Volume V, No. 1: 10–23 (2021)
ISSN 2507-9638

THE CLSU INTERNATIONAL
JOURNAL OF SCIENCE & TECHNOLOGY
www.clsu-ijst.org

Gross Anatomy of the Heart of Mature Philippine Water Buffalo (*Bubalus bubalis* L.)

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Submitted December 9, 2020. Accepted December 30, 2020. Published online February 28, 2021.

Abstract

The gross morphology of the heart of mature Philippine water buffalo was described by determining the weight, length, width, and circumference. This study measured the average external circumference of the pulmonary veins and artery, cranial and caudal vena cava, and the aorta; determined the presence and location of ligamentum arteriosum; measured the thickness of the atrial and ventricular wall; described the components of the left and right atrioventricular valves, pulmonary valves, and the aortic valves; determined the location and measured the length of trabeculae septomarginalis; and determined the location of the os cordis.

The hearts of 10 mature Philippine water buffalo of both sexes were collected from abattoirs of Cabanatuan City, Philippines. The absolute and relative weights of the heart were measured using digital weighing scale. Different dimensions like circumferences, length, and width of the heart; the external circumferences of major blood vessels; and the thickness of the wall of heart were determined using measuring tape and Vernier caliper. The number of cusps present in the left and right atrioventricular, pulmonary, and aortic valves was counted and the presence of ligamentum arteriosum was documented. Radiograph was used to determine the presence and location of os cordis.

All of the hearts studied were pointed and bilaterally flattened. The base of the heart was markedly surrounded with fatty tissues. The mean absolute weight was 2.42 kg. The heart had a mean dimension of 21.71 cm x 17.49 cm. The mean circumference at the level of the coronary groove, middle, and apex were 48.41 cm, 44.10 cm and 20.57 cm, respectively. An average of four pulmonary veins were documented to be present. The right ventricle had a constant three papillary muscles and three cusps, while the left ventricle had a constant two papillary muscles and two cusps. The number of cusps of both pulmonary valve and aortic valve was three. Ligamentum arteriosum was present in all samples and it was located between the pulmonary trunk and aorta. The os cordis which is located at the aortic fibrous ring was present in all heart of Philippine water buffalo examined.

Key Words: anatomy, heart, morphology, morphometry, Philippine water buffalo

Introduction

Buffalo (*Bubalus bubalis*) is not only used as a draft animal, but also produces meat, horns, skin, and milk from which cream, butter, yoghurt and many types of cheeses are made, including the mozzarella (Borghese, 2005). According to the Bureau of Agricultural Statistics (2014), the total carabao inventory in the Philippines, as of 2014, was approximately 2.9 million heads. This was 2.36% lower than the 2013 inventory. Inventories of carabao from backyard and commercial farms dropped by 2.35% and 3.00% respectively. Inventory in backyard farms accounted for 99.50% of the total carabao population. Buffalo has enormous zootechnical importance as a species but the description of its morphology is scarce. In the Philippines and other Asian countries, there were studies that had been done about the Philippine water buffalo but most of these were focused only on the productive aspects (Galvan, 2006).

In 2004, Maala et al. conducted a comparative study on the different internal organs, like the heart, between Philippine water buffalo and cattle. Yap and Herbosa (2004) further compared the weights of the heart between male and female Philippine water buffalo. In 2004, Boado conducted a survey of gross lesions of the heart and associated structures in slaughtered Philippine water buffalo. This was a preliminary approach for further study of cardiac diseases in the bubaline species. Numerous comparative anatomical studies of the heart of different domestic animals were given importance for the expansion of its anatomical descriptions including the development of its parts. Detailed morphological studies of the heart have been reported in mammals such as cattle, horse, dog, and giraffe (Thomas, 2006; Saulnier, 2012; Perez et al., 2008), but no such report could be cited for the detailed anatomical description and measurement for the heart of the Philippine water buffalo.

The study aimed to provide a detailed description of the gross morphology of the heart of Philippine water buffalo. This study provides useful data for the anatomical feature of the bubaline heart which is beneficial in diagnosing and treating cardiac diseases based on cardiac structures involved. Results can be used also as a reference for teaching purposes and researches in the field of veterinary medicine.

Materials and Methods

Sample Collection

A total of 10 heart samples from mature Philippine water buffalo, regardless of sex, were collected immediately after slaughter. The heart was carefully removed from the rest of the carcass using a sharp knife. Major blood vessels like pulmonary artery and veins, aorta, and vena cavae were cut at least 2 to 3 inches from the base of the heart. Any debris like clotted blood (acquired during slaughter) in the heart was removed with tap water. Heart samples were temporarily stored in a plastic box containing formalin after the values on dimensions were collected. The carcass weight of the animal was retrieved from records of the slaughterhouse.

Gross Appearance

The overall appearance of the heart such as color and shape were described. Pictures of all freshly collected samples were captured for documentation purposes. The extent of pericardial sac was noted and the description of fat deposition was also documented.

Heart Weight and Dimensions

The absolute weight of the heart was measured using a digital weighing scale. The percent weight relative to the carcass weight was computed by dividing the absolute weight of the heart over the carcass weight multiplied by 100. Heart dimensions were measured using a measuring tape. Heart length (cm) was measured from the base of pulmonary artery to the apex of the heart; the width (cm) was measured at its widest from the level of the pulmonary artery to the level of the pulmonary vein.

External Circumferences of the Heart and Major Blood Vessels

Since the heart is conically shaped, three sites were used to measure the external circumference, around the coronary groove, at the middle, and the apex, using a measuring tape. The external circumference of anterior vena cava, posterior vena cava, pulmonary artery, pulmonary vein and aorta were measured following the procedure of Lima et al. (2013). A wire was placed around the vessel, approximately 2 inches away from the base of the heart, and straightening it for the measurement.

Location of the Os Cordis

One from the 10 heart samples was subjected to radiographic examination for the determination of the presence and location os cordis.

Wall Thickness of the Atria and Ventricles

The heart was first dissected at the right atrium using a sharp cutter extending the cut to the right ventricle to expose the walls of both compartments. The middle part of the walls was measured using a Vernier caliper to determine the atrial and ventricular thickness. The same procedure was performed to determine the thickness of the left atrial and ventricular walls.

Number of Papillary Muscles and Chordae Tendinae

Papillary muscles are muscular projections found at the walls of both left and right ventricles and attached to these structures are numerous tendinous cords called chordae tendinae. The number of papillary muscles was counted per chamber together with the respective chordae tendinae regardless of the size.

Number of Cusps in Heart Valves

Since the heart was already cut to show the internal structures, the number of cusps associated with the right and left atrioventricular valves can be counted. A transverse section at the base of the heart was performed using a cutter to view the cusps of the pulmonary valve and aortic valve.

Location and Length of the Moderator Band

The location of the moderator band, or trabeculae septomarginalis, was first identified at the right ventricle. The length of the moderator band was measured using a Vernier caliper from its attachment at the interventricular septum to the associated papillary muscle.

Statistical Analysis

The mean of all morphometric values was computed and the standard deviation was calculated.

Results and Discussion

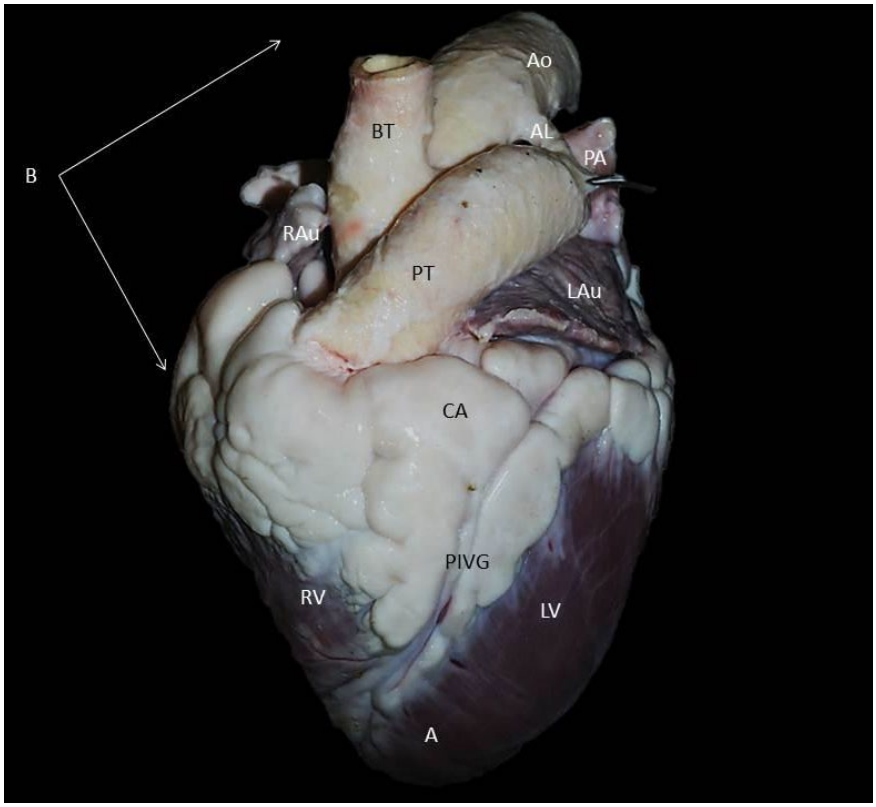
The hearts were collected from recently slaughtered Philippine water buffalo with age ranging from 5 to 12 years (mean age of 8.10 years old). Out of the 10 animals, three heart samples were collected from female and 7 from male.

Gross Appearance

All samples were surrounded by pericardium extending from the base of the heart to the apex. The pericardium is the fibroserous covering of the heart (König and Liebich, 2004). The bulk of fresh heart is dark red in color while it is white to yellow at the level of coronary groove due to markedly filled fats (Figure 1). Nickel (1986) stated that the adipose tissue can amount up to 24% of the weight of the heart muscle. The middle part of the heart down to the apex is free from fatty tissues. The same observation has been noted by Pahnwar et al., (2007) who described the heart of water buffalo as reddish-brown and Shah et. al., (2010) highlighted the white fatty tissues found concentrated at the coronary groove.

Figure 1

Cranial View of the Heart of the Philippine Water Buffalo Showing the Base (B), Apex (A), Left Ventricle (LV), Right Ventricle (RV), Left Auricle (Lau), Right Auricle (Rau), Coronary Groove (CG), Paraconal Interventricular Groove (PIVG), Pulmonary Trunk (PT), Pulmonary Artery (PA), Aorta (Ao), Brachiocephalic Trunk (BT), Ligamentum Arteriosum (LA).



Generally, all heart samples are partially pointed at the apex and are bilaterally flattened. In contrast to small ruminants, Miranda (2014) described the heart of a goat to have a very distinct pointed apex. The conical appearance is the typical shape of the heart of almost all domestic animals as described by Nickel et al. (1979), König and Liebich (2004), Frandson et al. (2009), and Dyce et al.

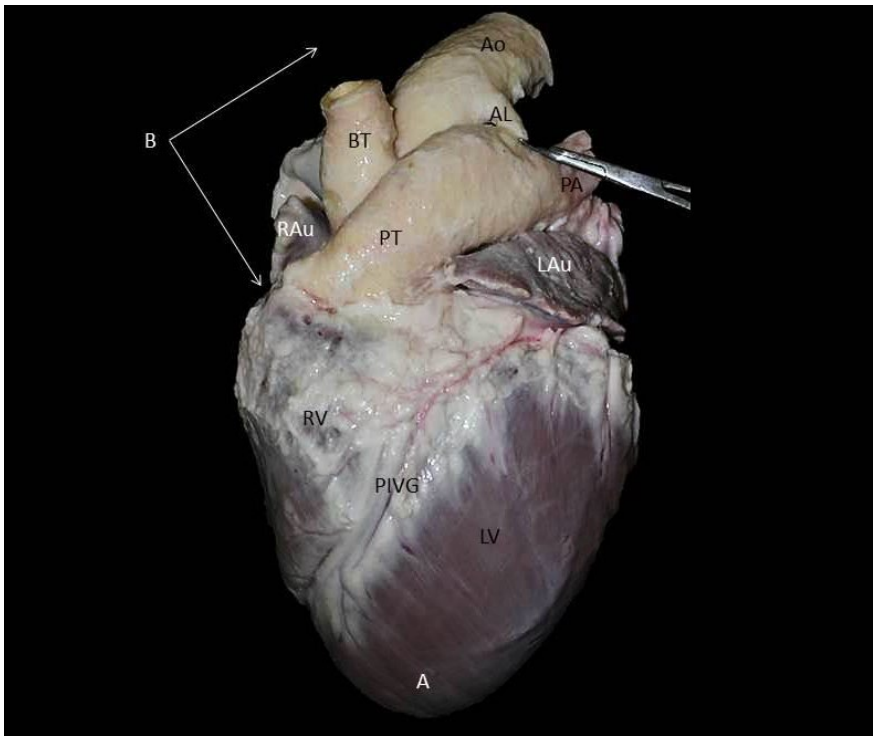
(2010). However, according to Lee et al. (1975), the heart of most mammals were described to be elongated, having a well-pointed apex.

Coronary Artery Branching

The coronary artery encircles the coronary groove within a massive concealment of fat. It arises from the aorta and it surrounds the coronary groove starting at the level of the left auricle and descends downward, becoming the paraconal interventricular branch (Figure 2). It continues to encircle the groove which makes up the circumflex branch and finally branches into subsinuosal interventricular (Figure 3) which lies at right side of the heart.

Figure 2

Left lateral view of the heart of Philippine water buffalo, fats removed, showing the base (B), apex (A), left ventricle (LV), right ventricle (RV), left auricle (LAu), right auricle (RAu), coronary artery (CA), paraconal interventricular groove (PIVG), pulmonary trunk (PT), pulmonary artery (PA), aorta (Ao), brachiocephalic trunk (BT), arterial ligament (AL).



According to Frandson et al. (2009), coronary arteries are the arterial blood supply for the myocardium, while Pasquini and Spurgeon (1989) stated that these are the first branches of aorta which encircle the heart like a crown.

The left coronary artery arises from the left aortic sinus that course to the left under the left auricle and immediately giving the descending and encircling branches. Pasquini and Spurgeon (1989) called these branches as the paraconal and circumflex, respectively. Dyce et al. (2010) stated that the left (paraconal) interventricular branch follows the like-named groove toward the apex of the heart. The trunk continues as a circumflex branch that follows the coronary groove toward the caudal aspect of the heart, where it may terminate close to the origin of the right (subsinuosal) interventricular groove (horse and pig) or continue into this (carnivores and ruminants).

Heart Weight

The mean absolute heart weight recorded was 2.42 kg, while the mean carcass weight was 237.20 kg. The relative heart weight was computed by dividing the mean absolute weight of the heart over the absolute mean weight of the carcass and multiplied by 100. The relative weight computed was 1.2%. This shows that the percentage of the heart to that of the carcass of the Philippine water buffalo is very small. Yap and Herbosa (2004) documented that the heart of a normal healthy male Philippine water buffalo weighs about 2 to 3.2 kg, while it ranges from 2 to 3 kg in female.

Heart Dimensions

Heart length was measured from the base of the pulmonary artery to the apex of the heart, while the width was measured at its widest from the level of the pulmonary artery to the level of the pulmonary vein. The mean length and width of heart samples were 21.71 cm and 17.49 cm, respectively. Findings of this study conform to Yap and Herbosa (2004), in which the greatest width of the base ranged from 15–20 cm for both males and females. On the other hand, the distance between the origin of pulmonary artery and apex ranged from 19–24 cm for both sexes. Table 1 shows the mean values on the circumference of the Philippine water buffalo's heart at the level of the coronary groove, middle segment and apex. The mean values are the same in the range documented by Yap and Herbosa (2004) in their study on the weights and measurements of the heart of the Philippine carabaos.

Table 1

Mean Values of Circumferences of Philippine Water Buffalo's Heart

Parameter	**Mean (cm)**
Circumference at coronary groove	48.41± 3.38
Circumference at middle	44.10 ± 4.84
Circumference at apex	20.57 ± 1.52

Table 2 shows the mean measurements of the external circumference of major blood vessels of the heart. The data shows that the caudal vena cava is larger than that of the cranial. Pulmonary veins range from four to five in number. The number of pulmonary veins varies among species as mentioned by Frandson et al. (2009) and Iaizzo (2010). On the other hand, Persaud (1997) reported that human hearts have four, while Holt (1970) reported five. Moreover, Hughes (1968) documented dog hearts to have five to six pulmonary veins, while Holt et al. (1968) reported two pulmonary veins in the heart of pig. Miranda (2014) documented 2–3 pulmonary veins in goat. In addition, ligamentum arteriosum was present in between the pulmonary trunk and aorta (Figure 2). Pasquini and Spurgeon (1989), Dyce et al., (2010), Frandson et al., (2009), König and Liebich (2004), and Getty (1975) stated that the ligamentum arteriosum is the remnant of the fetal ductus arteriosus (arterial duct) connecting the pulmonary trunk and aorta. Getty (1975) measured the width of ligamentum arteriosum in horse which is about 1.2 cm.

Table 2

Mean Values of External Circumferences of Main Blood Vessels

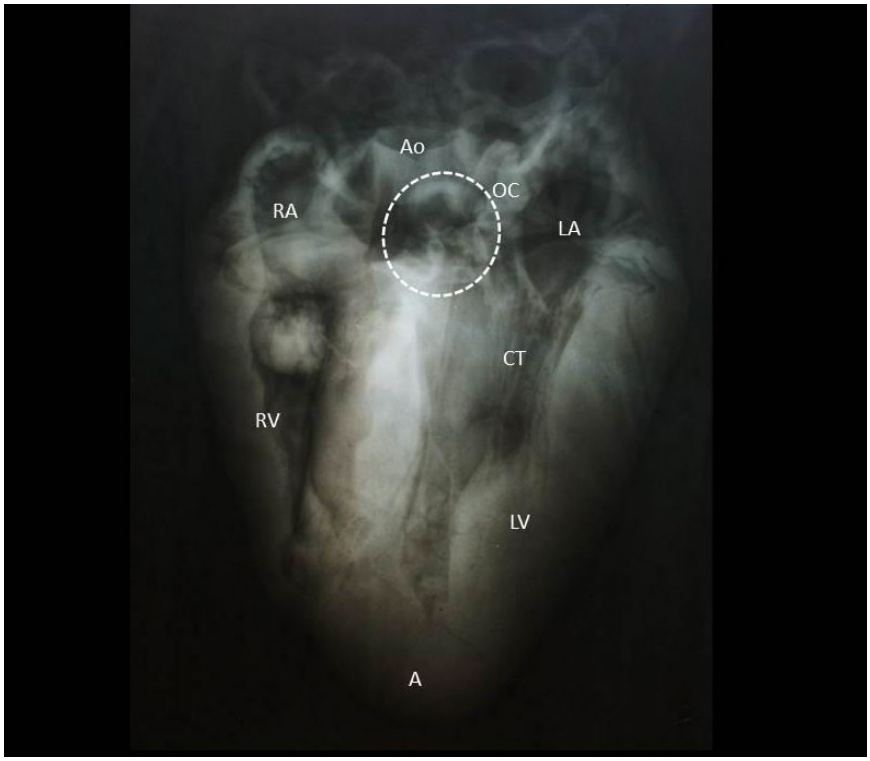
Parameter	Mean (cm)
Pulmonary artery	7.35 ± 1.32
Pulmonary vein	2.44 ± 1.10
Caudal vena cava	10.54 ± 1.04
Cranial vena cava	8.76 ± 1.21
Aorta	13.01 ± 1.55

Location of Os Cordis

Radiographic evaluation (Figure 3) revealed the presence of os cordis embedded at the base of the aortic fibrous ring close to the boundary between the walls of two atria and two ventricles. The present study examined hearts from Philippine water buffalo with age 5–12 years old. The same findings were documented by David (2004), however heart samples were collected from water buffalo with age ranging from 7 to 19 years old and no bones were found among 1.5 years old water buffalo. David (2004) also added that the measurements obtained for the Philippine water buffalo was smaller than those of cattle. In the study of Soberano (2007), os cordis were found to be in heart samples from water buffalo aging at least 9 years old onwards. This suggests that os cordis can only be found in mature animals and not in younger animals.

Figure 3

Cranial View of Radiographic Image of the Heart of Philippine Water Buffalo Showing the Location of Os Cordis (OC), Aorta (Ao), Right Atrium (RA), Left Atrium (LA), Right Ventricle (RV), Left Ventricle (LV), Chordae Tendinae (CT), and Apex (A).



Cardiac Wall Thickness

Table 3 shows the mean thickness of the right and left atrial wall and the right and left ventricular wall. The left atrial wall is thicker than the right atrial wall. The atrial wall which is the upper chamber of the heart lies immediately on the caudalmost part of the auricle. The auricle of both right and left possesses criss-crossing muscle bundles and irregular ridges called pectinate muscle. The mean thickness of the left atrial wall showed no significant difference (P <0.05) to that of the right.

The left ventricular wall is twice the thickness of the right ventricular wall (Figure 4) This is the same with the findings of Hussain and Quereshi (2007) who reported that the thickness of the wall of the left ventricles were significantly higher than the right. Dyce et al. (2010) also stated that the left ventricle forms the whole apex of the heart. The thicker wall of the left ventricle conforms to the greater work it performs in pumping blood throughout the body as stated by Pasquini and Spurgeon (1989), Dyce et al. (2010), Frandson et al. (2009), König and Liebich (2004). Hussain and Quereshi (2007) reported that higher values were obtained in adult buffaloes than younger ones.

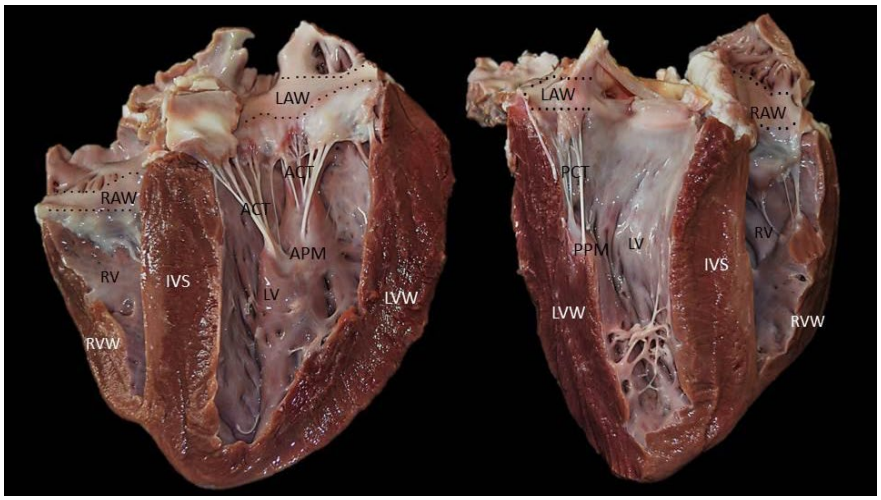
Table 3

Mean Values of Thickness of Right and Left Atrial and Ventricular Wall

Parameter	**Mean (mm)**
Right ventricular thickness	14.14 ± 1.74
Left ventricular thickness	30.53 ± 5.31
Right atrial thickness	7.97 ± 0.94
Left atrial thickness	8.44 ± 1.16

Figure 4

Sagittal Section of the Heart of Philippine Water Buffalo Showing the Right Atrial Wall (RAW), Left Atrial Wall (LAW), Right Ventricular Wall (RVW), Left Ventricular Wall (LVW), Interventricular Septum (IVS), Anterior Papillary Muscle (APM), Posterior Papillary Muscle (PPM), Anterior Chordae Tendinae (ACT), and Posterior Chordae Tendinae (PCT)



Valvular Cusps, Papillary Muscles, and Chordae Tendinae

Three cusps (Table 4) of the right atrioventricular valves were found in all heart samples. The three cusps were named as posterior cusp (cuspis septalis), anterior cusp (cuspis parietalis), and septal cusp (cuspis angularis) by König and Liebich (2004). The results were similar to those in sheep, goat, cow and man as reported by Komala (2006).

All heart samples have three papillary muscles on the right ventricle. The first papillary muscle of the right ventricle is called the septal papillary muscle and it is located near to the pulmonary trunk. The second is called the posterior papillary muscles which is also located on the septum. The third is the anterior papillary muscles located outside the outer wall. The anterior papillary muscle is the largest, followed by the posterior and the septal papillary muscle (Figure 6). The findings of this study were the same with the results by Roberts and Cohen (1972) and Rusted et al. (1952) which suggest that ruminants have the same number of papillary muscles. Papillary muscles are muscular projections serving as attachments for tendinous cords (chordae tendinae) of the atrioventricular (AV) valve (Pasquini & Spurgeon, 1989) and maintaining the tendinous chords under tension (Komala, 2006).

The chordae tendinae were counted one by one regardless of size and appearance. The chordae tendinae were observed and were named as anterior, septal, and posterior chordae tendinae, based on their attachment with the three papillary muscles. In the right ventricle, the study of Montabagani (2006) showed that there was a lower number of chordae tendinae from the posterior papillary muscle of human, sheep, and monkey in female than male which is in contrast with the results of the study where posterior chordae tendinae is higher with a mean value of 25 . The septal chordae tendinae is the most numerous among the tendinae of the right ventricle (Table 4).

Table 4

Mean Values of Parts of Right and Left AV Valve

Parameter	Mean
Number of right AV valve cusp	3
Number of right papillary muscle	3
Number of right anterior chordae tendinae	22.70
Number of right septal chordae tendinae	26.80
Number of right posterior chordae tendinae	25.40
Number of left AV valve cusp	2
Number of left papillary muscle	2
Number of left anterior chordae tendinae	38.40
Number of left posterior chordae tendinae	32.30

The left atrioventricular valve of all Philippine water buffalo examined has two cusps, the anterior and posterior cusps. The same was reported by Komala (2006). However, variations in the number of cusps in the left AV valves have been reported in other animals where Lima et al. (2013) reported two to five cusps on the left AV valve of pigs.

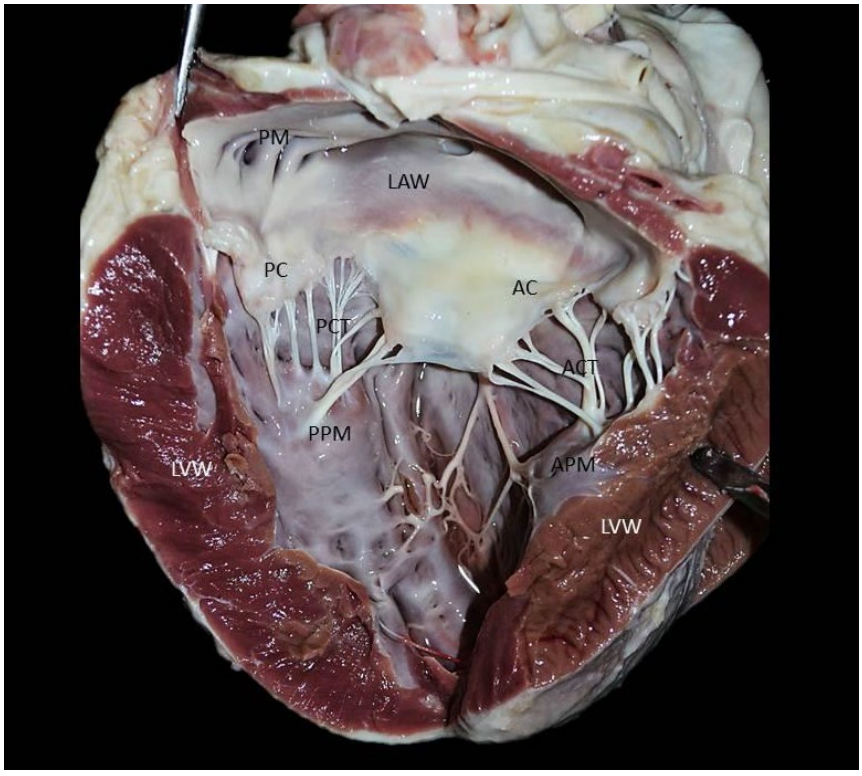
The present study documented two papillary muscles in the left ventricle. The anterior papillary muscle is larger than the posterior papillary muscle (Figure 6). The two papillary muscles of the left ventricle are situated on the outer wall and are termed, according to their location, m. papillaris subauricularis (anterior papillary muscle), and subatrialis (posterior papillary muscle). These findings are the same with the record of Komala (2006). Crick et al. (1998) had a comparative study of

the morphology of papillary muscles of the left ventricle in 135 normal adult hearts of different species and showed that anterior and posterior papillary muscles were always present.

The chordae tendinae were observed and were named as anterior and posterior chordae tendinae, based on their attachment with the two papillary muscles. This is in line with the description of Dyce et al. (2010) that the chordae tendinae are so arranged that they connect each cusp to two papillary muscles and each muscle to two cusps. The same author further explained that this arrangement prevents eversion of the cusps into the atrium during ventricular contraction.

Figure 5

Sagittal Section of the Heart of Philippine Water Buffalo Showing the Right Atrial Wall (RAW) Demarcated by Black Dots; Pectinate Muscle (PM); Valves: Posterior Cusp (PC), Anterior Cusp (AC), and Septal Cusp (SC); Papillary Muscles: Septal Papillary Muscle (SPM), Posterior Papillary Muscles (PPM), and Anterior Papillary Muscles (APM); and Chordae Tendinae: Anterior Chordae Tendinae (ACT), Septal Chordae Tendinae (SCT), and Posterior Chordae Tendinae (PCT); and Moderator Band (MB)



Pulmonary and Aortic Valves

Three cusps are present in both pulmonary and aortic valves (Figure 6). This study documented that the number of cusps of pulmonary and aortic valve is constant in Philippine water buffalo. The pulmonary valve lies between the pulmonary trunk and right ventricle while the aortic valve was at the junction of left ventricle and aorta. The location has been described previously by Dyce et al. (2010), Frandson et al. (2009), König and Liebich (2004), Nawaz (2013), and Pasquini and Spurgeon (1989).

Figure 6

Sagittal Section of the Heart of Philippine Water Buffalo Showing the Left Atrial Wall (LAW): Left Ventricle; Valves: Posterior Cusp (PC), Anterior Cusp (AC); Papillary Muscles: Posterior Papillary Muscles (PPM) and Anterior Papillary Muscles (APM); and Chordae Tendinae: Anterior Chordae Tendinae (ACT) and Posterior Chordae Tendiae (PCT)

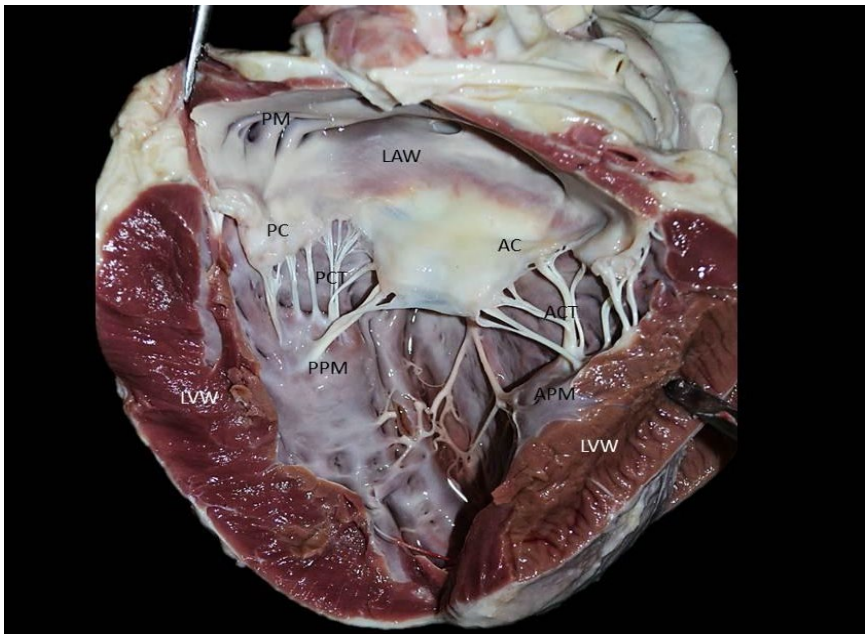
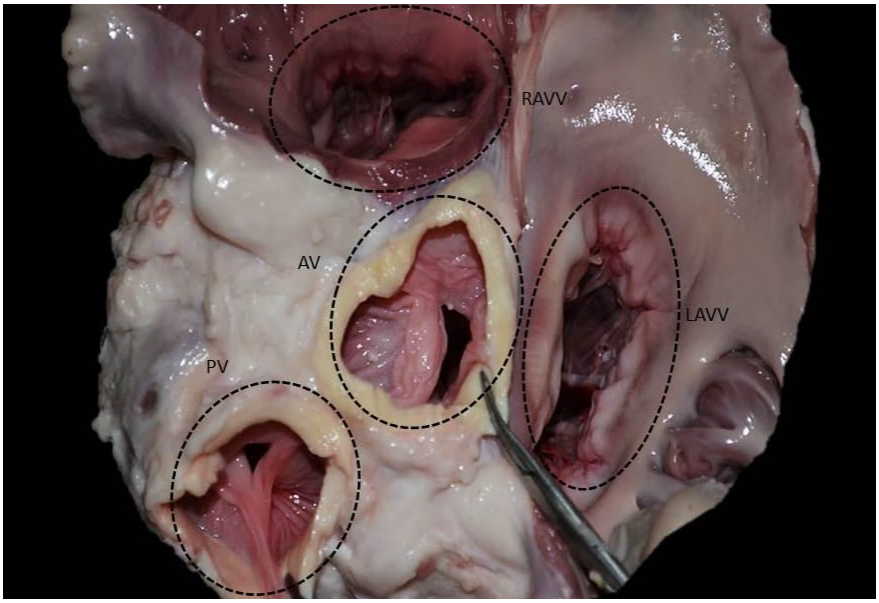


Figure 7 shows the aortic valve attached to the aortic fibrous ring on the origin of the aorta which was also mentioned by Pasquini and Spurgeon (1989) and Ritchie (2004).

Figure 7

Dorsal View of the Heart of Philippine Water Buffalo Showing the Pulmonary Valve (PV), Aortic Valve (Aov), Right Atrioventricular Valve (RAVV), and Left Atrioventricular Valve (LAVV), the Pulmonary Cusps (PC), Aortic Cusps (Aoc), Right Atrioventricular Cusps (RAVC), and Left Atrioventricular Cusps (LAVC)

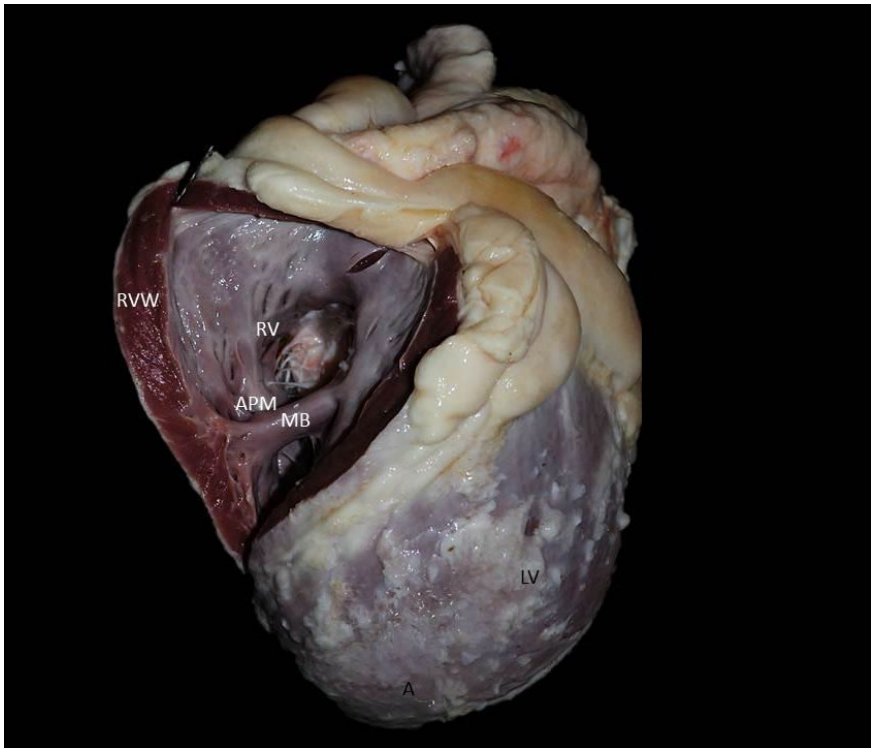


Trabeculae Septomarginalis

The lumen of the ventricle is crossed by a single cord of muscle (trabeculae septomarginalis) attached from the interventricular septum to the base of the anterior papillary muscle of the right ventricle (Figure 8). The mean length of trabeculae septomarginalis is 37.3 mm. Dyce et al. (2010) explained that it provides a shortcut for a bundle of the conducting tissue, thus ensuring a more nearly simultaneous contraction of all parts of the ventricle. The modification of the muscle is provided by the many irregular ridges (trabeculae carneae) that give the lower part of the wall a spongy appearance. These are confined to the "inflow" part of the cavity and are thought to reduce blood turbulence.

Figure 8

Cranial View of the Philippine Water Buffalo's Heart, Right Ventricle Cut Open, Showing the Trabeculae Septomarginalis or Moderator Band (MB) Situated at the Right Ventricle, Right Ventricular Wall (RVW), Right Ventricle (RV), Left Ventricle (LV), Anterior Papillary Muscle (APM), and Apex (A).



Acknowledgments

The assistance of the personnel at the Cabanatuan City slaughterhouse is highly recognized in this paper.

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