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Opportunities and difficulties of comparative anatomy in vertebrate palaeontology

Bharti S, Vaish R, Singh RP, Garg A, Shakya P, Lade D, Khare V, Maravi S and Pradeep Kumar Singh

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Abstract
Over the past decades, there has been a notable surge in research activity and publications in vertebrate palaeontology, which is crucial for comprehending the evolutionary processes of backboned creatures. Numerous other biology subdisciplines have embraced this teaching strategy since it has been demonstrated to promote deeper learning that may be integrated across biology sub disciplines. Comparative vertebrate anatomy is a vibrant and active field of biology that continues to evolve However, still lacks a basic set of principles. Integrating palaeobiology and evolutionary biology while having a solid grasp of which evolutionary issues can be addressed in light of the fossil record is the main problem facing paleontology in the ensuing decades. It has historically been difficult for paleontologists and evolutionary scientists to reconcile the knowledge of macro- and micro evolutionary processes.

Keywords: Palaeontology, comparative vertebrate anatomy, evolution, structure, bone

1. Introduction

Palaeontology has emerged as the most transparent window into the lengthy history of life on Earth since early polymaths recognized fossils as the remains of once-living animals. One of the oldest subfields of the biological sciences, the study of anatomical structures has helped us comprehend the role of organisms and provided us with knowledge about the development, operation, and evolution of phenotypes (Wanninger, 2015) [23]. Many scientists used the return of comparative anatomy in the late 18th and early 19th centuries to promote their evolutionary ideas, which held that animals' forms are determined by both their shared ancestry and their battle for survival (form-function), (Blits, 1999) [2].

Comparative vertebrate anatomy has advanced significantly in palaeontology in recent years. According to Michael *et al.* (2017) [16], foundational notions offer a collection of broad principles that are significant in all aspects of the living world and their application. Similar to research on the diversity of living things today in biology, palaeontology continues to place a strong emphasis on the dispersion and diversity of extinct life forms. It depends on three axes interactions in space (spatial interactions), time, and biological organization level any particular aspect of vertebrate anatomy is by its very nature integrative. Cell-to-cell and ecosystem-level interactions are examples of spatial interactions. Additional spatial interactions could exist, but they are probably uncommon and unlikely to have influenced the evolution of anatomy. The time spans that are documented in the fossil record range from millions of years to a few hours, which is the amount of time needed for the anatomy to grow embryologically. The total of evolutionary changes at various levels of biological organization referred to as the anatomical level in this context is vertebrate anatomy (Danos *et al.*, 2022) [7].

2. Core Priciples

The four primary core principles of comparative vertebrate anatomy that, perhaps surprisingly, align with those defined for biology in general in terms of vision and change are as follows:

Bharti S
Department of Veterinary Anatomy, College of Veterinary Science and Animal Husbandry, Jabalpur, Madhya Pradesh, India

Vaish R
Department of Veterinary Anatomy, College of Veterinary Science and Animal Husbandry, Jabalpur, Madhya Pradesh, India

Singh RP
Office of Directorate of Research Services, NDVSU, Jabalpur, Madhya Pradesh, India

Garg A
Department of Veterinary Anatomy, College of Veterinary Science and Animal Husbandry, Jabalpur, Madhya Pradesh, India

Shakya P
Department of Veterinary Anatomy, College of Veterinary Science and Animal Husbandry, Jabalpur, Madhya Pradesh, India

Lade D
School of Wildlife Forensic and Health, NDVSU, Jabalpur, Madhya Pradesh, India

Khare V
Department of Animal Genetics and Breeding, College of Veterinary Science and Animal Husbandry, Jabalpur, Madhya Pradesh, India

Maravi S
Department of Animal Genetics and Breeding, College of Veterinary Science and Animal Husbandry, Jabalpur, Madhya Pradesh, India

Pradeep Kumar Singh
Department of Livestock Product & Technology, College of Veterinary Science & AH, NDVSU, Jabalpur, Madhya Pradesh, India

Corresponding Author:
Singh RP
Office of Directorate of Research Services, NDVSU, Jabalpur, Madhya Pradesh, India

(A) Evolution

Evolution has produced vertebrate animal types. Evolutionary mechanisms account for the unity, diversity, and variation of vertebrate anatomy. One process that affects an organism's general phenotypic is natural selection. Because their functional performance affects survival, anatomical features that could increase an animal's fitness are therefore probably being selected for. Because of this, a lot of animal morphologies are closely linked to their roles in their surroundings.

The notion that anatomical features differ within a species is crucial to the hypothesis of evolution by natural or sexual selection (Charlesworth *et al.*, 2017) [5]. Some anatomical shapes, however, are limited by their evolutionary history or by their structural, functional, or developmental connection with other components. Evolutionarily integrated traits are those that change during the course of evolution (co-evolve) between species. In order to compare species forms and get a better grasp of vertebrate anatomy, vertebrate palaeontologists offer frameworks.

(B) Structure and function

The connection between an organism's shape and lifestyle is among the easiest parts of understanding palaeontology. Because demands vary over time and evolution acts on what already exists, an anatomical component may not have the best form for its current function at any particular time. Nevertheless, vertebrate morphology is heavily selected to fulfill its functional demands. The rules of physics must govern how anatomical structures work. Therefore, the proper background in physical laws must be provided, depending on the anatomical systems an educator chooses to explain this notion. Functional morphology is the study of the connection between a structure and its function at a specific moment in time.

There are only a limited number of answers to functional demands since natural selection only affects structures that are already in place. Furthermore, structures must typically fulfill several roles, frequently with conflicting demands, and are seldom chosen in isolation but rather as a component of an integrated organism. Because function is not constant and slight variations in function necessitate structural variation, or because the functional demand is so important to organismal fitness that redundancy is required, natural selection can also result in the existence of multiple structural solutions to a single functional demand. Consequently, in order to comprehend the variety of vertebrate structure over time and space.

(C) Morphological development

Phenotypes, which are the outcome of genotypes carried out by a developmental program, are the expression of vertebrate anatomy. Modularity, which permits some phenotypic features to change significantly while yet remaining integrated in other ways, can result in significant phenotypic alterations. The ability of traits, genotypes, and developmental pathways to be modular (independent) and have different degrees of structural and/or functional integration (co-variance) is a fundamental aspect of morphological development. A developmental module will typically continue to develop as a single unit even if it is moved to a petri dish or another area of the embryo (Schlosser and Wagner, 2004) [20].

The basic organizing principle of vertebrates and the majority of animal bodies. Everybody segment, such as the pharyngeal arch or the vertebral body, is a module. A region's several vertebral bodies, such as the lumbar or thoracic, also work together to form a module. The segments are functionally integrated in certain cases, such as the spinal column of mammals, which limits significant phenotypic alterations (Galis *et al.*, 2014, Varela-Lasheras *et al.*, 2011) [10, 22]. To allow for an evolutionarily new connection with the swim bladder and inner ear, some modules, such as the ostariophysan Weberian apparatus, undergo significant structural modification (in comparison to the remaining segments) (Bird *et al.*, 2020) [1].

(D) Integration

The idea of integration is significant not only because it can provide insights into biological processes at the genetic, functional, or ecological level, but also because it is a practical learning tool and a skill that students will need once they enter the workforce (Caratozzolo *et al.*, 2021) [4]. The opposite is also true: we can learn about the patterns of anatomical evolution by studying biological processes at the genetic, functional, or ecological level. Therefore, as integration mirrors actual biological processes, it is a vital core notion. Anatomical structures are integrated modules that grow, work, and change over time. These processes take place across biological levels of structure, time, and location.

3. Palaeontology and Evolution

The bones of extinct animals, idealized animal kinds that never existed, a ruse to disrupt the natural order, and a test of one's faith in God were some of the hypotheses put forth regarding the nature of the fossil items. The discovery by Cuvier in the early nineteenth century that imprints found in stones were remnants of ancient creatures is credited with establishing palaeontology as a scientific discipline. As a subfield of comparative morphology, paleontology evolved into the zoology, botany, and eventually biology of extinct species (Young, 1992) [25].

The idea that palaeontology is an evolutionary science, with changes in fossils over time reflecting evolutionary changes in extinct animals and their surroundings, is widely accepted today. This wasn't always the case; while fossils were widely acknowledged as proof of extinct life forms and their evolution across time, they weren't as widely acknowledged as proof of ongoing advancements or the pursuit of perfect life on Earth.

4. Contributions of palaeontology

Providing time as a dimension to evolutionary change in the history of vertebrate palaeontology is an evident contribution of palaeontology. The discovery of features no longer present in living forms or forms of extinct organisms constitute a second contribution to palaeontology; this intriguing and little-understood exercise in complex pattern recognition lies at the core of descriptive palaeontology (Budd, 2000) [3].

A. Inception of Vertebrate Palaeontology

In the tree of animal life, vertebrates can be found at several levels. For instance, it is debatable if vertebrates are descended from a creature that resembles a larval deuterostome or from a highly complicated urbilaterian. Regarding the derivation of vertebrates from their closest invertebrate progenitor, which is generally believed to have been a chordate invertebrate. The hypothesis that the emergence of a definitive neural crest was crucial to the evolutionary origin of the vertebrate body plan is one of our main conclusions, which is supported by recent developments in biology and palaeontology (Hall, 1999) [12].

Amphioxus and vertebrate homologies, as demonstrated by neural crest-related tissue and certain brain areas. Thankfully, the molecular and micro anatomical research have resolved a large portion of this disagreement. The neural crest cells, which express a distinctive set of genes, begin their development at the interface between the neural plate and epidermis in vertebrates. Several of these neural-crest-specific genes have homologues expressed by a similarly positioned population of cells throughout amphioxus embryology (Williams and Holland, 1996) [24].

B. Impact of new data on ideas about early Vertebrate Evolution

I. Marine versus fresh water origin of the vertebrates

The question of whether the invertebrate-vertebrate transition occurred in freshwater or the ocean has long been a source of debate. The traditional argument in favor of a marine origin for the vertebrates is definitively settled because it is now known that Lower Cambrian vertebrates existed in unquestionably marine habitats long before any known freshwater species (Halstead, 1985) [13].

II. The evolutionary origin of vertebrate paired fins

Only the gnathostomes and a few ostracoderm families among the agnathans were known to have lateral appendages in vertebrates until recently. Heterostracans with pectoral extensions of the head shield, anaspids with lateral folds, and osteostracans with pectoral appendages are examples of ostracoderms with lateral appendages. Only the pectoral appendages of osteostracans and gnathostomes may have had a common ancestor, as these appendages were evidently independently evolved within a certain ostracoderm group (Forey and Janvier, 1993) [9].

III. Mineralised teeth and dermal skeleton evolution

Although some have argued that the earliest mineralized skeletons of vertebrates were denticles in the oropharyngeal region, it has long been believed that vertebrate teeth developed from modified portions of the mineralized dermal skeleton (Smith and Coates, 1998) [21]. The revisionist theory that teeth arose before the mineralized dermal skeletons throughout vertebrate evolution is supported by the existence of teeth in euconodont animals and perhaps mineralized pharyngeal denticles in Yunnanozoon and Haikouella.

IV. Insights into feeding of early vertebrates

Filter feeders, invertebrate chordates use cilia to beat water containing food particles into the pharynx. The endostyle produces mucus, which retains the food particles, while the pharyngeal slits allow the water to exit. A stronger contractile pumping of the pharynx or a ciliary current may have pulled water into the mouth. The hypothesized flexibility of the pharyngeal arch skeleton suggests the latter way of pumping. Although they haven't been seen in the fossils, pumping by pharyngeal contraction also suggests that the flow system contained anti-reflux valves. Previously, it was generally believed that the earliest vertebrates used a strong, muscular velum to push water through their pharynx.

V. Controversy over anterior segmentation in chordates:

Regarding the anterior skeletal, muscular, and nervous systems, the contentious issue of vertebrate head segmentation can be reduced to a number of questions, such as which of these tissues is segmented, if any, whether one is more fundamentally segmented than the others, and the number of head segments. If, as segmentalists assert, such segmentation existed in early vertebrates (Holland, 2000) [14]. The evolution of chordates from metameric predecessors (such as an annelid-like creature) is reinforced. On the other hand, anti-segmentalists favor scenarios that generate chordates from non-metameric or oligomeric progenitors because they think that vertebrate head segmentation, if it exists at all, is a derived characteristic.

5. Prospects for further advances in understanding early vertebrate evolution

It is probable that palaeontologists will continue to discover highly significant early vertebrate fossils, but in ways that are difficult to foresee. At least for the foreseeable future, biological advancements in our understanding of the origin and early development of vertebrates are easier to predict than palaeontological advances. For instance, ongoing microanatomical research on the amphioxus larval nervous system is starting to suggest the existence of a limbic system (Zimmer, 2000) [26] and should eventually disclose the intricate anatomy of the hindbrain. Greater focus on the gastrula and neurula stages of higher deuterostomes can help comparative molecular genetics shed light on the evolutionary genesis of important developmental traits.

6. Challenges for paleontological research

In order to better comprehend the evolutionary processes that resulted in existing life forms and the communities they create, it is imperative that we continue to incorporate new data and findings into the larger evolutionary picture. Significant occurrences in the history of life, such as the emergence, adaptive radiation, and extinction of the main clades, are hence long-term patterns that can only be completely comprehended using the deep-time perspective that paleontology offers. In paleontology, this remains a significant frontier. An especially striking example comes from recent studies on the emergence and early diversification of tetrapods (Clack, 2009) [6]. The fossil record's patterns of extinction and diversification not only show the biosphere's history but also provide clues about what might happen if there are significant environmental changes in the future. The biological effects of the five great extinctions that have occurred in the last 540 million years or so, as well as the physical mechanisms that caused them, are currently being investigated by numerous researchers. At a time when worries about the effects of anthropogenic environmental change are growing, this is a particularly pertinent area of study.

Both the general public and the scientific community have given the problem of climate change a lot of attention in recent years. Although scientists generally agree that biological systems are significantly impacted by climate change, little is known about how ecosystems and individual species react to these changes. Paleontological research can play a significant role in each of these fields. Stable isotopes are one of many geological, biological, and chemical data sources that have been integrated to enable palaeoclimatic modeling. In order to evaluate future changes in the biosphere, a better understanding of the connection between climatic change and the diversification and extinction of ancient creatures and communities offers case studies.

The distinctive contributions that palaeontology can offer to our knowledge of the history of life, such as the identification of significant groups of hitherto undiscovered organisms, the study of new body plans, the investigation of rates of speciation and extinction, and the origins and subsequent modifications of marine and continental ecosystems, are what make it so strong. According to Dunne *et al.* (2014), the combination of geological data and information from the fossil record will continue to yield important new insights on such episodes in the history of life on Earth. Keeping up with the revolutionary changes in the other natural sciences and utilizing them to their fullest potential in order to preserve paleontology's position as the principal interpreter of the history of life on Earth are two other significant difficulties facing the field. Nowadays, computer modeling is used in state-of-the-art paleontological research to test theories about biological characteristics of extinct taxa in cases where there are no living relatives or even close analogs. Testing the locomotor skills of big, bipedal, non-avian dinosaurs is a sophisticated example (Hutchinson, 2004) [15].

CT scanning and similar imaging methods (such as neutron scanning) have created intriguing new opportunities for non-destructive studies of fossil structure during the past three decades. Although micro and even nano level imaging has recently been feasible, these studies were initially carried out on medical CT units with rather poor resolution (Sanchez *et al.*, 2012) [19]. Another important tool for researching the hard tissues of fossils is histology (Reisz *et al.*, 2013) [18]. This method has made it easier to study growth trends and reconstruct metabolic rates in extinct vertebrates, in particular (Padian *et al.*, 2004) [17].

A new field of study has emerged as a result of recent developments in our knowledge of the connection between development and evolution in living organisms. For instance, the early diversification of multicellular organisms has been greatly illuminated by the understanding of developmental control based on genomes and geochemical data for palaeo-environmental reconstruction (Erwin *et al.*, 2011) [8]. For the first time, theories on the growth and development of ancient species may now be tested using developmental data from living forms. Investigations of historical evolutionary events using molecular and developmental studies on living creatures are examples of cutting-edge research in this field (Gehrke *et al.*, 2015) [11].

7. Conclusion

Integrating palaeobiology and evolutionary biology while having a solid grasp of the evolutionary issues that can be addressed in light of the fossil record will be the main problem facing paleontology in the ensuing decades. Since reductionist explanations of significant evolutionary events do not meet the current requirements of contemporary evolutionary biology, balance is essential. Proposing straightforward theories based on a single causal relationship between biological or geological processes and complex big phenomena, like the co-evolution of terrestrial plants and animals or significant extinction events, is in many ways unhelpful. The intricate relationships between biological and earth systems that resist easy explanations have been made clear by modern evolutionary biology. For a long time, palaeontologists have struggled to bridge the gap between their knowledge of macro and micro evolutionary processes.

Conflict of Interest

The Author(s) declare(s) that there is no conflict of interest

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8. Reference

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