Review article

A lesson from our institute;
Why do veterinary schools need an anatomy museum?

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Abstract

Anatomy has always been a key discipline in the field of veterinary medicine, as this fundamental scientific discipline offers vital foundational knowledge on how the structure of an organ relates to its function and health. It demonstrates how the three-dimensional structure of an organism relates to the physical diagnosis of a disease, as well as to help shed light on how surgical and medical approaches can be employed to treat various diseases. This review provides supportive evidence on the importance and usefulness of the anatomy museum located within our veterinary institute. Furthermore, our outcomes will encourage all veterinary schools to consider having their own on-site anatomy museum. From our experience, the practical usefulness of an anatomy museum can be divided into 4 categories that include the study of anatomy, the study of histology, elemental study, and social education. The samples housed in an anatomy museum can increase the publishing potential of all staff members of the parent institute, as well as to elevate the reputation and general recognition of the institute. Moreover, an anatomy museum can facilitate out-of-class learning opportunities for non-university educational facilities such as kindergartens, and primary or secondary schools.

Keywords: Anatomy, Animal, Children, Education, Museum, Usefulness

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INTRODUCTION

Anatomy is the branch of science that is concerned with the structure of the body and its parts. It is a basic science discipline that lays down a vital foundation upon which the knowledge of a clinical practice in medicine can be built. Veterinary students worldwide have to gain a thorough understanding of anatomy in the early years of their academic studies. The most common cadavers used in the study of anatomy are dogs (*Canis lupus familiaris*), cats (*Felis catus*), horses (*Equus ferus caballus*), cattle (*Bos taurus*), chickens (*Gallus gallus domesticus*), and fish. However, some institutes may choose to study the cadavers of other animals such as wildlife or exotic animals. Currently, a combination of cadaveric dissection, required reading, and didactic lectures are the primary methods used by schools to teach veterinary anatomy (Sugand et al. 2010). The availability of adequate specimens for dissection has become more limited over the past 20 years (Inzunza & Bravo 2002). As a consequence, some institutes have resorted to using software programs to study anatomy as they allow for a virtual visualization of the organs in a three-dimensional and interactive manner (Little et al. 2018; Scherzer et al. 2010). However, the study of anatomy via the use of cadavers can provide more valuable and significant outcomes than by reading textbooks or only using software (McNulty et al. 2016). Moreover, our literature review has concluded that dissection-based teaching is central to anatomical education (Ghosh 2017). Anatomical specimen collection remains a very important educational tool that offers students and researchers a valuable resource pertaining to the increasing numbers and variations of animals and animal species. Furthermore, anatomical specimens can be used to not only instruct veterinary students but also other interested people. Therefore, anatomy museums would be a good option for the collection and display of various animal specimens (Table 1).

Table 1 Examples of veterinary museums that belong to the faculties of veterinary medicine at various universities throughout the world.

| Name	Institute	Website
Veterinary Anatomy Museum	College of Veterinary Medicine, University of Minnesota, USA.	http://vanat.cvm.umn.edu/museum/
Anatomy Museum Collection	Royal Veterinary College, England.	https://www.rvc.ac.uk/Review/anatomy/
Museum of Veterinary Anatomy	Faculty of Veterinary Medicine and Animal Science, the University of São Paulo (USP), Brazil.	http://vejasp.abril.com.br/estabelecimento/museu-da-anatomia-veterinaria-da-fmvz-da-usp
Ankara University Veterinary Anatomy Museum	Veterinary Faculty, Ankara University, Turkey	http://www.ankvetmuseum.com
Veterinary Anatomy Museum	Murdoch University, Australia	https://www.facebook.com/MurdochVetMuseum/
Museo Anatomico Veterinario	Università di Pisa, Italy	https://www.mav.sma.unipi.it/en/visit-us/
Worthman-Johnson Veterinary Anatomy Teaching Museum	College of Veterinary Medicine, Washington State University, USA	https://www.vetmed.wsu.edu/about-the-college/facilities/learning-resources
Veterinary Anatomy Museum	Faculty of Veterinary Medicine, Kasetsart university, Thailand	http://museum.vet.ku.ac.th/history.html
Anatomy Museum	Chattogram Veterinary and Animal Sciences University, Bangladesh	https://cvasu.ac.bd/pages/museum
Veterinary Museum	Missouri Veterinary Medical Association, USA.	https://www.movma.org/page/Museum
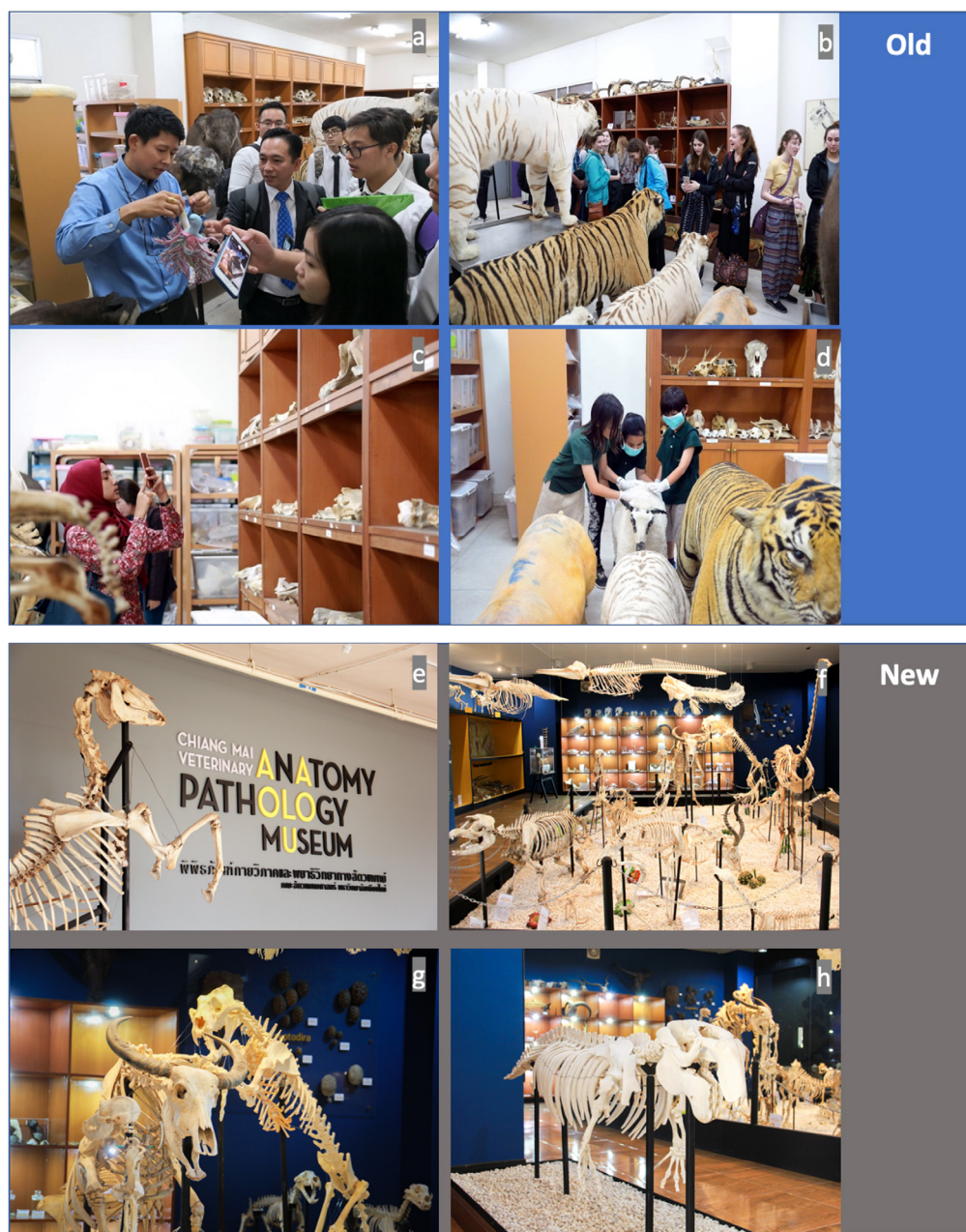
Figure 1 The old (a-d) and new (e-h) veterinary museums located at CMU. The old museum looks more like a storage room than a museum. After the renovation process, the new museum looks modern and clean.

The Faculty of Veterinary Medicine, Chiang Mai University, Thailand was founded 25 years ago, in the year 1996. Educational specimens have been collected in the faculty since then. The main specimens include dry bones, organs, and various taxidermic animals. In 2020, we officially opened our museum, namely the Veterinary Anatomy and Pathology Museum (Figure 1). This museum provides learning opportunities for veterinary students and primary school pupils, as well as the general public (Figure 2). Moreover, this museum is in line with the 4th item of the Sustainable Development Goals (SDGs), which refers to the quality of education (United Nations Statistics Division 2016). This article will research and assess the social impact of such a facility, using the specimens in our museum as a subject for research. This information will support the contention that all veterinary schools should have their own anatomy museum.

Figure 2 Primary school pupils on a field trip to the museum. Most schools come in small groups (a), as it is easy to organize tours by our staff (b). Children can first look around by themselves (c), while at the end of the tour we offer a basic anatomy class (d).

ANATOMICAL STUDY

As has been established above, most specimens housed in this museum are comprised of dry bones. Many studies have been successfully carried out that involve the bones of dogs, cats, elephants (*Elephas maximus*), dugongs (*Dugong dugong*), and various other wildlife animals.

The use of specimens for research in our museum began in 2015, when three studies were published. The first publication compared the ratio of cranial volume (CV) to skull volume (SV) in 25 mammalian species including malayan tapir (*Tapirus indicus*), camel (*Camelus dromedarius*), sunda sambar (*Rusa timorensis*), nilgai (*Boselaphus tragocamelus*), giraffe (*Giraffa camelopardalis*), spotted deer (*Axis axis*), red lechwe (*Kobus leche*), nyala (*Tragelaphus angasii*), common eland (*Tragelaphus oryx*), sitatunga (*Tragelaphus spekii*), greater kudu (*Tragelaphus strepsiceros*), gemsbuck (*Oryx gazella*), barking deer (*Muntiacus muntjac*), grant's gazelle (*Nanger granti*), barbary sheep (*Ammotragus lervia*), domestic sheep (*Ovis aries*), domestic goat (*Capra aegagrushircus*), cattle (*Bos taurus*), horse (*Equus ferus caballus*), mule (*Equus mule caballus*), domestic pig (*Sus scrofa*), domestic dog (*Canis familiaris*), lion (*Panthera leo*), hyena (*Hyaena hyaena*), and spinner dolphin (*Stenella longirostris*) (Chanpanitkitchote et al. 2015). The second publication was a comparative study on bone density in terms of the

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radius and tibia of dogs and cats. The study was performed on the specimens of 23 small dogs (8 male and 15 female) and 26 cats (16 male and 10 female) (Nithijane et al. 2015). In terms of the bone density of these dog and cat bones, no significant differences were observed between sexes, while the density of the radius bones in cats was greater than that of the tibia bone. The last publication developed a protocol that was able to extract DNA from "fresh" as well as "old" bones. These bones had been buried in soil or stored underwater in a pond for a period of up to three months (Chomdej et al. 2015).

In the domestic cat, many observations were made using the skull (Pitakarnnop et al. 2017), pelvic bone (Pitakarnnop et al. 2017), vertebrae bones (Boonsri et al. 2020), flat bones (Boonsri et al. 2019), and long bones (Boonsri et al. 2019). These observations enabled researchers to predict sex or skull shape. For the dog, it was determined that pelvic morphology was related to sex (Nganvongpanit et al. 2017e). The study found that the morphometric data obtained from the scapula, os coxae, humerus, radius , ulna, femur, tibia, and fibula indicated significant differences (P <0.05) between the right and left sides of a given limb, and between male and female specimens (Boonsri et al. 2019). However, the skull (both cranium and mandible) was not found to be significantly different in comparisons made between sexes (Pitakarnnop et al. 2017). Importantly, this information could be used for the purposes of sex identification (Table 2) in anatomical and forensic sciences.

Table 2 Accuracy of sex estimation based on bone measurements.

Animals	Bone	Sexing accuracy rate (%)	Reference
Cat	Mandible	64.9	(Pitakarnnop et al. 2017)
	Scapula	74	(Boonsri et al. 2019)
	Os coxae	93	(Boonsri et al. 2019)
		97.3	(Pitakarnnop et al. 2017)
	Humerus	93	(Boonsri et al. 2019)
	Radius	90	(Boonsri et al. 2019)
	Ulna	96	(Boonsri et al. 2019)
	Femur	89	(Boonsri et al. 2019)
	Tibia	94	(Boonsri et al. 2019)
	Fibula	94	(Boonsri et al. 2019)
Dog	Os coxae	86	(Nganvongpanit et al. 2017e)
Dugong	Large tusk	100	(Nganvongpanit et al. 2017e)
	Skull	98	(Nganvongpanit et al. 2017e)
	Scapula	68	(Nganvongpanit et al. 2017e)
	Os coxae	76-92	(Nganvongpanit et al. 2017e)

Moreover, in a previous study involving sex estimation methods in cats, which used morphological observations of the skull and os coxae, three hallmark observations were made indicating a remarkable difference between sexes: the coronoid process of the mandible (accuracy rate = 88.2%), the os coxae - caudal ventral iliac spine (accuracy rate = 94.4%), and the angle of the ischiatic arch (accuracy rate = 74.3%) (Pitakarnnop et al. 2017). In the dog, it was found that the morphometric data were significantly different between male and female specimens resulting in an 86% accuracy rate for sex identification (Nganvongpanit et al. 2017e).

In the dugong study, we collaborated with the Phuket Marine Biological Center which provided all samples for the study. We determined that the morphometry of the dugong skull (Nganvongpanit et al. 2017a), os coxae (Nganvongpanit et al. 2020a), and scapula (Nganvongpanit et al. 2017a) could be used as a tool for sex classification. Scapular morphology of the dugong using the caudal border tubercle and coracoid process resulted in 91.30% and 96.15% accuracy rates, respectively for identifying males and females (Nganvongpanit et al. 2017a). However, morphometric data yielded a low accuracy rate of only 68% (Nganvongpanit et al. 2017a). This approach could be used to identify whether the actual habitat of the dugong is the Gulf of Thailand or the Andaman Sea with an accuracy rate of 100% (Nganvongpanit et al. 2017a). This is because researchers found that the bones from dugongs who lived in the Andaman Sea were larger than those of the dugongs who lived in the Gulf of Thailand. Remarkably, the os coxae bones of immature dugongs provided a lower rate of accuracy for sex prediction than the os coxae bones of mature dugongs (Nganvongpanit et al., 2020).

Another very interesting article was published in the Journal of Anatomy. This article presented the findings of a study on the incidence of osteoarthritis (OA) from the dry bones of 2 marine mammals and 22 land mammals (Nganvongpanit et al. 2017h). The study showed that OA could occur in marine mammals, just as it could in `terrestrial mammals, even though their natural habitat is the ocean. There has also been impressive data that revealed no marrow cavity in the long bones of Asian elephants, which was established using computer thermographic scans (Nganvongpanit et al. 2017g).

In 2016, Phatsara and her colleagues determined whether bone morphometry analysis (morphometric index measurements and angular measurements) of long bones would be robust enough as a technique to distinguish between humans and animals; cows, dogs, horses, monkeys, and pigs (Phatsara et al. 2016). She reported that morphometric measurements of long bones do have the potential for being used in distinguishing between human bones and those of animals.

Other organs have also been used in various studies. Wanpitak and colleagues (Pongkan et al. 2020) demonstrated the presence of variations in cat heart vessels. The findings of this study could help fill the existing gap of knowledge on the anatomical variations of supra-aortic arteries in cats and could also be used in clinical applications based on relevant anatomical data.

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HISTOLOGICAL STUDY

Many samples of dogs, elephants, and monkeys have been used to study histology. Some of these studies have presented basic knowledge, while other have focused on forensic science.

A study of the normal structure of canine bone histology found that osteon structure; Haversian canal diameter, Haversian canal area, osteon diameter, osteon area, and the number of lacunae per osteon, were different in the bones of different animals, and indicated that there were differences between the sexes (Nganvongpanit et al. 2017f). In elephants, the osteon structures were different between humerus, radius, ulna, femur, tibia, fibula, and rib bones (Nganvongpanit et al. 2017g). The compact bones in elephants contain secondary osteon structures and double cement lines in the radius, tibia, and fibula bones (Nganvongpanit et al. 2017g). While the structure referred to as the 'Plexiform bone' could be found in three bones of puppies, i.e. the femur, humerus, and tibia (Nganvongpanit et al. 2017f), while this was not the case in elephants (Nganvongpanit et al. 2017g) or the Assam macaque (Nganvongpanit et al. 2015).

In 2018, we published an article on the histology of 24 organs, including the skin, brain (cerebrum, cerebellar hemisphere, vermis, thalamus, and midbrain), spinal cord, sciatic nerve, striated skeletal muscle, cardiac muscle, bone (flat bone and long bone), cartilage (hyaline cartilage and fibrocartilage), heart (right atrium and right ventricle), blood vessels (aorta, pulmonary artery, and caudal vena cava), trunk, trachea, lungs, tongue, esophagus, stomach, small intestines (duodenum, jejunum, and ileum), large intestines (cecum, colon, and rectum), liver and pancreas, kidney, ovary, uterus (body and horn), and spleen of two juvenile Asian elephants (Thitaram et al. 2018). We determined that the histological information obtained from various organs could serve as an important foundation of basal data in histological studies.

Two research studies conducted involving the Thai black-bone chickens aimed to examine the distribution of the melanin pigment in 33 organs (Nganvongpanit et al. 2020b) and 34 skeletal muscles (Kriangwanich et al. 2021). Thirty-two organs including the brain, spinal cord, sciatic nerve, larynx, trachea, syrinx, lungs, heart, pericardium, aorta, brachial vein, kidney, cloaca, oviduct, testis, gastrocnemius muscle, femur, tongue, esophagus, crop, proventriculus, gizzard, duodenum, jejunum, ileum, cecum, pancreas, liver, gall bladder, omentum, abdominal fat, spleen, and skin were examined in this study. Histological sections taken from tissue samples of each of these organs were studied. In the muscle tissue samples, the results revealed that the accumulation of melanin pigment was found in the endomysium, perimysium, and epimysium (Kriangwanich et al. 2021). The findings revealed that the presence of the melanin pigment in all organs and muscles was not significantly different (P > 0.005) in comparisons made between male and female specimens (Kriangwanich et al. 2021; Nganvongpanit et al. 2020b).

In studies that employed a forensic approach, four out of five parameter measurements were used that included the diameters and areas of the Haversian canal and osteon. It was found that significantly higher ($P < 0.05$) values of these parameters were present in humans than in Assam macaques (Nganvongpanit et al. 2015). Therefore, the compact bone microstructure could be used as a potential tool to differentiate between humans and nonhuman primates.

ELEMENTAL STUDY

One of the highlighted studies involved species classification using elemental composition in dace connective tissue involving bones, teeth, and horns. All dry bone specimens housed in our museum have not been coated with chemicals because we found that the chemicals can interfere with the results of studies on these bones (Buddhachat et al. 2019). Nganvongpanit and his colleagues have published over 10 studies involving our specimens. These studies analyzed the elemental composition of the bones for various purposes such as an understanding of the biology and pathology of the bones, and the identification or classification of different animal species.

In 2017, 48 various canine compact bones were used in an analysis of the elemental composition (Nganvongpanit et al. 2017d). From a total of 26 detected elements, only 13 elements were found in all 48 bones. The ratio of Ca and P was significantly different when certain bones were compared: there was a higher Ca/P ratio in the patella, calcaneus, and sternum as opposed to a lower ratio observed in the radius, rib, phalanx, and carpus. This data is of significant value in the selection of bones that would be appropriate for elemental studies. Furthermore, it was revealed that the elements were not equally distributed in every bone in the body. In 2020, it was conclusively proven that the elements were not equally distributed throughout the bones (Pitakarnnop et al. 2020). Moreover, it was found that high Mn and Fe values were identified in severe grades of the OA bone. This study analyzed 45 os coxae bones and these were categorized as normal, mild grade OA, moderate grade OA, and severe grade OA. The findings of this study suggest that these two elements may be useful in future studies on the etiology and pathophysiology of OA (Nganvongpanit et al. 2016b).

Many studies have shown that a knowledge of elemental composition can be an excellent resource for species identification involving the dense connective tissue in humans (Nganvongpanit et al. 2016c; Nganvongpanit et al. 2016d; Nganvongpanit et al. 2017c) and animals (Buddhachat et al. 2016a; Buddhachat et al. 2016b; Nganvongpanit et al. 2016a; Nganvongpanit et al. 2016d; Pitakarnnop et al. 2021). This approach can be particularly applicable in studies involving animals that live in different areas, such as with the differences between Asian and African elephants (Buddhachat et al. 2016b) or the differences between the dugongs that live in the Andaman Sea or the Gulf of Thailand (Nganvongpanit et al. 2017b). Moreover, the previous studies found that the elements were not necessarily different between sexes (Buddhachat et al. 2016b; Nganvongpanit et al. 2016a; Nganvongpanit et al. 2016c; Nganvongpanit et al. 2017b; Nganvongpanit et al. 2017c; Nganvongpanit et al. 2017d). Importantly, this technique can also be used to distinguish real from fake ivory products (Buddhachat et al. 2017).

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SOCIAL EDUCATION

The learning environment that is created by an anatomy museum would promote an active-collaborative student learning strategy by utilizing various facilities outside of the classroom (Astuti et al. 2020; Branscombe 2016; Braund & Reiss 20015). This type of environment could also serve as an effective educational medium, as this museum can be used as a place for students from kindergarten up to high school in their learning of the structure of the animal body. Along with reading books, students can see, touch, and feel real animal bones, organs and taxidermy specimens. These learning environments can be used to enhance a variety of skills and life experiences (Ortug et al. 2021). In addition to visiting the facility as a group organized by their schools, there are still a lot of people who would travel by themselves or who would be accompanied by their parents to visit the museum. The notion of parental involvement is also positively correlated with their children's academic performance (Sorbing et al. 2019). Visiting a museum with their parents may not only enhance the child's knowledge, but it can also increase parent-child interactions (Willard et al. 2019). This is because parents may ask their child to explain something in the museum or encourage them to further explore a specific part of the museum. Both parents and children will have the opportunity to work collaboratively, and in turn, children will benefit from the learning experience as well as from having a good relationship with their parents. Moreover, children might not be the only ones who benefit from the positive experience associated with visiting a museum, as parents could also enjoy visiting the museum as well.

There have been many studies detailing the benefits of museums. Museums can provide a number of learning opportunities to students. To illustrate, children can learn about a range of socio-cultural, cognitive, aesthetic, motivational, and collaborative aspects by visiting museums (Anderson et al. 2002; Andre et al. 2017; Paris 1997; Song et al. 2017). In particular, visiting a museum can significantly improve a child's sense of originality, which is a subset of their own creativity (Gong et al. 2020). Learning in a science museum can enhance a child's own knowledge, self-efficacy, sense of value, and scientific aspirations (Martin et al. 2016).

Usually, students learn about animals by going to certain popular places with their parents like zoos. Children get to see what animals look like and how big they actually are. In our case, our museum helps children understand what animals' bodies look like by having them practice imagining which skeleton belongs to which animal. Moreover, Bunce (Bunce 2016; Bunce 2019) also suggests that interactions with taxidermy animals as authentic objects can foster curiosity and engagement, as well as to encourage critical thinking. This would occur to a greater extent than from interactions with models or replicas. This truly supports our contention that learning outside the classroom helps children enjoy the learning process even more. As a consequence of visiting a museum, the children actually become more curious and interested. More importantly, they practice critical thinking, a key skill for advanced learning. All of these examples can create an exciting and positive experience for both students and the general public.

Apart from being an educational facility for children and the public, museums can be a good environment to promote collaborative work between students, faculty members, and the community. College students, who volunteer or work as service-learning facilitators in museums gain positive outcomes such as a greater sense of personal efficacy, the ability to work with others, and leadership and communication skills, while enhancing the students' understanding of the academic content (Cress 2005; Eyler et al. 2021; Williams & Sparks 2011).

With regard to a university's mission, teaching and research are essential roles for higher education, but educational service can also be one of the core missions in any institute of higher education, including at Chiang Mai University. Having a veterinary museum at Chiang Mai University has proven to be a great opportunity for the university to promote certain academic service-based contributions of the faculty's expertise to both the public and society.

CONCLUSION

In actuality, few veterinary schools worldwide have their own museums (Table 1). As a result of our positive experience of over 20 years, we can encourage all institutes to have their own museums. Not only will staff from the institute be able to use samples for their research, it will support learning for students at all levels of their educational process. Some of the advantages of a museum have been mentioned above, but we believe that our museum offers even further advantages. Accordingly, these advantages would depend upon the policies of the university and the samples that are housed in the museum.

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