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VERTEBRATE ZOOLOGY

— Basic Anatomy and Dissection Guide —

Napat Ratnarathorn and Chalita Kongrit

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Foreword

The study of vertebrate comparative anatomy is, or should be, core for students of biology, zoology, and veterinary medicine, but can also greatly benefit medical students. By highlighting the similarities and differences in morphology across the vertebrates, comparative anatomy provides the foundation from which to understand how structures and systems evolved through time, prompts questions about the relationship of structure to function, puts studies of human (and animal) embryonic development into context, and provides a firm basis for an understanding of human anatomy. Nowadays, at least in western countries, there is a tendency for greater emphasis on cellular and molecular biology, to the detriment of a more comprehensive understanding of how *all* levels of biological systems (cells, organs, systems) interact within an organism.

Modern imaging techniques like micro-CT scanning can greatly enhance the study of animal structure, but nothing can match the experience of hands-on dissection. Dissection alone gives the student a comprehensive three-dimensional appreciation of how organs, blood vessels, nerves, and other tissues are packed within the body cavity; an understanding of different tissue types and textures; an appreciation of muscle bundles, tendons, and fibre directions; and an appreciation for structures like fascial sheets and sheaths that rarely feature in textbook descriptions.

In this book, the two authors (Drs Napat Ratnarathorn and Chalita Kongrit) have assembled a comprehensive guide to the dissection of a range of different vertebrates using examples that will be familiar to students in Thailand and neighbouring regions. The anatomy is illustrated by fully labelled original photographs of specimens (external morphology) and actual dissections, supplemented by line drawings, Fun Facts, and thought-provoking questions. The authors also do not shy away from addressing ethical aspects of animal-based research and rightly encourage their students to consider these issues in their work.

I congratulate the authors on the production of a comprehensive guide to vertebrate dissection that has a distinct regional voice, and I hope that all students using this book will enjoy the journey on which it will lead them.

Susan E. Evans
Professor of Vertebrate Morphology & Palaeontology
University College London.
August 2023

Foreword

This *Vertebrate Zoology: Basic Anatomy and Dissection Guide* by Napat Ratnarathorn and Chalita Kongrit represents an important milestone in the Department of Biology of Mahidol University. Having taught in this department for many years, I know that most courses have faced the problem of providing suitable texts and reading materials for students that are not fluent or at home in English. Most undergraduate curricula in Thailand are taught in the Thai language, but the top universities are increasingly promoting English as a teaching language, because in most professions or graduate programs to which students are headed fluency in English is essential for success. This *Vertebrate Zoology* text will admirably enhance the preparation of students for later studies and work.

Selecting an English language text for non-English-speaking students can be a difficult problem in itself. When I took undergraduate comparative anatomy long ago, we used L. H. Hyman's *Comparative Vertebrate Anatomy*, and also had to read A. S. Romer's *The Vertebrate Body*. These classic texts, whose authors ranked among the greatest zoologists of the 20th century, have been updated and revised, but now there are many other anatomy texts available to choose from. The main problem in choosing one for Thai students is that their English reading level is usually insufficient for mastering 500 pages of text per course in one semester.

Another problem that often appears is that the content of texts written primarily for American or British students is not entirely suitable for students in faraway places like Thailand, with their different cultures, fauna, and flora. These problems have been admirably solved by the authors of this *Vertebrate Zoology*. Not only have they written a concise and easily understandable text, but they have chosen representative subjects for dissection more familiar to Thai students. The species selected representing the major classes of vertebrates include the Nile tilapia (now common in Thai waterways and a major food fish), the Chinese edible frog, the monocled cobra, the domestic chicken, and the laboratory mouse. The domestic chicken originated from the wild jungle fowl of South and Southeast Asia, whose calls are heard throughout the forests of Thailand.

Vertebrate Zoology includes some features that are usually not well covered, if at all, in similar Western texts. Chapter 1 covers "Tools and equipment for animal dissection" in considerable detail, and ends with a sensible discussion of proper dress and safety measures during lab work. Chapter 2 follows with a brief review of the diversity of vertebrates, with an up-to-date explanation of modern phylogenetics. The next five chapters cover basic anatomy of the vertebrate classes, and include exquisite color photographs of representative species and labelled anatomical features of the main subjects.

The next chapter is a thoughtful discussion of animal ethics, including animal welfare, treatment, and conservation. This is something new in an anatomy text, but where else in the curriculum will a student be exposed to such ethical issues? The final chapter covers the reasons for studying anatomy and its importance to society. I doubt if students in Western cultures would question the rationale and ethics of opening and dissecting cadavers, but in Eastern cultures this can be a philosophical issue for some people.

Overall, this text is an extremely welcome addition to the Biology curriculum, and I hope it becomes a model for texts in other courses. The authors are to be congratulated for achieving this milestone.

Warren Y. Brockelman
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Mahidol University, Salaya
October 2023

Foreword

Exploring vertebrate comparative anatomy stands as a cornerstone in biology and zoology, offering benefits to veterinary, medical, and life science students. This discipline's impact lies in uncovering parallels and deviations in basic morphology across diverse vertebrates. Comparative anatomy narrates the evolution of structures and systems, casting light on the interplay between structure and function. It spotlights the developmental journey of human and animal embryos, laying a strong foundation for understanding human anatomy.

In education's evolving landscape, a discernible trend emerges: a shift towards prioritizing cellular and molecular biology. While recognizing their importance, it is vital not to overshadow the harmonious interplay of biological systems within an organism. In this context, dissection remains timeless, providing a tangible three-dimensional experience, revealing the coexistence of organs, blood vessels, nerves, and tissues. This exploration navigates diverse tissue textures, illuminates muscle dynamics, unveils tendon and fiber pathways, and unearths often-neglected structures like fascial sheets and sheaths.

This book embeds the collective effort of authors orchestrating a comprehensive guide to vertebrate dissection. The selected specimens resonate with Mahidol University's biology students and learners across Thailand. The narrative unfolds through captioned photographs capturing external morphology and actual dissections. Augmented by line drawings, anecdotes, and thought-provoking queries, this guide fosters exploration and understanding. The authors candidly address the ethical dimensions of animal-based research, urging students to reflect deeply.

With deep appreciation, I commend the authors for creating a guide that imparts knowledge and embodies the region's spirit. It is my fervent hope that students embarking on this intellectual journey guided by this book will find enlightenment and fulfillment.

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Deputy Director at Queen Saovabha Memorial Institute,
Thai Red Cross Society
August 2023

Preface

The motivation to start writing this book came from our interest in vertebrates and the lack of locally available anatomical information for vertebrate teaching. In Mahidol University and other Thai universities, Vertebrate Zoology is one of the most important subjects taught in higher education, impinging on conservation, medicine, veterinary, and other biological disciplines. Studying vertebrates has greatly contributed to scientific knowledge and added to the development of techniques such as cloning, drug testing, population biology, genetics, etc. Knowledge of vertebrates and their anatomy and structure is crucial.

Our vertebrate course development during the Covid outbreak in 2020 was hindered by a shortage of information and photographs, *etc*., that might facilitate online teaching. As we ourselves conduct research based on vertebrate animals, we have therefore developed a manual that aims to help students understand more about the diversity of vertebrate structures. Specimens of the five main groups of vertebrates, obtained from our prior teaching and research, were used to examine their morphology and anatomy in the preparation of this manual. We follow the 3R principle (Reduction, Replacement, and Refinement) in animal usage ethics. We have since upgraded the manual to a book version in the hope that its contents may be shared more widely with students from other institutions and, indeed, all those interested in vertebrates.

All vertebrate specimens were examined and photographed by authors and team during 2020–2021. They were obtained legally and ethically from different sources. Fishes, frogs, and chickens were sourced in local markets while the cobra specimens were provided by The Snake Farm, Queen Saovabha Memorial Institutes (QSMI), Bangkok. The laboratory rats were obtained from the Central Animals Facility (CAF), Faculty of Science, Mahidol University. Both the snake and rat specimens were previously used for other research projects. Feather specimens were provided by the Conservation Biology Programme (Kanchanaburi campus). Equipment and laboratory space were provided by the Department of Biology, Faculty of Science, Mahidol University. We both gained our own experience and knowledge of animal dissection from zoology classes and training received during our higher education and careers. The specimens were carefully dissected to reveal the organ systems following other available dissection manuals. A wide range of publications and academic sources were referred to in preparing this book. Illustrations were generated by those students of the department who were especially adept in drawing and by a department staff person who is an expert in photography and graphic design.

During this book's compilation, we faced many challenges throughout two years (2020–21) when both country-wide and university closures took place repeatedly, hindering access to dissection laboratories. We were nevertheless able to write and revise

the content information via access to online sources. The contents in this book's chapters follow the lessons of the Vertebrate Zoology classes that aim to help students understand the divergence in morphology and anatomy among groups of vertebrates. After completing a first draft, each chapter was successively used to provide laboratory direction during classes, where we regularly asked for feedback from the students. This enabled us to further develop and refine this book's contents. We have kept the vocabulary and English writing as simple as possible, explaining technical terms where necessary so as to facilitate learning by students, including beginners and also readers from other fields. After completing a final draft, proof-reading, and editing was carried by a native speaker, and academic content was reviewed by experts in zoology, following the regulations of Mahidol University Press. Consequently, this Vertebrate Dissection textbook was completed in our fervent hope that it will help students and lay people to learn animal dissection with happiness, legitimacy, and improved comprehension.

Figure I. Dismembered animal organs preserved for biological research (A) and dissection of a model rat in Vertebrate Zoology class (B). *See Photo credit pages 191.*

Napat Ratnarathorn, PhD
Chalita Kongrit, PhD

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The authors wish to extend their deepest gratitude and utmost respect to the Department of Biology, Faculty of Science, Mahidol University, for the invaluable support they provided in enriching the teaching of Vertebrate Zoology classes. This support has been instrumental in inspiring and motivating us to embark on the creation of this Vertebrate Zoology: Basic Anatomy and Dissection Guide textbook. We express profound appreciation to the esteemed units within the Faculty of Science, Mahidol University, namely the Central Animals Facility, the Department of Anatomy, the Department of Biology (Biology Programme and Bioresources and Environmental Biology Programme), Conservation Biology Programme (Kanchanaburi campus), and The Snake Farm, Queen Saovabha Memorial Institute, Thai Red Cross Society. Their unwavering provision and subsidization of specimens and tools have been pivotal in shaping the contents of this book.

The gracious contributions of Professor Emeritus Dr. Narongsak Chaiyabutr, DVM MS FRS(T) (Queen Saovabha Memorial Institute and Chulalongkorn University), Professor Dr. Susan E. Evans (Division of Biosciences, University College London), and Professor Dr. Warren Y. Brockelman (Department of Biology (retired), Faculty of Science/ Institute of Molecular Biosciences, Mahidol University) deeply humble us. Their kind gestures in penning forewords for this textbook have added immense value to its essence. Sincere thanks are also extended to the dedicated staff and students of the Biology Department, as well as the numerous kind-hearted individuals and friends who generously shared their drawings, graphics, and photographs, making this endeavor all the more enriching.

We wholeheartedly appreciate the invaluable comments and suggestions provided by the anonymous reviewers, Associate Professor Philip D. Round, esteemed faculty members, and students of the Vertebrate Zoology classes. Their insightful feedback has significantly elevated the quality and essence of this textbook. A special word of thanks is dedicated to Associate Professor Philip D. Round for his professional expertise in meticulously revising and refining the English text, making it truly polished.

Furthermore, we are profoundly grateful to Dr. Rapee Boonplueang, the Head of the Biology Department, Faculty of Science, for his invaluable knowledge and unwavering support throughout the creation of this book. Our heartfelt appreciation also goes to Professor Dr. Suvaluck Satumanatpan and her team at the Mahidol University Press, as well as the esteemed Research Management and Development Division, Mahidol University.

Finally, we are deeply indebted to our cherished families and friends whose unwavering support and encouragement have been the cornerstone of this journey. Their love and belief in us have been a constant source of inspiration and strength. With the utmost honor and gratitude, we humbly acknowledge their presence in our lives.

Napat Ratnarathorn, PhD
Chalita Kongrit, PhD

Introduction

Vertebrates are a group of animals that evolved more than 500 million years ago since the Cambrian Period, alongside invertebrates and plants. Having vertebrae as an endoskeleton, supports the body of the animals, provides sites for muscle attachment that facilitate their movement, and protects their central nervous system, thus further promoting animal adaptations in numerous ways. Humans are familiar with vertebrates in our everyday life, and obtain benefits from vertebrates as high-quality food sources, pets, working animals as well as laboratory and research animals.

Despite the fact that vertebrates are diverse, studying their morphology and anatomy by dissection is the most fundamental technique for learning vertebrate classification. Biology students generally expect to learn how to dissect animals and study their internal organ systems. Although 3D models and high-quality virtual dissection of animals are globally available, hand-on skills in animal dissection from specimens are important for students who are keen to learn animal science, histology, developmental biology, and physiology, and wish to pursue research in this field. To facilitate self- and in-class laboratory learning, we gathered essential knowledge of vertebrate anatomy and related information, and prepared this book, Vertebrate Zoology: Basic Anatomy and Dissection Guide, for everyone who would like to gain experience in vertebrate dissection.

First of all, it is crucial to know the definitions of "Anatomy" and "Dissection". These two words can be used interchangeably for some occasions. In etymology, the origin of the word anatomy could be traced back to the ancient Greek era. It was derived from a combination of two root words; 'ana' which means 'up' and 'temnein or tomia' which means 'to cut or cutting'. This implies that the word anatomy is equivalent to 'to dissect' or 'dissection'. In terms of processes to study anatomy, dissection is one of the most classical approaches which is used to open up the body and explore the internal organs or anatomical structure. Thus, the definition of both words is strongly linked to each other. **Anatomy** refers to the biological discipline that studies the structure of organisms at different levels of body organizations such as organ systems, organs, and tissues. Meanwhile, **dissection** is the process of dismembering the body in order to study anatomical structure.

This book includes nine chapters and one appendix. Before the dissection practice, it is necessary to know standard dissection tools and how to correctly choose and use them in order to properly cut open specimens and avoid destroying delicate structures. In addition, animal dissection must be carried out under a standard biological safety. A person who does dissection must wear suitable laboratory personal protective equipment (PPE) to protect themselves from harmful preservative chemicals and spills from specimens. The details of standard dissection tools and PPE are provided in Chapter I. Chapter II introduces diversity and the diagnostic characteristics of the five major groups

of vertebrates, as well as concepts and work sheets of phylogenetic tree construction before starting dissection in the following chapters. Chapters III to VII provide knowledge and steps of specimen dissection for the five major groups of vertebrates that are fishes, amphibians, reptiles, birds and mammals. External morphology and organ systems including the musculoskeletal system, nervous system, digestive system, excretory system, respiratory and circulatory system, and reproductive system, are described. The uniqueness of each vertebrate group appears in the Focused characters box. We include interesting information of the vertebrate groups in **Fun Facts**, and encourage readers to further think about and answer questions related to the vertebrate groups in the **Think Box**. We also prepared checklists for important characters to facilitate self-learning. Besides dissection steps and anatomical details of the specimens' organ systems, we introduce the uniqueness of each group of vertebrates.

Chapter III emphasizes the diverse shapes and forms of fish body and fins, and various mouth positions of fishes. External shape and form as well as the internal organs reflect their foraging strategies and ecology. External morphology, musculoskeletal and internal organ systems, mainly, of the well-known Nile Tilapia (*Oreochromis niloticus*) and the torpedo scad or hardtail scad (*Megalaspis cordyla*) are described in this chapter.

In Chapter IV, the Chinese edible frog (*Hoplobatrachus rugulosus*) is used as a model for the amphibian group. Amphibians were the first vertebrate group that evolved to live on land by exhibiting legs. The adult stage utilizes oxygen in gaseous form. This chapter explains its special respiratory and circulatory systems that facilitate gas exchange through skin and lung. Their muscles and skeletons that support their movement on land are demonstrated.

Chapter V introduces two distinct types of skulls in reptiles. Both anapsid and diapsid skull types are presented in the extant species. In this chapter, the monocled cobra (*Naja kaouthia*) is used as a representative for the reptile group. The snake not only shows basic characteristics of reptiles, but also a highly modified musculoskeletal system and internal organs. Snake venom glands and different types of fangs are illustrated and described in detail.

In Chapter VI, the two major groups of birds, the Palaeognathae and the Neognathae are briefly explained. The domestic chicken (*Gallus gallus domesticus*) is used as a model for the avian group. Although this bird is not a good flyer, it shows important characteristics that have evolved for flight. The characters that facilitate flight include the structure of the wings, various types of feathers, its modified skeleton for large-muscle attachment, the development of a four-chambered heart and a unique respiratory system. Additionally, birds are toothless animals. They have special modified digestive organs that help them physically and chemically digest their foods.

Chapter VII starts with the three major groups of living mammals, the monotremes, the metatherians and the eutherians. The unique characteristics of mammals, e.g., hair morphology, production of milk and highly developed brain, are explained in detail. The laboratory rat (*Rattus norvegicus domestica*) is used as a representative to illustrate the external characteristics of mammals, e.g., hairs, vibrissae, nipples and pinna, and the internal organs of the circulatory system, digestive system and reproductive system of both male and female rats.

Chapter VIII sets out important ethical concerns over animal uses in scientific research. As humans gain enhanced understanding of animal lives, we must use animals and specimens under an ethical framework. This chapter emphasizes the implementation of research according to standard scientific codes of conduct which are crucial in the scientific community. The final chapter, Chapter IX, presents the authors' perspectives on a traditional cadaveric dissection as an educational tool for studying animal anatomy. Even though virtual educational technologies may augment students' experience, hands-on practice from real specimens definitely enhances their cognitive learning. Studying animal anatomy may sound like an old-fashioned approach, but it is important in many career paths. Many new discoveries have resulted from animal anatomical research. We emphasize that concerns about animal life and its well-being, incorporating both traditional tools and present-day technologies, will result in the greatest output for both teaching and research.

We hope that this Vertebrate Zoology: Basic Anatomy and Dissection Guide will deliver essential knowledge of the anatomy and diversity of all groups of vertebrates, and enhance the readers' practical skills of animal dissection under standard protocols. We also hope that this book may stimulate further research ideas to those interested in the field of Vertebrate Zoology.

Napat Ratnarathorn, PhD
Chalita Kongrit, PhD

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