Modern Aspect of a Classic Anatomy: What does it mean to know body structures in other species?

Megu Gunji (Assistant Professor, Toyo University Faculty of Life Sciences, Department of Life Sciences)

When you hear the word "anatomy," do you think of the human anatomy diagrams on display in the school nurse's office or the supposedly creepy mannequins walking the halls late at night? In any case, you're probably under the impression that anatomy is a study related to medicine. It's true that modern anatomy is seen more as basic medical and veterinary training than as being part of basic science, and it has even been described as a "boring rote-learning subject that forces you to memorize a lot of anatomical names."

From anatomy to taxonomy. Looking outward.

Originally, anatomy was not an academic discipline intended only to contribute to medicine, but for about 2,000 years it played a central role in biology as a basic science. In "natural history," which can be said to be the origin of modern biology, anatomy was a powerful tool for identifying and classifying collected organisms. Long before the concept of genes and the theory of evolution, the act of slicing open a body and looking at its internal structure played an extremely important role in the scientific process of grouping the animals that live around us and trying to understand the universal regularities that exist in the natural world. The basic and ultimate question of anatomy, "What kind of structure does the body of an organism have?" has fascinated many researchers since the ancient Greek philosopher Aristotle and produced many discoveries.

From anatomy to embryology. Looking inward.

By the beginning of the 19th century, however, knowledge of the anatomy of living things on Earth had accumulated, and a "certain level" of understanding of the body structure of organisms had been achieved. Interest then moved from simple questions such as "What kind of body does this organism have?" to "How is this body constructed?" Anatomy, which looks at the function of body structure and form, moved into embryology, which unravels the origins of body development and form. This trend was closely related to the fact that a certain level of accumulated anatomical knowledge had been achieved and the technological developments that made it possible to observe minute structures invisible to the naked eye. In anatomy itself, research was actively pursued from a more microscopic perspective, from the individual level to the organ level and the tissue/cell level.

Then, anatomy entered a vacuum

At the same time, with the establishment of the concept of genes and genetic laws and the development of science and technology, taxonomy was updated from a classical taxonomy based on anatomical and morphological findings to a taxonomy based on the inference of phylogenetic relationships using gene sequences. In contrast, anatomy gradually lost momentum since the 20th century and was in a state of decline. In response to this history, the summary section of "Comparative Anatomy" in Japanese Wikipedia concludes with the following text:

"(Since the 20th century) As the anatomy of major animal groups became known, the study of their anatomy became more of an internal matter within each group. The study of anatomy also evolved from the organ level to the tissue and cell level. As a result, comparative anatomy lost at least some of its coherence as a discipline and reached the end of its role as a field that had been developmentally solved."

This may seem a bit extreme, but the number of research papers on the anatomy of nonhuman organisms actually peaked in 1835 and declined sharply in the second half of the 19th century. It is difficult to say why this decline occurred in general, but one reason might be that the basic work of gross anatomy, which is to "describe what we see with our eyes," is often seen as lacking the "objectivity" and "reproducibility" that are essential elements of modern science. Indeed, when different researchers look at the same organ, their descriptions often differ. And it has been pointed out that these differences are rarely due to individual differences in the specimen. This means that individual differences in observers may have a greater impact on the description than individual differences in the specimen. In modern science, objectivity and reproducibility are important, and a subjective description that says "this is what it looks like to me" is inconsistent.

Is comparative anatomy a discipline whose "role is finished" and that no longer needs to be studied in the 21st century? Or is it starting to take on new roles in promoting and stimulating interdisciplinary research? What does it benefit us as humans to understand our own body structure, to figure out different types of body structures, and to compare them? In this paper, I would like to discuss the state of comparative anatomy in today's society, its importance, and its potential as an academic field from different perspectives.

The power of the real, and the discovery of many new cases

In summary, it is sometimes said that anatomy is "finished" based on the academic evolution of anatomy → taxonomy → evolution → genetics and embryology, but if we change our view of this process, it can be said that anatomy is the original discipline. In other words, updating anatomy has the potential to shake the foundations of all of science. Below I will present many examples of new discoveries (which may be boring to readers familiar with the field).

I mentioned earlier that subjective descriptions of "what it looks like to me" are not compatible with modern science, but observational descriptions of "the existence of certain types of tissues, organs, and structures" have sufficient value regardless of the era as long as they are documented by actual photographs and sketches. This is why new discoveries in anatomy continue to be made in the 21st century.

Even in humans, arguably the organisms about which we are most anatomically knowledgeable, new organs have been discovered and reported. For example, in 2015, the discovery of lymphatic vessels in the meninges covering the brain caused a sensation and was selected by the journal Science as one of the ten groundbreaking studies of 2015 (although some researchers claim that these lymphatic vessels were reported as early as 1787). In 2020, the existence of a new salivary gland in the human nasal cavity was reported using state-of-the-art PET/CT equipment. Although it is unlikely that the discovery of a new salivary gland will directly and immediately enrich our lives, the discovery of this new organ may lead to the elucidation of mechanisms of diseases and disorders previously considered "unexplained" and to the establishment of treatment methods.

The discovery of new facts is not limited to human anatomy. Only by comparing our bodies with those of other species can we learn whether a feature is unique to humans or is also found in nonhumans, and we cannot learn everything about humans without looking at other organisms. Even in species that are less studied than humans, including so-called "stars of the zoo" such as giraffes, elephants, and pandas, new anatomical discoveries continue to be reported to this day. For example, in 1999 it was discovered that two small protrusions on either side of a panda's wrist help the animal grasp a round piece of bamboo in the palm of its hand. In 2011, it was reported that large cartilaginous sesamoid bones exist in elephant toes that serve to support the body and change the posture of the foot. In 2016, a study by the authors showed that the muscles and bones at the base of the neck of giraffes are specialized to allow them to move part of their trunk and extend their head forward when they move their neck.

Common to all three examples, in addition to anatomy, is the use of CT scans to observe the three-dimensional structure of bones and soft tissues. As the resolution of observations continues to increase with the development of examination equipment and devices, we can expect to discover many new tissues, both in humans and in other organisms, that we have not been able to detect before. In addition, the development of techniques for observing the internal structure of the body while living may lead to new insights into the function of individual organs and tissues and the coordination between organs.

Anatomy and advanced technology

Interdisciplinary research between anatomists and robot engineers has also advanced since the 20th century. Ongoing development of robots including bipedal robots such as ASIMO and AIBO, quadrupedal robots, and robotic hands that mimic the muscle and bone structure of the human hand has been achieved using basic anatomical knowledge. Robots that learn from and mimic living organisms are called bio-inspired or bio-mimetic robots. It is expected that this research will lead to the development of "robots that respond instantly to changing environments and show adaptability like living organisms."

The author himself is involved in a research grant project that started in 2018 titled “Science of Soft Robots” and is conducting interdisciplinary research on the topic “What do we mean by the ‘softness’ of living things?” While most conventional robots are made of hard materials and strive for “strength” and “precision,” living organisms behave safely and adaptively, using their soft bodies to adapt to their environment in a “reasonable” (i.e., appropriate) way. The team, which includes the author, is working with experts in robotics and mathematical analysis to uncover the roots of the ostrich’s “flexible” neck. Ostriches eat their food by deftly moving their extremely flexible necks and hitting the ground with their beaks. This is quite different from the behavior of robotic hands and manipulators, whose goal is to perform precise picking operations with minimal contact with objects. Detailed studies of the structure and movement of the necks of various birds, including ostriches, should lead to the development of robotic manipulators that do not break even when they impact the ground.

Some critics argue that organisms may not have optimal body structures due to evolutionary and embryological constraints, but since both organisms and robots are moving real-world objects subject to the same physical laws, we can learn much from studying living organisms. It can be said that there are still many opportunities for technical application of anatomy. For example, discovering the secrets to moving quickly and nimbly while supporting one’s weight against gravity, or the mechanisms of energy efficient and low energy consumption behaviors.

Moreover, in recent years, in addition to applying biological knowledge to technology, a new type of biological research has emerged called “Robotics-inspired Biology,” which aims to understand living organisms by building robots. Recent examples include the development of a robot that mimics the physique of an extinct primitive quadruped to reconstruct the gait of an extinct animal, and the development of a bio-hybrid flying robot with real bird feathers attached to its mechanical frame. Traditional anatomy has sometimes been derided as “dead science” rather than “biology,” and there have been certain obstacles to understanding the function of organisms while they are alive. In addition to previous attempts to explore the function and behavior of muscles and joints using physical simulators, a “constructivist approach” that explores the function of body structures by operating robots that very closely resemble living organisms has the potential to take anatomy to a new level.

With the remarkable technological developments of recent years, it has become possible to observe and evaluate complex biological systems in greater detail and to “mimic organisms” at a higher level, and anatomy is certainly not an academic field of little significance. Anatomists often say “we can’t say we’ve really seen something until we’ve drawn it,” but we may soon be approaching a time when we say “we can’t say we’ve really understood something until we’ve built it.”

The basic tasks of anatomy, such as “seeing and observing with one’s own eyes,” “describing observed phenomena,” and “comparing, classifying, and finding patterns among different species,” are, of course, general procedures that can be applied to other fields. Since anatomy is the origin of understanding living things, including humans, it can impact the way we view both nonhuman and human organisms. Therefore, anatomy has not ended and will never end.