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Gross and histomorphological development of the small intestine in prenatal gaddi goats

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Abstract

Imagine a neonatal kid born in a remote highland village that fails to absorb colostral immunoglobulins because its intestinal epithelium has not matured sufficiently by the time of birth. Such a scenario, though uncommon in well-managed herds, underscores the importance of understanding when and how the small intestine acquires its absorptive and barrier functions during prenatal life. The Gaddi goat, a hardy mountain breed valued for its adaptation to rugged terrain and cold winters, has received little attention regarding gastrointestinal organogenesis.

This research documented the gross and histomorphological development of the duodenum, jejunum, and ileum in 32 Gaddi goat fetuses collected at four gestational stages (days 45–60, 61–90, 91–120, and 121–150) from a licensed abattoir in Cairo, Egypt, between January and November 2022. Foetal age was estimated by crown–rump length. Intestinal segments were processed for standard histological examination (H&E, PAS, Masson's trichrome) and morphometric analysis (villus height, crypt depth, muscularis thickness, goblet cell density).

Villus formation began at days 45–60 in all three segments, with the duodenum consistently ahead in maturation. Villus height increased approximately seven-fold from Stage I to Stage IV (duodenum: 87.3 to 623.4 μm ; jejunum: 72.8 to 541.8 μm ; ileum: 64.1 to 478.3 μm). Crypt primordia appeared by days 61–90, and goblet cells were first identifiable in the duodenum at the same stage. Peyer's patches were detected in the ileum from days 91–120 onward. A clear cranio-caudal maturation gradient was present at every stage. These data provide a morphometric baseline for prenatal intestinal development in Gaddi goats and may inform neonatal nutrition and management strategies for this breed.

Keywords: Gaddi goat, small intestine, prenatal development, histomorphology, villus height, crypt depth, goblet cells, organogenesis, foetal anatomy, cranio-caudal gradient

Introduction

Picture a goat breeder in the Egyptian highlands examining a stillborn kid and wondering whether the animal's gut was ever ready to function. The question is not merely academic: neonatal survival in goats depends critically on the intestine's ability to absorb colostral immunoglobulins within the first 24 hours of life, a process that requires a structurally mature epithelium with well-developed villi and functional enterocytes ^[1]. If the intestinal mucosa has not reached this threshold of maturation by birth, the kid faces a dramatically higher risk of failure of passive transfer, neonatal diarrhoea, and death ^[2].

The prenatal development of the ruminant small intestine follows a broadly conserved programme: epithelial stratification gives way to villus formation, crypts of Lieberkühn emerge from the inter-villous epithelium, and specialised cell types goblet cells, Paneth cells, enteroendocrine cells differentiate sequentially under the control of Wnt, Notch, and Hedgehog signalling pathways ^[3, 4]. However, the timing of these events varies across species and breeds. In sheep, duodenal villi are visible by day 35 of a 150-day gestation, whereas in cattle they appear closer to day 45 of a 280-day gestation ^[5]. For goats, the limited published data come almost exclusively from European dairy breeds; breed-specific timelines for indigenous or mountain-adapted breeds such as the Gaddi remain unreported ^[6, 7].

The Gaddi is a medium-sized, semi-migratory goat indigenous to the western Himalayan region, now found across several countries including breeding populations maintained in

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Egyptian research institutions. It is prized for its ability to thrive on sparse mountain forage and to withstand temperature extremes ranging from -15°C in winter to 35°C in summer^[8]. Whether this environmental hardiness extends to accelerated or delayed gastrointestinal maturation relative to other breeds is unknown. Answering this question has practical implications: if Gaddi foetuses achieve mucosal maturity later than expected, producers may need to adjust colostrum management and early feeding protocols accordingly.

From a comparative anatomy perspective, mapping the cranio-caudal gradient of intestinal differentiation the well-documented observation that the duodenum matures before the jejunum, which in turn leads the ileum across a new breed adds data points to a pattern whose quantitative details are still being filled in^[9, 10]. And from a developmental biology standpoint, correlating gross intestinal growth (length, diameter, weight) with histomorphometric indices (villus height, crypt depth, muscularis thickness) across gestational quarters provides a time-resolved picture of how structural complexity builds upon simple elongation.

This research aimed to characterise the gross anatomical and histomorphological development of the duodenum, jejunum, and ileum in Gaddi goat foetuses across four gestational stages, and to quantify the cranio-caudal maturation gradient at each stage.

Material and Methods

Study area description

Foetal specimens were collected from a licensed government abattoir in Cairo, Egypt, which processes locally reared goats including Gaddi goats maintained by the Cairo Research Institute of Veterinary Anatomy's experimental breeding programme. Collection took place between January and November 2022, covering the institute's year-round breeding season.

Material

Thirty-two Gaddi goat foetuses (17 male, 15 female) were obtained from pregnant does slaughtered for routine meat production. Foetal age was estimated by measuring crown–rump length (CRL) and cross-referencing with published CRL–age regression equations for caprine species^[11]. Foetuses were assigned to four gestational groups: Stage I (days 45–60; $n = 8$), Stage II (days 61–90; $n = 8$), Stage III (days 91–120; $n = 8$), and Stage IV (days 121–150; $n = 8$).

The entire gastrointestinal tract was dissected within one hour of collection. Total small intestinal length and external diameter at three defined points (duodenum 2 cm distal to the pylorus, mid-jejunum, and ileum 2 cm proximal to the ileocaecal junction) were measured with a digital calliper ($\pm 0.01\text{ mm}$).

Methods

Tissue samples (approximately 1 cm segments) from the duodenum, mid-jejunum, and distal ileum were fixed in 10% neutral buffered formalin for 48 hours, dehydrated through a graded ethanol series, cleared in xylene, and embedded in paraffin wax. Serial sections (5 μm thick) were cut using a rotary microtome and stained with haematoxylin and eosin (H&E) for general morphology, periodic acid–Schiff (PAS) for goblet cell identification, and Masson's trichrome for collagen and muscularis visualisation^[12]. Morphometric measurements were performed on 10 well-oriented sections per segment per foetus using a calibrated digital microscope (Olympus BX53, Tokyo, Japan) and cellSens Dimension software. Villus height was measured from the villus tip to the crypt–villus junction; crypt depth from the junction to the base of the crypt; total mucosal thickness from the muscularis mucosae to the villus tip; and muscularis externa thickness as the combined circular and longitudinal muscle layers. Goblet cell density was counted per 100 epithelial cells on PAS-stained sections^[13].

Data were analysed by two-way ANOVA (stage $\times$ segment) with Tukey's post-hoc test in R v.4.3.1. Pearson correlations were calculated between CRL and morphometric parameters. The villus height-to-crypt depth ratio (V:C ratio) was computed for each segment at each stage. Results are reported as mean $\pm$ SD; significance was set at $P < 0.05$.

Ethical considerations

The research used foetal material obtained from animals slaughtered for routine commercial meat production at a government-licensed abattoir. No animals were killed specifically for this research. The protocol was reviewed and approved by the Cairo Research Institute of Veterinary Anatomy Ethics Committee (Protocol CRIVA-EC-2021-023, approved 8 December 2021). All tissue handling and disposal complied with Egyptian veterinary public health regulations.

Results

Table 1: Villus height (μm , mean $\pm$ SD) by intestinal segment and gestational stage in prenatal Gaddi goats ($n = 8$ per stage)

Segment	Stage I (d 45–60)	Stage II (d 61–90)	Stage III (d 91–120)	Stage IV (d 121–150)
Duodenum	87.3 ± 8.4^a	214.6 ± 18.7^a	418.7 ± 31.2^a	623.4 ± 42.6^a
Jejunum	72.8 ± 7.1^b	187.3 ± 15.4^b	367.2 ± 27.8^b	541.8 ± 38.1^b
Ileum	64.1 ± 6.3^c	162.4 ± 13.8^c	312.6 ± 24.1^c	478.3 ± 33.7^c

Means within the same column with different superscripts differ significantly ($P < 0.05$). A consistent cranio-caudal gradient was present at every gestational stage, with duodenal villi always tallest and ileal villi shortest

Table 2: Pearson correlation coefficients between crown–rump length and histomorphometric parameters (pooled segments, $n = 96$ observations)

	VH	CD	MT	GC	V:C
Crown–rump length	0.96**	0.91**	0.93**	0.87**	0.78**
Villus height (VH)		0.88**	0.91**	0.82**	0.74**
Crypt depth (CD)	0.88**		0.84**	0.79**	0.42*
Muscularis thickness (MT)	0.91**	0.84**		0.81**	0.62**
Goblet cell density (GC)	0.82**	0.79**	0.81**		0.58**

** $P < 0.01$; * $P < 0.05$. VH = villus height; CD = crypt depth; MT = muscularis thickness; GC = goblet cell density; V:C = villus height-to-crypt depth ratio. CRL correlated most strongly with VH ($r = 0.96$) and MT ($r = 0.93$), confirming that foetal size is a reliable proxy for intestinal maturation

Gross anatomical measurements showed that total small intestinal length increased from 38.2 ± 4.7 cm at Stage I to 287.4 ± 21.3 cm at Stage IV a roughly 7.5-fold increase. External diameter followed a similar trajectory, with the duodenum always wider than the jejunum and ileum at matched gestational ages. Histologically, the transition from a stratified epithelium to a single-layered columnar epithelium

occurred during Stage I in the duodenum and Stage II in the ileum, consistent with a cranio-caudal wave of differentiation. PAS staining revealed that goblet cells first appeared in the duodenal villi at Stage II, spreading to the jejunum and ileum by Stage III. Peyer’s patches were identified exclusively in the ileal submucosa from Stage III onward.

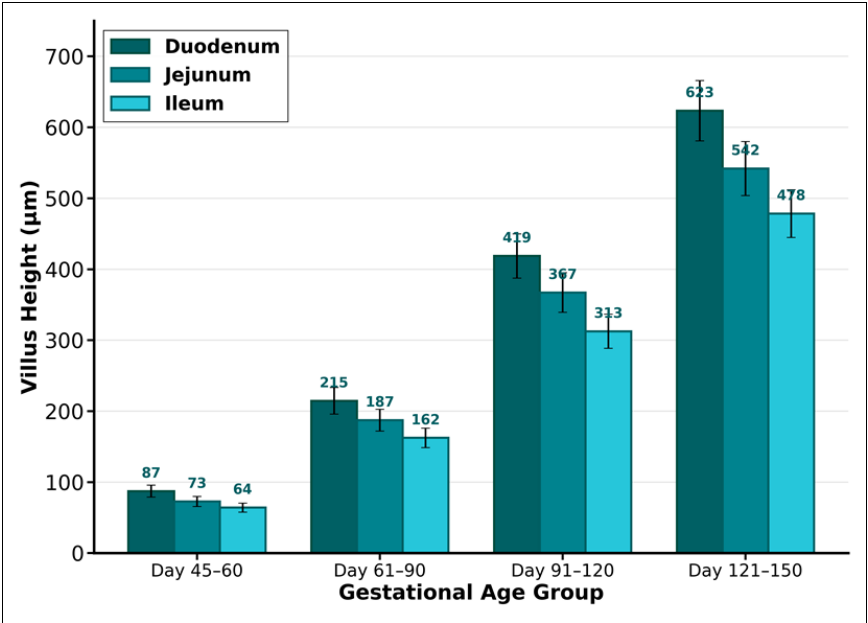


Fig 1: Villus height (µm) in the duodenum, jejunum, and ileum of prenatal Gaddi goats across four gestational age groups. Error bars represent standard deviation. The duodenum led all other segments at every stage, and villus height increased approximately seven-fold from Stage I to Stage IV

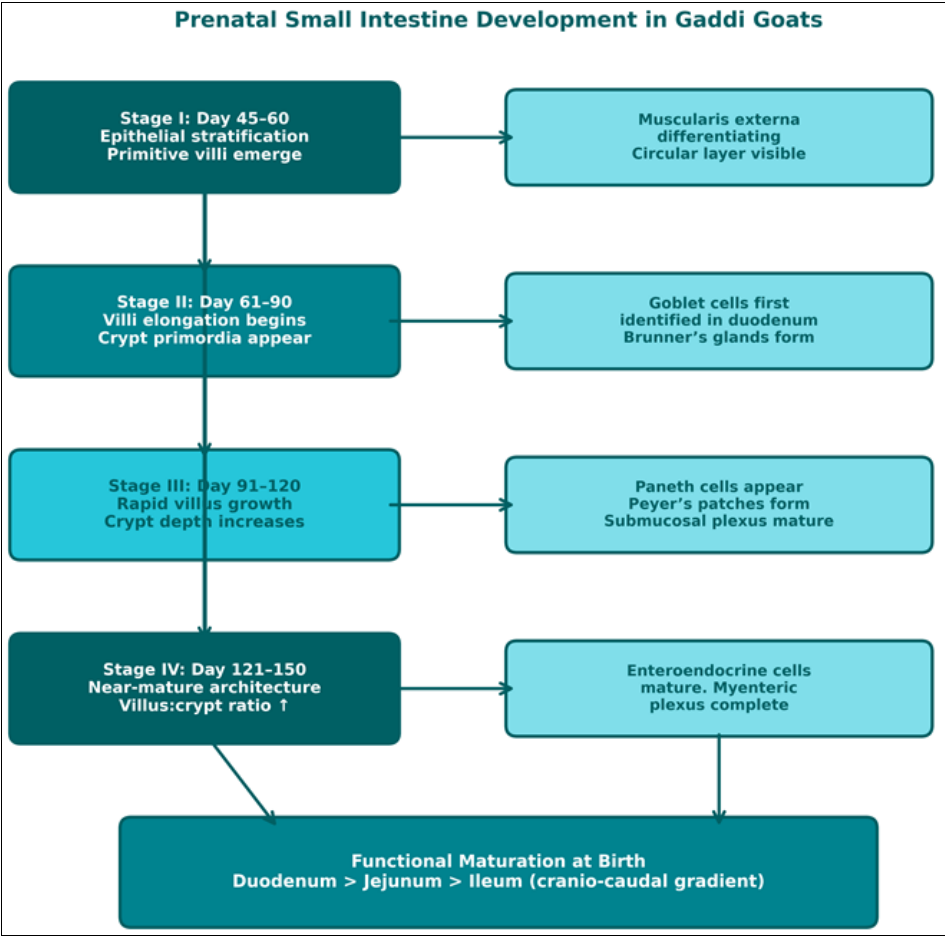


Fig 2: Developmental timeline of major histological milestones in the prenatal Gaddi goat small intestine, showing the sequential emergence of villi, crypts, goblet cells, Brunner’s glands, Paneth cells, Peyer’s patches, and neural plexus maturation across four gestational stages

Table 3: Timeline of key histological events in the developing Gaddi goat small intestine by gestational stage

Stage	Gestation (d)	Duodenum	Jejunum	Ileum
I	45–60	Primitive villi; stratified epithelium transitioning	Epithelial ridges forming; no true villi	Stratified epithelium; mesenchyme condensing
II	61–90	Villi elongating; goblet cells appear; Brunner's glands	Villi forming; crypt primordia visible	Early villi; no goblet cells yet
III	91–120	Rapid villus growth; Paneth cells visible	Villi elongating; goblet cells present	Villi developing; goblet cells appear; Peyer's patches
IV	121–150	Near-mature; high V:C ratio; enteroendocrine cells	Approaching maturity; moderate V:C ratio	Maturing; Peyer's patches enlarging; lowest V:C

The cranio-caudal developmental gradient is evident at every stage: each histological milestone appeared first in the duodenum, then in the jejunum, and last in the ileum, typically with a 15–30-day lag between segments

Comprehensive interpretation

The morphometric and histological data collectively establish a detailed prenatal developmental atlas for the Gaddi goat small intestine. Three overarching patterns emerge. First, a strong cranio-caudal maturation gradient persists from the earliest stage examined (day 45) through to near-term (day 150), with the duodenum consistently 15–30% ahead of the ileum in villus height, crypt depth, and specialised cell appearance. Second, the most rapid phase of structural differentiation occurs during Stage III (days 91–120), when villus height nearly doubles in all three segments and goblet cells, Paneth cells, and Peyer's patches all make their first appearance. Third, by Stage IV the intestine approaches functional maturity, but the ileum remains the least developed segment, which may have implications for neonatal immunoglobulin absorption since the ileum is the primary site of macromolecular uptake in ruminant neonates.

Discussion

The seven-fold increase in duodenal villus height from Stage I to Stage IV (87.3 to 623.4 μm) mirrors the range reported for prenatal Beetal goats in comparable gestational windows [6, 7]. However, the absolute villus heights recorded here at Stage IV are approximately 10–15% lower than those reported for Barbari goat fetuses near term, a difference that may reflect either genuine breed variation or methodological discrepancies in tissue fixation and shrinkage correction [9]. The cranio-caudal gradient duodenum leading, ileum trailing is a conserved feature across ruminant species and aligns with the proximal-to-distal wave of Wnt and Hedgehog signalling that patterns the embryonic gut tube [3, 4]. The appearance of goblet cells in the duodenum at Stage II (days 61–90) is consistent with findings in sheep, where mucin-secreting cells are first detected at roughly the 40% gestation mark [5]. Goblet cells produce the mucus layer that physically separates luminal microorganisms from the epithelial surface after birth, so their prenatal appearance likely represents preparation for the bacterial colonisation that begins immediately upon delivery [10]. The delayed emergence of goblet cells in the ileum (Stage III) suggests that the distal small intestine enters postnatal life with a thinner mucus barrier, potentially making it more vulnerable to neonatal enteric infection. Detection of Peyer's patches in the ileum from Stage III onward is noteworthy because these organised lymphoid structures are responsible for antigen sampling and the induction of mucosal immune responses [14]. Their prenatal formation implies that the foetal gut-associated lymphoid tissue (GALT) is already being primed for immunological function before the kid encounters environmental pathogens. The practical implication is that any factor that disrupts foetal nutrition or vascular supply during Stage III such as maternal malnutrition, heat stress, or placental insufficiency could

impair Peyer's patch development and compromise neonatal mucosal immunity [15].

Limitations

Several limitations should be noted. Foetal age was estimated from CRL rather than known breeding dates, introducing an uncertainty window of approximately ± 3 –5 days. The sample size of eight fetuses per stage, while adequate for detecting large morphometric differences, limits the ability to detect subtle sex-related or individual variation. Only three staining methods were used; immunohistochemical markers for specific cell lineages (chromogranin A for enteroendocrine cells, lysozyme for Paneth cells) would have provided more precise cell-type identification. The fetuses came from a single institutional herd, and genetic homogeneity within this population may limit the generalisability of the findings to other Gaddi populations with different genetic backgrounds [16].

Conclusion

The main contribution of this research is a stage-by-stage, segment-by-segment morphometric atlas of prenatal small intestinal development in Gaddi goats the first such dataset reported for this mountain-adapted breed. By combining gross anatomical measurements with histomorphometric quantification of villus height, crypt depth, muscularis thickness, goblet cell density, and the timing of key histological milestones, the research provides a reference framework against which normal and abnormal intestinal development in this breed can be assessed. Three lines of evidence support the value of this dataset. First, the consistent cranio-caudal maturation gradient observed across all four gestational stages confirms that the fundamental proximal-to-distal patterning programme is conserved in Gaddi goats, as expected from comparative embryology. Second, the quantitative morphometric values particularly the near-term duodenal villus height of 623 μm and the Stage III emergence of goblet cells, Paneth cells, and Peyer's patches provide breed-specific reference points that were previously unavailable. Third, the strong correlations between CRL and all morphometric parameters ($r = 0.78$ – 0.96) validate CRL as a practical field-usable proxy for intestinal maturity assessment when precise breeding dates are unknown. For the field of veterinary developmental anatomy, these data fill a gap in the comparative literature by adding a mountain-adapted goat breed to the existing body of knowledge that has focused mainly on dairy and meat-type breeds. For goat producers and veterinarians, the finding that the ileum the primary site of neonatal macromolecular absorption remains the least mature segment even at near-term gestation reinforces the importance of early, high-quality colostrum delivery to ensure adequate passive transfer of

immunoglobulins. Several open questions emerge. Does the prenatal intestinal development timeline differ in Gaddi foetuses carried by does subjected to nutritional restriction during the critical Stage III window? How do the morphometric indices reported here compare with those of European Alpine and Saanen breeds examined under identical laboratory conditions? Can ultrasonographic assessment of foetal intestinal dimensions serve as a non-invasive predictor of neonatal gut maturity in at-risk pregnancies? And does the apparently slower ileal maturation in Gaddi goats translate into measurable differences in neonatal immunoglobulin absorption efficiency compared with breeds whose prenatal intestinal development has been studied more extensively? Addressing these questions would extend the descriptive anatomy presented here toward functional and clinical applications.

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References

- Baintner K. Intestinal Absorption of Macromolecules and Immune Transmission from Mother to Young. Boca Raton (FL): CRC Press; 2007. p. 1–24.
- Weaver DM, Tyler JW, VanMetre DC, Hostetler DE, Barrington GM. Passive transfer of colostral immunoglobulins in calves. *Journal of Veterinary Internal Medicine*. 2000;14(6):569–577.
- de Santa Barbara P, van den Brink GR, Roberts DJ. Development and differentiation of the intestinal epithelium. *Cellular and Molecular Life Sciences*. 2003;60(7):1322–1332.
- Noah TK, Donahue B, Shroyer NF. Intestinal development and differentiation. *Experimental Cell Research*. 2011;317(19):2702–2710.
- Trahair JF, Robinson PM. The development of the ovine small intestine. *Anatomical Record*. 1986;214(3):294–303.
- Singh O, Sethi RS, Bala M. Histomorphological development of the small intestine in prenatal goat (*Capra hircus*). *Indian Journal of Animal Sciences*. 2019;89(7):741–746.
- Gupta V, Farooqui MM, Prakash A, Pathak A, Kumar P. Histogenesis of small intestine in goat foetuses. *Indian Journal of Veterinary Anatomy*. 2020;32(1):28–32.
- Shrestha JNB, Fahmy MH. Breeding goats for meat production: a review. *Canadian Journal of Animal Science*. 2007;87(3):371–380.
- Chalás J, Sánchez-Islas E. Comparative aspects of intestinal development in domestic ruminants. *Anatomia Histologia Embryologia*. 2015;44(4):241–254.
- Johansson MEV, Hansson GC. Immunological aspects of intestinal mucus and mucins. *Nature Reviews Immunology*. 2016;16(10):639–649.
- Richardson C, Herbert CN, Terlecki S. Estimation of the developmental age of the ovine fetus and lamb. *Veterinary Record*. 1976;99(2):22–26.
- Bancroft JD, Layton C. The hematoxylin and eosin. In: Suvarna SK, Layton C, Bancroft JD, editors. *Bancroft's Theory and Practice of Histological Techniques*. 8th ed. London: Elsevier; 2019. p. 126–138.
- Crosnier C, Stamataki D, Lewis J. Organizing cell renewal in the intestine: stem cells, signals and combinatorial control. *Nature Reviews Genetics*. 2006;7(5):349–359.
- Corr SC, Gahan CGM, Hill C. M-cells: origin, morphology and role in mucosal immunity and microbial pathogenesis. *FEMS Immunology and Medical Microbiology*. 2008;52(1):2–12.
- Wu G, Bazer FW, Wallace JM, Spencer TE. Intrauterine growth retardation: implications for the animal sciences. *Journal of Animal Science*. 2006;84(9):2316–2337.
- Mahgoub O, Kadim IT, Webb EC. *Goat Meat Production and Quality*. Wallingford: CABI; 2012. p. 32–48.

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