was made up of an epithelium, which was a single layer of squamous epithelial cells, together with a supporting layer of elastin rich collagen. Tunica media was broad and elastic with concentric fenestrated sheets of elastin, and collagen and only relatively few smooth muscles. Tunica adventitia was the outer layer and had small 'vasa vasorum'.

Echocardiographically, the internal diameter of left and right atria, left and right ventricles, pulmonary artery and aorta was significantly higher in buffalo followed by sheep and least in goat. The thickness of left and right atrial wall, left and right ventricular wall, interventricular septum, pulmonary artery and aorta was more in buffalo as compared to sheep and goat but there was no significant difference observed between sheep and goat.

The comparative biometrical and echocardiographic studies depicted that the echocardiographical observations were significantly higher as compared to the biometrical observations. The echocardiographical values of aorta and pulmonary artery were significantly different $p \leq 0.05$ from biometrical and micrometrical values

in buffalo, sheep and goat, but there was no significant difference between biometrical and micrometrical data was found. It may be depicted from the present study that the thickness of aorta and pulmonary artery was significantly higher echocardiographical followed by biometrical and least micrometrical observations in buffalo, sheep and goat.

CONCLUSIONS

- Heart was located in lower ventral part of mediastinal space between lungs from 3rd to 6th intercostal space in all the three species studied.
- It was conical in shape with pointed apex and broad base in buffalo, triangular in shape with blunt apex in sheep and goat.
- The grooves were occupied by coronary vessels and fat. The amount of fat was highest in buffalo followed by goat and lowest in sheep.
- In buffalo and sheep, the right moderator band was single and unbranched, but in goat, it was single and branched. The left moderator band was single and highly branched in buffalo, but there were three moderator bands (small, medium and large sized) present in the left ventricle of sheep and goat
- Biometrical observations revealed that there was significant difference in weight, volume, length of anterior border, posterior border and circumference, left and right atrial wall thickness, left and right ventricle wall and interventricular septum of buffalo as compared to sheep and goat but no significant difference was found between sheep and goat.
- There was significant difference in internal and external diameter, wall thickness and circumference of aorta and pulmonary artery of buffalo as compared to sheep and goat, but there was no significant difference observed between sheep and goat.
- The histological studies revealed that all four chambers were composed of three different layers i.e. endocardium, myocardium, and epicardium.
- The endocardium was subdivided into three layers i.e. endothelium, subendothelium and subendocardium layers in buffalo, sheep and goat. Abundance of adipose tissue was seen in subendothelial layer in the atrium of buffalo, whereas it was present as isolated bundles in sheep and goat

- Purkinje fibres were present in the subendocardium, between the myocardial bundles and cytoplasm of Purkinje fibres was lightly stained and cluster as group.
- The bundles of cardiac muscles were comparatively larger in the ventricles as compared to the atrium in all the species studied.
- These cardiac muscles were arranged in sheath in a complex and spiral manner oriented in various directions viz. longitudinal, circular and oblique. Myocytes were elongated, branched and connected with each other. The cardiac muscle fibres showed different staining affinity, striations and intercalated discs.
- The atrium was having thick layer of epicardium as compared to ventricle in buffalo, sheep and goat. The right ventricle contained more amount of interstitial connective tissue as compared to left ventricle.
- The aorta and pulmonary arteries were consisted of three layers viz. tunica intima, tunica media, tunica adventitia. The tunica media of aorta and pulmonary arteries were thickest of three layers and consisted primarily of concentrically arranged, fenestrated elastic lamellae.
- The tunica adventitia of both arteries was composed of longitudinally arranged bundles of collagenous and elastic fibres interspersed with connective tissue cells and blood vessels, the vasa vasorum.
- Echocardiographically, the internal diameter of left and right atria, left and right ventricles, pulmonary artery and aorta was significantly higher in buffalo followed by sheep and least in goat.
- The thickness of left and right atrial wall, left and right ventricular wall, interventricular septum, pulmonary artery and aorta was more in buffalo as compared to sheep and goat but there was no significant difference observed between sheep and goat.
- The echocardiographical values of aorta and pulmonary artery were significantly different from biometrical and micrometrical values in buffalo, sheep and goat, but there was no significant difference between biometrical and micrometrical data was found.

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