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A review of microscopic anatomy in veterinary science

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Abstract
The microscopic appearance of these organs has become the foundation of veterinary medicine to compare form with function in both normal and sick animals. This article focuses particularly on how imagination canresult in useful learning, diagnosis, and research; and the aspect of opportunity is stressed it offers to connect structure-function relationships, such asproteomics in Dupuytren's contracture or pathology of various organisms. The development of advanced histological techniques, 3D visual systems, and molecular pathology has added a new layer of interpretation to the old microscopic anatomy: classifying normal versus abnormal tissue. The clinical significance of anatomy in species-specific diagnosis and therapy is also discussed in the review, which has particular relevance for reproductive medicine, toxicology and microbial disease. Educational Bottle-Necks: Curriculum Coverage and Visualization Issues that can be generated via Computational Tools Combined with Immersive Technologies. Comparative anatomy is essential to the One Health Approach One Health. This same point is made one more time here, to emphasize that mutual understanding of kinds offers benefits for both human and animal health. This review combines traditional and current anatomical findings to illustrate just how important a fundamental discipline microscopic anatomy is in veterinary medicine a swell as diagnosing old as well as new health issues.

Keywords: Microscopic anatomy, veterinary science, histological techniques, molecular pathology

Introduction

1. Fundamentals of Veterinary Microscopic Anatomy

Veterinary microscopic anatomy is of interest to students and specialists studying morphology in general, as well as having relevance to all veterinary courses and disciplines. Being one of the key discipline subjects in medicine, it provides basic knowledge to understand the structure-to-function relationship of animal health and diseases (Choudhary *et al*., 2023) [7]. This area is investigating the associations between three-dimensional features in organisms and physical diagnosis of disease, and revealing about surgical and medical treatments (Kongtueng *et al*., 2021) [18] (Figure 1).

Veterinary microscopic anatomy deals with the structures of organs, and systems as studied under a microscope. The "shape" of the sem (as described by experts within the field), 'concentrate(s) in the description of form, that is, how body structures looks at different levels' (Blazquez-Llorca *et al*., 2023) [5]. This is also a crucial course to establish the base of diagnosis and treatment of diseases, surgery as well as research work in veterinary medicine (Choudhary *et al*. conclusion as Veterinary Medicine or Surgery have been integrated into various medical sciences students in Animal Science discipline should have knowledge of these areas.

Conventional anatomic research has been limited to macroscopic, microscopic, and histologic methods for the study of tissue and organ architecture. Nevertheless, applications of new technology such as improved imaging methods and molecular biology approaches have continually renewed interest in anatomy as a vibrant, active field (Stabile *et al*., 2023) [35]. These technological advances have improved our ability to perceive and explain intricate anatomical relationships at the microscopic level. Background in veterinary education, microscopic anatomy belongs to the group of knowledge identified as basic science knowledge that includes those facts that need to be known for future professional activities and further learning in subjects such as (microscopic) anatomy, (molecular) physiology, (general and specific) pathology, microbiology and pharmacology. In accordance with the AVMA COE standards (Danielson *et al*., 2024) [8], this understanding "encompass[es] central biological

principles and mechanisms that underlie health and disease of animals moving from molecular and cellular level to individual organismal level and population expression". Notwithstanding its intrinsic relevance, as a discipline and even as microscopic anatomy field have faced teaching/scholarly recognition difficulties. (Aversi-Ferreira *et al*., 2018) [47] (Pfrimer *et al*., 2012) [27]. This is alarming because even today health sciences continue to rely on anatomical data for clinical and surgical purposes. In addition, phylogenetic, taxonomic and evolutionary studies are built on anatomy (Aversi-Ferreira *et al*., 2018) [47] (Aversi-Ferreira *et al*., 2013) [48]. Comparative aspects between species are the most important part of microscopic anatomy and it is essential for veterinarians in their work with various animals. The lack of comparative anatomy in numerous species make it difficult to build precise evolutionary trees, to analyze taxa correctly (Aversi-Ferreira *et al*., 2018) [47] and to effective the appropriate clinical or surgical procedure even for wild animals. This emphasizes the necessity of further research and education in veterinary microscopic anatomy to cover up these fields of deficits.

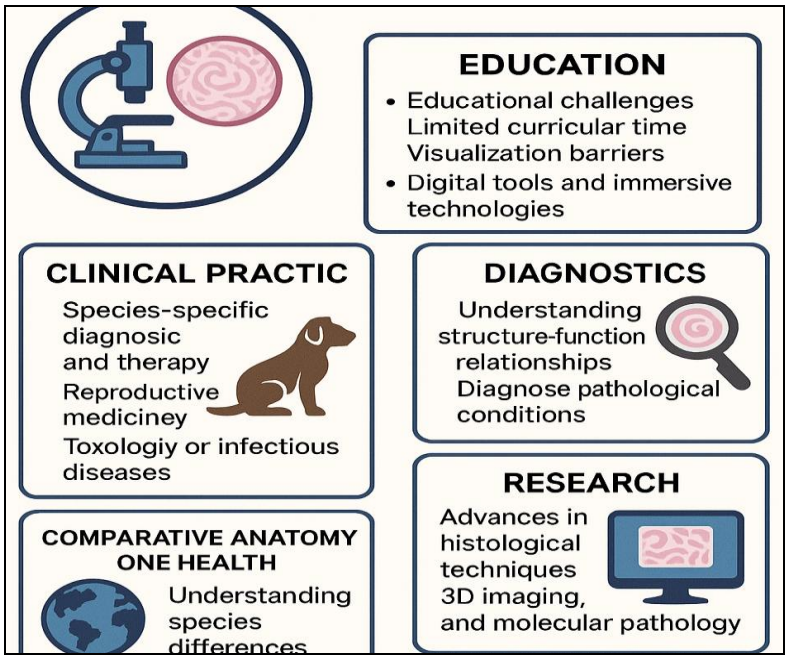

Fig 1: Role of microscopic anatomy in veterinary science

2. The Relationship Between Structure and Function

In animal pathology, there is no bridge between structure and function as it exists in cells or tissues because the microscope is a symbolic metaphor for this interplay. According to this basic point, whatever particular adaptations to disease any organs or tissues have, they occur second through the 3D architecture of their own textures (Kongtueng *et al*., 2021) [18].For veterinarians' conceptual theoretical models of disease diagnosis and treatment, understanding tissue structure and function at the microscopical level is a cornerstone (Kongtueng *et al*., 2021) [18].Topography at molecular and organ levels (Tamizhazhagan *et al*., 2017) [36] There is a wide field of practical application behind the conceptual foundation concerning the relationship between structure and function in veterinary Microscopic Anatomy. Histology also encompasses within its realm those structures which represent an organ's differentiation process from very fine cells, such as major collections ofnervous tissue (e.g. brain), while representing them as cells on-screen. In addition, TAMIZHAZHAGAN considers groups of cells conducting specialized functions as elements in tissues. To be able to integrate all this knowledge and win success demands from a veterinarian that he can infer relationships among facts adopted from various branches of the sciences and offer deductive reasoning which is noticed in clinical diagnostics to be absolutely necessary to accountable solving problems (Tamizhazhagan *et al*., 2017) [36].

For seasoned clinicians, learning anatomy includes the relationship to function long after they graduated. Studies on equine (Schirone *et al*., 2024) [31] and farm- animal practitioners have demonstrated that clinically irrelevant anatomy with access to difficult anatomical features is a strong pre-requisite of professional life (Homfray GT gains *et al*., 2022) [13]. This information enable the professional to communicate effectively with their client and co-worker leading to increased trust and confidence from the profession in decision making (Schirone *et al*., 2024) [31]. The practical importance of an understanding of relationships between structure and function is evident when one thinks in terms of specific veterinary problems. In equine cardiology, for example, detailed knowledge of the anatomy of the horse's heart is necessary in order to understand pathophysiology and pathological anatomy: prerequisites that are important to understand cardiac physiology (Bielinska *et al*., 2024) [4]. This anatomical expertise enables veterinarians to comprehend both the pathogenesis of a diseases and more effective diagnostic and therapeutic procedures (Bielinska *et al*., 2024) [4] (Schirone *et al*., 2024) [31].

3. Microscopic Anatomy Techniques and Methods

With the access now to such methods that permit vets to visually examine and determine differences in the tissues of diverse organs including lung, liver, gut, heart (cardiac muscle), kidney and those parts of the digestive system (Jayashree *et al*., 2020) [15]. The histopathology processes could be tailor made in detecting the pathological specimens with altered manifestations of cells owing to cell proliferation, oedema, haemorrhage, congestion and fibrosis and malignancies (Jayashree *et al*., 2020) [15]. The study of veterinary histology has developed into different sub

disciplines in function of the purpose (research or method) pursued. These comprise cytology (cell science), general histology (tissue science) and special histology (microscopic body structure) as well as more specific fields of study such as histophysiology, cytochemistry and histochemistry that focus on the functional and biochemical considerations of tissues[20] Dildora *et al*., 2023 [9]. Furthermore, two subdisciplines of histology are imaging histology that investigates normal structure of tissues, and experimental histology that studies artificial (induced) morphological changes, with disease-related tissue alterations as the subject matter in pathohistology (Dildora *et al*., 2023) [9].

Current imaging modalities have fundamentally changed microscopic anatomy's place in veterinary medicine as compared to the previous anecdotal approach. Although such descriptions have traditionally been derived from detailed dissections and histological serial sections, one can now obtain similarly (at least) informative photographs for many species as an adjunct to directly observe animal welfare. (Bergamino *et al*., 2015 [3]

According to the authors, "These are computed tomography (CT), magnetic resonance image (MRI) and positron emission tomography (PET) machine, which the anatomic part of a body can all be examined with relevant diagnostic information." (Bergamino *et al*., 2015) [3]. These are the words spoken before significant progress began to characterize modern biological research equipment from its equipment-making tools through computers and with online services; major pains included developing hydraulic outputs that were not harmful to humans! With continued use these structural signals continued to become stronger, but one day their meaning was completely clear: those cells were infected. none of the fluffy white cells mentioned in my textbook would be identified or displayed through data onto cell membranes however I had successfully isolated such from live tissue slices Statements were recorded on an integrative rough - cut narrative tape recorder and subjected to further critical analysis.

A mighty new addition to the line-up is 3-D reconstruction-anatomic structures. These 3D visual analysis methods above have a great many examples in medical diagnosis and anatomic research including spatial context that is difficult to encounter in normal 2 D histological section (Yitbarek *et al*., 2022) [42]. For example, when used in conjunction with anatomical slicing, CT has been found to be effective for the investigation of more intricate structures such as the nasal passages of birds (Morales-Espino *et al*., 2024) [23], indicating that these methods really are viable options for complete anatomical examination.

Brand new microscope-based procedures have also altered recent veterinary science. For example, cleared tissue protocols such as CLSM and LFM can be combined to image through the entire volume of an intact sample which may provide crucial spatial information when studying host-pathogen relationships and disease pathology (Smallridge *et al*., 2025) [33]? (Zaeck *et al*., 2021) [45]? (Zaeck et esal, 2019) [44]. These methods make it possible to map the distribution, localization and cell tropism of a virus in living animals - information which is clinically relevant for disease pathophysiology on topography not attainable with conventional histopathological methods (Smallridge *et al*., 2025) [33] (Urano *et al*., 2021) [38] (Nelson *et al*., 2022) [25]. Macroscopic examination of tissues Ideally, sequential review can be done through several organs to observe and learn about normal anatomy and the disease processes in those organ systems. Veterinary pathologists might consider forty or more tissues when examining toxicity and disease, such as endocrine organs that are non-lobular, brain, digestive organs including mouth structures) and reproductive system enamel organ's manifestations), cardiovascular system lung lobes), respiratory counterparts tympanic membrane), lymphoid tissue iliac-sternal joint) or skeletal counterparts (Kim *et al*., 2024) [17]. This systematic procedure enables assessment of all on-target as well as off-target effects in a research and/or diagnostic context.

4. Application in Disease Diagnosis and Pathology

Veterinary anatomical pathology is a veterinarian's specialized area of veterinary medicine, in which the focus is on the diagnosis of diseases based on laboratory analysis of body fluids such as blood and urine, as well as tissues using histopathology (the microscopic examination of biopsies), or post-mortem examination (autopsy). This subspecialty is characterized by the use of diagnostic criteria originated from a deep understanding of macroscopic and microscopic lesions to establish unequivocal veterinary pathological diagnoses (Tome *et al*., 2012) [37]. The main goal of pathology is problem-solving, and the purposes vary in each type of investigation, from establishing cause of death to explaining decreased production in groups of animals, determining legal aspects (forensic cases) or guiding therapy (surgical pathology) (Miller *et al*., 2017) [21].

Clinical application of microscopic anatomy for disease diagnosis is the goal of teaching and learning in veterinary education, where students start to learn normal structure (anatomy) and function (physiology) but finally to know diseases. This educational continuum serves to identify abnormal tissue changes by comparison with what is known about normal structure (Littlewood *et al*., 2021) [19]. It is not surprising, at least to veterinarians, that comparative anatomy continues to be “turned towards pathology… applied practice” as William Youatt described in 1829 (Woods, 2017) [40], when one recognizes the benefit of knowing species differences in normal anatomy as critical information for interpreting species-specific expressions of disease.

Here too Histology is the cornerstone of pathology (proper, not tissue diagnosis). Most people would agree that we get invaluable diagnostic information when, in the vast majority of cases, you send a biopsy or CUP cases away for examination. For example, the bitch reproductive tract: Microscopic evaluations of the B vtx re-productive tract may yield useful data on breeding soundness, infertility which cannot be obtained in any other way and where we are working at the level of ultimate upset. The vets who examine this matter need to observe closely tiny streaked structural/histological and functional breakdowns of small cell by-products that we find everywhere yet remain also have to let people know that tissues like the cervix (cranial vagina) and endometrium change a great deal throughout every stage within its estrus cycle In truth, the particular examples illustrate this is a normal or vs. abnor-mal anatomic basis for understanding physiologic shifts.

There is a wide variety of lesions in veterinary medicine and many times there is simply extensive examination of multiple organs. Sometimes pathologists also want to examine other normal tissues; such as leiomyoma's and endocrine glands or cortical bone. (Consequentlythese examinations. go along with "my car" histological sections and so histomorphologically-Morriavian-Will *et al*., 2204). This "whole body approach" permits complete investigation not

just into a disease process itself but how it affects the entire body. Field veterinarians experienced all sorts of tissue responses to infection. These include growth, edema and inflammation with bleeding, fibrosis and sarcoma. For instance, pathologists always check all non-healthy tissues from primary organs such as the heart, liver, kidney or lung for identification of different pathological changes that might occur, whether it is cirrhosis or cancer (Jayashree*et al*., 2020) [15]. Many of these histopathological findings not only need to be recognized but also have major implications for the correct diagnosis and treatment. Veterinary pathology is not only to apply what you have learned (in clinics) and it is a huge part of the work in research and pedagogy. Pathologists also function at all levels ranging from formulating plans for experiments to outcome analysis, that is measuring the pathological relevance of morphological changes, relationship between clinical data and the disease process (Miller et at, 2017) [21]. These trends have advanced veterinary medicine's passage from bench to bedside more toward physiological mechanisms.

5. Microscopic Anatomy Across Different Species and Systems

Canine Reproductive System: The female canine reproductive tract undergoes dramatic microscopic changes throughout the estrous cycle, particularly in the cranial vagina and endometrium. These dynamic structural alterations provide critical diagnostic information about reproductive health and fertility, requiring veterinarians to understand both baseline anatomy and cyclical variations. (Premanandan *et al*., 2019) [28]

Rodent Models: Mice and rats serve as important models in veterinary research, with distinctive respiratory system characteristics. Their unique lung anatomy and particle deposition patterns in the respiratory tract make them valuable for inhalation toxicology studies. (Xi *et al*., 2023) [41] (Raabe *et al*., 1988) [30]

Skin Morphology: The microscopic structure of skin varies significantly between species, with notable differences between dogs, cats, and humans. These variations mean that knowledge of human dermatopathology cannot be directly applied to veterinary patients, requiring species-specific understanding of skin structure for accurate diagnosis. (Souza *et al*., 2009) [34] Ovine Models: Sheep serve as important large animal models for cardiovascular research, including veno-arterial extracorporeal membrane oxygenation (VA-ECMO) studies. Their tissue responses and anatomical characteristics make them suitable for investigating physiological mechanisms and testing clinical applications. (Xi *et al*., 2023) [41] (Qi *et al*., 2021) [29]

Caprine Models: Goats provide valuable models for studying infectious diseases like bovine tuberculosis. Their pulmonary anatomy allows for detailed examination of disease progression through advanced imaging techniques such as computed tomography, revealing lesion patterns and granuloma formation at the microscopic level. (Xi *et al*., 2023) [41] (Wedlich *et al*., 2022) [39]. Orthopedic Anatomy: The sheep carpometacarpal joint has been established as a translational model for human foot and ankle studies, demonstrating comparable ligamentous healing responses and tissue architecture. This anatomical parallel enables investigation of orthopedic devices and repair techniques with relevance to both veterinary and human medicine. (Xi *et al*., 2023) [41] (Gadomski *et al*., 2022) [10]. New Companion Animals (NCAs): Veterinary professionals increasingly encounter exotic pets and wildlife with unique anatomical adaptations that differ substantially from domestic species. These animals have developed specialized microscopic structures corresponding to their evolutionary niches and physiological needs. (Yllera *et al*., 2025) [43]

Conservation Species: Wildlife anatomy presents significant knowledge gaps in veterinary medicine, as most training focuses primarily on domestic species. This lack of species-specific anatomical understanding creates challenges for veterinarians working in conservation settings, where extrapolation from known species may be inadequate. (Yllera *et al*., 2025) [43]. Comprehensive Tissue Evaluation: Veterinary microscopic examination typically encompasses a wide range of tissues including abnormal lesions, endocrine glands, neural tissues, digestive organs, reproductive organs, cardiovascular structures, respiratory tissues, lymphoid organs, and skeletal components. This systematic approach enables thorough assessment across multiple organ systems. (Kim *et al*., 2024) [17]

Veterinary diagnostic cytology shares similarities with human applications but exhibits important species-specific differences. These variations reflect fundamental differences in anatomy, physiology, disease prevalence, and biological behavior of pathogens and neoplasms across species. While human cytology advances provide foundational principles, veterinary cytology must account for species-specific characteristics. (Sharkey *et al*., 2014) [32].

Table 1: Literature Comparison

Papers	Species Studied	Methodologies
Premanandan *et al*, 2019 [28].	Canine (dog) female reproductive tract.	Cytology, histopathology, sampling techniques, microscopic evaluation.
Qi *et al*, 2021 [29].	Sheep (ovine model)	Cannulation via right jugular vein and artery, real-time monitoring, blood gas analysis, complete blood count, coagulation tests, necropsy.
Wedlich *et al*, 2022 [39].	Goats	Video-guided endoscopy, intrabronchial inoculation, computed tomography (CT), digital radiography (DR).
Gadomski *et al*, 2022 [10].	Sheep (skeletally mature)	Radiography, histology, histomorphometry, histopathology.
Kim *et al*, 2024 [17].	Yucatan minipigs (Sus scrofa)	Histopathological assay, dermal scores, biochemical and toxicokinetic analyses.
Sharkey *et al*, 2014 [32].	Dog, cat, and horse.	Cytology, fluid analysis in respiratory, gastrointestinal, genitourinary, endocrine, ocular, central nervous systems.

6. Challenges and Advances in Veterinary Microscopic Anatomy

Veterinary microscopic anatomy teaching is currently seen as facing challenges on several fronts, which have forced revision of teaching methods and curriculums. Difficulties encountered are many, but some of the most important include covering a high volume of anatomy content, problems with conveying 3D relationships in a 2D environment and more generally the intrinsic difficulty of helping students visualise what they cannot see, namely microscopic structures (Gummery *et al*., 2023) [11]_(Hall *et al*., 2018) [12]. Aside from these generic barriers of good educational practice, there are some additional practical constraints within the institutions such as limited time in the curriculum for teaching anatomy, faculty deficiencies (shortage of personnel trained in veterinary anatomy) and burgeoning costs associated with acquisition or maintenance of cadaveric specimens required for teaching purposes (Gummery *et al*., 2023) [11] (Naidoo *et al*., 2020) [24].

Growing interdisciplinary in veterinary science provides a challenge and chance for microscopic anatomy. One instance of this is the new field-of-disciplines, 'vetinformatics'', derived by integrating traditional veterinary disciplines (anatomy, physiology, pathology, microbiology) with computational/data sciences techniques (Pathak *et al*., 2022) [26]. The integration across these disciplines will require to veterinary anatomists to roll-up their sleeves and step outside their comfort zone, while at the same time proving a means to address more complex research questions through the application of novel methodological approaches. There are, however, ongoing problems in the teaching of veterinary microscopic anatomy. The vast amount of information students are expected to learn, and problems associated with curriculum design (Gummery *et al*., 2023) [11] (Cheung *et al*., 2021) [6], result in learners feeling out of their depth. Decreased time spent in the anatomy laboratory has created a thirst for students to seek alternative resources, yet there may not be enough opportunities for students to test their knowledge on real specimens and the successful conversion of learning from theoretical sensory-based knowledge to practical application (Gummery *et al*., 2023) [11] (Cheung *et al*., 2021) [6]. In addition, poor application and contextualization of the clinical situation in basic anatomy teaching can undermine students' ability to transfer an anatomical knowledge base into practical care scenarios (Cheung *et al*., 2021hari) [6].

7. One Health Perspective and Comparative Anatomy

The One Health paradigm is considered as an integrated approach for a comprehensive understanding of diseases by focusing on the interface among human, veterinary and environmental health sciences. This view recognises the interaction and co-dependent relations between animals, humans and common environment in triggering infectious diseases (Johnson *et al*., 2024) [16] (Bhattacharjee *et al*., 2021) [2]. The historical development of comparative anatomy as an integrative discipline that provides a broader perspective on the role and function of different animal species in nature is an ideal match for One Health, creating unique opportunities to bring together research areas that have evolved independently until now (Johnson *et al*., 2024) [16].

The application of this comparative approach has implications not only for academic research but also with regard to practical repercussions in veterinary and human medicine. In the words of William Youatt, animal medicine is "Comparative anatomy made to bear upon pathology... brought home to practice," thus acknowledging that interspecies anatomical differences feed directly into differences in disease expression and thus treatment (Woods 2017) [40]. This view was further championed by William Lawrence when he claimed that "comparative anatomy bears the same relation to the veterinary art that human anatomy and physiology do to medicine... The peculiarities in organic structure and functions of particular genera or species lead to corresponding peculiarities in their disorders or derangements" (Woods, 2017) [40].

The comparative study of microscopic anatomy between species fills important gaps for veterinary medicine. Today veterinary professionals work with wild or exotic animals in conservation projects, zoos and animal parks, and even at their own practices, where these animals have become the new companion animals (NCAs). Nevertheless, the bulk of veterinary training is traditionally dedicated to domestic species and few veterinarians are prepared to treat wildlife or other exotic patients. This problem is exacerbated because wild species have evolved their own specific anatomical and physiological adaptations to occupy the niches into which they have diversified, inappropriate to extrapolate from either dog or cat anatomy (Yllera *et al*., 2025) [43].

The comparative anatomy of many species remains to amoeboid which hinders veterinary medicine, biological sciences and conservation. The absence of anatomical references for a variety of species, especially wild animals, create issues for veterinarians regarding suitable clinical and surgical procedures (Aversi-Ferreira *et al*., 2018) [47]. These difficulties in knowledge represent, also, a challenging obstacle for correct analysis of taxonomic relationships and construction of evolutionary trees emphasizing the importance of comparative anatomy in phylogenetic, taxonomic, ethological perspectives as well (Aversi-Ferreira *et al*., 2018) [47]. In spite of the alleged academic and scientific collapse of anatomical sciences in some cases, this field is indispensable for health in humans (Kritzky *et al*., - Rivaben *et al*.) and animals Aversi-Ferreira *et al*.(2018) [47] (Pfrimer *et al*. The approach of One Health is one way forward and "encourages research to help address fundamental questions related to One Health and One Medicine using molecular, cellular, tissue, and organ models" (Mobasheri 2015) [22] (Bhattacharjee *et al*., 2021) [2] (Johnson *et al*., 2024) [16].

Conclusion

Anatomy, at the cellular and subcellular level, remains a core discipline of veterinary science from which to bridge anatomic form and physiologic function in the study and treatment of disease. This demonstrates the value of its inclusion in the education of students at large and for practitioners and pathologists alike in all branches of comparative medicine, including human translational research from bench to bedside. However, thanks to new technology in veterinary medicine (and encompassing all medical sciences), research on microscopic anatomy will enhance our understanding with the tools provided by imaging and 3D visualization, as well as an interdisciplinary dialogue through concepts like One Health. While the field already has significant challenges like curriculum anatomy design, anatomical education, and species-specific knowledge base anatomy, the scope for expansion is vast.

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