International Journal of Bio-resource and Stress Management https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM June 2026, 17(6): 01-10 **Article** AR7028

Research Article *Natural Resource Management*

DOI: HTTPS://DOI.ORG/10.23910/1.2026.7028

Regional Variations in Lobe-wise Micrometrical Parameters of the Porcine Liver from Jammu Region

Haneet Singh[1], Jasvinder Singh Sasan[1], Shalini Suri[1], Kamal Sarma[1] and Dibyendu Chakraborty[2]

[1]Division of Veterinary Anatomy, [2]Division of Animal Genetics and Breeding, F.V.Sc and A.H, SKUAST-Jammu, R. S. Pura, Jammu (181 102), India

Open Access

Corresponding jssasan216@gmail.com

0000-0002-7175-477X

ABSTRACT

The present study was conducted from January, 2025 to August, 2025 at the Division of Veterinary Anatomy, F.V.Sc and A.H, SKUAST-Jammu, R.S., Pura, Jammu (181102), India to generate detailed quantitative histomorphometric data on the hepatic microarchitecture of the pig liver and to evaluate regional and lobar variations. Liver samples were collected and processed using standard histological techniques, and various structural parameters of the hepatic tissue were measured to assess microanatomical differences among different lobes and regions of the liver. The capsule showed minor regional variations, being consistently thickest in the middle region, with significant variation observed only in the left lateral lobe. Hepatic lobule dimensions demonstrated both regional and lobar variation, with the left lateral lobe exhibiting significantly larger lobules. Central vein diameter varied significantly in the right and left lateral lobes, whereas inter-central vein distance showed no significant differences among lobes. Hepatocyte size and nuclear diameter were consistently greater in the periportal region compared with the centrilobular region, indicating zonal heterogeneity within hepatic lobules. Inter-lobular septa was thickest in the right lateral lobe, while sinusoidal diameters were generally larger in the centrilobular region, particularly in the left medial and left lateral lobes. Overall, the study highlighted distinct lobar and zonal histomorphometric variations in the pig liver, suggesting functional heterogeneity among hepatic lobes and providing baseline reference data for comparative anatomy and experimental research.

KEYWORDS: Capsule, hepatocyte, liver, micrometry, pig

***Citation* (VANCOUVER):** Singh et al., Regional Variations in Lobe-wise Micrometrical Parameters of the Porcine Liver from Jammu Region. *International Journal of Bio-resource and Stress Management,* 2026; 17(6), 01-10. HTTPS://DOI.ORG/10.23910/1.2026.7028.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, author have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The author has declared that no conflict of interest exists.

RECEIVED on 02nd March 2026 RECEIVED in revised form on 16th May 2026 ACCEPTED in final form on 30th May 2026 PUBLISHED on 04th June 2026

1. INTRODUCTION

Swine belonged to the genus Sus and family Suidae that are raised for food around the world. These animals have even-toed hooves. Pigs belonged to the suborder Bunodontia with 44 teeth. India had a large pig population, the production of swine is not fully developed (Chauhan et al., 2016). Pigs have great potential to provide quick economic benefits to farmers because of their efficient feeding, early maturity, and short generation time (Banerjee, 1998). Pig farming requires less investment in buildings and equipment and can offer nutritional and economic stability to the poorer communities. Pigs are also of interest in biomedical research because they are similar to humans in their body structure, function, and disease processes. They are widely used in various scientific fields, such as immunology, organ transplantation, heart disease, and wound healing (Wang et al., 2023). The liver (hepar) is a vital organ in mammals and vertebrates, playing many important roles for survival. It is the largest internal gland in the body, accounting for 1-2% of total adult body weight. Often called the "Jack-of-all-trades", the liver is strategically placed in the circulatory system and is essential for the digestive process (Culling, 1974). The liver has a dual blood supply, has many different cell types, helps regulate blood volume, and is a major organ for breaking down chemicals and defending the body against harmful substances (Burt and Day, 2002). The liver is both structurally and functionally complex, second only to the brain in complexity (Malarkey et al., 2005). It has many important roles, such as efficient uptake of amino acids, carbohydrates, bile acids, cholesterol, proteins, lipids, and vitamins (Burt and Day, 2002). It also helps in removing waste, producing clotting factors, fibrinogen, albumin, and other proteins, fighting infections, breaking down toxins, processing drugs, and supporting the body's ability to produce blood cells (Eurell and Frappier, 2006). Understanding the liver's anatomy is crucial for interpreting these processes.

A healthy liver allows pigs to digest food better, use nutrients efficiently, and remove toxins more effectively. This leads to improved feed conversion, faster growth, and reduced illness. A healthy liver also increases resistance to diseases like fatty liver and hepatitis. Understanding the liver's structure at both the gross and microscopic levels is essential. The study of the anatomy of pig liver serves as an excellent framework for the instruction and training of surgery teams for hepatectomy and partial hepatic transplantation (Swindle et al., 2012). Regarding micrometry of the liver, literature is available on the pig (Sasan et al., 2017; Sivakumar et al., 2023; Singh et al., 2025). Literature is also available on the micrometry of the liver of non-descript goats of the Jammu region in different age groups (Sethi et al., 2021). However, lobe-related micrometrical data on the liver of pigs of the Jammu region remained undocumented. The existing studies on porcine liver micrometry have been conducted in different geographical regions, under different climatic and management conditions, which limits their applicability to pigs reared in Jammu. In light of the above fact, the current study was undertaken to gather micrometric data the will be helpful to scientists engaged in basic, clinical, and paraclinical sciences, as well as meeting the needs of researchers working in the field of pig liver. Moreover, the research will provide baseline reference values for future research in veterinary anatomy, pathology, and biomedical sciences.

2. MATERIALS AND METHODS

The present study was conducted from January, 2025 to August, 2025 at the Division of Veterinary Anatomy, F.V.Sc. and A.H., SKUAST-Jammu, R.S Pura (181102), India, with the objective to generate detailed quantitative histomorphometric data on the hepatic microarchitecture of the pig liver and to evaluate regional and lobar variations.

2.1. Collection of samples

Liver samples of apparently healthy adult (1–1.5 years) pigs (irrespective of sex) were collected from slaughterhouses in and around Jammu City of the union territory of Jammu and Kashmir. Age was estimated by examining the dentition. Ten (N=10) samples were collected.

2.2. Micrometrical studies

Immediately after collection, the samples were cleaned with running water and was brought to the laboratory. Tissue samples (2 mm in size) were preserved in 10% Neutral Buffered Formalin (NBF) solution. For each of the principal hepatic lobes (excluding the caudate and quadrate lobes), tissue samples were obtained from three sites, namely the upper, middle, and lower portions. For caudate and quadrate lobes, tissue samples were obtained from the middle portions. These tissue samples were processed for paraffin block preparation by the alcohol-benzene schedule (Luna, 1968). Tissue sections of 5 µm thickness were obtained from these blocks on clean glass slides with the help of rotary microtome. Hematoxylin and Eosin-stained sections were analyzed using an optical microscope (Magnus microscope, MX21i-TrLED) and were used for micrometry by microscopic image analysis software (MagVision). Following micrometrical observation were recorded for all the lobes:

i. Thickness (µm) of liver capsule

ii. Greater and shorter diameter (µm) of hepatic lobule

iii. Diameter (µm) of central vein

iv. Inter-central vein distance (µm)

v. Size of hepatocyte (μm) in centrilobular and periportal areas

vi. Nuclear diameter (μm) of hepatocyte in centrilobular and periportal areas

vii. Thickness of inter-lobular septum (μm)

viii. Size (μm) of sinusoids in centrilobular and periportal areas

2.3. Statistical analysis

All the data was subjected to the Standard Statistical Analysis (Snedecor and Cochran, 1994).

3. RESULTS AND DISCUSSION

Micrometry of the porcine liver was a crucial tool for understanding liver anatomy, function, and pathology, reinforcing the pig's value as a model in biomedical research. Pigs were anatomically and physiologically similar to humans. Micrometric data enabled accurate comparisons between porcine and human livers, supporting translational studies in hepatology and biomedical research. Quantitative measurement of liver components provided baseline data on normal hepatic structure and organization.

3.1. Capsule thickness

In the current study, the capsular thickness of the principal hepatic lobes (right lateral, right medial, left medial, and left lateral) showed minor regional variations (Table 1). In all four principal lobes, the capsule was consistently thickest in the middle region, suggesting greater structural reinforcement near the central portion of each lobe.

Table 1: Micrometry of the thickness of the capsule (μm) of different regions of the lobes of the pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	22.19^{a}± 1.79	23.20^{a}± 0.79	20.83^{a}± 0.79	22.0^{p}± 0.70
Right medial lobe	21.49^{a}± 1.86	22.18^{a}± 1.56	20.82^{a}± 1.93	21.49^{p}± 0.98
Left medial lobe	21.63^{a}± 2.02	22.03^{a}± 1.53	21.08^{a}± 1.42	21.58^{p}± 0.91
Left lateral lobe	22.66^{ab}± 1.41	24.95^{b}± 0.76	20.87^{a}± 1.26	22.82^{p}± 0.76
Caudate lobe	-	-	-	21.96^{p}± 0.39
Quadrate lobe	-	-	-	22.16^{p}± 1.13

*Means with different superscripts (a, b) in a row differ significantly ($p \leq 0.05$), *Means with different superscripts (p, q) in a column differ significantly ($p \leq 0.05$)

Among the principal lobes, the left lateral lobe exhibited comparatively higher capsular thickness values, particularly in the middle region (24.95±0.76 μm), and was the only lobe to show statistically significant regional variation ($p<0.05$). This finding suggested a lobe-specific adaptation. In contrast, regional differences within the right lateral, right medial, and left medial lobes were minimal and statistically non-significant ($p>0.05$). The accessory lobes showed capsular thickness values comparable to those of the principal lobes. Overall, although the left lateral lobe had the greatest mean capsular thickness (22.82±0.76 μm) among all lobes examined, the differences in average capsular thickness between lobes were statistically non-significant ($p>0.05$), indicating a generally uniform capsular architecture across the liver. When compared with previous reports, the capsular thickness values observed in the present study were markedly lower than those recorded in pigs (58.03±4.87 μm) (Sasan et al., 2017) and pigs from Tamil Nadu (34.30±13.36 μm) (Sivakumar et al., 2023). These discrepancies may be attributed to differences in breed, age, nutritional status and environmental factors. Conversely, a comparatively lower average capsular thickness (18.126±0.48 μm) was recorded in porcine liver (Singh et al., 2025), which was slightly less than the values obtained in the present study, indicating inter-study variability even within the same species.

3.2. Hepatic lobule diameter

Hepatic lobule size can reflect the functional aspect of different liver regions. Larger lobules may indicate greater volume of hepatocytes, which may support higher metabolic activity. In the present study, both greater and smaller diameters of the hepatic lobules were recorded (Table 2, 3). The greater diameter of hepatic lobules exhibited both regional and lobar variations across the liver. In all the principal lobes, the middle region consistently had the largest lobule diameter, suggesting enhanced functional or metabolic activity in this central portion. Among the principal lobes, only the left lateral lobe showed a significant ($p<0.05$) variation between its upper (1221.1±94.73 μm), middle (1833.5±114.78 μm), and lower regions (1676.0±136.36 μm). Among accessory lobes, the quadrate lobe (1248.5±69.27 μm) showed slightly larger hepatic lobules than the caudate lobe (1187.2±45.52 μm). Overall inter-lobar comparison revealed that the left lateral lobe possessed significantly ($p<0.05$) larger hepatic lobules (1576.91±89.22 μm) than most other lobes except for the left medial lobe (1565.82±65.65 μm), where the difference was not statistically significant ($p>0.05$), indicating a close structural similarity between these two lobes.

The shorter diameter of hepatic lobules varied slightly among the different lobes of the liver. Among the principal lobes, only the left lateral lobe showed a significant regional variation ($p<0.05$). In the left lateral lobe, the measurements

Table 2: Micrometry of greater diameter of hepatic lobule (µm) of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	1048.2^{a}± 101.15	1476.5^{a}± 111.56	1317.2^{a}± 126.59	1280.7^{pq}± 75.05
Right medial lobe	1242.2^{a}± 95.36	1539.5^{a}± 182.55	1288.2^{a}± 114.62	1356.62^{pq}± 80.32
Left medial lobe	1499.6^{a}± 84.17	1664.8^{a}± 173.22	1533.0$^{a±}$ 61.46	1565.82^{qr}± 65.65
Left lateral lobe	1221.1^{a}± 94.73	1833.5^{b}± 114.78	1676.0^{b}± 136.36	1576.91^{r}± 89.22
Caudate lobe	-	-	-	1187.2^{p}± 45.524
Quadrate lobe	-	-	-	1248.5^{pq}± 69.27

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q, r) in a column differ significantly (p≤0.05)

Table 3: Micrometry of the shorter diameter of hepatic lobule (µm) of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	821.49^{a}± 114.54	756.04^{a}± 101.57	861.68^{a}± 85.68	813.07^{p}± 55.94
Right medial lobe	827.06^{a}± 66.70	876.51^{a}± 66.21	1005.2^{a}± 121.78	902.92^{p}± 51.49
Left medial lobe	977.89^{a}± 47.65	887.79^{a}± 85.82	894.45^{a}± 143.29	920.04^{p}± 55.26
Left lateral lobe	692.74^{a}± 35.21	1008.5^{b}± 67.08	1057.1^{b}± 49.57	919.44^{p}± 48.35
Caudate lobe	-	-	-	839.27^{p}± 70.08
Quadrate lobe	-	-	-	807.43^{p}± 79.94

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

were 692.74±35.21 µm (upper), 1008.5±67.08 µm (middle), and 1057.1±49.57 µm (lower). Among accessory lobes, the shorter lobular diameters of the caudate lobe slightly exceeding the quadrate lobe. Overall inter-lobar comparison revealed no significant differences in mean smaller lobular diameter among all lobes (p>0.05). Despite this, the consistently larger lobular dimensions observed in the left medial and left lateral lobes suggested a greater hepatocyte packing density and potentially enhanced metabolic capacity, indicating a more prominent functional contribution of these lobes to overall hepatic activity.

Overall, the larger greater and shorter lobular diameters observed in the left medial and left lateral lobes suggested a higher hepatocyte mass per lobule, suggesting that these lobes might have a greater metabolic and functional contribution compared with the right and accessory lobes.

The present findings were broadly consistent with earlier reports on hepatic lobule dimensions. Sasan et al. (2017) reported a mean lobular diameter of 1403.25±64.90 µm in pigs, which is comparable to the overall lobular dimensions recorded in the present investigation. Similarly, Sivakumar et al. (2023) documented a mean lobular diameter of 1193.20±196.65 µm in pigs of Tamil Nadu, which is slightly lower but still within a comparable range. Singh et al. (2025) reported an average hepatic lobule size of 1288.5±40.29 µm in porcine liver, which was slightly lower than the mean values observed in the left medial and left lateral lobes in the present study.

3.3. Diameter of central vein

In the present study, the diameter of the central vein varied across different lobes of the liver (Table 4). Among the principal lobes, the right lateral lobe showed a statistically significant (p<0.05) regional difference, with the central vein having a maximum diameter in the middle region (113.02±9.07 µm) compared with the upper (63.48±8.77

Table 4: Micrometry of the diameter of central vein (µm) of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	63.48^{a}± 8.77	113.02^{b}± 9.07	92.69^{ab}± 12.94	89.73^{pq}± 7.51
Right medial lobe	71.71^{a}± 6.82	96.19^{a}± 9.17	74.55^{a}± 7.50	80.82^{pq}± 5.04
Left medial lobe	61.27^{a}± 9.62	76.02^{a}± 11.09	65.40^{a}± 10.53	67.57^{p}± 5.85
Left lateral lobe	81.06^{ab}± 4.17	90.99^{b}± 2.58	67.22^{a}± 8.24	79.75^{pq}± 3.82
Caudate lobe	-	-	-	97.50^{q}± 8.01
Quadrate lobe	-	-	-	98.85^{q}± 7.56

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

μm) and lower regions (92.69±12.94 μm). Consequently, this lobe exhibited the highest average central vein diameter of 89.73±7.51 μm among the principal lobes. A similar pattern was observed in the left lateral lobe, where significant regional variation (p<0.05) was evident and the middle region again displayed the largest central vein diameter (90.99±2.58 μm). These findings suggest that the middle regions of the lateral lobes may possess enhanced venous drainage capacity, possibly reflecting increased sinusoidal inflow and metabolic activity in these areas. In contrast, the right medial and left medial lobes showed differences that were statistically non-significant (p>0.05). This relative uniformity may indicate a more evenly distributed venous outflow pattern within the medial lobes. Among the accessory lobes, the quadrate (98.85±7.56 μm) and caudate (97.50±8.01 μm) lobes exhibited nearly similar central vein diameters, suggesting comparable venous drainage characteristics in these lobes. Overall inter-lobar comparison revealed that the quadrate lobe possessed a significantly larger central vein, whereas the left medial lobe had the smallest diameter (p<0.05). These findings may indicate heterogeneity in venous drainage capacity across hepatic lobes, suggesting that lobes with larger central veins may accommodate greater blood flow and exhibit enhanced functional capacity.

The central vein diameters observed in the current study were lower than those reported by Sasan et al. (2017), who documented a much wider range (82.5–187.5 μm) with a higher mean value (149.25±12.13 μm) in porcine liver. This discrepancy may be attributable to variations in breed, age or physiological status of the animal. In contrast, the present findings were comparable to those reported in pigs of Tamil Nadu (Sivakumar et al., 2023), where the mean central vein diameter was 79.90±24.51 μm. Similarly, the mean central vein diameter was 81.74±11.58 μm in porcine liver (Singh et al., 2025), which closely aligned with the values observed in the present investigation.

3.4. Inter-central vein distance

The inter-central vein distance reflected the size of hepatic lobules and the organization of the microvascular network. In the current study, the inter-central vein distance showed only minor regional variation among each principal lobe (Table 5). However, these variations did not show any significant difference (p>0.05). Among the accessory lobes, the caudate lobe (1035.39±11.74 μm) exhibited a greater inter-central vein distance than the quadrate lobe (852.04±42.29 μm). Overall, although the left medial lobe (1167.81±82.13 μm) showed comparatively larger inter-central vein distances, suggesting broader hepatic lobules and potentially greater hepatocyte mass, the inter-lobar variation remained statistically non-significant (p>0.05).

Table 5: Micrometry of inter-central vein distance (μm) of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	808.30^{a}± 65.80	1022.9^{a}± 174.26	962.53^{a}± 127.65	931.23^{p}± 74.01
Right medial lobe	1126.6^{a}± 38.06	824.47^{a}± 92.46	1122.0^{a}± 122.63	1024.36^{p}± 60.25
Left medial lobe	1237.0^{a}± 147.10	1345.8^{a}± 150.75	920.62^{a}± 70.18	1167.81^{p}± 82.13
Left lateral lobe	848.91^{a}± 74.67	1171.5^{a}± 119.30	1182.6^{a}± 135.14	1067.69^{p}± 71.71
Caudate lobe	-	-	-	1035.39^{p}± 11.74
Quadrate lobe	-	-	-	852.04^{p}± 42.29

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

The available literature on inter-central vein distance in porcine liver was scarce, limiting direct comparisons. Nevertheless, comparative evaluation with studies conducted in other domestic species revealed notable interspecies differences. Liman (1996) reported significantly lower inter-central vein distances in lambs (629.77±34.70 μm) and adults (740.00±14.35 μm) than those observed in the present study. These findings suggested that hepatic lobules in pigs might be larger than those in sheep, possibly reflecting species-specific differences in liver size, metabolic demand, and growth patterns. Similarly, inter-central vein distances in adult Bakerwali and non-descript goats (Sethi, 2020) were consistently lower than the values observed in the present investigation. In Bakerwali goats, the mean inter-central vein distance measured 808.49±83.46 μm in the upper part of the main lobe, 780.71±101.54 μm in the middle part, and 764.02±62.97 μm toward the ventral part. Corresponding values in non-descript goats were 797.06±91.15 μm, 764.02±61.03 μm, and 743.75±56.09 μm, respectively. In the caudate lobe, the distance was 784.84±110.81 μm in Bakerwali goats and 750.69±115.28 μm in non-descript goats (Sethi et al., 2021). Compared to these caprine values, the porcine liver exhibited higher inter-central vein distances across most lobes. This observation might be attributed to species-specific variations in hepatic lobular architecture. Larger inter-central vein distances in pigs indicated wider hepatic lobules, accommodating greater hepatocyte mass and potentially higher metabolic activity.

3.5. Size of hepatocyte

Hepatocyte size reflected the metabolic activity and functional load of the liver tissue. In the present study, hepatocyte size was measured in both the centrilobular and periportal regions of each hepatic lobe (Table 6, 7). Centrilobular hepatocyte size showed regional and lobar variations across the liver. In all the principal lobes, hepatocytes were largest in the middle region but only the right lateral and left lateral lobes showed a significant difference (p<0.05). The right medial and left medial lobes showed almost uniform hepatocyte dimensions across all regions. Among the accessory lobes, hepatocyte size was comparable, measuring 12.20±0.24 µm in the caudate lobe and 12.39±0.18 µm in the quadrate lobe. Overall, despite the left lateral lobe (13.18±0.31 µm) exhibiting comparatively larger hepatocytes, inter-lobar differences in hepatocyte size were statistically non-significant (p>0.05), indicating a generally uniform hepatocyte morphology across the liver.

Periportal hepatocyte size exhibited a different pattern. In all the principal lobes, hepatocytes were largest in the middle region but the difference was statistically non-significant (p>0.05). Among the accessory lobes, periportal hepatocyte size was comparable, measuring 14.58±0.51 µm in the caudate lobe and 14.73±0.44 µm in the quadrate lobe. In contrast to the non-significant regional variation, inter-lobar comparison revealed a statistically significant difference in mean hepatocyte size (p<0.05), with the right medial lobe (15.16±0.25 µm) having the largest hepatocytes and the right lateral lobe (13.50±0.35 µm) the smallest.

Table 6: Micrometry of the size of hepatocytes (µm) around the centrilobular area of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	12.96^{ab}± 0.53	14.13^{b}± 0.64	11.90^{a}± 0.28	12.99^{p}± 0.35
Right medial lobe	12.57^{a}± 0.43	12.69^{a}± 0.38	12.61^{a}± 0.39	12.63^{p}± 0.22
Left medial lobe	12.41^{a}± 0.33	12.50^{a}± 0.31	12.31^{a}± 0.13	12.41^{p}± 0.15
Left lateral lobe	12.48^{a}± 0.15	14.08^{b}± 0.66	12.99^{ab}± 0.53	13.18^{p}± 0.31
Caudate lobe	-	-	-	12.20^{p}± 0.24
Quadrate lobe	-	-	-	12.39^{p}± 0.18

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

Table 7: Micrometry of the size of hepatocytes (µm) towards periportal area of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	13.01^{a}± 0.42	13.95^{a}± 0.89	13.55^{a}± 0.41	13.50^{p}± 0.35
Right medial lobe	15.11^{a}± 0.45	15.28^{a}± 0.51	15.09^{a}± 0.40	15.16^{q}± 0.25
Left medial lobe	13.46^{a}± 0.30	14.49^{a}± 0.48	13.81^{a}± 0.31	13.92^{p}± 0.23
Left lateral lobe	14.07^{a}± 0.88	14.71^{a}± 0.41	13.05^{a}± 0.41	13.95^{p}± 0.22
Caudate lobe	-	-	-	14.58^{pq}± 0.51
Quadrate lobe	-	-	-	14.73^{pq}± 0.44

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

A consistent and noteworthy finding of the present study was the significant difference in hepatocyte size between centrilobular and periportal regions within the hepatic lobule. Periportal hepatocytes were consistently larger than centrilobular hepatocytes across all lobes. This regional difference in cell size was statistically significant (p<0.05) in all the lobes except the right lateral and left lateral lobes, where the difference, although present, did not show statistical significance (p>0.05). The observation of larger hepatocytes in the periportal region aligned with the functional zonation of the liver. Periportal hepatocytes (zone 1) generally received blood that was richer in oxygen and nutrients, whereas centrilobular hepatocytes (zone 3) were exposed to lower oxygen concentrations. Thus, the significantly larger periportal hepatocytes observed in most lobes of the liver reflected the functional specialization of zone 1 cells, highlighting the structural and physiological zonation within the hepatic lobule.

Comparative evaluation with earlier studies further substantiates these findings. Mean hepatocyte diameter was 16.08±0.30 µm in adult sheep (Aziz and Khatra, 1985) whereas in the black Bengal goat, hepatocyte diameter was 16.30±0.40 µm (Khan and Prasad, 1989). These values were higher than those recorded in the present study, suggesting species-specific differences in hepatocyte dimensions, possibly related to variations in metabolic demands and liver architecture. Different researchers recorded the diameter of hepatocytes in different breeds of pigs. Sasan et al. (2017) estimated the mean hepatocyte diameter of

12.86±0.49 µ which closely approximated the centrilobular hepatocyte dimensions observed in the present investigation. Sivakumar et al. (2023) recorded higher hepatocyte diameter (17.43±4.75 µ) indicating substantial variability that may be attributed to differences in breed, age or nutritional status.

In the present study, hepatocyte size was compared between the centrilobular and periportal regions within each hepatic lobule (Table 13). Across all lobes of the liver, hepatocytes in the periportal region were consistently larger than those in the centrilobular region. This regional difference in cell size was statistically significant (p<0.05) in all the lobes except the right lateral and left lateral lobe, where the difference, although present, did not show statistical significance (p>0.05). Singh et al. (2025) recorded the average size of hepatocytes in periportal (15.74±0.30 µm) as well as centrilobular regions (12.36±0.25 µm) and reported that hepatocytes were significantly larger at periportal area. These findings were in close agreement with the present study and strongly corroborate the observed zonal variation in hepatocyte morphology.

3.6. Nuclear diameter of hepatocyte

In the present study, hepatocyte nuclear diameter was measured in both the centrilobular and periportal regions of each hepatic lobe (Table 8, 9). In the centrilobular region, statistically significant regional variation (p<0.05) was observed only in the left lateral lobe, where hepatocyte nuclear diameter was highest in the middle region (6.32±0.25 µm), followed by the lower (5.62±0.23 µm) and least in the upper region (5.29±0.14 µm), yielding an overall average of 5.74±0.16 µm. Among the accessory lobes, mean nuclear diameters were comparable, measuring 5.07±0.20 µm in the caudate lobe and 5.28±0.13 µm in the quadrate lobe. Inter-lobar comparison revealed statistically significant differences (p<0.05), with the right lateral lobe exhibiting the largest mean nuclear diameter (5.80±0.18 µm), followed closely by the left lateral lobe (5.74±0.16 µm), while the right medial lobe (4.96±0.15 µm) showed the smallest nuclei.

Hepatocyte nuclear diameters in the periportal region were generally higher across all hepatic lobes, with some regional variation. Statistically significant regional variation (p<0.05) was evident only in the left medial lobe, where the middle region (7.10±0.30 µm) displayed the largest nuclei, followed by the upper region (7.05±0.29 µm) and the smallest in the lower region (5.92±0.07 µm), resulting in an overall average of 6.69±0.19 µm. Among the accessory lobes, the caudate and quadrate lobes again showed comparable nuclear diameters, measuring 5.89±0.06 µm and 5.96±0.06 µm, respectively. Inter-lobar comparison revealed a statistically significant difference in nuclear diameter (p<0.05), with the left medial lobe exhibiting the largest hepatocyte nuclei and the caudate lobe (5.89±0.06 µm) the smallest.

Table 8: Micrometry of nuclear diameter of hepatocytes (µm) around the centrilobular area of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	5.61^{a}± 0.23	6.36^{a}± 0.28	5.44^{a}± 0.32	5.80^{q}± 0.18
Right medial lobe	4.76^{a}± 0.24	4.95^{a}± 0.26	5.18^{a}± 0.28	4.96^{p}± 0.15
Left medial lobe	5.46^{a}± 0.30	5.51^{a}± 0.28	5.08^{a}± 0.20	5.35^{pq}± 0.15
Left lateral lobe	5.29^{a}± 0.14	6.32^{b}± 0.25	5.62^{a}± 0.23	5.74^{q}± 0.16
Caudate lobe	-	-	-	5.07^{p}± 0.20
Quadrate lobe	-	-	-	5.28^{pq}± 0.13

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

Table 9: Micrometry of nuclear diameter of hepatocytes (µm) towards periportal area of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	6.36^{a}± 0.15	6.54^{a}± 0.39	6.15^{a}± 0.33	6.35^{pq}± 0.17
Right medial lobe	6.06^{a}± 0.23	6.22^{a}± 0.24	6.17^{a}± 0.24	6.15^{p}± 0.13
Left medial lobe	7.05^{b}± 0.29	7.10^{b}± 0.30	5.92^{a}± 0.07	6.69^{q}± 0.19
Left lateral lobe	5.96^{a}± 0.07	6.39^{a}± 0.16	6.17^{a}± 0.33	6.17^{p}± 0.13
Caudate lobe	-	-	-	5.89^{p}± 0.06
Quadrate lobe	-	-	-	5.96^{p}± 0.06

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

Comparison of periportal and centrilobular regions demonstrated that hepatocyte nuclei were consistently larger in the periportal region across all the lobes, and these regional differences were statistically significant (p<0.05) (Table 13). The consistent increase in nuclear diameter

in periportal hepatocytes compared to centrilobular hepatocytes supported the concept of hepatic zonation. The increased nuclear size observed in this study therefore indicated enhanced metabolic and synthetic demand in periportal hepatocytes compared with their centrilobular counterparts.

The findings of the present study were generally in agreement with earlier reports, although variations in nuclear size across species were evident. Mean hepatocyte nuclear diameter was 7.56±0.12 µm in adult sheep (Aziz and Khatra, 1985), whereas nuclear diameter was 6.70±0.17 µm in the black Bengal goat (Khan and Prasad, 1989). These values were higher than those recorded in the present study, suggesting species-specific differences in hepatocyte nuclear diameter, possibly related to variations in metabolic demands and liver architecture. In pigs, Sasan et al. (2017) estimated the mean hepatocyte nuclear diameter of 6.65±0.48 µ which closely approximated the periportal hepatocyte nuclear size reported in the present study. Furthermore, Singh et al. (2017) recorded hepatocyte nuclear diameter of 5.72±0.08 µm in the periportal region and 5.33±0.08 µm in the centrilobular region, noting that although nuclei were larger in the periportal zone, the difference was statistically non-significant. These observations were in close agreement with the present findings, particularly regarding the trend of larger periportal nuclei, although the present study demonstrated statistically significant regional differences.

3.7. Thickness of inter-lobular septum

The thickness of the inter-lobular septum exhibited variation in the present study, underscoring the structural heterogeneity of hepatic connective tissue architecture. Statistically significant regional differences (p<0.05) were observed in the left medial and left lateral lobes, indicating that septal development was not uniform even within the same lobe (Table 10). In the left medial lobe, the middle region (64.95±6.26 µm) had higher values than the upper (44.10±6.68 µm) and lower regions (38.90±3.59 µm), resulting in a mean of 49.32±4.11 µm. A similar pattern was recorded in the left lateral lobe where the middle region (74.27±9.72 µm) showed the greatest thickness followed by the upper (58.39±4.16 µm) and lower regions (44.12±7.87 µm), with an overall mean of 58.93±5.09 µm. Among the accessory lobes, the caudate and quadrate lobes had the thinnest septa, measuring 45.30±0.95 µm and 43.46±4.66 µm, respectively. Overall comparison revealed that the right lateral lobe had the thickest inter-lobular septa (67.54±3.76 µm), followed by the left lateral lobe (58.93±5.09 µm), while the quadrate lobe had the thinnest (43.46±4.66 µm). These differences were statistically significant (p<0.05). Quantitative micrometric data on inter-lobular septum thickness in normal liver were relatively scarce in the literature, particularly across different lobes. However, Sasan et al. (2017) reported a mean inter-lobular septum thickness of 49.50±4.50 µm in pig liver, which closely approximated the mean thickness observed in the left medial lobe in the present study. This similarity suggested a degree of structural conservation in hepatic connective tissue organization among porcine breeds, although variations across lobes, as demonstrated in the present study, were not extensively explored by earlier workers.

Table 10: Micrometry of thickness of inter-lobular septum (µm) of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	62.27^{a}± 5.35	67.87^{a}± 4.92	72.48^{a}± 8.98	67.54^{q}± 3.76
Right medial lobe	57.06^{a}± 4.58	51.62^{a}± 4.40	50.15^{a}± 6.96	52.94^{p}± 3.04
Left medial lobe	44.10^{a}± 6.67	64.95^{b}± 6.26	38.90^{a}± 3.59	49.32^{p}± 4.11
Left lateral lobe	58.39^{ab}± 4.16	74.27^{b}± 9.72	44.12^{a}± 7.87	58.93^{pq}± 5.09
Caudate lobe	-	-	-	45.30^{p}± 0.95
Quadrate lobe	-	-	-	43.46^{p}± 4.66

*Means with different superscripts (a, b) in a row differ significantly (p≤0.05), *Means with different superscripts (p, q) in a column differ significantly (p≤0.05)

3.8. Size of sinusoids

In the present study, the size of sinusoids was measured in both the centrilobular and periportal regions of each hepatic lobe (Table 11, 12). In the centrilobular region, statistically significant (p<0.05) regional variation was observed only in the left medial lobe, where sinusoids were widest in the upper region (11.45±0.84 µm) resulting in a mean of 9.43±0.57 µm. Among the accessory lobes, the caudate and quadrate lobes had comparable sinusoidal diameters of 9.12±0.58 µm and 8.95±0.58 µm, respectively. However, when comparisons were made across hepatic lobes, centrilobular sinusoidal diameters did not differ significantly (p>0.05), indicating a relatively uniform microvascular arrangement among lobes.

In contrast, the periportal region showed significant (p<0.05) intralobar as well as interlobar variation in sinusoidal diameter. All the principal lobes showed significant regional differences (p<0.05). The right lateral lobe showed the widest sinusoids in the lower region (11.69±0.86 µm) with an average value of 9.36±0.57 µm whereas the right medial

Table 11: Micrometry of size of sinusoids (µm) towards centrilobular region of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	$9.29^{a}\pm 0.94$	$8.83^{a}\pm 0.78$	$11.18^{a}\pm 0.51$	$9.76^{p}\pm 0.48$
Right medial lobe	$11.48^{a}\pm 1.20$	$11.25^{a}\pm 0.32$	$9.40^{a}\pm 0.46$	$10.71^{p}\pm 0.47$
Left medial lobe	$11.45^{b}\pm 0.84$	$8.96^{a}\pm 0.90$	$7.87^{a}\pm 0.64$	$9.43^{p}\pm 0.57$
Left lateral lobe	$9.00^{a}\pm 1.06$	$9.23^{a}\pm 0.66$	$8.33^{a}\pm 0.51$	$8.85^{p}\pm 0.43$
Caudate lobe	-	-	-	$9.12^{p}\pm 0.58$
Quadrate lobe	-	-	-	$8.95^{p}\pm 0.58$

*Means with different superscripts (a, b) in a row differ significantly ($p\leq0.05$), *Means with different superscripts (p, q) in a column differ significantly ($p\leq0.05$)

Table 12: Micrometry of size of sinusoids (µm) around periportal region of different regions of lobes of pig liver

Different lobes of the liver	Different regions in a lobe			Average value
	Upper	Middle	Lower	
Right lateral lobe	$8.71^{a}\pm 0.69$	$7.67^{a}\pm 0.63$	$11.69^{ab}\pm 0.86$	$9.36^{pq}\pm 0.57$
Right medial lobe	$13.22^{c}\pm 0.61$	$10.27^{b}\pm 1.27$	$7.12^{a}\pm 0.19$	$10.20^{q}\pm 0.75$
Left medial lobe	$8.80^{b}\pm 0.60$	$7.93^{ab}\pm 0.65$	$6.30^{a}\pm 0.47$	$7.68^{p}\pm 0.40$
Left lateral lobe	$7.93^{b}\pm 0.76$	$8.06^{b}\pm 0.34$	$5.93^{a}\pm 0.51$	$7.31^{p}\pm 0.39$
Caudate lobe	-	-	-	$7.15^{p}\pm 0.62$
Quadrate lobe	-	-	-	$8.36^{pq}\pm 0.54$

*Means with different superscripts (a, b, c) in a row differ significantly ($p\leq0.05$), *Means with different superscripts (p, q) in a column differ significantly ($p\leq0.05$)

lobe displayed the widest sinusoids in the upper region (13.22±0.61 µm), resulting in the highest overall average among lobes (10.20±0.75 µm). The left medial lobe also showed the widest sinusoids in the upper region (8.80±0.60 µm) with a mean of 7.68±0.40 µm. In the left lateral lobe, sinusoid size was largest in the middle region (8.06±0.34 µm), resulting in an overall average of 7.31±0.39 µm. Among accessory lobes, the caudate lobe had a sinusoidal diameter of 7.15±0.62 µm, while the quadrate lobe measured 8.36±0.54 µm. Inter-lobar comparisons indicated that the right medial lobe had significantly ($p<0.05$) the widest sinusoids and the caudate lobe showed the narrowest sinusoids.

Comparison of periportal and centrilobular regions demonstrated that sinusoidal diameters were consistently larger in the centrilobular region across all hepatic lobes (Table 13). The regional differences were statistically significant ($p<0.05$) in the left medial, left lateral, and caudate lobes, underscoring that these lobes might exhibited a more pronounced structural distinction between periportal and centrilobular zones. This may also aligned with the previous findings that the hepatocyte was densely arranged in the periportal region as compared to the centrilobular region.

The present findings partially agreed with the observations by Singh et al. (2025) who recorded the size of sinusoids as 9.26±0.21 µm at the periportal area and 9.87±0.34 µm at

Table 13: Comparative micrometry of size of hepatocytes (µm), nuclear diameter of hepatocytes (µm) and size of sinusoids (µm) of different lobes of pig liver

Different lobes of the liver	Size of hepatocytes		Nuclear diameter of hepatocytes		Size of sinusoids	
	Centri-lobular area	Periportal area	Centri-lobular area	Periportal area	Centri-lobular area	Periportal area
Right lateral lobe	$12.99^{a}\pm0.35$	$13.50^{a}\pm0.35$	$5.80^{p}\pm0.18$	$6.35^{q}\pm0.17$	$9.76^{x}\pm0.48$	$9.36^{x}\pm0.57$
Right medial lobe	$12.63^{a}\pm0.22$	$15.16^{b}\pm0.25$	$4.96^{p}\pm0.15$	$6.15^{q}\pm0.13$	$10.71^{x}\pm0.47$	$10.20^{x}\pm0.75$
Left medial lobe	$12.41^{a}\pm0.15$	$13.92^{b}\pm0.23$	$5.35^{p}\pm0.15$	$6.69^{q}\pm0.19$	$9.43^{x}\pm0.57$	$7.68^{y}\pm0.40$
Left lateral lobe	$13.18^{a}\pm0.31$	$13.95^{a}\pm0.22$	$5.74^{p}\pm0.16$	$6.17^{q}\pm0.13$	$8.85^{x}\pm0.43$	$7.3^{y}\pm0.39$
Caudate lobe	$12.20^{a}\pm0.24$	$14.58^{b}\pm0.51$	$5.07^{p}\pm0.20$	$5.89^{q}\pm0.06$	$9.12^{x}\pm0.58$	$7.15^{y}\pm0.62$
Quadrate lobe	$12.39^{a}\pm0.18$	$14.73^{b}\pm0.44$	$5.28^{p}\pm0.13$	$5.96^{q}\pm0.06$	$8.95^{x}\pm0.58$	$8.36^{x}\pm0.54$

*Means with different superscripts [(a, b), (p, q), (x, y)] in a row differ significantly ($p\leq0.05$)

the centrilobular area, with the difference being statistically non-significant. While our study also recorded larger centrilobular sinusoids, the differences reached statistical significance in specific lobes. These discrepancies may be attributed to differences in species or age.

4. CONCLUSION

Micrometric evaluation revealed that the porcine liver exhibited subtle but meaningful regional variations both within and between hepatic lobes. The results highlighted the importance of considering lobe-specific microanatomical features when the porcine liver is to be used in experimental, surgical, or toxicological research. Overall, this lobe-wise micrometric evaluation provided an important baseline information on normal hepatic structure in pigs and further supported the value of the porcine liver as a reliable comparative model for human liver studies.

5. REFERENCES

Aziz, S.H., Khatra, G.S., 1985. Quantitative histomorphology of the liver lobule and gall bladder of sheep. Indian Journal of Animal Sciences 55, 428–430. Available from: https://arccjournals.com/journal/indian-journal-of-animal-research/B-4555.

Banerjee, G.C., 1998. In "A textbook of Animal Husbandry". 8th Edn. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi: 54–55. Available from: https://www.scribd.com/document/735961362/Textbook-of-Animal-Husbandry-by-G-C-Banerji-LPM-2

Burt, A.D., Day, C.P., 2002. Pathophysiology of the liver. In: MacSween, R.N.M., Burt, A.D., Portmann, B.C., Ishak, K.G., Scheuer, P.J., Anthony, P.P. (Eds), Pathology of the liver. Churchill Livingstone, New York, 67–105. DOI: https://doi.org/10.1038/modpathol.3880523.

Chauhan, A., Patel, B.H.M., Maury, R., Kumar, S., Shukla, S., Kumar, S., 2016. Pig production system as a source of livelihood in Indian scenario: An overview. International Journal of Science, Environment and Technology 5(4), 2089–2096. Available from: https://www.researchgate.net/publication/319207623_.

Culling, C.F.A., 1974. In: Handbook of histopathology and histochemical technique. 3rd edition, Butterworths & Co. Ltd. pp: 302. Available from: https://www.journalsocialscience.com/Journal/references/id/NDcwNQ==/?year=2021&month=June&volume=Volume%2011&issue=Issue%203.

Eurell, J.A., Frappier, B.L., 2006. In: Dellmann's Textbook of Veterinary Histology. Blackwell Publishing, 6th Edn., 201–206. Available from: https://www.usab-tm.ro/utilizatori/medicinaveterinara/file/LS%20FMV%20LVI%284%29%202024.pdf.

Khan, M., Prasad, J., 1989. Histology of the duct system of liver of black Bengal goats. Indian Journal of Animal Sciences 59, 945–948. Available from: https://arccjournals.com/journal/indian-journal-of-animal-research/B-4555.

Liman, N., 1996. Quantitative histomorphology of liver growth in sheep at prenatal and postnatal Stages. Anatomia Histologia Embryologia 25(1), 43–48. DOI: https://doi.org/10.1111/j.1439-0264.1996.tb00058.x.

Luna, L.G., 1968. Manual of histological staining methods of the armed forces institute of pathology. 3rd Edn., McGraw-Hill Book Company, New York. 34–157. Available from: https://pesquisa.bvsalud.org/portal/resource/pt/biblio-1081120.

Malarkey, D.E., Johnson, K., Ryan, L., Boorman, G., Maronpot, R.R., 2005. New insights into functional aspects of liver morphology. Toxicologic Pathology 33(1), 27–34. Available from: https://pubmed.ncbi.nlm.nih.gov/15805053/.

Sasan, J.S., Sharma, A., Sarma, K., Suri, S., Malik, M.R., 2017. A quantitative histological study of the liver of pig (*Sus scrofa*). Indian Veterinary Journal 94(04), 14–16. Available from: https://www.researchgate.net/publication/316137020_.

Sethi, L., Suri, S., Sarma, K., Sasan, J.S., 2021. Micrometry of the liver of non-descript goats of the Jammu region in different age groups. International Journal of Bio-resource and Stress Management 12(5), 485–489. https://doi.org/10.23910/1.2021.2434.

Singh, K., Uppal, V., Bansal, N., Gupta, A., Pathak, D., 2025. Characterizing morphological heterogeneity in porcine hepatocytes. Indian Journal of Animal Sciences 95(2), 136–143. DOI: https://doi.org/10.56093/ijans.v95i2.151817.

Sivakumar, S.A., Kannan, T.A., Basha, S.H., Ramesh, G., 2023. Histological and micrometrical observation on the liver of the indigenous pig of Tamil Nadu. The Pharma Innovation Journal 12(9), 264–267. Available from: https://www.thepharmajournal.com/archives/2023/vol12issue9S/PartD/S-12-8-227-110.pdf.

Snedecor, C.W., Cochran, W.G., 1994. Statistical methods. 9th Edn., Iowa State University Press, Ames, Lowa.

Wang, L., Piao, Y., Guo, F., Wei, J., Chen, Y., Dai, X., Zhang, X., 2023. Current progress of pig models for liver cancer research. Biomed Pharmacotherapy 165, 115256. DOI: https://doi.org/10.1016/j.biopha.2023.115256.