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# Avian organoids: emerging platforms in poultry science and veterinary research

**Sittipon Intarapat[1]*, Guojun Sheng[2]***

*[1] Department of Anatomy, Faculty of Science, Mahidol University, Bangkok, Thailand; [2] International Research Center for Medical Sciences, Kumamoto University, Kumamoto, Japan.*

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## Abstract

Progress in developmental biology has advanced rapidly as the field has evolved. Recently, the generation of miniature three-dimensional organs, known as organoids, has transformed *in vitro* organism modeling. While organoids are well established in mammalian regenerative medicine, their application in poultry science is still limited. This review covers avian developmental and stem cell biology as well as organoid development across various avian species and organs. It highlights a major milestone in avian organoid technology, summarizes current methods and the derivation of organoid types—including skeletal muscle, enteroid, intestinal, respiratory and reproductive organoids—and discusses their applications in poultry and veterinary science, including infectious diseases, host-pathogen interactions, development, nutrition and toxicology. It also discusses the emergence of avian organoid technology platforms and future perspectives. Overall, this innovative technology offers significant potential for poultry and veterinary research, advancing disease modeling and precision health, aligning with the One Health approach that links animal and human health.

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## Introduction

Avian species are increasingly recognized as valuable model organisms in fields such as toxicology,[1] stem cell research[2-4] and developmental biology.[5,6] Their advantages include unique features that make avian embryos excellent models for multidisciplinary studies, allowing comprehensive investigation.[5-7] First, avian embryos can be derived from fertilized commercial eggs and incubated year-round to produce embryonated eggs. Birds are essential for meat, egg, and protein production, and they are susceptible to diseases that cause high mortality and can transmit zoonotic diseases to humans.[8] Therefore, avian embryos are valuable for studies related to human health.

Recently, organoid technology has advanced significantly in developmental biology, enabling the creation of miniaturized, self-organizing tissue structures that replicate organ functions. This technology began in 2009 with the development of intestinal organoids, or mini-guts, from Lgr5-positive stem cells in mouse intestinal crypts.[9] While most research focuses on mammals, veterinary science has fewer studies. Organoid technology allows detailed *in vitro* research into pathogen- or chemical-induced diseases which is vital for under-standing disease mechanisms. In birds (aves), the first organoids were derived from three-dimensional (D) skeletal muscle tissue of embryonic chickens—known as skeletal muscle organoids—and are used in muscle biology and tissue engineering.[10] Similarly, mammalian intestinal organoids have been extensively studied with the first chicken intestinal organoids grown *in vitro*.[11] Although organoid-derived organ systems are well documented in mammals, avian organoid derivation and culture remain poorly categorized by organ system.

This review introduces the development of avian organoid technology and its relevance to avian development and stem cell biology over time. It also categorizes different avian organoids by organ system. The review emphasizes applications of avian organoids in five key areas: infectious disease, host-pathogen interactions, developmental biology, nutrition and metabolism, and toxicology and safety.

***Correspondences:**
Sittipon Intarapat. PhD
Department of Anatomy, Faculty of Science, Mahidol University, Bangkok, Thailand
**E-mail:** sittipon.int@mahidol.ac.th
Guojun Sheng. PhD
International Research Center for Medical Sciences, Kumamoto University, Kumamoto, Japan
**E-mail:** sheng@kumamoto-u.ac.jp

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Finally, it addresses current limitations and future perspectives for avian organoids, promoting a multidisciplinary approach to enhance poultry, veterinary sciences and overall animal and human health within a One Health approach.[12]

**Methodology and limitations.** A literature search on avian organoid systems in poultry science and veterinary research was conducted using PubMed/MEDLINE, Scopus, and Web of Science. Studies on avian organoids, spheroids, 3D culture, poultry, chicken, stem cells, disease modeling, drug screening, and developmental biology from 1998 to 2026 were reviewed. Additional studies from references and reviews were included. Relevant studies on the development, characteristics and applications of avian organoids in areas such as developmental biology, toxicology, poultry and veterinary sciences were also selected. As a narrative review, studies were selected for their relevance, contribution, and support for the main ideas and for emerging applications. This review has limitations including that it was not a systematic review, possibly missing some relevant studies despite searching key databases and reference screening. The literature on avian organoids is limited compared to mammals, with differences in species, tissue sources, developmental stages, culture conditions and methods hindering direct comparison and quantitative analysis. Most evidence is from chicken models with less data on other birds. As avian organoid technology is emerging, some applications are supported mainly by early experiments or mammalian data. Interpreting conclusions in light of current progress in the field would promote standardized, cross-species comparisons for broader applications.

**Development of avian organoid technology.** The development of avian organoid systems has progressed through successive advances in tissue isolation, three-dimensional culture, and cellular differentiation, creating increasingly specialized models for poultry and veterinary research. Early avian organoid work included three-dimensional skeletal muscle models derived from chicken embryonic muscle, establishing a foundation for long-term tissue culture and tissue-engineering applications. Chromiak and colleagues subsequently demonstrated that a perfusion bioreactor could support long-term maintenance of chicken skeletal muscle organoids. The system maintained metabolic activity and growth-factor secretion, providing an early example of how bioreactor-based culture could support functional avian muscle tissue.[10] A major milestone in avian intestinal organoid research was the establishment of three-dimensional cultures from embryonic chicken intestine in a Matrigel-based system. Identification of prostaglandin E2 as a growth-promoting factor subsequently helped define the culture requirements for maintaining embryonic chicken intestinal organoids.[11] Subsequent experiments showed that microbial-derived stimuli, including *Lactobacillus acidophilus* and synthetic toll-like receptor 2 agonists, could modify organoid growth and proliferation, demonstrating the responsiveness of the cultured intestinal epithelium to environmental cues. These findings further indicated that epithelial-stromal cultures can respond to microbial-associated signals during organoid growth.[13] A subsequent advance was the establishment of crypt derived chicken intestinal organoids containing intestinal stem cells. Isolation of small-intestinal crypts and three-dimensional culture in Matrigel yielded viable, proliferative organoids that express intestinal stem cell markers and respond to external stimuli. This shift established tissue-resident stem cell-derived organoids as a complementary platform for studying avian intestinal physiology and pathology.[14] Pierzchalska and colleagues establish a reliable 3D culture protocol for epithelial organoids from embryonic chicken intestine, useful for various avian gastrointestinal research.[15] A major advance in 2020 was the generation of crypt-villus enteroids containing multiple differentiated epithelial populations, including goblet, enteroendocrine and antimicrobial cells. Adding multiple distinct epithelial populations enhanced the physiological complexity of the chicken intestinal model.[16]

The subsequent development of apical-out chicken enteroids represented an architectural advance, exposing the luminal epithelial surface while retaining epithelial and immune cell populations. This orientation provides direct access to the epithelial surface and expands the utility of enteroids for studying intestinal infection and mucosal immune responses.[17] The avian 3D culture repertoire subsequently expanded beyond epithelial organoids through a cost-effective protocol for generating fetal organ spheroids (FOSs) from brain, heart, liver, stomach and intestinal tissues. These fetal spheroids provided simplified multicellular models for examining tissue organization and organ development.[18] Regionalization of the gastrointestinal tract was subsequently incorporated into avian organoid modeling. Ileal- and cecal-derived chicken organoids subsequently enabled direct comparison of region-specific responses to *Salmonella typhimurium* infection. The contrasting bacterial replication and inflammatory responses between the two regions demonstrated the value of organoids for dissecting tissue-specific host–pathogen interactions.[19] The field also expanded beyond tissue-derived epithelial models with the generation of neural organoids from chicken induced pluripotent stem cells (iPSCs). Following poly (I : C) stimulation, these iPSC-derived neural organoids activated RIG-I-like Receptor (RLR)-associated antiviral pathways including Melanoma-differentiation-associated gene 5 (MDA5) and Laboratory of genetics and physiology 2 (LGP2), together with inflammatory and antiviral markers such as interleukin -6, interleukin -1β, and Myxovirus resistance 1 (Mx1). This study emphasized the significance

of avian organoids in infectious disease research.[20] In recent years, chicken intestinal organoids have expanded into applied poultry research, particularly for the evaluation of dietary interventions and feed-associated hazards. Organoid-based assays were used to evaluate feed additives under microbial challenge, providing a controlled system for assessing intestinal responses to dietary interventions. This study positioned intestinal organoids as practical screening platforms for functional effects of dietary interventions on gut health and disease-associated responses.[21] The same organoid framework was also applied to feed-safety research using the mycotoxin deoxynivalenol. Deoxynivalenol exposure produced measurable alterations in epithelial barrier function and permeability, illustrating the suitability of avian intestinal organoids for toxicological assessment.[22] Standardized culture procedures were also established for turkey oviductal organoids, extending avian organoid technology to the reproductive tract. The turkey oviduct model provides a species-specific system for investigating reproductive-tract epithelial biology and responses relevant to infectious challenges.[23] By 2025, avian organoid research had expanded substantially into respiratory tissues, complementing the earlier emphasis on intestinal models. Chicken- and duck-derived tracheal tissues were used to establish organoid models of the avian airway. Air-liquid interface differentiation further increased the physiological relevance of these models for examining airway epithelial biology and viral tropism.[24] Establishment of duck intestinal organoids required optimization of crypt isolation and culture conditions including adaptation of the medium to the duck system. The resulting organoids expressed markers of differentiated intestinal cell populations, supporting their use for studies of duck intestinal physiology and health.[25] More recently, adult stem cell-derived chicken lung organoids extended respiratory modeling beyond the trachea to pulmonary tissue, providing a multicellular system for investigating respiratory organization, viral infection, and pathogenesis.[26] In 2026, researchers created new organoids from various bird species including germline and kidney types. Long-term gonadal-derived germline organoids in zebra finch further expand avian organoid systems into germline-associated tissues, providing a three-dimensional context for investigating reproductive-lineage organization and development.[27] Goose kidney organoids have also been developed as a disease model for astrovirus-associated gout, renal injury and altered purine metabolism. This model illustrates the potential of avian kidney organoids for mechanistic studies of viral renal disease and evaluation of therapeutic interventions.[28]

Future avian organoid systems could incorporate immune, vascular, microbial and multi-organ components to support more precise modeling of poultry health and disease. Species-specific organoids may also strengthen One Health research by connecting avian disease biology with zoonotic, environmental, and food-health questions. By providing physiologically relevant *in vitro* alternatives to selected experimental questions, avian organoids may contribute to the 3Rs (replacement, reduction, refinement) in animal testing,[12] while supporting integrated approaches to animal, human and environmental health.[8] For instance, the avian chorioallantoic membrane has been demonstrated as a model for human chorioallantoic membrane-tumor metastasis models,[29] (fitting the 3Rs principle) and for *in ovo* flu vaccine production, suggesting a powerful bridge between ethical laboratory practices and holistic health research.[30] Figure 1 shows milestones in the development of avian organoid technology.

**Avian developmental biology and stem cell perspectives.** Organs develop from spatially and temporally coordinated groups of progenitor cells. In most cases, these progenitors are derived from different embryonic germ layers.[31] A brief account of early development leading to organogenesis is therefore necessary for proper modeling and utilization of avian organoids *in vitro*. Despite many salient, distinct features in reproductive strategies, both birds and mammals belong to a clade of vertebrates called Amniota and have very well-conserved genetic makeups and developmental blueprints.[32] Developmental processes leading to organogenesis include fertilization, cell cleavage, blastoderm/blastocyst formation, pre-gastrulation epiblast morphogenesis, gastrulation/germ layer formation, germ layer regional patterning/differentiation, germ layer integration, and organ rudiment formation.

As in mammals, fertilization in birds takes place internally at the infundibulum (opening of the oviduct) after ovulation. In chickens, the first zygotic cell division takes about 4 - 5 hr post-fertilization, and subsequent divisions proceed rapidly. In contrast to mammalian embryos, early zygotic divisions in birds are meroblastic (i.e., cytokinesis lags behind nuclear division).[33-35] After completion of cellularization at about 10 hours post-fertilization, the embryo reaches the early blastoderm stage and has a diameter of approximately 3.00 mm (in chicken), a small portion of the initial fertilized egg, which has a diameter of approximately 3.00 cm (in comparison, a mature human egg has a diameter of 0.10 mm). The blastoderm cells divide further, undergo radial intercalation and subsequently form the well-described embryonic structure in a freshly laid egg: A central area pellucida with pluripotent epiblast cells and a peripheral area opaca, which still attaches to the underlying yolk cell. The epiblast breaks its symmetry and determines the future dorsal-ventral axis, undergoes planar polonaise movement, initiates a primitive streak where mesoderm and endoderm progenitors will be internalized to form the mesoderm and endoderm germ layers, whereas the

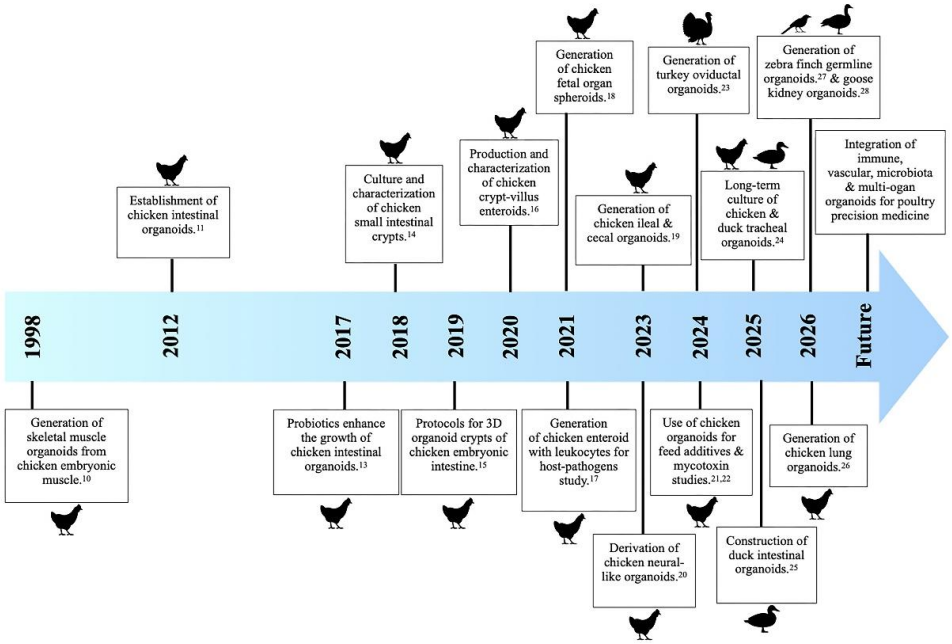



**Fig.1.** Milestones in the development of avian organoid technology. The timeline summarizes representative advances in avian organoid systems, including skeletal muscle organoids, intestinal organoids, enteroids, fetal organ spheroids, respiratory organoids, oviductal organoids, neural-like organoids, germline organoids, and kidney organoids. Superscript numbers in the figure correspond to the cited references. Created by the authors with assistance from Pages version 15.3.1; Apple, Vancouver, USA).

remaining non-internalized epiblast cells will contribute to neural ectoderm, placode, neural crest and epidermis. The internalized mesoderm cells are subsequently patterned to form axial (notochord), paraxial (somite and its derivatives), intermediate (urinary and reproductive tract), lateral plate (body cavity linings and their derivatives) and extraembryonic mesoderm. The internalized endoderm cells are subsequently patterned to form the definitive endoderm (the foregut, midgut and hindgut) and their derivatives (lung, liver, pancreas, intestines, etc.).

As mentioned earlier, most of the organs in a mammalian or avian body require contributions from cells with different germ layer origins as well as from distinct sub-lineages of the same germ layer. For example, muscle development needs somitic mesoderm-derived myogenic cells, lateral plate mesoderm-derived vessel cells and ectoderm-derived motor neuron input. Lung development requires ventral foregut endoderm-derived lung epithelium cells, mesoderm-derived endothelial cells, smooth muscle cells, macrophages and neural crest (ectoderm)-derived neurons and glial cells. Small intestine development receives input from endoderm-derived midgut epithelium, lateral plate mesoderm-derived smooth muscle, vessel and immune cells and ectoderm-derived enteric neurons.

Current achievements in avian organoid research primarily rely on tissue resources from post-organogenesis stages of embryonic development, thus still requiring *in vivo* work and conflicting with the 3Rs principle. In contrast, mammalian organoid research is mainly focused on pluripotent stem cell-based *in vitro* models, with the potential of completely avoiding animal use, ensuring experimental reproducibility and facilitating scaling-up for commercial use. The gap between avian and mammalian organoid research is primarily based on the lack of optimization of *in vitro* culture and differentiation protocols for various types of embryonic stem cell (ESCs) in birds. As mentioned above, pre-gastrulation (epiblast stage), gastrulation (primitive streak stage) and post-gastrulation (germ layer regional specification and integration) development in birds and mammals are very similar in morphogenesis and genetic regulation. A totipotent cell *in vitro* (equivalent to a morula-stage cell in mammals) would correspond to the blastoderm cell at the early blastoderm stage in avian development. A naïve ESC would correspond to the peri-ovipositional stage epiblast, a formative ESC to the epiblast from a freshly laid egg and a primed ESC to the epiblast at late-stage Hamburger and Hamilton (HH)1 and HH2,[36] before gastrulation and pluripotency loss. Stem cell-based approaches currently being used for the mammalian organoids are likely applicable to avian ones in the near future.[37]

**Types of avian organoids and applications.** This section presents organoids according to their distinct cellular and tissue origins. It also covers their applications in poultry science and veterinary research across five areas: Infectious diseases, host-pathogen interactions, developmental biology, nutrition and metabolism, and toxicology and safety (Fig. 2).

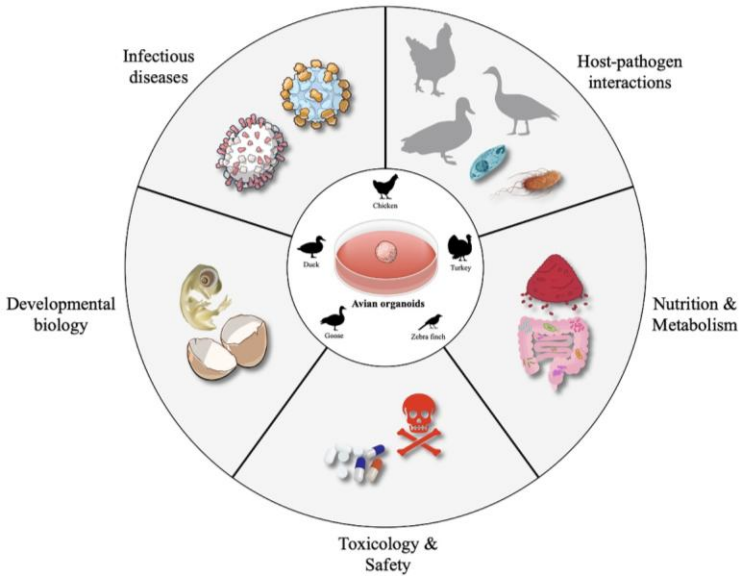



**Fig. 2.** Applications of avian organoids in poultry science and veterinary research. (Created by the authors with assistance from bioart.niaid.nih.gov/ and togotv.dbcls.jp/en/pics.html licensed under CC-BY 4.0).

**Skeletal muscle organoids.** As previously noted, this type of organoid was the initial one created from chicken embryonic muscle. These three-dimensional skeletal muscle organoids, developed in tissue culture by fusing dividing myoblasts into parallel, unbranched myofiber networks, serve as an *in vivo*-like model to study how growth factors, tension, and space flight influence muscle cell growth and metabolism.[10] This type of organoid is mainly used in developmental biology, particularly in tissue engineering and gene therapy.

**Enteroids and intestinal organoids.** Two types of gastrointestinal organoids are discussed: Enteroids and intestinal organoids. Nomenclature-wise, enteroids are distinct from intestinal organoids because they consist only of epithelial cells and are derived from isolated intestinal epithelium, crypts or single epithelial cells.[15] Enteroids can be obtained from various tissues and organs including intestinal crypts, villi and mucosa from the chicken duodenum, jejunum, and cecum. Their uses cover all five aspects. For infectious diseases, these organoids were used to evaluate the effects of chemicals such as lipopolysaccharide from *S. typhimurium* and Monensin (an ionophore antibiotic and anticoccidial) in cases of Salmonellosis and Coccidiosis, respectively.[16] The chicken enteroids were used to study host-pathogen interactions, with a focus on barrier function and intestinal cell biology. They provide a novel, physiologically relevant *in vitro* platform for analyzing pathogen interactions with the avian gut. These enteroids are also ideal for high-throughput testing of paracellular transport and epithelial integrity. Moreover, crypt-derived organoids from chicken intestines were created, with optimized protocols for cell growth, enrichment, passaging and cryopreservation. The research also examined immune responses and innate immunity mechanisms.[17,38-40] In developmental biology, 2D enteroids are reportedly used in high-throughput experiments to evaluate paracellular transport, gut barrier function and tissue repair.[39] In modern poultry research, chicken enteroids are essential for evaluating intestinal health, verifying alternative feed additives and mapping nutrient metabolism.[16,21] Applications in toxicology and safety: Chicken intestinal stem cell-derived enteroids are utilized in poultry science for toxicological screening and safety evaluations, as they replicate the cellular structure and physiological functions of chickens *in vivo*.[16,22,39]

The second category includes intestinal organoids used as disease models for diverse infectious diseases such as salmonellosis,[19,21,41-43] coccidiosis,[44,45] avian influenza,[46,47] spondylitis and bacterial osteomyelitis in chickens,[48] and waterfowl parvovirus in ducks,[49] suggesting a platform for a reliable infection model for viral research in poultry. Research on host-pathogen interactions in organoids includes studies of immune responses,[46,49] innate immunity,[15,21,42] host-bacteria,[13,41,48] and host-parasite interactions and barrier function.[50,51] Additionally, intestinal organoids are utilized in developmental biology to examine intestinal integrity,[14] tissue and crypt development, differentiation,[52-54] barrier function,[50] intestinal stem cells and gut biology.[11]

To advance poultry health science, researchers have used intestinal organoids to study nutrition and metabolism through various approaches including thermal stress,[55] nutrition,[25,55] feed and probiotic additives,[13,21,56] microbiome interactions,[56,57] poultry production,[13,57] gut health,[57] and intestinal growth.[58] These studies support that integrating intestinal organoids can increase poultry production yields. Similar to enteroids, researchers have also developed toxicology and safety methods using

intestinal organoids including mycotoxin toxicity, food safety,[22,50] drug screening and development.[58]

**Respiratory organoids.** The initial airway organoid is created from avian trachea tissue, including from chicken and duck. It supports long-term growth of avian respiratory epithelial cells that mimic the natural respiratory lining. These organoids are useful in infectious disease research especially for studying pathogens such as highly pathogenic avian influenza viruses that threaten poultry.[24] They have also been employed to examine host-pathogen interactions, notably highly pathogenic avian influenza virus (HPAIV) tropism.[24] A year later, lung organoids were developed similarly to tracheal ones, focusing on respiratory diseases.[26] Both types of organoids are used in toxicology and safety studies including antiviral testing.[26] Additionally, nasal turbinates have been used to isolate respiratory tract organoids as both lung and nasal tissues from chicken and buzzard have served as sources for airway organoids for infectious disease research such as avian influenza and zoonotic disease monitoring.[59]

**Reproductive organoids.** Reproductive tracts have become a focus in avian organoid research. Researchers first created reproductive tract-derived organoids in chickens.[60] Researchers have used these organoids in reproductive biology studies, including receptor functions and cell interactions such as Utero-vaginal junction-sperm interactions.[60] Notably, they showed that avian oviductal organoids enriched in sperm storage tubules release extracellular vesicles when co-cultured with avian sperm. In infectious disease research, avian influenza was studied using a turkey model,[23,61] and the first turkey oviductal organoid protocol was developed.[23] These organoids confirm the cellular identity and regional features of turkey oviduct epithelium, supporting their use as a reliable *in vitro* model for avian reproductive research and avian influenza virus-host interaction studies.[61] Interestingly, the emphasis has moved from reproductive tracts to reproductive organs. The initial germline organoids were created from zebra finch embryonic gonads mainly to progress developmental biology by examining germline development in birds.[27]

**Other organoids.** Advances in stem cell biology, especially iPSCs, have led to the creation of neural-like organoids derived from chickens. Researchers used chicken iPSCs to develop organoids with neural-like cells, employing PiggyBac-transactivation domain-7 factors (PB-TAD-7F).[20] These avian iPSC-based organoids can serve as valuable tools for assessing infectious disease risks in bird species.[20] Consequently, these neural-like organoids offer promising avenues for studying infectious diseases such as avian influenza as well as host-pathogen interactions—such as innate immunity—and disease risk assessment. Recently, avian organoid technology has progressed to creating kidney organoids from a goose. These Goose Kidney Organoids, developed from embryonic kidney tissue, are used to investigate a newly identified bird pathogen that causes deadly gout in goslings, marked by kidney damage and high death rates.[28] Goose Kidney Organoids serve as a physiologically relevant model for understanding Goose astrovirus pathogenesis.[28] They can be used to study astrovirus-caused infectious diseases and apply not only to geese but also to other species such as chickens, turkeys, ducks and other fowl. This section concludes with a discussion of two other organoid types: gut contractile- and FOSs. The gut contractile spheroids were derived from the muscle layer of the chicken embryonic hindgut. The research focused on developmental biology aspects of gut formation, emphasizing how rhythmic activity coordination among interstitial cells of Cajal and smooth muscle cells is controlled and maintained during gut development.[62] Finally, FOSs were generated from chicken embryos. The FOSs were derived from organs including the brain, heart, liver, stomach and head epidermis of 12-day-old embryos as well as the lung and intestine of 14-day-old embryos. They were grown in an anchorage-independent manner and recapitulate many cellular and structural aspects of their organs *in vivo*.[18] They serve as developmental biology models for studying disease mechanisms, cancer and invasion. Table 1 summarizes avian organoid platforms and their applications.

**Conclusion and future perspective.** Emerging avian organoid technology platforms integrate disciplines including developmental biology, stem cell research, poultry science and veterinary medicine. Improvements in 3D culture systems and avian stem cell- and tissue-derived organoids allow the use of diverse avian organoids, including skeletal muscle, enteroids, intestinal, airway, oviductal, germline, neural-like, kidney organoids as well as gut contractile spheroids and FOSs. These platforms facilitate research on cellular differentiation, tissue development, epithelial function, host-pathogen interactions, immune responses and disease models in avian species vital to poultry and veterinary science.

From a developmental and stem cell biology perspective, avian organoids can bridge the gap between 2D cell cultures and *in vivo* systems. Their versatility allows them to recapitulate the structural and functional features of essential organs, capturing developmental processes and disease-related issues. This aligns with 3R principles, especially replacement, where organoids can serve as alternatives to animal experiments. Currently, research on avian organoids is limited to certain organ systems and species. Challenges such as tissue complexity, variability in standardization, and reproducibility still need to be addressed. To effectively translate *in vitro* organoid findings into *in vivo* applications, further validation is necessary. Establishing reproducible protocols is crucial for developing different types of avian organoids across various bird species.

**Table 1.** Avian organoid platforms and their applications in poultry science and veterinary research.

| Type of organoids | Origin | Species | Applications | References |
|---|---|---|---|---|
| **Skeletal muscle organoids** | Embryonic muscle | Chicken | Developmental biology: tissue engineering; gene therapy | 10 |
| **Enteroids** | Tissue: Intestinal crypts; villi; mucosa<br>Organ: Duodenum; jejunum; cecum | Chicken | Infectious diseases: Salmonellosis; Coccidiosis | 16 |
| | | | Host-pathogen interactions: barrier function & integrity; immune responses, innate immunity | 17, 38 ,39, 40 |
| | | | Developmental biology: epithelial biology | 39 |
| | | | Nutrition & metabolism: intestinal gut health; feed additives; nutritional supplements | 16, 21 |
| | | | Toxicology & safety: chemical & pharmaceutical screening; bioactive compounds | 16, 22 ,39 |
| **Intestinal organoids** | Organ: Jejunum; ileum; cecum<br>Embryonic intestines | Chicken<br>Duck | Infectious diseases: Salmonellosis; Coccidiosis; Avian influenza; waterfowl parvovirus; spondylitis; bacterial osteomyelitis | 19, 21, 41, 42, 43, 44, 45, 46, 47, 48, 49 |
| | | | Host-pathogen interactions: immune responses; innate immunity; host-bacterial & parasite interactions; barrier function | 13,15, 21, 41, 42, 46, 48, 49, 50, 51 |
| | | | Developmental biology: intestinal integrity; tissue & crypt development; differentiation; barrier function; intestinal stem cells; gut biology | 11, 14 ,50 , 52, 53 ,54 |
| | | | Nutrition & metabolism: thermal stress; microbiome interactions; nutrition; feed & probiotic additives; gut health; poultry production; intestinal growth | 13, 21, 25, 51, 55, 56, 57, 58 |
| | | | Toxicology & safety: mycotoxin toxicity; food safety; drug screening & development | 22, 50, 58 |
| **Tracheal organoids** | Trachea | Chicken | Infectious diseases: Avian influenza | 24 |
| | | Duck | Host-pathogen interactions: HPAIV tropism | 24 |
| **Lung organoids** | Lung | | Infectious diseases: Avian influenza; respiratory disease | 26 |
| | | | Toxicology & safety: antiviral treatment & testing | 26 |
| **Airway organoids** | Lung; nasal turbinate | Chicken<br>Buzzard | Infectious diseases: Avian influenza; Zoonotic disease surveillance | 59 |
| **Oviductal organoids** | Oviduct & reproductive tract | Turkey | Infectious diseases: Avian influenza | 23, 61 |
| | | Chicken | Reproductive biology: receptor studies; cell-cell interactions | 60, 61 |
| **Germline organoids** | Gonads | Zebra finch | Developmental biology: germline development | 27 |
| **Neural-like organoids** | Induced pluripotent stem cells (iPSCs) | Chicken | Infectious diseases: Avian influenza<br>Host-pathogen interactions: innate immunity; disease-risk research | 20 |
| **Kidney organoids** | Embryonic kidney | Goose | Infectious diseases: astrovirus | 28 |
| **Gut contractile spheroids** | Muscle layer of embryonic hindgut | Chicken | Developmental biology: gut development | 62 |
| **Fetal organ spheroids** | Fetal organs: brain; heart; liver; stomach; epidermis; lung; intestine | Chicken | Developmental biology: developmental model; disease mechanism; cancer; invasion | 18 |

Future prospects for avian organoids focus on evaluating their reliability and practicality. Incorporating genome editing can enable more precise, targeted approaches in poultry medicine. Additionally, omics research can enhance our understanding of cellular heterogeneity and differentiation, providing deeper functional insights. Organoids can also be preserved long-term in biobanks for future research with avian genetic resources available for conservation and comparative studies. Notably, combining avian organoid technology with regenerative medicine—specifically engineering tissue-specific models for translational applications—poses a significant challenge.

Finally, an in-depth understanding of avian organoid systems complements traditional poultry science. This technology may enhance our understanding of the link between infectious diseases in animals and humans such as zoonotic pathogens found in the environment, thereby, supporting the one health approach. A network of developmental biologists, veterinarians, avian experts and geneticists would facilitate translating this platform into tangible benefits for both animal and human health. Overall, avian organoids are increasingly contributing to the field serving as a valuable alternative platform that advances knowledge in poultry science and veterinary medicine while supporting a translational approach to health and sustainability for animals and humans.

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## Conflict of interest

There is no conflict of interest to be declared.

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