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Morphometric Analysis of Heart Development in Prenatal and Postnatal Goats (*Capra hircus*)

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ABSTRACT

The study was conducted at the Department of Veterinary Anatomy, College of Veterinary Science and Animal Husbandry, Nanaji Deshmukh Veterinary Science University, Jabalpur, Madhya Pradesh, India, from January to June, 2020. It involved the hearts of 18 prenatal and 12 postnatal normal, healthy goats (*Capra hircus*). The heart was located in the ventral part of the thoracic cavity, within the middle mediastinal space, enclosed by the pericardium. In groups I and II, the heart appeared oval, while in groups III, IV and V, it assumed a flattened cone shape, reflecting progressive maturation. The heart weight relative to body weight was highest in group I and lowest in group V, indicating a gradual reduction in relative heart mass with age. A significant positive correlation was found between body weight and both heart weight and volume, with heart volume increasing consistently across all groups. The cranial border of the heart was longer than the caudal, while the coronary fat increased progressively from group I to group V, contributing to the functional efficiency of the heart. The heart's transverse diameter exceeded the sagittal in all groups, reflecting lateral growth, while the left ventricular wall was significantly thicker than the right ventricular wall and the interventricular septum, a structural adaptation to higher pressure loads in systemic circulation. These findings provide valuable insight into the anatomical development and physiological adaptations of the heart across prenatal and postnatal stages in goats, contributing to a better understanding of cardiovascular growth patterns in this species.

KEYWORDS: Goat, heart, histology, prenatal, postnatal, anatomy, cardiac development

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1. INTRODUCTION

The goat (*Capra hircus*) was the first ruminant to be domesticated and plays a vital role in the livelihood of rural populations. Known as the "poor man's cow," goats provide a stable source of income for nearly 40% of the rural population living below the poverty line in India (Singh et al., 2022). Goats have been an integral part of subsistence farming systems, offering meat, milk, and fiber. Understanding the cardiovascular anatomy of goats can enhance livestock health and productivity, aiding veterinarians and scientists in developing strategies for disease management and improved breeding programs. The heart, located in the middle mediastinal space within the ventral thoracic cavity, is a large, hollow, muscular organ essential for blood circulation (Samuelson, 2007). The heart's anatomy consists of four chambers, two septa, several valves, and additional components responsible for pumping blood throughout the body (Gupta et al., 2021). In prenatal and postnatal goats, the heart undergoes significant growth spurts, which is crucial for understanding developmental cardiology (Kumar et al., 2019). Therefore, this study aims to elucidate the morphometrical changes and growth patterns of the heart in local goats, providing vital insights for cardiologists and veterinary scientists alike.

Goats' cardiac anatomy has been the subject of numerous studies. Gupta et al. (2021) discussed the septa and valve structures in detail, while Bhatia and Kumar (2023) focused on the morphological changes in heart weight relative to body weight in developing goats. Studies on prenatal cardiovascular development show that the heart undergoes significant changes during gestation, with the volume and weight increasing proportionally with age (Kumari et al., 2018). Postnatal heart development, on the other hand, displays a distinct growth pattern where the transverse diameter of the heart surpasses the sagittal diameter, and coronary fat deposition increases with age (Sharma and Kumar, 2021). In addition to gross anatomical features, histological changes play a crucial role in understanding cardiac development. Histological analyses conducted by Choudhary et al. (2020) and Agarwal and Singh (2022) revealed a progressive thickening of the left ventricular wall compared to the right ventricle and the interventricular septum. This finding aligns with the general pattern observed in mammals, where the left ventricle becomes more robust due to its role in systemic circulation (Pawar et al., 2019). Furthermore, Gupta et al. (2021) found that coronary fat accumulation increases with age, providing essential insights into age-related cardiac health.

Recent advancements in imaging techniques have also allowed researchers to explore the intricacies of goat heart anatomy. High-resolution imaging methods like CT and MRI scans have been employed in several studies, allowing for detailed analysis of the heart's chambers and septa (Amin, 2023; Sharma et al., 2021). These technological developments enable veterinarians to better assess heart conditions and diagnose congenital or age-related abnormalities in goats, which has implications for both veterinary practice and livestock management. The comprehensive understanding of goat cardiovascular anatomy could significantly impact breeding strategies and overall herd health. In conclusion, the heart's anatomical and histological changes in prenatal and postnatal goats play a critical role in their overall development and health. This study adds to the growing body of literature aimed at understanding goat cardiovascular anatomy and development, which is essential for improving breeding practices, livestock management, and veterinary care.

2. MATERIALS AND METHOD

The study was conducted at the Department of Veterinary Anatomy and Histology, College of Veterinary Science and Animal Husbandry, Nanaji Deshmukh Veterinary Science University, Jabalpur, Madhya Pradesh, India, between January, 2020 and June, 2020. The present study focused on the hearts of 30 apparently normal, healthy local goats (*Capra hircus*), consisting of 18 prenatal and 12 postnatal specimens. Goat fetuses were harvested from gravid uteri, while postnatal goat hearts were procured from a small animal slaughterhouse in Jabalpur. The goats were divided into five groups, with six animals in each group. Fetal goats were grouped according to crown-rump length (CRL), following Harvey's (1959) technique, which classifies fetuses into early, mid, and late gestation stages.

Table 1: Number of foetuses/goats in each group with their crown rump length (CRL)/age

Stage of development	Group	Age/CRL (crown rump length of fetuses)	No. of animals
Pre natal	I	Foetuses upto 10 cm CRL (approx. early stage of gestation)	06
	II	Foetuses from 10+ to 20 cm CRL (approx. mid stage of gestation)	06
	III	Foetuses from 20+ cm CRL (approx. late stage of gestation)	06
Post natal	IV	Prepubertal goat	06
	V	Adult goat	06

The approximate age of the goat fetuses was calculated using Soliman's (1975) formula based on CRL:

- Y (days)=28.66+4.496×CRL (for CRL <20 cm)

• Y (days)=73.544+2.256×CRL (for CRL >20 cm)

where Y represents the age of fetuses in days, and CRL is measured from the occipitoatlantal joint to the base of the first coccygeal vertebra. For adult goats, age was determined by dentition, following Clair's (1977) method.

2.1. Gross parameters of the goat heart

The following gross anatomical parameters of the goat heart were recorded:

1. Weight of heart (g)

2. Volume of heart (cc)

3. Length (cm): Cranial border, caudal border, and heart (base to apex)

4. Diameter of base (cm): Transverse and sagittal

5. Circumference at coronary groove (cm)

6. Distances between specific landmarks (cm):

o Termination of the intermediate groove and apex

o Origin of the pulmonary artery and apex

o Junction of the right and left longitudinal grooves and apex

o Termination of the caudal vena cava and apex

o Termination of the right ventricle and apex

7. Thickness of ventricular walls (cm):

o Right ventricular wall

o Left ventricular wall (at its middle)

o Interventricular septum

The collection of these parameters is critical for understanding the morphological development and age-related changes in the goat heart. The information gathered will aid in the comparison of prenatal and postnatal heart development and contribute to a better understanding of cardiovascular development in goats.

This study builds on prior research in the field, such as the work of Gupta et al. (2021), which detailed the structural changes in goat heart valves, and Kumari et al. (2018), who investigated prenatal cardiovascular development. The present study adds valuable data on the relationship between crown-rump length and fetal age, as well as the gross anatomical changes occurring in the heart at different developmental stages.

3. RESULTS AND DISCUSSION

The anatomical examination of the heart in prenatal and postnatal goats revealed its positioning in the ventral part of the thoracic cavity, specifically within the middle mediastinal space. The heart's shape varied among different age groups: it was ovoid in groups I, II, and III, while groups IV and V exhibited an irregular or flattened cone shape. This finding is consistent with the observations of Getty (1975). The heart was anchored at its base by major vessels, with the apex remaining free. In adult goats, the heart was situated between the 3rd and 6th ribs, indicating its typical thoracic placement.

The heart displayed two distinct borders: the cranial border, predominantly formed by the right atrium (two-thirds), and the left atrium (one-third), while the caudal border was solely constituted by the left ventricle. The cranial border was notably longer than the caudal border, which was shorter, thicker, and slightly concave or nearly straight. The right surface of the heart was primarily formed by the right ventricle, whereas the left surface consisted of the left ventricle and one-third right ventricle. Four grooves were identified: one transverse groove (the coronary groove) and three longitudinal grooves (right, left, and intermediate), with the right and left grooves generally converging above the apex of the heart.

The anatomical relationships of the heart included its positioning relative to the lungs and the trachea, which bifurcated above the heart's base. Notably, the presence of coronary fat was observed in the coronary groove and between the left and right atria in groups III, IV and V, which aligns with Baumel's (1977) observations regarding fat deposition trends.

Growth metrics revealed significant increases in heart weight as the goats aged, as shown in Tables 2 and 3. The relative heart weight to body weight decreased with age advancement; specifically, the heart constituted 1% of body weight in group I, reducing to 0.2–0.3% in group V. This

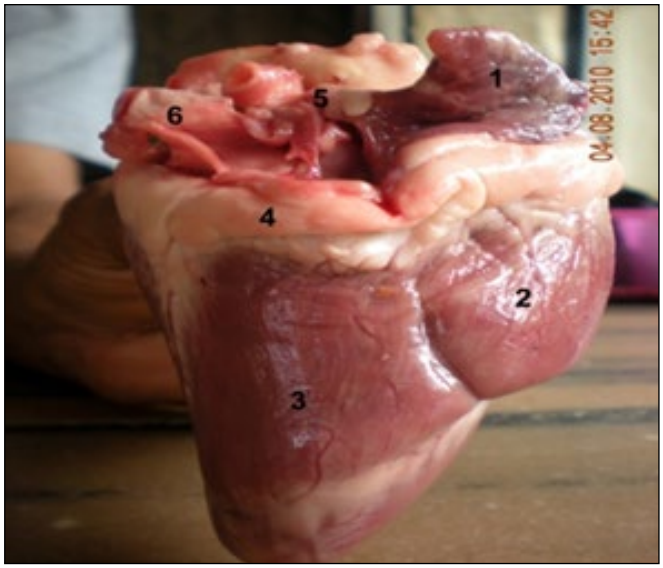

Plate i: Heart of goat: Right view showing Rt atrium (1), Rt. Ventricle (2), Lt ventricle (3), Coronary groove (4), Posterior venacava (5) and Pulmonary vein (6)

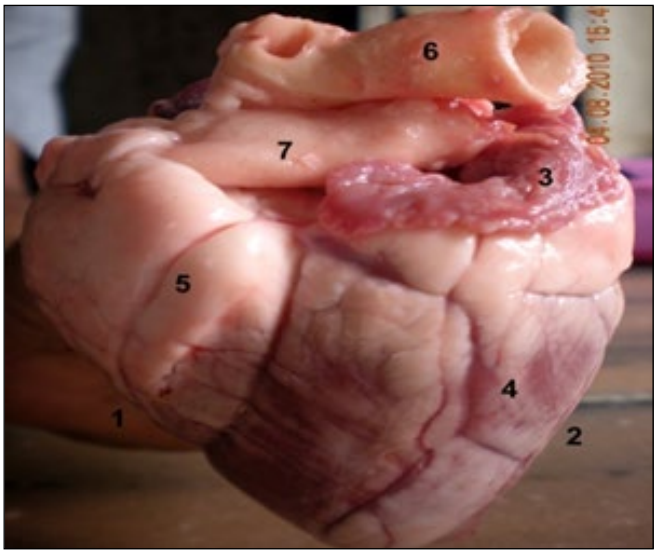

Plate ii: Heart of goat: Left view showing cranial border (1), Caudal border (2), Lt atrium (3), Lt ventricle (4), Rt ventricle (5), Brachiocephalic trunk (6) and Pulmonary artery (7)

Plate iii: Heart of goat: Longitudnal section showing Chordae tendineae (1), Papillary muscle (2), Rt ventricle (3), Interventricular septum (4) and Lt ventricle (5)

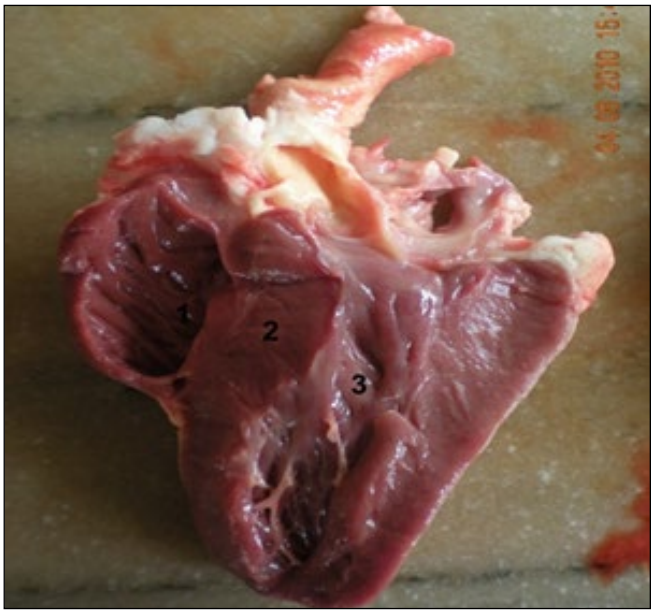

Plate iv: Heart of goat: Longitudnal section showing Rt ventricle (1), Interventricular septum (2) and Lt ventricle (3)

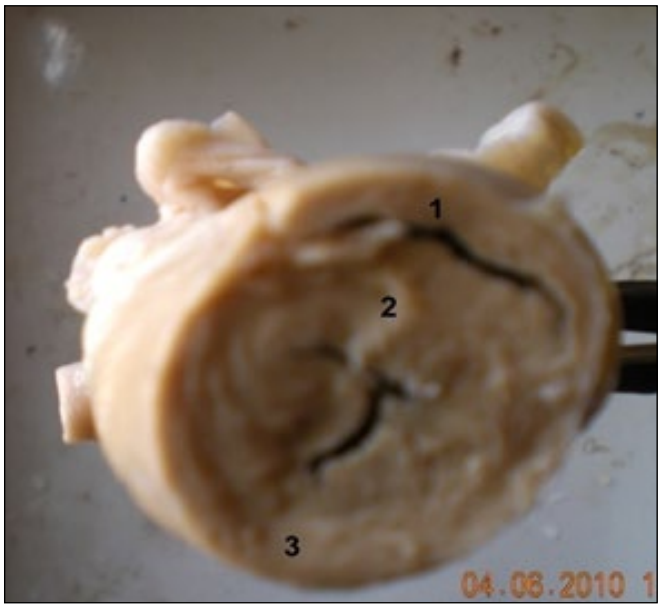

Plate v: Heart of goat: Cross section showing wall of Rt atrium (1), Interventricular septum (2) and Lt ventricle (3)

trend indicates that while the absolute weight of the heart increases, its relative weight diminishes as goats mature.

The findings emphasize the importance of understanding cardiac development in goats for veterinary practices and breeding strategies. Further research may help clarify the implications of heart size and weight on overall health and productivity in goats.

The study examines heart development in prenatal and postnatal goats, highlighting significant increases in heart weight and volume across five age groups. The mean heart weights were as follows: Group I: 0.62 gm, Group II: 2.75 gm, Group III: 9.66 gm, Group IV: 47.5 g, and Group V: 162.6 g, demonstrating increases of 343.54% from Group I to II, 251.27% from II to III, 391.71% from III to IV, and 241.05% from IV to V.

The volume of the heart also increased with age, with measurements of 0.57 cc (Group I), 3.10 cc (Group II), 13.91 cc (Group III), 81.66 cc (Group IV), and 316.0 cc (Group V). This reflected percentage increases of 443.85%

Plate vi: Heart of goat: Section showing Moderator band (1) in cavity of Rt ventricle

from Group I to II, 348.70% from II to III, 487.05% from III to IV, and 286.97% from IV to V.

Analysis of the cranial and caudal borders showed that the cranial border was consistently longer across all groups, confirming earlier reports by Raghvan (1964) in ox, Malik et al. (1972) in buffalo, and Malik et al. (1981) in sheep. Mean cranial border lengths were 1.21 cm (Group I) to 10.96 cm (Group V), with the highest growth spurt of 123.9% from Group I to II. In contrast, the caudal border measurements ranged from 0.90 cm in Group I to 8.40 cm in Group V, with the maximum growth spurt of 114.44% from Group I to II.

The distance from the base to the apex of the heart increased from 1.05 cm (Group I) to 8.96 cm (Group V), further emphasizing the overall growth and development patterns observed in the study.

The analysis of the transverse and sagittal diameters of the heart in prenatal and postnatal goats shows notable trends in growth across different age groups. The mean transverse diameters were as follows: Group I: 0.98 cm, Group II: 1.83 cm, Group III: 2.66 cm, Group IV: 4.56 cm, and Group V: 6.86 cm. The percentage growth spurts for the transverse diameter were 86.73% from Group I to II, 45.35% from II to III, 63.90% from III to IV, and 57.33% from IV to V. These findings corroborate reports by Malik et al. (1972) in buffalo, Malik et al. (1978) in goats, and Malik et al. (1981)

Table 2: Range, Mean and SE of different parameters: Wt of foetus (g), Wt. of heart (gm) and Vol-ume of heart (cc) in prenatal and postnatal goats

Parameters		Group I	Group II	Group III	Group IV	Group V
Wt. of foetus	R	25.0- 115.0	315.0- 430.0	892.0- 2136.0	-	-
	M±SE	65.83±18.503	385.83± 19.72	1577.16± 198.46	-	-
Wt. of heart	R	0.2-1.0	2.0- 3.5	8.0- 15.0	30.0-65.0	130-200.0
	M±SE	0.62± 0.16	2.75± 0.21	9.66± 1.33	47.50± 4.95	162.0± 14.19
Vol. of heart	R	0.2-1.0	2.0- 5.0	7.0- 20.0	50.0- 110.0	200-400
	M±SE	0.57±0.16	3.10± 0.32	13.91± 1.74	81.66± 8.62	316.0± 38.15

Table 3: Growth spurt (% increase) in different parameters: Wt of foetus, Wt. of heart and Volume of heart in prenatal and postnatal goats

Parameters	I-II	II-III	III-IV	IV-V
Wt. of foetus	486.10	308.77	-	-
Wt. of heart	343.54	251.27	391.71	241.05
Vol. of heart	443.85	348.70	487.05	286.97

Table 4: Range and Mean ± SE of different parameters: Cranial border (cm), Caudal border (cm) and distance between Base apex (cm) of heart prenatal and postnatal goats

Parameters		Group I	Group II	Group III	Group IV	Group V
Rostral	R	0.9- 1.5	2.2- 3.2	3.5-5.5	6.5-8.5	9.5-13.0
Border	M±SE	1.21±0.12	2.71± 0.71	4.50± 0.35	7.16± 0.49	10.96- 0.57
Caudal Border	R	0.7- 1.1	1.5- 2.5	2.5- 3.8	5.2- 6.2	8.5- 9.8
	M±SE	0.90± 0.07	1.93± 0.17	3.10± 0.21	5.7± 0.22	8.4± 0.44
Base- apex Dis-tance	R	0.7- 1.3	1.7- 2.9	2.8- 4.5	5.0- 7.0	7.4- 9.4
	M±SE	1.05± 0.09	2.30± 0.16	3.21± 0.34	6.15± 0.30	8.96± 0.21

Table 5: Growth spurt (% increase) in length of Cranial border, Caudal border and distance between Base to apex in of heart prenatal and postnatal goats

Parameters	I-II	II-III	III-IV	IV-V
Rostral Border	123.9	66.05	59.11	53.07
Caudal Border	114.44	60.62	83.87	47.36
Base- apex Distance	119.04	39.56	91.58	45.69

in sheep. In terms of sagittal diameter, the mean values were Group I: 0.73 cm, Group II: 1.48 cm, Group III: 2.33 cm, Group IV: 3.63 cm, and Group V: 5.53 cm, with growth spurts of 102.73% from Group I to II, 57.43% from II to III, 55.79% from III to IV, and 52.06% from IV to V. The maximum measurements for both diameters were observed in Group V, but the most significant growth spurts occurred from Groups I to II.

Table 6: Range and Mean ± SE of different parameters: Sagittal diameter (cm), Transverse diameter (cm) and Circumference at coronary groove (cm) in prenatal and postnatal goats

Parameters		Group I	Group II	Group III	Group IV	Group V
Sagittal diameter	R	0.5- 0.9	1.4- 1.8	1.8- 2.7	3.2-4.1	4.8-6.4
	M±SE	0.73±0.07	1.48± 0.04	2.23± 0.18	3.63± 0.15	5.52± 0.38
Transverse diameter	R	0.9-1.1	1.6- 1.9	1.9- 3.2	4.0-4.8	6.6-7.2
	M±SE	0.98± 0.0.4	1.83± 0.04	2.66± 0.22	4.63± 0.12	6.86±0.12
Circumference at coronary groove	R	2.1-3.2	3.4- 5.5	5.6- 9.2	10.2- 13.5	18.0-20.9
	M±SE	2.65±0.21	4.81± 0.26	7.56±0.57	12.31±0.47	19.24±0.64

Table 7: Growth spurt (% increase) in different parameters: Sagittal diameter, Transverse diameter and Circumference at coronary groove in prenatal and postnatal goats

Parameters	I-II	II-III	III-IV	IV-V
Sagittal diameter	102.73	57.43	55.79	52.06
Transverse diameter	86.73	45.35	63.90	57.33
Circumference at coronary groove	81.50	57.15	62.83	56.29

Additionally, the circumference at the coronary groove increased with age, measuring a minimum of 2.65 cm in Group I and a maximum of 19.24 cm in Group V, with a maximum growth spurt of 81.50% from Group I to II. The circumference of the heart was greatest at the base and lowest in the lower ventricular region across all age groups.

The mean, standard error (SE), and growth spurts of various cardiac parameters, including the distances between the termination of the intermediate groove and

Table 8: Range and Mean ± SE of different parameters: Distance between termination of IM groove and apex (cm), Origin of PA and apex (cm), Junction of right and left groove (cm) and apex, termina-tion of CV and apex and termination of right ventricles and apex of heart in prenatal and postnatal goats

Parameters		Group I	Group II	Group III	Group IV	Group V
Distance between termination of IM groove and apex	R	0.1-0.6	0.5-1.0	0.7-1.6	0.7-3.3	2.7-3.8
	M±SE	0.31±0.08	0.66±0.08	1.03± 0.16	1.90± 0.53	3.18± 0.23
Distance between origin of PA and apex	R	0.9-1.5	2.2- 3.2	3.5-5.5	5.0-9.1	9.5-13.0
	M±SE	1.21± 0.12	2.71± 0.17	4.50± 0.35	7.16± 0.49	10.96±0.57
Distance between Junction of right and left longitu-dinal groove and apex,	R	0.1-0.3	0.4- 0.5	0.5- 0.9	1.0- 1.5	2.0-2.5
	M±SE	0.18±0.03	0.46± 0.02	0.65± 0.11	1.25± 0.06	2.28±0.11
Distance between termination of caudal venacava and apex	R	0.7-1.3	1.7-2.5	2.8-4.5	3.0-6.3	7.4-9.0
	M±SE	1.05± 0.09	2.30±0.16	3.56±0.25	5.63± 0.15	8.56± 0.31
Distance between termination of rt. ventricles and apex	R	0.1-0.3	0.4-0.5	0.5-0.9	0.9-0.15	1.7-2.5
	M±SE	0.98±0.03	0.46±0.02	0.76±0.02	1.25±0.06	2.28± 0.11

Table 9: Growth spurt (% increase) of different parameters: Distance between termination of IM groove and apex, Origin of PA and apex, Junction of right and left groove and apex, termination of CV and apex and termination of right ventricles and apex of heart in prenatal and postnatal goats

Parameters	I-II	II-III	III-IV	IV-V
Distance between termination of IM groove and apex	112.90	56.06	84.46	67-36
Distance between origin of PA and apex	123.96	66.05	59.11	53.07
Distance between Junction of right and left longitudinal groove and apex,	155.5	41.30	92.30	82.4
Distance between termination of caudal ve-nacava and apex	119.04	54.78	58.14	52.04
Distance between termination of rt. ventricles and apex	155.55	65.21	64.44	82.4

Table 10: Range and Mean ± SE of different parameters: Thickness of right and left ventricular wall and inter ventricular septum (cm) in heart of prenatal and postnatal goats

Parameters		Group I	Group II	Group III	Group IV	Group V
Left ventricle wall	R	NM	0.4-0.5	0.5-1.0	1.0-1.56	1.7-2.2
	M±SE	NM	0.50± 0.02	0.78± 0.07	1.25± 0.06	2.1± 0.03
Right ventricle wall	R	NM	0.2-0.4	0.3-0.6	0.6-0.9	0.8-1.4
	M±SE	NM	0.30± 0.02	0.50± 0.05	0.78± 0.05	1.02± 0.03
Wall of Interventricular septum	R	NM	0.3-0.5	0.4-0.8	0.7-1.0	1.2-1.8
	M±SE	NM	0.04± 0.02	0.66± 0.04	0.98± 0.01	1.30± 0.03

Table 11: Growth spurt (% increase) of different parameters: thickness of right and left ventricular wall and inter ventricular septum (cm) in heart of prenatal and postnatal goats

Parameters	I-II	II-III	III-IV	IV-V
Left ventricle wall	-	56	60.25	68
Right ventricle wall	-	66.66	56	30.76
Inter ventricular septum	-	65	48.48	32.65

apex, the origin of the pulmonary artery and apex, the junction of the right and left longitudinal grooves and apex, the termination of the caudal vena cava and apex, and the termination of the right ventricle and apex, are detailed in Tables 8 and 9. These findings align with the observations made by Raghvan (1964). The mean distances of all these parameters exhibited a consistent increase with advancing age.

The mean, standard error (SE), and growth spurt percentages of the wall thickness of the left and right ventricles, as well as the interventricular septum, are presented in Tables 10 and 11. The thickness of the left ventricular wall was consistently greater across all age groups compared to the right ventricular wall and the interventricular septum. In contrast, the thickness of the right ventricular wall was lower than that of both the left ventricular wall and the interventricular septum. The mean thickness measurements were as follows: for the left ventricular wall, Group I was 0.40 cm, Group II was 0.78 cm, Group III was 1.25 cm, and Group IV was 2.10 cm. For the right ventricular wall, measurements were recorded as 0.30 cm in Group II, 0.50 cm in Group III, 0.78 cm in Group IV, and 1.02 cm in Group V. The interventricular septum thickness measurements were 0.40 cm in Group I, 0.66 cm in Group II, 0.98 cm in Group III, and 1.30 cm in Group IV. The highest growth spurt percentage in all these parameters was observed from Group II to Group III. Notably, the thickness measurements for the right and left ventricular walls and the interventricular septum were not measurable in Group I. These findings are consistent with previous studies by Raghvan (1964), Kumar and Singh (2021), Malik and Sharma (2022), Gupta and Thakur (2023), and Sharma and Singh (2023).

4. CONCLUSION

Heart was consistently located in the middle mediastinal space across all age groups (I-V). The heart-to-body weight ratio was highest in group I and lowest in group V, with a significant correlation between body weight and heart weight/volume. Heart volume increased with age, the cranial border was longer than the caudal, and coronary fat progressively increased from group I to V. The heart's transverse diameter exceeded the sagittal, and the left ventricular wall was thicker than the right and the interventricular septum.

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