

Fundamental Anatomy and Physiology

Chaleamchat Somgird, D.V.M., M.Sc.
Faculty of Veterinary Medicine
Chiang Mai University, Thailand

The elephant body structures are similar to the other mammals, excluding some special structures such as the trunk, tusks, respiratory and reproductive systems.

- **Skeletal system**

Because of the large body size of the elephants, the skeleton must be very large and strong to support the body weight. The whole skeleton weight is approximately 16.5 percent of body weight.

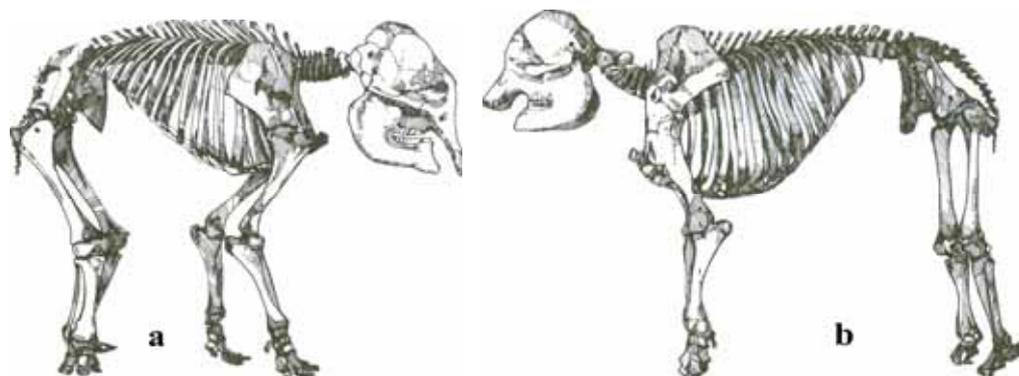


Figure 1. Skeleton of the elephant, *Elephas maximus* (a) and *Loxodonta africana* (b) (modified from Redmond I., 1997)

Axial skeleton

1. Skull

The elephant skull is large but light weight because of the pneumatic bone which has air cavities making it appear like a honey comb or sponge on cut section. Pneumatization of the bones of the skull occurs the elephant is 3-4 year old. The big skull allows strong attachment of muscles supporting the movements of the trunk, ear and jaw, and houses various organs especially the brain, eyes, ears, tusks, and upper part of respiratory and digestive tracts. The largest cavity in the skull contains the brain. Molar teeth are in the maxillary and mandibular bones and the tusks alveolar sockets of the maxillary bones. The skull structure is not different between genders but the skulls of young elephants are more dorsally ventrally flattened than those of adult elephants.

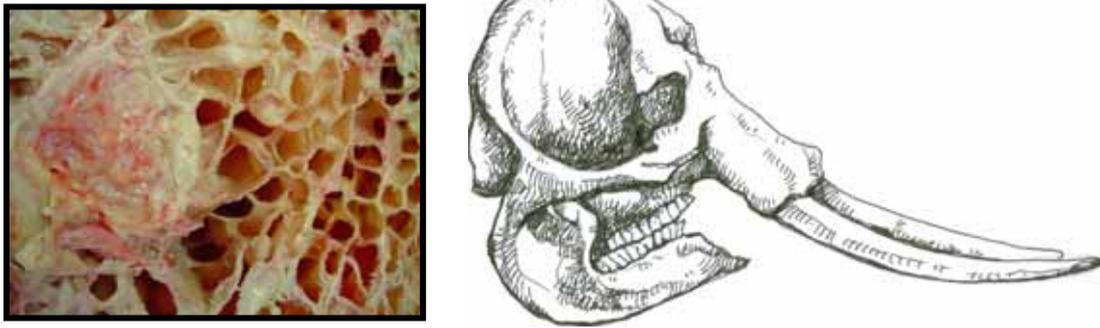


Figure 2. (Left) Air cavities in the cranium (Right) The elephant skull (Asian elephant) (modified from Redmond I., 1997)

2. Vertebrae

The vertebral column of the Asian elephants are divided into basic five regions, cervical (7), thoracic (19-20), lumbar (4-5), sacral (4-5) and coccygial or caudal (24-33), the parentheses is a numbers of each region. The vertebral column is a curved linear, arch-like structure in Asian elephants, but is more nearly a straight horizontal line in African elephants. The movement of elephant vertebrae is limited because of fixed and tightened vertebral junctions.

3. Ribs

The number of ribs are 19-20 pairs depending on the subspecies for the Asian elephants, and 21 pairs for African elephants. The first six pairs of ribs are sternal ribs, the next nine pairs are asternal ribs and last four or so pair of ribs are true floating ribs in the Asian elephants.

4. Sternum

These flat cartilages and bones lay in the pectoral position and serve as points of attachment for ribs and pectoral muscles, while protecting the organs in the thoracic cavity.

Appendicular skeleton

The elephant appendicular skeleton includes the fore or thoracic limbs and hind or pelvic limbs. The both are arranged in an almost vertical position under the body, similar to a pillar or leg of a table rather than being in the angular position seen in many other quadraped mammals. The legs are built to support great weight. The marrow cavities are lacking in the elephant long bones but there is a network of the dense cancellous bone which contains hemopoietic cells responsible for

manufacturing blood cells. This structure makes the bones stronger and better able to withstand pressure than if they contained a marrow cavity.. A special structure in the plantar region of the foot to increase support for the massive weight and gaits of the elephant is called the cushion pad. The plantar surface of the elephant foot is covered with thick keratin layer. Elephants can walk, run and swim, however they do not trot, canter, gallop and jump. Normally an elephant gait involves lifting two feet on one side of the body together while the two feet on the other side remain on the ground (a rack gait). .The speed of elephant gaits varies from slow to quite fast, and elephants can outrun most humans.. Elephants can remain standing for long periods because of the position of bones and limbs.

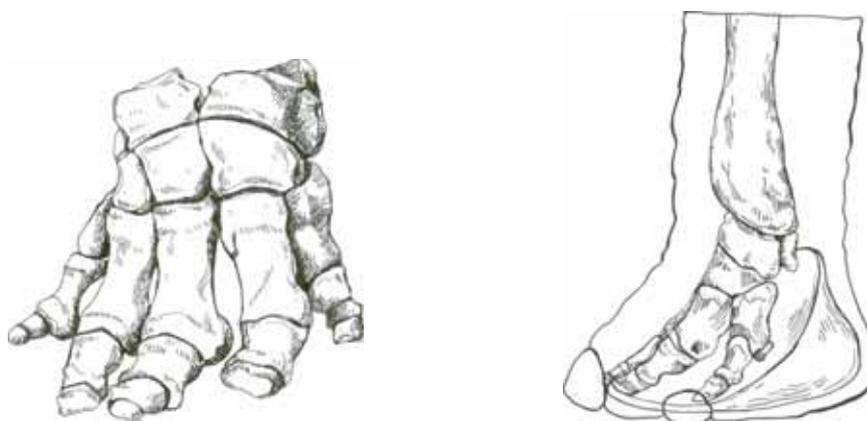


Figure 3. (Left) Elephant carpal bone (modified from Shoshani J., 1992) (Right) Structure of an elephant foot (modified from Redmond I., 1997)

- **Muscular system**

Muscular structures of an elephant are large, including muscle fibers, tendons and ligaments. There are three types of muscle, voluntary (skeletal) and involuntary (smooth and cardiac), as is the case in all mammals. Their function effects the movements of the bones, when stimulated by signals from nerve fibers. The muscles are nourished by their vascular supply.

Trunk

The elephant trunk is an interesting organ. It is composed of muscles, vessels, nerves, fat and other connective tissues, and skin. The trunk evolved from fused muscles of nose, upper lip and cheeks. It contains no bone or cartilage, although cartilage is found around the nostrils and at the base of the trunk. The muscles are including superficial

and internal muscles. The total number of muscles is approximately 150,000. Superficial muscles run longitudinally along the dorsal, ventral and lateral aspects of the trunk. The internal muscles are deep to the superficial muscles and include radial muscles and transverse muscles. The two nostrils are separated by a membranous septum and are connected to openings in the frontal aspect of the cranium. The functions of the trunk include feeding, watering, dusting, smelling, touching, communicating (touch and sound promoter), defense and others. The trunk of an adult Asian elephant can hold about 10 liters of water.



Figure 4. The structure of elephant trunk (modified from Redmond I., 1997)

- **Integument system**

Skin

The skin of elephant is not equally thick at all locations of the body. The thin skin is 1.8 millimeters, found in the ear, around the mouth and anus. The thicker skin is found on the head, back and buttock. This skin can be 2.5-3.5 centimeters or more thick. The skin is a highly sensitive organ with a rich nerve supply. Like other mammals, the skin is composed of two major layers (dermis and epidermis), which include glands and hair follicles. The color of skin is darker (brown or reddish) in African elephants and lighter in Asian elephants (gray). The Asian elephants have localized areas of depigmentation on their forehead, neck, ears and forelimbs. Normally the skin is covered with dust, soil or mud for prevent insect bites, ultraviolet radiation damage and moisture loss.

Hair

Hair can found of a body of baby and young elephant, especially on the head and back. Adult elephants have less hair than young elephants and African elephants have less hair than Asian elephants. Hairs concentrate around eyes, mouth, chin, the ear opening and the end of the tail. Hair color varies from brownish, to brown, black, gray or white.

Nail and plantar pad

The structure of elephant nails is similar to other mammals. Elephants stand on the plantar surface of their foot with the cushioned pad supporting the heavy weight. The nails grow about 1 centimeter per month. The plantar surface of the foot is covered with keratinized layer, called the keratinized sole, which is approximately 4-12 millimeters thick and grows at a rate of 0.5-1 centimeters per month.

Sweat gland

The elephants lack of sweat glands over most of their body, and cannot use them for thermoregulation. Some sweat glands may be seen in coronet line of the toenail. The ears are used as the primary means of thermoregulation dispersing heat through radiation and with the assist of flapping the ears to move air to increase the efficiency of the radiator.

Temporal or musth gland

An adapted sebaceous gland is located midway between eye and ear on the temple on both sides of the head. Its opening or orifice can be visualized with the unaided eye. The glands are covered with skin that is 2 or more cm thick. The glands produce chemical substances important in elephant reproduction. The secretion is oily and smells foul when secreted through the glands opening. Elephants in musth are aggressive, especially males. Females in musth are normally not aggressive.

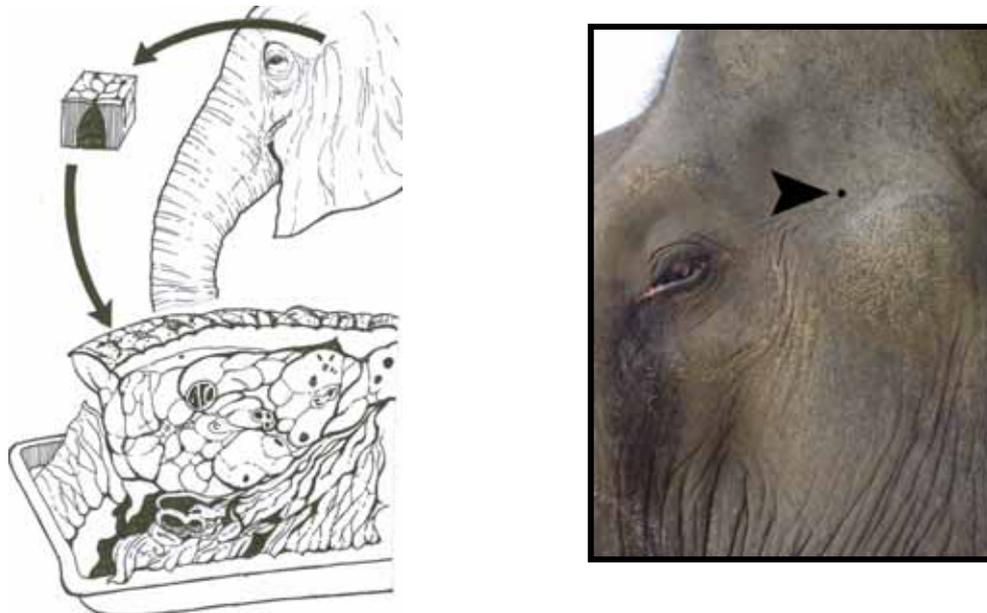


Figure 5. (Left) The temporal or musth gland structures(modified from Shoshani J., 1992), and microscopic structure (x 40) (Right) The opening of temporal



- **Respiratory system**

The respiratory tract of elephants is comprised of the conducting portion (external nares, nasal tubes, internal nares, pharynx, larynx and trachea) and the respiratory portion (bronchi, bronchioles, alveolar duct and alveolar sac in lung). Sound is produced from larynx. The lungs are attached to the thoracic walls and diaphragm, oblithrating the potential pleural space normally maintained in negative pressure to assist breathing in other mammals. . Unlike most other mammals, elephants rely on intercostals and diaphragmatic muscle movement alone to inflate and deflate the lungs. If there is an impediment in the muscular excersion of the key muscles in respiration for the elephant, the resulting dyspnea is severe. For example, long periods of sternal recumbency increase abdominal pressure thereby limiting diaphragm motion. Elephants poorly tolerate sternal recumbency and assume lateral recumbency when they lay down. This can be observed at times when elephants sleep.

- **Gastrointestinal system**

Elephants are herbivoroussingle stomached or monogastric animals. The major alimentary structures are similar to those of the horse. Elephants lack a gall bladder and rely on hind gut fermentation of fecal matter in their large cecum using bacterial symbiosis. The elephant digestive tract consists of (from oral to aboral) the mouth, pharynx, esophagus, stomach, small and large intestine, cecum, rectum and anus. Accessory organs such as molar teeth, tongue, salivary gland, liver and pancreas complete the system. The digestive system of elephant is not very efficient at absorpction of nutrients. Elephants digest and absorb only about 44 percent of what they eat. The consumption of an adult Asian elephant is approximately 150-200 kilograms of food (10 percent of body weight) and 200 liters of water per day, although larger amounts of food may be required in some circumstances.

Mouth

The opening of the mouth of the elephant is smaller relative to body size compared to many other mammals. The oral cavity has molar teeth, a tongue, and openings of the salivary ducts and salivary glands. The mouth is connected to the pharynx and the upper respiratory tract. The strong mandibular movement and coordination of teeth and tongue function are important in generating the horizontal grinding action of mastication of elephants.

Molar teeth

The dental formula of adult elephants for both species is I 1/0 C0/0 PM 3/3 M 3/3, with a total number of 26 teeth, the two upper incisors are the tusks. The average weight of the teeth of elephants is approximately 5 kilograms. New born elephants have 2-3 teeth in each jaw quadrant; these teeth develop in the fetus and can be observed in jaw within a few months after the birth. Elephants have 6 sets of molar teeth during their life span but they cannot hold all 6 sets at one time. The molar teeth are shed periodically. They move foreword in the jaw to displace old and worn teeth that fragment and usually fall out on their own and are swallowed. The structure of the teeth of elephants is complex and very much like the structure of the teeth of other mammals. They are comprised of cementum, enamel, dentin, a pulp cavity and pulp tissue that includes odontoblasts, odontocytes, vessels and nerves.

All elephantteeth are held together by cementumwhich forms the foundation for the projections on the occlusal surfaces of the molars which are covered with light or white enamel. These ridges contrast with the grooves where the darker colored dentin is seen. The shape of projections on molar occusal surfaces can be used to identify theelegant species. Molar projections are lozenge shaped in African elephants and loop shaped in Asian elephants.



Figure 6. The molar teeth of an Asian elephant

Tusks

Elephant tusks are the upper incisor teeth. The elephant tusk is a hypsodont tooth capable of growing through out the life of the elephant (elephant molar teeth are brachydont teeth). The deciduous tusks can found in new born elephants. The permanent tusks are observed in 2-3 year old elephants. Tusks normally grow about 15-18 centimeters per year. The structure of tusk is similar to that of a tooth except that enamel is only found on milk tusks. Elephant tusks have a unique characteristic refered to as the checered pattern (a net liked pattern) which can be seen in the cross section of the tusk. About 1/3 of the tusk length lie in the alvelolar socket of the maxillary bone. The sulcus is approximately the the length between the eye and the tusk sulcus. The pulp of the tusk extends about 2/3 of the tusk length, (see the figure 8). The position of the pulp is important for properly trimming the tusk.

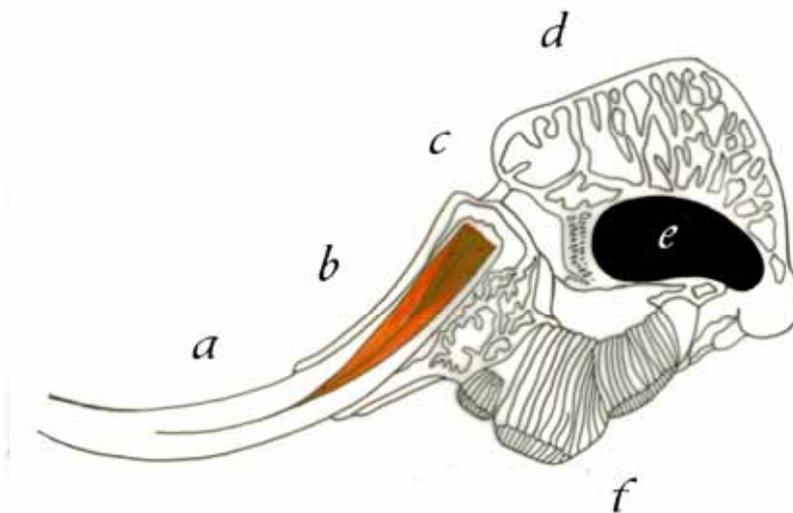


Figure 7. The longitudinal section of an elephant head and tusk, a tusk (a), pulp (b), internal nare (c), air cavities (d), brain cavity (e) and molar teeth (f) (modified from GrÖning K, 1999)

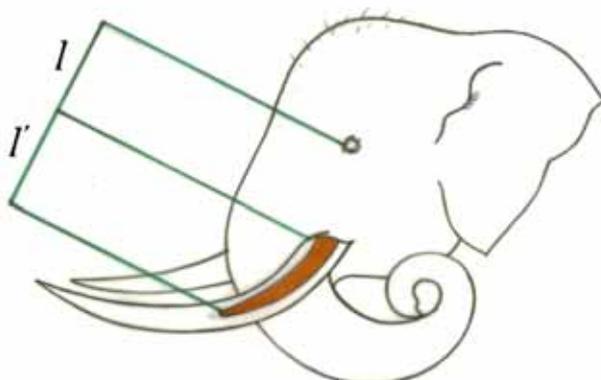


Figure 8. The measuement useful for estimating the leghth of the pulp cavity in the elephant (modified from Robinsom and Schmidt, 1986)

Esophagus

The esophagus extends from the pharynx to the stomach running in close relation to the trachea. Its structure is that of a musculomembranous tube, formed primarily by the tracheoesophageal muscle. The esophageal mucosa has numerous mucous glands which secrete mucus to lubricate the food bolus as it passes through the esophagus.

Stomach

The elephant stomach is cylindrical and approximately 75-90 centimeters in long in adult elephants. The capacity of adult elephant stomach is between 30 and 70 liters.

Intestine, cecum and rectum

The length of small intestine of adult elephants is about 66 to 74 feet. The intestines are divided into the duodenum (approximately 1.5 feet long), jejunum (approximately 11 feet long) and the ileum. The large intestine of an adult elephant is approximately 38-43 feet long divided into a 20 to 22 foot long colon followed by a 12 to 14 foot rectum terminating at a muscular anus under the tail. The cecum is 5 to 7 feet long, located coming off of the junction of the ileum and the colon. It is a major site of fermentation in the elephant. The capacity of the small intestines of an adult elephant is approximately 135 liters and the large intestines and caecum hold approximately 480 liters of matter.

Liver and pancreas

Although the elephants lack the gall bladder, bile is secreted and passes to the small intestine through multiple ducts. The bile functions to enhance lipid digestion and absorption in the intestine. Pancreatic secretions function to facilitate protein and carbohydrate digestion along with secretions from the glands in intestinal wall.

- **Circulatory, hemopoetic and lymphatic systems**

Heart

The elephant heart is large (about 12-21 kilograms). It is apple shaped with double ventricular apices. Large sinuses moderate the high blood pressure from cardiac contraction to prevent damage of peripheral blood vessels. These sinuses can be found in both sides of the temporal area, along the trachea, sternum, axillae and inguinal areas. The vasculature of elephants is thicker walled and stronger than found in most other mammals.

Blood

The blood components of the elephant are similar to other mammals, except that the blood cells are larger.

Lymph and lymphoid organs

The thymus, tonsils, lymph nodes and spleen are the lymphoid organs of the elephant. The lymphatic system plays an important role in the elephant immune response.

- **Nervous system**

The elephant nervous system is comprised of a brain, spinal cord and peripheral nerves. The brain to body size ratio is smaller than other mammals. The brains of male elephants weigh between 4.2-4.5 kilograms and the brains of female elephants weigh between 3.6-4.2 kilograms. Although the elephants have a small brain to body size ratio, they are one of the most intelligent animals, with a highly complex and developed pattern of gyri and sulci. No intelligence difference has been observed between male and female elephants. The spinal cord of the elephant has two enlargements referred to as the cervical and lumbar enlargements. These enlargements contain numerous nerve cells that function in control of the limbs. ,

- **Urinary system**

This system is comprised of bilateral kidneys, and ureters, a urinary bladder, urethra and urethral opening. Like the ox, elephant kidneys are multilobar. An elephant kidney has 5-7 lobules. The urinary bladder capacity of an adult elephant is approximately 6-18 liters. Normal elephants urinate 10-15 times per day.

- **Reproductive system**

Male

The testes are located inside the abdominal cavity. They are tennis ball sized structures just posterior to the kidneys. The elephant penis is the muscular type similar to that of horses and humans. The length of penis is about 2 meters, and it is S-shaped. The other organs involved in the male elephant reproductive system are the seminal vesicles, the sperm storage organ, and prostate gland, the ampullae and the bulbourethral glands.

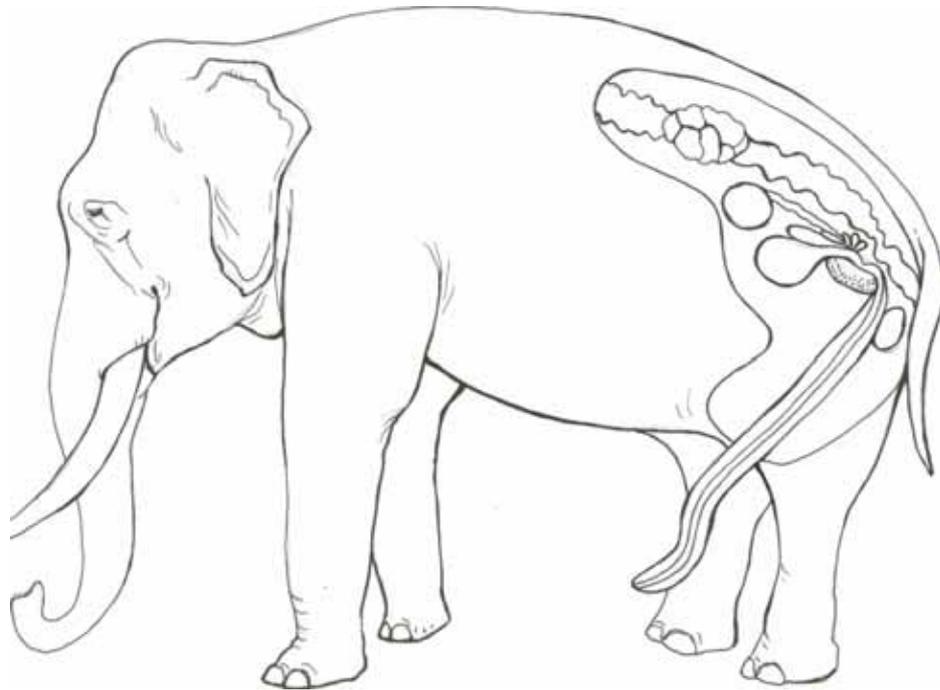


Figure 9. The male elephant reproductive system (modified from Hildebrandt et al., 2006)

Female

Like a cow or mare, the female elephant has bilateral uterine horns. The ovaries are located behind the kidneys. The genital canal is 68-88 centimeters long and consists of a vagina, vaginal os and vestibule. The vulva position is between the inguinal regions, ventrally, which is different from most other mammals which have the vaginal oss located perineally under the tail. The clitoris lies in the vulva and is about 40 centimeters long, about the same length as the vulva. The two mammary glands are located pectorally between the forelegs. The placenta of the elephant is zonary. The gestation period of the elephant is very long, about 17-22 months. A male calf has a longer gestation period, (average 21-24 month) compared to a female calf (17-23 months).

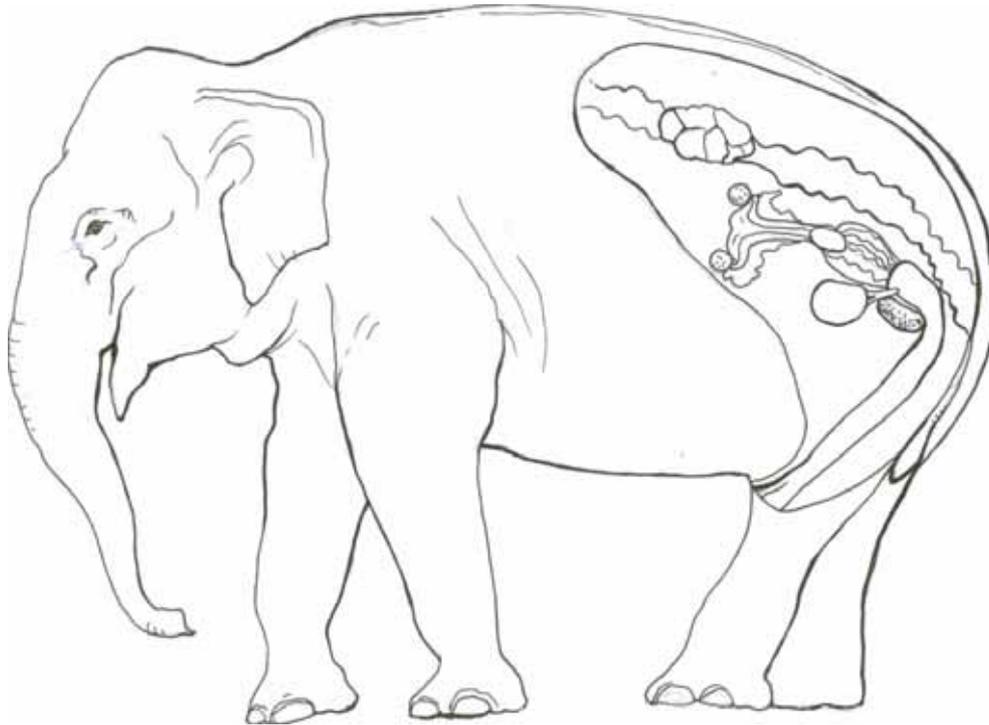


Figure 10. The female elephant reproductive system (modified from Hildebrandt et al., 2006)

- **Special sense organs**

Eye

The structure of elephant eye is similar for both species. The elephant does not have a lacrimal apparatus, but the hardarian gland can be observed close to the third eyelid. The gland secretion plays the important role of preventing drying of the eye. The third eyelid is well developed and strong to protect the globe of the eye. The pupil and iris are circular shaped and colors of iris vary between greenish-brown and blue. The visual ability of elephants is limited because of the eye, ear and trunk locations and the limited mobility of the eye..

Ear

The ear of the elephant is a second highly sensitive organ. The elephant can hear at 12,000 Hertz in the upper limit, compared to bats (80,000 Hertz), dogs (40,000 Hertz) and humans (20,000 Hertz). On the other hand, elephants can hear and produce sound which has a long wave length, 14-16 Hertz, below the hearing range of the human ear (20 Hertz). Therefore elephant communication is not entirely audible to humans.

They can communicate to other elephants at a great distance using these ultrasonic wavelengths. The functions of the ear include acoustic detection, balance, thermoregulation and information transfer. The constriction and dilatation of blood vessels in the elephant ear are controlled by signals from nerves, which are sensitive to temperature. We can estimate an elephant’s age from the ear fold, which progresses in size with age.

Nose (trunk)

The nose or trunk is the smelling organ of the elephants, and is associated with the special sensory organ called the vomeronasal organ located on the palate of the mouth. The vomeronasal organ structure consists of two small pits connected by numerous nerve endings which transmit smelling sensation to the brain. The vomeronasal organ is a highly sensitive organ for smell. When elephants want to detect an odor, they rising and wave their trunk in the air to better inhale the smell. They can find and locate water sources about 50 kilometers away, and can detect the reproductive status of the other elephants from a long distance, especially males detecting female elephants in estrous.



Figure 11. The opening of a vomeronasal organ of the elephant