Original Article

Uterine Tube Changes in Cattle: A Morphometric Study Across Estrous Phases and in the Presence of Follicular Cysts

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ABSTRACT

Background: The bovine uterine tube (oviduct) is essential for gamete transport, fertilization, and early embryonic development. Its epithelium undergoes dynamic morphological and functional changes across the estrous cycle under the influence of ovarian steroid hormones. However, the extent to which pathological conditions, such as cystic ovarian disease (COD) affect oviductal morphology remains poorly understood.

Objectives: This study aimed to evaluate and compare morphometric and histochemical characteristics of the bovine oviduct (infundibulum and ampulla) during normal reproductive cycles and in the presence of follicular cysts.

Methods: Oviductal samples were collected from slaughtered cows and classified by ovarian status. Morphometric parameters, including the number, length, and thickness of mucosal folds and epithelial height, were measured histologically. Histochemical assessment of secretory activity was performed using periodic acid-Schiff (PAS) staining.

Results: In the follicular phase, the infundibulum and ampulla displayed the highest morphometric values, with numerous tall mucosal folds and predominantly ciliated epithelia. During the luteal phase, fold dimensions were reduced, but secretory cells exhibited strong PAS reactivity, indicating enhanced glycoprotein secretion. In contrast, specimens from cows with follicular cysts showed significant regression in mucosal folds and epithelial height across both regions. Secretory cells in these cases demonstrated irregular or diminished PAS staining, suggesting impaired or dysregulated function.

Conclusion: These findings provide the histomorphometric and histochemical characterization of bovine oviductal changes under cystic conditions. The observed structural regression and altered secretory activity in cows with follicular cysts may contribute to impaired fertilization and subfertility, highlighting the broader reproductive consequences of COD.

Keywords: Ampulla, Bovine oviduct, Cystic ovarian disease (COD), Histomorphometry, Infundibulum

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Introduction

The uterine tube (oviduct) plays a crucial role in the reproductive physiology of mammals by providing a suitable environment for gamete transport, fertilization, and early embryonic development (Mahé et al., 2022; Killian, 2004). In cattle, the oviduct is divided into three anatomical segments: the infundibulum, ampulla, and isthmus. Each region is morphologically specialized to perform distinct functions, such as oocyte capture, sperm storage, and support of zygote development (Ardon et al., 2016; Abe, 1996). The oviductal epithelium comprises ciliated cells, non-ciliated secretory cells, and, less frequently, peg and basal cells (Abe, 1996; Mokhtar, 2015). These epithelial cells undergo dynamic structural and functional changes during the estrous cycle, influenced by fluctuations in ovarian steroid hormones. Estrogen, which dominates the follicular phase, promotes ciliogenesis and epithelial hypertrophy, while progesterone, elevated in the luteal phase, enhances secretory activity (Pascua et al., 2024; Verhage & Brenner, 1975). These changes are essential for optimizing conditions for fertilization and early embryo development. Similar cycle-dependent effects of hormones on other physiological systems have also been demonstrated in rodent models, where neuromodulators, such as phoenixin and anti-inflammatory agents show differential activity across estrous stages (Azadi et al., 2023; Fazlelahi et al., 2023).

Histological studies have demonstrated that during the follicular phase of the bovine estrous cycle, the oviductal epithelium, especially in the infundibulum, is dominated by tall, densely packed ciliated cells, which facilitate the rapid transport of the oocyte toward the ampulla (Mokhtar, 2015; Ardon et al., 2016). These cells exhibit active ciliation under the influence of elevated estrogen levels, which are known to stimulate ciliogenesis and epithelial hypertrophy (Pascua et al., 2024; Verhage & Brenner, 1975). The mucosal architecture in this phase is highly folded, with numerous primary and secondary folds contributing to the increased surface area for interaction with gametes (Abe, 1996). Conversely, during the luteal phase, the number of ciliated cells declines while secretory cells become more prominent, particularly within the crypts of the ampulla, coinciding with a rise in circulating progesterone (Mokhtar, 2015; Killian, 2004). These secretory cells display characteristic apical protrusions and an abundance of cytoplasmic granules, indicating active production and release of oviductal glycoproteins. Histochemical analysis using periodic acid-Schiff (PAS) staining reveals a stronger positive reaction during the luteal phase, reflecting increased secretion of neutral mucopolysaccharides that support sperm viability, early embryo development, and modulation of the luminal environment (Lopera-Vásquez et al., 2022; Mahé et al., 2022).

Recent morphometric data have demonstrated significant increases in the number and length of mucosal folds in the ampulla during the follicular phase, while the overall thickness of the folds remains relatively constant across the estrous cycle (Mokhtar, 2015). Notably, epithelial height also increases significantly during the follicular phase, reflecting estrogen-induced hypertrophy of ciliated cells (Mokhtar, 2015). These structural changes are closely linked to the functional requirements of the oviduct, such as gamete transport and fertilization (Lopera-Vásquez et al., 2022; Killian, 2004). Moreover, the cytological composition of the infundibular epithelium changes with the cycle. During the follicular phase, there is a predominance of dark and light ciliated cells with well-defined cilia and an absence of secretory activity (Abe, 1996; Lopera-Vásquez et al., 2022; Mahé et al., 2022). In contrast, the luteal phase shows increased numbers of secretory cells with prominent apical protrusions and reduced ciliation (Abe, 1996), highlighting the functional shift from oocyte capture to embryo support and secretion-driven modulation of the oviductal environment.

Despite these well-documented cyclic changes, there is limited information regarding how pathological conditions, such as follicular cysts, alter oviductal morphology and function. Cystic ovarian disease (COD) is a common endocrine disorder in dairy cattle, characterized by the persistence of anovulatory follicular structures ≥17 mm in diameter for more than six days in the absence of a functional corpus luteum (CL), thereby interrupting normal cyclicity (Borş & Borş, 2020; Stassi et al., 2022). The pathogenesis of COD involves both dysfunctions of the hypothalamic-pituitary-gonadal axis and local intraovarian factors (Noakes et al., 2001; Ortega et al., 2016). Clinically, COD is associated with significant reproductive failure, reduced milk yield, increased treatment costs, and prolonged calving intervals, all contributing to substantial economic losses in the cattle industry (Cattaneo et al., 2014; Borş et al., 2018). Traditionally, cysts are categorized as follicular, which are estrogenic and thin-walled, or luteal, which are associated with elevated progesterone and a thicker cyst wall (Stassi et al., 2022). A third category, known as follicular cyst with luteinization, represents an intermediate state and remains less clearly defined (Ortega et al., 2016).

Although research has focused on ovarian and systemic hormonal profiles in COD (Gareis et al., 2023), its effects on the structure and function of the oviduct remain largely unexplored. This knowledge gap is critical because the oviduct is not only a conduit but also an active participant in reproduction, contributing to gamete interaction, sperm reservoir formation, fertilization, and early embryo-maternal signaling (Kölle, 2022; Suarez, 2008). Disruptions in oviductal morphology due to chronic hormonal imbalance may impair these essential functions, even if ovarian ovulation is pharmacologically induced. Cows affected by COD have a significantly lower pregnancy rate and may remain subfertile despite ovulation induction (Cattaneo et al., 2014; Borş & Borş, 2020).

This study aimed to assess morphometric parameters of the bovine uterine tube during the follicular phase, luteal phase, and in the presence of follicular cysts, with emphasis on the infundibulum and ampulla. The isthmus was excluded because its role is mainly restricted to sperm storage and post-fertilization embryo transport (Suarez, 2008), with limited morphometric variability and relevance to fertilization.

Materials and Methods

Tissue collection and classification

Uterine tubes (infundibulum and ampulla) were collected from multiparous Holstein cows (aged 45–90 months) within 30 min after routinely slaughter at slaughterhouses in Phuxuyen, Hanoi, Vietnam. Based on the characteristics of ovarian follicles and corpora lutea, samples were categorized into three groups: follicular phase, luteal phase, and follicular cysts (Brodzki et al., 2019; Scully et al., 2021). Only follicular cysts were included in the cystic group, as they represent the most prevalent type, accounting for approximately 65% of ovarian cysts compared with 19% luteal cysts and 16% cystic corpora lutea (Nakao et al., 1983). Ovarian morphology was assessed to determine the reproductive stage or the presence of pathological conditions. The stages of estrous cycle were estimated by the appearance of ovarian follicles and corpora lutea (Scully et al., 2021). Follicular cysts were determined when one or both ovaries contained anovulatory follicles larger than 25 mm in diameter in the absence of a CL (Brodzki et al., 2019). Follicular cysts were characterized by a thin wall (0.06±0.01 cm) and the absence of luteinization, indicated by the lack of yellow or orange coloration on the inner surface (Brodzki et al., 2019). After classification, ten pairs of cow oviducts (infundibulum and ampulla) were collected from each group, resulting in a total of 30 pairs of cow oviducts for analysis. Cases of COD were identified at slaughter based on ovarian morphology. According to farmer reports, these cows were at least three months postpartum, had a history of reproductive failure, including repeated unsuccessful artificial inseminations, and were therefore culled.

Tissue fixation and processing

The dissected tissues were rinsed in physiological saline and fixed in 10% neutral-buffered formalin for a minimum of 4 hours for proper fixation. The tissues were dehydrated through a graded ethanol series, cleared in xylene, and embedded in paraffin wax. Serial sections with a thickness of 5 µm were obtained using a rotary microtome and mounted on glass slides for histological and histochemical staining.

Histological and histochemical staining

The sections were stained with hematoxylin and eosin (H&E) to evaluate general tissue morphology and epithelial cell types (Mokhtar, 2015). PAS staining was used to detect neutral mucopolysaccharides and assess the secretory activity of epithelial cells in the uterine tube (Mokhtar, 2015). PAS-positive granules were evaluated in all three groups to compare secretory intensity.

Morphometric analysis

Morphometric analysis was carried out on histological cross-sections of the infundibulum and ampulla from uterine tubes in three groups: the follicular phase, the luteal phase, and follicular cysts. Using the Image Analysis Tools (IT system) on an Olympus CX31 microscope, the following parameters were quantitatively assessed: the number of primary mucosal folds per cross-section, the length and thickness of the primary mucosal folds, and the height of the epithelial lining.

The number of primary mucosal folds was determined by counting all complete folds visible in each cross-section. Fold length was measured from the base at the lamina propria to the apex, selecting the largest, clearly visible “finger-like” fold not distorted by sectioning. Fold thickness was measured perpendicularly at the midbody, avoiding the apex and base. Epithelial height was measured from the basal membrane to the apical surface at the midbody of an intact fold. For each parameter, at least five well-preserved folds per sample were measured, and mean values were used for analysis. Measurements were taken from representative regions of each anatomical segment and averaged for each sample.

Statistical analysis

Statistical comparisons among the three groups were performed using one-way ANOVA, followed by Tukey's post-hoc test to determine differences between groups. A significance level of $P<0.05$ was applied. All analyses were conducted using SPSS software, version 22 (IBM Corp., Armonk, New York, United States).

Results

Infundibulum

The mucosa of the bovine infundibulum exhibited a complex, highly folded architecture across all examined physiological states. In general, the mucosa consisted of prominent primary folds and well-defined secondary folds (Figure 1A). Quantitative analysis revealed that the number, length, and thickness of mucosal folds varied significantly among the estrous phases and in the presence of follicular cysts (Table 1).

During the follicular phase, the infundibulum showed the highest morphometric values among all groups, with a significantly greater number of primary folds (32.87±2.11), greater fold length (3067.77±93.72 µm), greater fold thickness (265.06±10.02 µm), and greater epithelial height (42.64±2.31 µm) compared to the luteal phase and follicular cyst condition ($P<0.05$; DF=147). Histologically, the epithelium was predominantly composed of ciliated cells characterized by long apical cilia and centrally located oval vesicular nuclei. Secretory cells were sparse or absent, reflecting minimal secretory activity (Figure 1C).

In the luteal phase, the infundibular mucosa displayed a moderate number of mucosal folds (24.33±2.53), with shorter fold length (1843.82±67.63 µm), thinner folds (235.19±9.96 µm), and a lower epithelial height (34.89±2.24 µm) compared to the follicular phase ($P<0.05$; DF=147). The epithelium contained mixed cell types, including secretory cells with distinct apical cytoplasmic protrusions, which suggest merocrine secretion, as well as two morphologically distinct types of ciliated cells. The dark ciliated cells exhibited centrally located nuclei and well-developed cilia, while light ciliated cells possessed pale cytoplasm, apically displaced nuclei, and few or no visible cilia. Slender peg cells, lacking cilia and distinguished by their narrow shape and darkly stained basally located nuclei, were occasionally observed interspersed among other epithelial cells (Figure 1B).

In specimens associated with follicular cysts, the infundibular epithelium showed signs of structural and functional regression. The number of mucosal folds (20.63±2.09), fold length (1534.49±69.77 µm), and epithelial height (30.95±1.73 µm) were all significantly reduced compared to both the follicular and luteal phases ($P<0.05$; DF=147) (Table 1). Histologically, the epithelium consisted of tall columnar cells with basally positioned nuclei, markedly reduced ciliation, and an absence of prominent apical secretory specializations, indicating diminished functional capacity (Figure 1D).

Ampulla

The ampulla of the uterine tube demonstrated notable histomorphological and histochemical variations across the luteal phase, follicular phase, and in the presence of follicular cysts. Structurally, the mucosa was folded to varying degrees, with prominent primary folds and an epithelium composed primarily of simple columnar cells, including ciliated and non-ciliated secretory cells.

During the follicular phase, the ampullary mucosa exhibited a higher number of primary mucosal folds (21.47±1.33), greater fold length (2769.78±55.06 µm), and thicker folds (300.4±6.25 µm) than those observed under the luteal and cystic conditions ($P<0.05$; DF=147) (Table 1). The epithelial height also peaked at 38.5±1.23 µm ($P<0.05$; DF=147). Histochemically, the secretory cells showed moderate PAS positivity, indicating the presence of neutral glycoproteins within apical cytoplasmic granules (Figure 2B).

During the luteal phase, the ampulla showed a relatively lower number of mucosal folds (16.27±1.41), shorter fold length (1688.52±43.06 µm), and thinner folds (262.8±5.21 µm) than those observed during the follicular phase ($P<0.05$; DF=147). However, the secretory cells exhibited intense PAS-positive staining, reflecting an increased secretion of glycoproteins (Figure 2A). This finding suggests heightened secretory activity during the luteal phase. The epithelial height measured 33.07±1.04 µm, slightly lower than that during the follicular phase but significantly higher than that in cystic cases ($P<0.05$; DF=147).

In specimens from animals with follicular cysts, the ampullary mucosa displayed the lowest values for all morphometric parameters: the number of primary folds (14±0.86), fold length (1484.59±30.63 µm), fold thickness (240.65±5.51 µm), and epithelial height (29.32±0.81 µm) ($P<0.05$; DF=147) (Table 1). Histochemically, the secretory cells demonstrated inconsistent and often di-

minished PAS staining, with some cells showing irregular or weak reactivity (Figure 2C), suggesting reduced or dysregulated secretory function under cystic conditions.

Discussion

The present study showed that both the bovine infundibulum and ampulla undergo pronounced histomorphological remodeling across the estrous cycle, which is markedly attenuated in the presence of follicular cysts. During the follicular phase, both segments exhibited the greatest morphometric values, including increased numbers, lengths, and thicknesses of primary mucosal folds, along with a taller epithelium, compared with those observed during the luteal phase and under the cystic condition. The luteal phase was characterized by moderate fold dimensions but heightened secretory cell activity, particularly in the ampulla, as indicated by strong PAS reactivity. In contrast, follicular cysts were associated with pronounced structural regression in both segments, reduced epithelial height, diminished ciliation, and weak or inconsistent PAS staining, reflecting impaired functional capacity. These results are consistent with previous reports of cyclical remodeling of oviductal folds and epithelial cell populations in cattle (Mokhtar, 2015). Recent morphometric analyses demonstrated that COD alters the epithelial profile of the ampulla and enhances glycoprotein and acidic mucopolysaccharide synthesis (Scully et al., 2024). COD was also associated with structural regression and reduced epithelial height compared with the hormonally regulated follicular phase (Scully et al., 2024).

The pronounced morphological complexity, characterized by significantly increased numbers, lengths, and thicknesses of mucosal folds during the follicular phase, is consistent with previous findings in cattle, sheep, and rabbits that reported enhanced mucosal folding during the periovulatory period (Abe, 1996; Ozen et al., 2010). The development of tall, branched primary folds during this phase likely facilitates oocyte capture and directional transport. These changes appear to be driven by estrogenic stimulation, which promotes epithelial hypertrophy, ciliary development, and an increase in epithelial height (Verhage & Brenner, 1975; Pascua et al., 2024). Histological examination during the follicular phase revealed a predominance of ciliated cells, particularly those with elongated apical cilia and centrally located nuclei. These cells are believed to play a crucial role in propelling the oocyte toward the ampulla, where fertilization takes place (Ito et al., 2016). Light ciliated cells with minimal or absent cilia, as noted by Mokhtar (2015), may represent transitional or functionally immature forms and appeared more frequently during the luteal phase. Secretory cells during the follicular phase were sparse and lacked distinct apical features, indicating low secretory activity during this estrogen-dominant stage of the cycle.

In contrast, the luteal phase was characterized by reduced epithelial height, fewer mucosal folds, and decreased infundibular complexity. Secretory cells became more prominent and functionally active, displaying apical cytoplasmic protrusions consistent with progesterone-stimulated oviductal secretion (Gonella-Diaza et al., 2018). Similar eccrine- or apocrine-like activity, including broken apical membranes and deep plasma membrane invaginations, was also described by Mokhtar (2015). The identification of two distinct types of ciliated cells, referred to as dark and light cells, may indicate a functional hierarchy or differences in their responsiveness to hormonal signals. In addition, the presence of peg or intercalary cells, characterized by their narrow shape and dark, compressed nuclei, was also confirmed. These cells are thought to contribute to epithelial regeneration or may represent a terminal, depleted form of secretory cells (Mahé et al., 2022).

In cows with follicular cysts, the infundibular epithelium exhibited significant structural and functional regression. Morphometric analysis showed marked reductions in the number and length of mucosal folds, as well as in epithelial height, compared with both the follicular and luteal phases, suggesting a diminished surface area for oocyte capture and transport. Histologically, the epithelium consisted of tall columnar cells with basally located nuclei, but showed a notable reduction in ciliation and a loss of apical secretory features, suggesting impaired epithelial differentiation and function (Scully et al., 2024). Given the infundibulum's critical role in guiding the oocyte into the oviductal lumen (Kölle et al., 2009; Kölle et al., 2020), such structural compromise may significantly reduce the efficiency of oocyte retrieval. The diminished presence of ciliated cells likely hampers oocyte transport, while the apparent suppression of secretory activity may impair the local environment necessary for gamete viability and fertilization (Suarez, 2008; Yamamoto et al., 2023). The structural and functional differences in the infundibular epithelium between cows with follicular cysts and those in physiological follicular stages may be attributed to variations in hormonal stimulation. Although follicular cysts are estrogenic structures, the hormonal stimulation they provide is typically dysregulated and prolonged and lacks the cyclic fluctuations characteristic of normal follicular development. This abnormal endocrine environment may attenuate epithelial responsiveness, resulting in regression rather than the proliferative remodeling normally induced during the follicular phase (Ortega et al., 2016; Ghosh et al., 2017).

Table 1. Morphometrical and statistical analysis of the uterine tube during the luteal and follicular phases of the estrous cycle and in the presence of follicular cysts

Parameter	Mean±SD					
	Infundibulum During the Luteal Phase	Infundibulum During the Follicular Phase	Infundibulum with a Follicular Cyst	Ampulla During the Luteal Phase	Ampulla During the Follicular Phase	Ampulla with a Follicular Cyst
Number of primary mucosal folds per cross-section	24.33±2.53[a]	32.87±2.11[b]	20.63±2.09[c]	16.27±1.41[a]	21.47±1.33[b]	14.00±0.86[c]
Length of primary mucosal folds (µm)	1843.82±67.63[a]	3067.77±93.72[b]	1534.49±69.77[c]	1688.52±43.06[a]	2769.78±55.06[b]	1484.59±30.63[c]
Thickness of the primary mucosal folds (µm)	235.19±9.96[a]	265.06±10.02[b]	205.53±10.48[c]	262.80±5.21[a]	300.40±6.25[b]	240.65±5.51[c]
Epithelial height (µm)	34.89±2.24[a]	42.64±2.31[b]	30.95±1.73[c]	33.07±1.04[a]	38.50±1.23[b]	29.32±0.81[c]

Note: Different superscript letters within the same row and within the same anatomical region (infundibulum or ampulla) indicate significant differences among reproductive stages (follicular phase, luteal phase, and follicular cyst) at $P<0.05$. Comparisons were not made between the infundibulum and ampulla.

These findings support the view that COD, particularly in its follicular form, disrupts the hormonal environment. Sustained elevations in estradiol without the corresponding luteinizing hormone (LH) surge may impair the normal morphological and functional differentiation of the oviductal epithelium (Noakes et al., 2001; Ortega et al., 2016). Although Scully et al. (2024) reported increased secretory cell activity and glycoprotein synthesis in the ampullary epithelium of cows with follicular cysts, the current study suggests that cystic pathology has a more degenerative impact on the infundibulum. This difference may be attributed to region-specific sensitivity to hormonal signaling or intrinsic variation in epithelial plasticity (Ito et al., 2020; Ghosh et al., 2017). Overall, these observations highlight the importance of examining localized responses along the oviduct in order to fully understand the reproductive consequences of COD (Kölle, 2022; Cattaneo et al., 2014).

The ampulla of the bovine uterine tube demonstrated distinct histomorphological and histochemical variations across the estrous cycle and in the presence of follicular cysts. These findings reinforce the role of the ampulla as A hormonally responsive segment of the oviduct, structurally and functionally specialized to support fertilization and early embryonic development (Abe & Hoshi, 2007). The present observations are consistent with previous reports by (Mokhtar, 2015), who described similar cyclical alterations in mucosal folding and epithelial composition in *Bos indicus*.

During the follicular phase, the ampullary mucosa reached its highest degree of morphological development, with the greatest number and length of mucosal folds, increased fold thickness, and maximal epithelial height, reflecting an estrogen-dominant environment that promotes epithelial proliferation, ciliary development, and expansion of the mucosal surface area (Verhage & Brenner, 1975; Pascua et al., 2024). The predominance of ciliated cells and moderate reactivity to PAS staining in secretory cells suggest a balanced functional state, in which mechanical gamete transport is emphasized, while secretory activity remains relatively low. Similar patterns were described by Mokhtar (2015), who noted minimal apical specializations in secretory cells during the estrogenic phase, consistent with limited secretory output. In contrast, the luteal phase was characterized by a moderate reduction in structural parameters, including fewer and shorter mucosal folds and decreased epithelial height. Secretory activity increased, as indicated by intensified PAS staining and the presence of cytoplasmic granules and apical protrusions in secretory cells, consistent with apocrine and eccrine modes of secretion described by Mokhtar (2015). This shift in cellular activity is likely driven by rising progesterone levels, which enhance oviductal fluid production to support fertilization and early embryonic development (Killian, 2004; Ito et al., 2016).

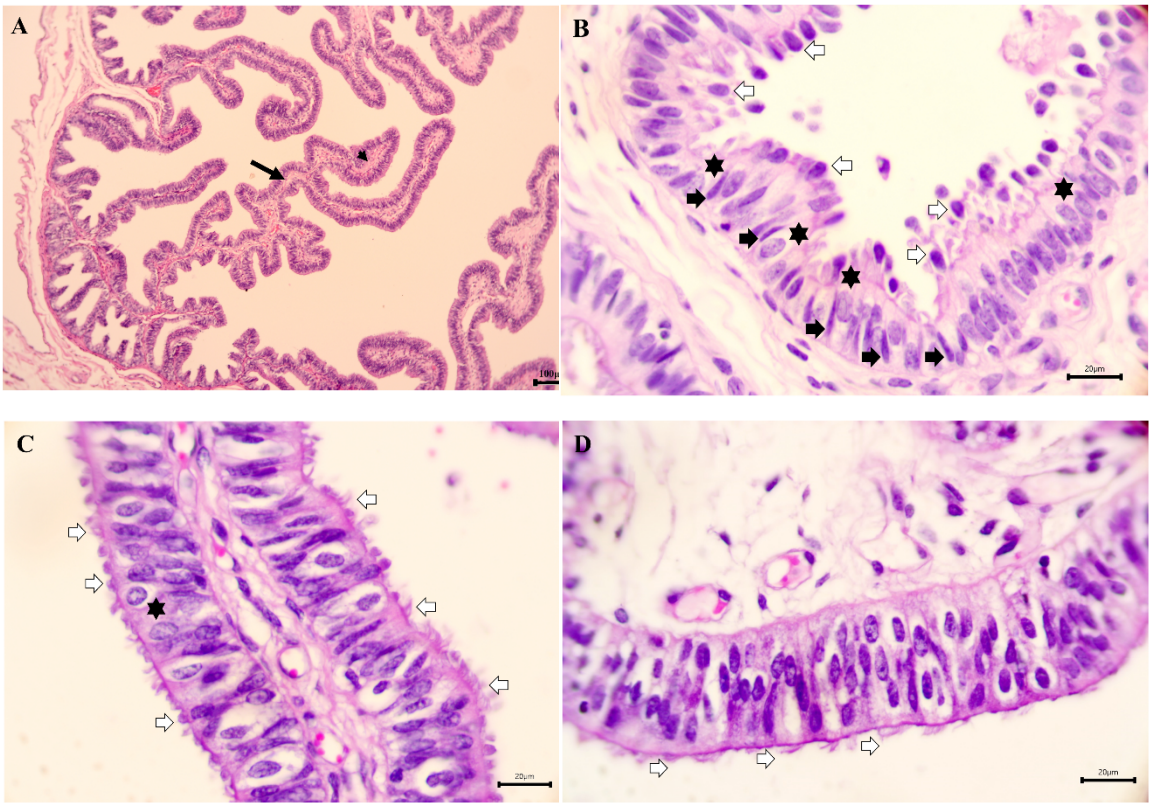
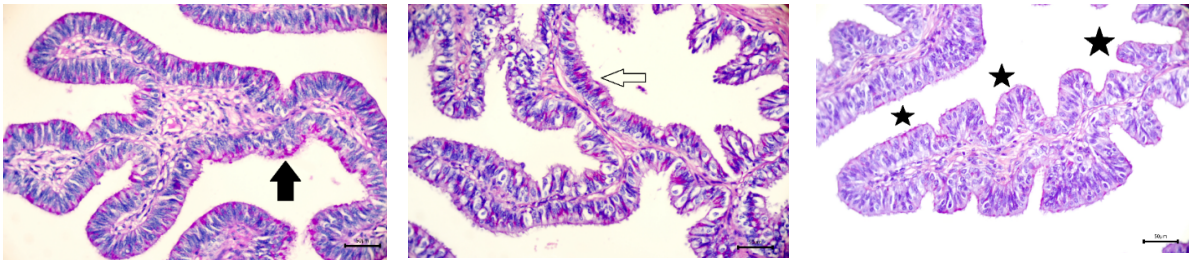


Figure 1. Histological features of the bovine infundibulum during the follicular and luteal phases and in the presence of follicular cysts, stained with H&E

A) General view of the infundibulum demonstrating extensively folded mucosa with prominent primary folds (arrow) and secondary folds (arrowhead); B) Infundibular epithelium during the luteal phase composed of dark ciliated cells with distinct cilia (white arrow), light ciliated cells with sparse or absent cilia (asterisks), and narrow, slender peg cells (black arrow); C) Infundibular epithelium during the follicular phase characterized by a predominance of ciliated cells (white arrow) and an absence of secretory activity: Note the presence of light ciliated cells (asterisk); D) Infundibular epithelium in the presence of a follicular cyst lined by tall columnar epithelial cells with basally located nuclei and noticeably reduced ciliation (white arrow) Note: Secretory cells are present but lack prominent apical specializations.



(A) Luteal phase (B) Follicle phase (C) Follicle cystic

Figure 2. Histochemical analysis of the ampullary epithelium during the follicular and luteal phases and in the presence of follicular cysts

A) Secretory cells during the luteal phase exhibit a strong PAS-positive reaction (black arrow), B) Secretory cells during the follicular phase show a moderate PAS-positive reaction (white arrow), C) Under the follicular cyst condition, secretory cells demonstrate variable and often diminished or irregular staining (asterisk)

In specimens from cows with follicular cysts, the ampullary mucosa showed clear evidence of structural regression. Quantitative analysis revealed significant reductions in morphometric parameters, reflecting a substantial loss of epithelial surface area that may compromise the ampulla's ability to facilitate gamete transport and successful fertilization (Kölle et al., 2009; Abe & Hoshi, 2007). The mucosal folds appeared simplified and flattened compared with those of healthy controls. Such alterations suggest diminished responsiveness to estrogen, a hormone that normally promotes epithelial remodeling and structural complexity during the follicular phase (Noakes et al., 2001; Pascua et al., 2024). This apparent paradox may be explained by the abnormal endocrine environment in cows with COD, in which estrogen secretion is persistent and dysregulated and lacks the transient surge characteristic of a normal estrous cycle. Prolonged hormonal imbalance may desensitize epithelial cells to estrogenic stimulation, leading to attenuated differentiation, reduced ciliation, and ultimately structural regression rather than the proliferative remodeling expected during a normal follicular phase (Ortega et al., 2016; Ghosh et al., 2017). Similar epithelial simplification and reduced estrogenic responsiveness have also been described in other reproductive pathologies, further supporting the link between hormonal dysregulation and structural regression in the oviduct (Scully et al., 2024).

Histochemical evaluation showed that PAS staining patterns in cows with COD, particularly those with non-luteinized follicular cysts, were irregular and often reduced in intensity. This pattern indicates disrupted or downregulated glycoprotein synthesis. These findings differ from those reported by Scully et al. (2024), who observed increased glycoprotein production in the ampullae of cows with COD, especially in cases involving luteal cysts. The elevated glycoprotein synthesis in luteal cysts has been attributed to increased progesterone secretion (Noakes et al., 2001; Stassi et al., 2022). Similarly, in cows with follicular cysts undergoing luteinization, an intermediate hormonal state may exist, although this condition has not yet been fully characterized (Ortega et al., 2016). The discrepancies between studies may reflect differences in the stage or severity of cystic pathology, variability in secretory cell responses to chronic hormonal disturbances, or differences in the duration of cyst persistence. Because cysts are dynamic in nature, with follicular turnover ranging from 13 to 19 days (Hampton et al., 2003; Todoroki et al., 2004) and some cysts persisting for less than 10 days (Cook et al., 1990), it is difficult to establish the exact duration of their presence in individual animals. This limitation is common in slaughterhouse-based studies, as also acknowledged by Scully et al. (2024). Nonetheless, it is reasonable to assume that longer-lasting or recurrent cysts may have greater effects on reproductive tissues than shorter-lasting cysts. In some specimens examined in the present study, weak or inconsistent PAS staining persisted even in cases in which high circulating estrogen levels would typically be expected, suggesting functional impairment of the secretory machinery. This dysfunction may result from altered intracellular signaling, prolonged hormonal imbalance, or incomplete epithelial differentiation (Ghosh et al., 2017; Ortega et al., 2016).

This altered secretory profile is particularly concerning given the critical role of the ampulla in producing oviductal fluid, which is essential for sperm survival, capacitation, and embryo development (Yamamoto et al., 2023; Suarez, 2008). The observed decrease in epithelial height and loss of apical specializations are also consistent with reports that prolonged estrogen exposure in the absence of ovulation can lead to epithelial exhaustion or desensitization (Ito et al., 2020; Peter, 2004). These cumulative morphological and histochemical changes likely impair the functional integrity of the ampulla, compromising not only fertilization but also early embryo–maternal interactions (Kölle et al., 2020; Cattaneo et al., 2014).

Conclusion

This study provides a detailed understanding of the histological, histochemical, and morphometrical changes in the bovine uterine tube, focusing specifically on the infundibulum and ampulla during different phases of the estrous cycle and under follicular cystic conditions. Under physiological conditions, both regions exhibited dynamic cyclical remodeling: the follicular phase was characterized by increased mucosal folding, epithelial height, and ciliation, driven by estrogenic stimulation, while the luteal phase showed enhanced secretory activity, consistent with progesterone influence. In contrast, specimens from cows affected by follicular cysts demonstrated marked structural regression in both the infundibulum and ampulla, including reduced epithelial height, simplified mucosal folding, and diminished or irregular glycoprotein production. These histoarchitectural and functional impairments suggest that COD may alter the oviductal environment in ways that could hinder gamete transport, fertilization, and early embryonic development. Although anovulation remains the primary cause of infertility in COD, our findings indicate that concurrent oviductal alterations may be additional contributing factors to subfertility in affected cows.

Ethical Considerations

Compliance with ethical guidelines

This study involved the use of ovaries collected post-mortem from slaughtered Holstein cows and did not include any live animal handling or experimental intervention. Therefore, formal ethical approval was not required. However, all procedures were conducted in accordance with recognized ethical standards for the use of animal tissues in research.

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Authors' contributions

Conceptualization, methodology, review, editing, and final approval: All authors; Investigation, data collection, data analysis and writing the original draft: Bui Van Dung.

Conflict of interest

The author declared no conflict of interest.

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