SHORT COMMUNICATION

QR Code-Integrated Standardization of Permanent Histological Slide Preparation: An Innovative Approach for Teaching Practical Histology

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Abstract

Histological slides are essential tools for teaching and research in veterinary anatomy and histology. Standardized preparation of permanent slides across multiple domestic species, combined with modern digital integration, can enhance their educational and research utility. This study was aimed to standardize slide preparation and incorporate QR code-based digital access for improved visualization and learning. A total of 86 tissue samples were collected from buffalo (n=38), domestic fowl (n=20), dog (n=15), and goat (n=13). Representative tissues from major organs were fixed in 10% neutral buffered formalin and processed using routine histological techniques, including graded dehydration, clearing, and paraffin embedding. Sections of 4-6 µm thickness were cut using a rotary microtome, stained with hematoxylin and eosin, and permanently mounted with DPX. High-resolution photomicrographs were captured using a compound microscope equipped with a digital imaging system, and QR codes were generated and linked to the corresponding digital images for instant access via smart devices. The prepared slides demonstrated excellent preservation of tissue architecture, with clear cellular and structural details across all species. QR code integration enabled efficient digital cataloging, rapid retrieval, and enhanced visualization of histological features. The standardized protocol proved reliable and reproducible for permanent slide preparation in multiple domestic species, while the incorporation of QR code technology significantly improved accessibility and educational value.

Key words: Digital integration, Domestic animals, Permanent histological slides, QR code, Tissue histology, Veterinary education.

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Introduction

Histology is a core discipline in veterinary anatomy, providing essential understanding of the microscopic organization of cells, tissues, and organs and their functional correlations. Permanent histological slides are indispensable tools for teaching, research, and diagnostic purposes in veterinary sciences. The quality of histological interpretation largely depends on standardized procedures for tissue fixation, processing, sectioning, staining, and mounting, which ensure consistency, reproducibility, and long-term preservation of tissue architecture (Kiernan, 2015; Bancroft and Gamble, 2019). Comparative histology of domestic animals such as ox, goat, dog, and domestic fowl forms an integral part of veterinary curricula. However, variations in histological preparation techniques across laboratories often result in inconsistent tissue preservation and staining quality, thereby affecting microscopic clarity and learning outcomes (Dellmann and Eurell, 1998; Samuelson, 2007). Moreover, the limited availability of systematically prepared and well-documented permanent slide collections restricts effective revision, demonstration, and self-directed learning.

Advances in educational technology have led to increased adoption of digital tools in medical and veterinary education. Digital histology and image-based learning resources enhance accessibility and support blended learning, particularly where physical slide access is limited (McLean, 2018). Nonetheless, exclusive reliance on virtual microscopy is often constrained by infrastructure, cost, and technical requirements. Quick Response (QR) codes provide a simple, economical, and efficient method for linking physical teaching resources with digital content. QR code-based systems allow instant access to high-resolution photomicrographs and related information through smart

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devices, enhancing interactivity and flexibility in learning environments (Aboo, 2026). In histology education, QR codes effectively integrate permanent glass slides with corresponding digital images, facilitating rapid retrieval, visualization, and long-term archiving without diminishing the value of conventional microscopy. Despite these advantages, the application of QR code-integrated digital documentation in veterinary histology, particularly in conjunction with standardized permanent slide preparation across multiple domestic species, remains limited. The present study was therefore undertaken to standardize the preparation of permanent histological slides of major organs in ox, goat, dog, and domestic fowl and to incorporate QR code-based digital documentation linking each slide to its corresponding photomicrographs. This approach was aimed to enhance histology teaching, improve slide archiving, and promote technology-assisted learning in veterinary education.

Materials and Methods

Collection of Tissue Samples

A total of 86 tissue samples were collected from clinically normal domestic animals, including buffalo (n=38), domestic fowl (n=20), dog (n=15), and goat (n=13). Representative samples from major organs were obtained immediately after slaughter or post-mortem examination, following standard ethical and institutional guidelines. Tissue specimens of approximately 0.5-1.0 cm thickness were excised to ensure optimal fixation and preservation of histological architecture (Bancroft and Gamble, 2019).

Tissue Fixation, Processing and Embedding

All tissue samples were fixed in 10% neutral buffered formalin (NBF) for 24-48 h at room temperature. Adequate fixation was ensured by maintaining a fixative-to-tissue volume ratio of at least 10:1. Fixation in NBF was employed to preserve cellular morphology, prevent autolysis, and maintain tissue integrity during subsequent processing (Kiernan, 2015).

Following fixation, tissues were washed in running tap water to remove excess fixative and processed routinely using graded alcohol or ethanol series (70%, 80%, 90%, and absolute alcohol) for dehydration. Clearing was carried out using xylene until tissues became translucent. The cleared tissues were then impregnated and embedded in molten paraffin wax maintained at 56-58 °C using standard histological techniques (Bancroft and Gamble, 2019). Processed tissues were oriented appropriately in embedding moulds to obtain optimal sectional planes.

Sectioning, Staining and Mounting

Paraffin-embedded tissue blocks were trimmed and sectioned at a thickness of 4-6 µm using a rotary microtome. Sections were floated on a warm water bath (40-45 °C) to remove wrinkles and mounted on clean frosted glass slides coated with glycerin-based adhesive to enhance section adherence. Mounted sections were dried on a hot plate and further dried in a hot air oven to ensure proper attachment prior to staining (Kiernan, 2015).

Routine staining was performed using hematoxylin and eosin (H&E) following standard protocols to demonstrate general tissue architecture and cellular details. After staining, sections were dehydrated through graded alcohols, cleared in xylene, and permanently mounted using DPX mountant. Cover slips were applied carefully to avoid air bubbles and ensure long-term preservation of the stained sections (Samuelson, 2007; Bancroft and Gamble, 2019).

Photomicrography

Prepared slides were examined under a compound light microscope, and representative photomicrographs were captured at various magnifications using a digital camera attached to the microscope. Images were evaluated for clarity, staining quality, and preservation of histological details. High-resolution images were stored systematically with appropriate labeling for species, organ, and magnification (Dellmann and Eurell, 1998).

QR Code Generation and Digital Integration

Selected high-quality photomicrographs were digitally catalogued and stored in organized folders or cloud-based repositories. Unique Quick Response (QR) codes were generated for each histological slide using QR code generation software. Each QR code was linked to the corresponding digital photomicrograph and related information, enabling instant access through smartphones or other smart devices. The QR codes were affixed to slide labels or storage boxes to facilitate easy retrieval, digital documentation, and technology-assisted learning.

Results and Discussion

The standardized histological processing protocol employed in the present study resulted in the successful preparation of high-quality permanent histological slides from all 86 tissue samples obtained from buffalo, goat, dog, and domestic fowl. Fixation in 10% neutral buffered formalin provided effective preservation of tissue morphology, with minimal artifacts such as shrinkage or distortion. Similar observations have been reported by Bancroft and Gamble (2019), who emphasized that proper fixation is critical for maintaining morphological integrity and ensuring

reliable histological interpretation. Likewise, Suvarna *et al.* (2019) described neutral buffered formalin as the most widely accepted fixative for routine histopathological investigations because of its ability to preserve both nuclear and cytoplasmic details.

Routine paraffin processing and microtomy consistently produced uniform sections of 4-6 µm thickness, enabling clear and reproducible microscopic evaluation across different organs and species. Comparable section thickness has been recommended for optimal histological visualization in veterinary and medical histology laboratories (Culling *et al.,* 2014). The uniformity achieved in the present study indicates that the protocol is suitable for producing teaching and reference slides with minimal technical variation.

Hematoxylin and eosin staining provided excellent differentiation of nuclear and cytoplasmic components, enabling clear visualization of epithelial, connective, muscular, vascular, and nervous tissues. The staining quality observed in this study was consistent with the findings of Kiernan (2015), who noted that H&E remains the gold standard for routine tissue evaluation because of its simplicity, reproducibility, and ability to demonstrate overall tissue architecture effectively. The microscopic features observed in buffalo, goat, dog, and domestic fowl tissues corresponded closely with established descriptions reported in standard veterinary histology texts (Dellmann and Eurell, 1998; Eurell and Frappier, 2013), confirming the accuracy of tissue identification and the reliability of the prepared slides.

An important outcome of the study was the successful documentation of species-specific histological variations. Comparative histology has long been recognized as an essential component of veterinary education because it enhances understanding of anatomical and physiological adaptations among species (Banks, 1993). The ability of the prepared slides to demonstrate these differences highlights their value as educational resources for undergraduate and postgraduate veterinary curricula.

The high-resolution photomicrographs generated from the permanent slides accurately represented microscopic structures without appreciable loss of detail (Fig.1-4). Digital histology resources have increasingly been adopted in biomedical and veterinary education owing to their ability to supplement conventional microscopy and improve accessibility to teaching materials (Dee, 2009; Blake *et al.,* 2018). The close correspondence observed between the physical slides and their digital counterparts indicates that the image acquisition process used in the present study was sufficiently robust for educational and archival purposes.

A notable innovation of the present work was the integration of QR codes with individual histological slides.

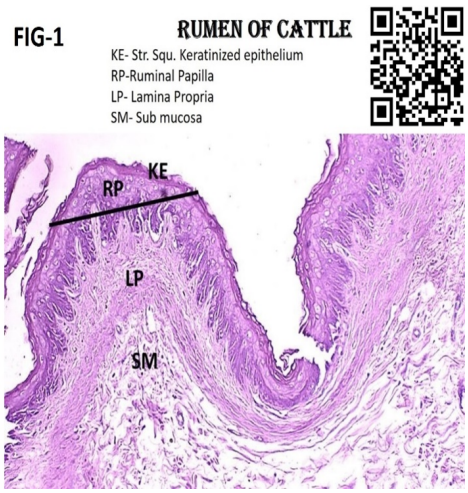


Fig. 1: Histological section of rumen of cattle showing keratinized stratified squamous epithelium (KE) forming prominent ruminal papillae (RP), supported by the lamina propria (LP) and underlying submucosa (SM). H&E X10

Note: Legends are not given for QR code, but the contents of legend are mentioned in the QR code. Moreover, the QR code provided with each figure is specific to that individual histological image (figure) and is not a generalized QR code for the entire tissue or organ.

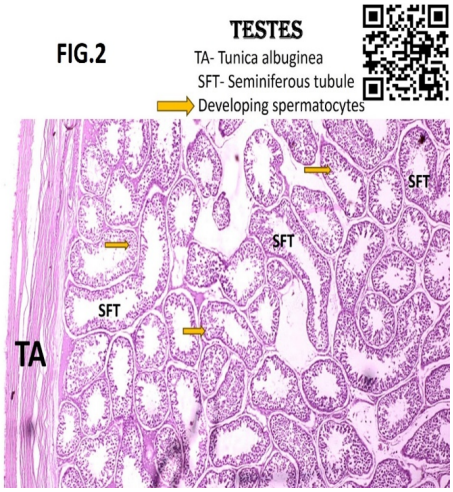


Fig. 2: Histological section of testes of goat showing the tunica albuginea (TA) and numerous seminiferous tubules (SFT) containing developing spermatogenic cells, including spermatocytes, indicative of active spermatogenesis. H&E X40

QR-code technology enabled rapid linkage between physical specimens and their corresponding digital photomicrographs, facilitating efficient cataloging, retrieval, and sharing of histological information. Similar applications of QR codes in educational settings have been reported to improve information accessibility, enhance student engagement, and support mobile learning environments (Law and So, 2010; Rikala and Kankaanranta, 2014). The absence of discrepancies between physical slides and digital records further demonstrates the reliability of the

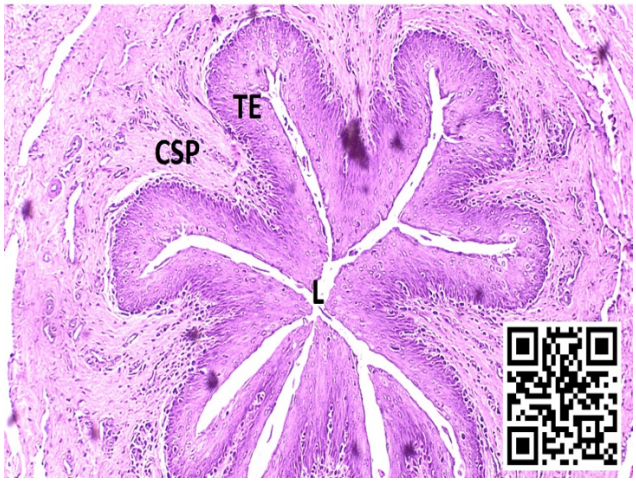


Fig. 3: Histological section of penile urethra of dog showing the transitional epithelium (TE), lumen (L), corpus spongiosum penis (CSP). H&E X40

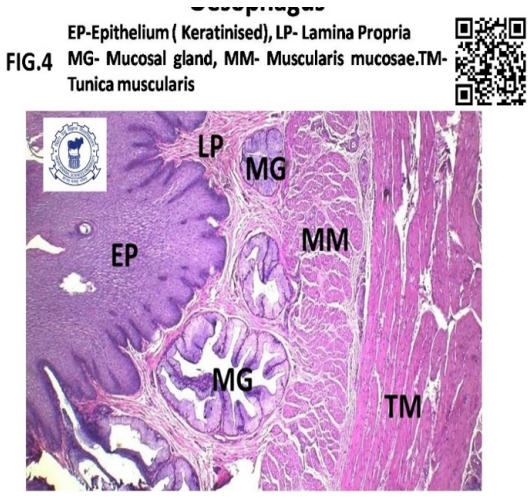


Fig. 4: Histological section of esophagus of fowl showing epithelium (EP), lamina Propria (LP), mucosal gland (MG), muscularis mucosae (MM) and tunica muscularis (TM). H&E X10

QR code-based system as a tool for histological resource management.

The incorporation of QR code-enabled digital access addresses several limitations associated with traditional microscopy-based teaching. Conventional histology laboratories often face challenges related to limited microscope availability, deterioration of teaching slides, restricted laboratory access, and variability in slide interpretation among students. Digital histology platforms have been shown to improve learning flexibility, facilitate remote access, and promote self-directed learning (Harris *et al.,* 2011; Trelease, 2016). The present findings support these observations and suggest that QR-linked digital repositories can serve as valuable adjuncts to conventional practical instruction.

Overall, the combined standardization of permanent histological slide preparation and QR code-based digital integration proved reliable, reproducible, and educationally effective across multiple domestic animal species. The methodology developed in this study provides a practical framework for modernizing veterinary histology laboratories and establishing organized digital histological repositories. Such systems have the potential to enhance teaching efficiency, preserve valuable teaching collections, and facilitate long-term access to histological resources for veterinary education and research.

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