UNIVERSITI PUTRA MALAYSIA

THE VALUE OF CONE BEAM COMPUTED TOMOGRAPHY ANGIOGRAPHY IN STUDYING THE ARTERIAL SYSTEM IN VICINITY TO GUTTURAL POUCH IN HORSES

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THE VALUE OF CONE BEAM COMPUTED TOMOGRAPHY ANGIOGRAPHY IN STUDYING THE ARTERIAL SYSTEM IN VICINITY TO GUTTURAL POUCH IN HORSES

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DEDICATION

This project paper is dedicated

To my family,

Apak, Mak, and my brothers.

And to all my teachers who guiding me in completing this project.

CERTIFICATION

It is hereby certified that we have read this project paper entitled "The Value of Cone Beam Computed Tomography Angiography in Studying the Arterial System in vicinity to Guttural Pouch in Horses", by Haniza binti Jais and in our opinion it is satisfactory in terms of scope, quality, and presentation as partial fulfilment of the requirement for the course VPD 4999 – Final Year Project.

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NILAI ANGIOGRAFI TOMOGRAFI BERKOMPUTER BERALUR KON DALAM MEMPELAJARI SISTEM ARTERI BERDEKATAN DENGAN KANTUNG GARAU DI DALAM KUDA

Oleh

Haniza binti Jais

2017

Penyelia: Dr. Nurul Hayah Khairuddin

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Dr. Lau Seng Fong and Prof. Dato' Dr. Tengku Azmi Tengku Ibrahim

Kantung garau adalah divertikulum besar tiub Eustachia yang menghubungkan tekak dengan bahagian tengah telinga. Ia adalah struktur yang unik di dalam kuda kerana anatominya terletak berdekatan dengan struktur penting yang lain seperti arteri karotid internal, arteri maksilari, arteri karotid eksternal, saraf glosofaringeal, dan saraf hipoglosal. Struktur ini adalah penting sekiranya berlaku mikosis kantung garau di mana kerosakannya boleh menyebabkan deficit neurologi dan pendarahan teruk yang boleh membawa maut kepada kuda. Oleh itu, satu kajian telah dijalankan untuk menentukan nilai menggunakan angiografi tomografi berkomputer beralur kon dalam mengkaji sistem arteri di sekitar kantung garau. Dua ekor kuda yang sudah bersara

telah dimatikan dengan berperikemanusiaan atas sebab-sebab atau masalah yang tidak berkaitan dengan kantung garau telah digunakan untuk kajian ini. Media kontras yang berasaskan iodin (Iomeprol) telah disuntik melalui arteri karotid sesama untuk menyerlahkan arteri dalam kepala kadaverik. Berdasarkan imej angiografi tomografi berkomputer, arteri-arteri penting di sekitar kantung garau boleh dikenal pasti dan dilihat dalam tiga satah yang berbeza iaitu satah transversal, satah sisi, dan satah dorsal. Walaupun terdapat beberapa batasan dalam menggunakan kaedah ini, kajian tomografi berkomputer di dalam kantung garau serta arteri-arteri yang berdekatan dengannya telah menghasilkan imej laluan anatomi arteri yang sangat baik.

Kata kunci: Kantung garau, angiografi tomografi berkomputer beralur kon, arteri karotid internal, kuda

ABSTRACT

An abstract of the project paper presented to the Faculty of Veterinary Medicine in partial fulfilment of the course VPD 4999 Final Year Project.

THE VALUE OF CONE BEAM COMPUTED TOMOGRAPHY ANGIOGRAPHY IN STUDYING THE ARTERIAL SYSTEM IN VICINITY TO GUTTURAL POUCH IN HORSES

by

Haniza binti Jais

2017

Supervisor: Dr. Nurul Hayah Khairuddin

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Dr. Lau Seng Fong and Prof. Dato' Dr. Tengku Azmi Tengku Ibrahim

Guttural pouches are the large diverticula of the eustachian tubes that connect the pharynx to the middle ear. It is a unique structure in equine as it is anatomically located very closely to other important structures such as internal carotid artery, maxillary artery, external carotid artery, glossopharyngeal nerve, and hypoglossal nerve. These structures are important in the event of guttural pouch mycosis as the damage can cause neurological deficit and severe haemorrhage, which may be fatal to the horse. Hence, a study was conducted to determine the value of using cone beam computed tomography angiography in studying the arterial system in vicinity to the guttural pouch. Two retired horses were euthanized humanely for reasons or problems unrelated to the guttural pouches were used for this study. Iodine based contrast media

(Iomeprol) was injected via common carotid arteries to highlight the arteries of the cadaveric heads. Based on the computed tomography angiography images, the important arteries in vicinity to the guttural pouch can be recognized and observed in three different plane, which are the transverse plane, the sagittal plane, and the dorsal plane. Even though there are several limitations in using this method, computed tomography study of the guttural pouch and the important arteries provided excellent imaging of the anatomical pathways of the associated arteries in relation to the pouch.

Keywords: *Guttural pouch, cone beam computed tomography angiography, internal carotid artery, horses.*

CHAPTER 1

INTRODUCTION

Guttural pouches are large diverticula of the eustachian tubes that connect the pharynx to the middle ear (Hardy and Le´veille, 2003). The exact function of the guttural pouches in horses remains unclear but Baptiste (1998) has provided evidence that the guttural pouches of horse may function as brain cooling system by allowing air from the nasopharynx goes into and ventilate the guttural pouches to reduce the temperature of blood flowing within the internal carotid arteries (ICA). Guttural pouch of a horse can be related to a mycotic or fungal disease, known as guttural pouch mycosis. It can cause fatal haemorrhage, whereby the fungal erodes the wall of the guttural pouch and subsequently the wall of the internal carotid artery (Cook, 1968), as well as wall of the external carotid artery and the maxillary artery (Markus *et al.*, 2005). The invasion of the mycotic lesion at specific anatomical region of the guttural pouch is still unclear (Lepage *et al.,* 2004). In relation to guttural pouch mycosis, a computed tomography angiography of the guttural pouch and the arterial system in vicinity to it could shed some lights in terms of passage of fungal infection into the guttural pouch. Thus, the purpose of this study is to determine the value of using cone beam computed tomography angiography in studying the arterial system in vicinity to the guttural pouch in horse.

CHAPTER 2

LITERATURE REVIEW

2.1 Guttural Pouch

Guttural pouch in a horse is a unique membranous, epithelium lined, and air-filled pouch found in the horse and other Perissodactyla such as hyraxes, certain bats, and a South American mouse, whose function is still not clear (Baptiste, 1998; Dyce *et al.* 2010; Khairuddin *et. al.*, 2016).

Dyce *et al.* (2010) stated that the guttural pouch is a diverticulum of the auditory tube, which is formed by the escape of the mucosal lining of the tube through a ventral slit between medial and lateral supporting cartilages and reach a volume capacity of 300 to 500 ml. Both Dyce *et al.* (2010) and Seahorn (2004) explained that the dorsal part of the pouches located in between the base of the skull and atlas, and the ventral part of the pouches located on the pharynx and commencement of the oesophagus, while the lateral part of the pouches is covered with pterygoid muscles, parotid glands, and mandibular glands. Furthermore, the guttural pouches are separated into medial and lateral compartments, where the floor of the guttural pouches are moulded to the stylohyoid bone. A thin layer of membrane separates the two guttural pouches in the median plane for the rostral part of the pouches, and as for the caudal part of the pouches, they are in contact through the *rectus capitis ventralis* muscles (Lepage *et al.*, 2004).

The exact function of the guttural pouches in horses remains unclear, and there have been many functions proposed in many studies, but none have been proven (Seahorn, 2004). However, in 1998, Baptiste has substantiated that the guttural

pouches of horse may function as brain cooling system by allowing air from the nasopharynx goes into and ventilate the guttural pouches to reduce the temperature of blood flowing within the internal carotid arteries (ICA), especially during activities that can cause high thermal stress, such as during heavy exercise.

2.2 Vascular Anatomy of Guttural Pouch

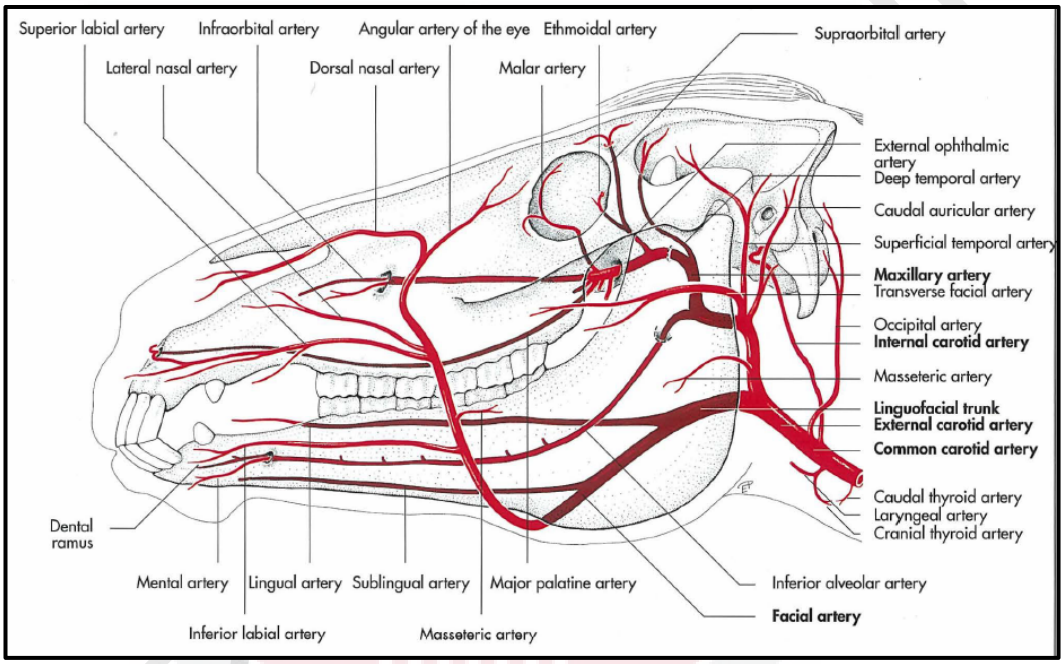


Figure 1: Principal arteries of the head, schematic (König et al., 2004)

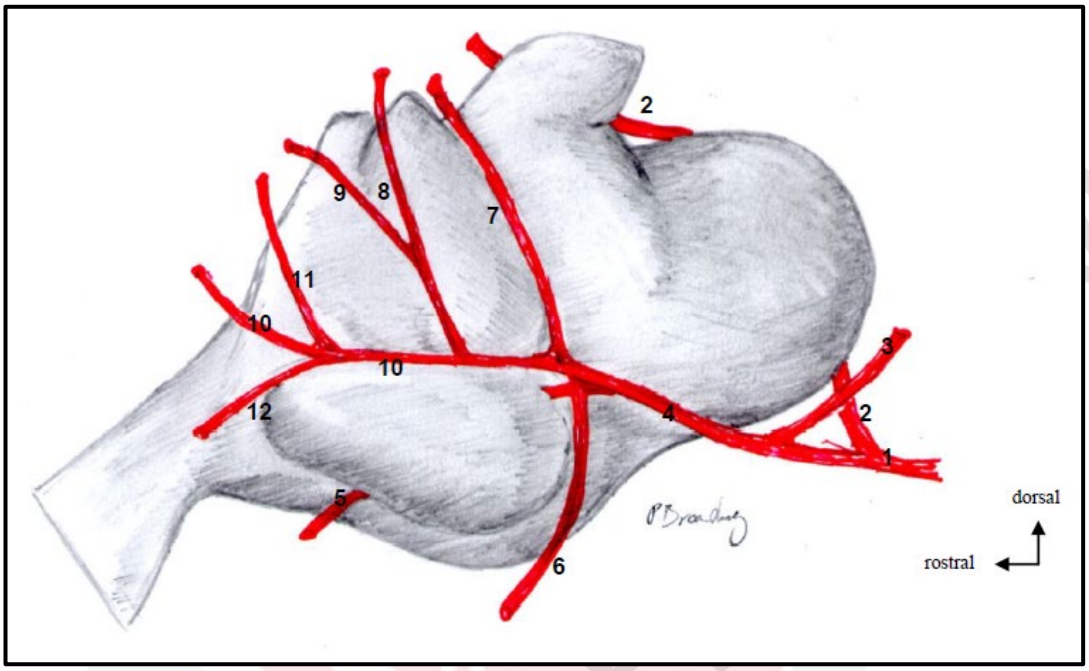


Figure 2: Arteries associated with the guttural pouch (Hayah, 2012)

1 *common carotid artery;* ***2*** *internal carotid artery;* ***3*** *occipital artery;* ***4*** *external carotid artery;* ***5*** *linguofacial trunk;* ***6*** *masseteric branch;* ***7*** *caudal auricular artery;* ***8*** *superficial temporal;* ***9*** *transverse facial;* ***10*** *maxillary artery;* ***11*** *middle meningeal;* ***12*** *inferior alveolar.*

Based on Figure 1 and Figure 2, two common carotid arteries arise from the brachiocephalic trunk and ascend the neck to each side of the trachea together with the vagosympathetic trunk and the caudal laryngeal nerve (König *et al*., 2004; Hayah, 2012). In the horse, the common carotid artery ends by separating into the external carotid artery, internal carotid artery, and occipital artery or it can also be known as the equine carotid trifurcation (Hayah, 2012).

External carotid artery is the largest terminal branch appears as the direct continuation of the common carotid artery (Dyce *et al.* 2010). It continues as the maxillary artery, which travels along the roof of the lateral compartment of the guttural

pouch (Hayah, 2012) and divided again to several branches to provide blood supply to the muscles, bones, and organs of the head, other than the brain (König *et al*., 2004).

In the book written by König *et al*. (2004), internal carotid artery is one of the most important arteries related with the guttural pouch as erosion of this vessel's wall in horses with guttural pouch mycosis causes bleeding, which can be fatal. In horses, this artery is a bit different from other mammals as it passes through the guttural pouch, which is a diverticulum of the auditory tube, peculiar to the horse. It will then enter the cranial cavity after forming a characteristic of sigmoid flexure at the base of the skull and vascularize the brain.

The third artery that originates from the common carotid artery is the occipital artery, which usually larger than the internal carotid artery (Hayah, 2012). Starting from the origin, the artery passes dorsally and slightly lateral to the fossa atlantis. Later, it divides into cranial branch, which is the cerebrospinal artery, and caudal branch, which contributes to the formation of the vertebral artery (Colles and Cook, 1983). The occipital artery may run deep to the guttural pouch and longus carpitis muscle, but there is no consistent relation between these structures and the artery (Nanda and Getty, 1975; Hayah, 2012).

2.3 Guttural Pouch Mycosis

Guttural pouch mycosis is a fungal infection and life-threatening disease of the horse (Ludwig *et al.*, 2005) that occurs within the guttural pouches that disrupt the integrity of surrounding neurovascular supply, leading to severe haemorrhage and neurological deficits (Yiew *et al.*, 2015). In addition to that, the horse may exhibit clinical signs such as mucoid nasal discharge from one nostril, an acute or multiple

episodes of epistaxis, moderate to severe guttural pouch haemorrhage, or neurologic dysfunction (Hardy and Léveillé, 2003) such as dysphagia, laryngeal or pharyngeal paralysis, oesophageal obstruction, Horner's syndrome, and facial nerve paralysis (Hardy and Léveillé, 2003; Pollock, 2007).

Many species of fungi can cause guttural pouch mycosis (Ludwig *et al.*, 2005; Pollock, 2007). However, *Aspergillus spp* has been the most common fungus causing the disease (Allison *et al*., 2008; Baptiste, 2004; Ludwig *et al.*, 2005), and other reported fungi are *Mucor*, *Penicillium*, *Paecilomyces*, *Chrysosporium*, *Rhizopus*, *and Alternaria spp* (Allison *et al*., 2008). Although the aetiology of the disease is still unknown, it is possible that the infection of the mucosa in the guttural pouch is a sequel to a primary arterial lesion (Markus *et al.* 2005).

Based on the study done by Allison *et al*. (2008), mycotic infection of the guttural pouch generally occurs on the dorsal wall of the medial compartment or on the lateral wall of the lateral compartment. Typically, mycotic ulcerations located over the internal carotid artery in two third of cases and less commonly located over the external carotid artery or maxillary artery (Markus *et al*., 2005; Allison *et al*., 2008). The plaques can vary in size and can expand to cover the entire roof of the pouch, and the infection may erode through the median septum into the other pouch, causing bilateral infection (Allison *et al*., 2008).

2.4 Diagnostic Imaging of Guttural Pouch

Several studies involving diagnostic imaging of the guttural pouch had been done such as endoscopy (Seahorn, 2004; Hardy and Léveillé, 2003), radiography (Farrow, 2006), subtraction angiography ((Macdonald *et al.*, 1999), and computed tomography (Alsafy *et al.*, 2008; Borges and Watanabe, 2011; El-Gendy, 2013; Solano and Brawer, 2004). Recent study was done by Hayah (2012) to study on the anatomy of the carotid trifurcation and the course of the internal carotid artery in horses, using rotational angiography.

Endoscopic examination of the guttural pouch is the most effective technique in visualizing the structure inside the guttural pouch (Hardy and Léveillé, 2003; Borges and Watanabe, 2011). Through endoscopy, the guttural pouch was seen and it associate with many vital structures such as pharynx, larynx, oesophagus, nerves and arteries (Seahorn, 2004).

Farrow (2006) stated in his book that the air-filled guttural pouches of a horse appear radiolucent in radiograph. In lateral projections of the head, the guttural pouches will appear as superimposed radiolucent objects and roughly has triangular shape. Fluid accumulation, excessive air filling, and mass in the guttural pouches can be diagnosed by using this diagnostic technique (Hardy and Léveillé, 2003).

Other than that, several studies related to guttural pouch was also done using the computed tomography to study on the anatomy of equine head, particularly the guttural pouch (Puchalski, 2012; Solano and Brawer, 2004) and the neurological structures related to guttural pouch (Borges and Watanabe, 2011).

CHAPTER 3

MATERIALS AND METHODS

3.1 Animals

Two retired Criollo female horses (mean weight 450 kg) were donated to the institution and were used for this study. The study protocol was approved by the Institutional Animal Care and Use Committee (IACUC - AUP No. FYP.2016/FPV (33,53,59)), Universiti Putra Malaysia for the use of the cadaver materials.

3.2 Endoscopic Examination

Endoscopic examination was carried out on the two horses before it was brought to Post Mortem Unit for euthanization.

1. The horse was brought to the crush and sedated with xylazine, 0.5 mg/kg.
2. For examination of the guttural pouch on the right side, the endoscope was inserted into the ipsilateral nostril, and vice versa.
3. After determine the location of the nasopharyngeal opening, a biopsy wire was inserted into the opening as a guide for the insertion of the endoscope. The endoscope was manipulated until successful insertion into the guttural pouch and the biopsy wire was retracted back to allow full visualization of the guttural pouch.

3.3 Computed Tomography Angiography (CTA)

1. The horse was walked to the Post-mortem unit and sedated with xylazine, 1 mg/kg, intravenously. After a few minutes, the horse was euthanized with pentobarbital, 1 ml/kg, intravenously.
2. The head of the horse was disarticulated from the level of third and fourth cervical vertebra. Then, the left and right common carotid arteries were identified and catheterized using 20Fr Foley catheter.
3. The arterial system was flushed with 0.9% normal saline through the right and left common carotid artery simultaneously until there is no resistance and the fluid can be seen flowing out from the other arteries.
4. The cadaveric head was put on the table of FIDEX cone beam computed tomography machine on the right lateral recumbency and the beam was focused on the region of the guttural pouch.
5. To reduce the presence of gas bubbles and blood clots in the arterial system, 0.9% of normal saline was flushed again via the left and right common carotid arteries simultaneously. In the period of changing syringes, the Foley catheter was kinked to prevent air from getting into the artery.
6. Iomeprol, 300 mg/ml was used as the contrast agent in studying the arterial system in the horses. 80 ml of Iomeprol was infused into each left and right common carotid artery simultaneously.
7. After that, the cadaveric head was scanned using the FIDEX cone beam computed tomography machine.

CHAPTER 4

RESULTS

4.1 Endoscopic Examination

There were no significant findings of abnormality found in the guttural pouches of both horses. Hence, the study was focused only on horses without the specific disease of guttural pouch mycosis.

Through endoscopic examination, we can observe the internal view of the guttural pouch and several structures in vicinity to it. The guttural pouches were seen connected to the pharynx via the pharyngeal openings (Figure 3), which looks like an oblique slit located ventral and rostral to the pharyngeal recess (Borges and Watanabe, 2011).

Once we gain access into the guttural pouch through the pharyngeal opening, the stylohyoid bone was clearly seen separating the pouch into medial and lateral compartment. The most important artery that became the subject of interest in most previous studies lie within the medial compartment of the guttural pouch, which is the internal carotid artery. Surrounding the internal carotid artery, we can find several nerves, which are the cranial nerve IX (glossopharyngeal), cranial nerve X (vagus), and cranial nerve XII (hypoglossal) (see Figure 4).

On the lateral compartment of the guttural pouch, we can locate the external carotid artery, which arise from the common carotid artery. Then, the external carotid artery branches into maxillary and superficial temporal artery as shown in Figure 4.

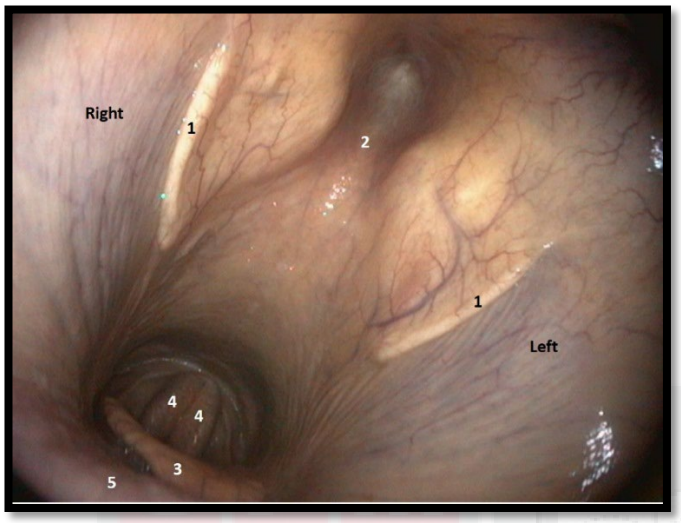


Figure 3: Endoscopic image of pharynx and larynx

1. *Pharyngeal openings of guttural pouches*
2. *Dorsal pharyngeal recess*
3. *Epiglottis*
4. *Arytenoid cartilages*
5. *Soft palate*

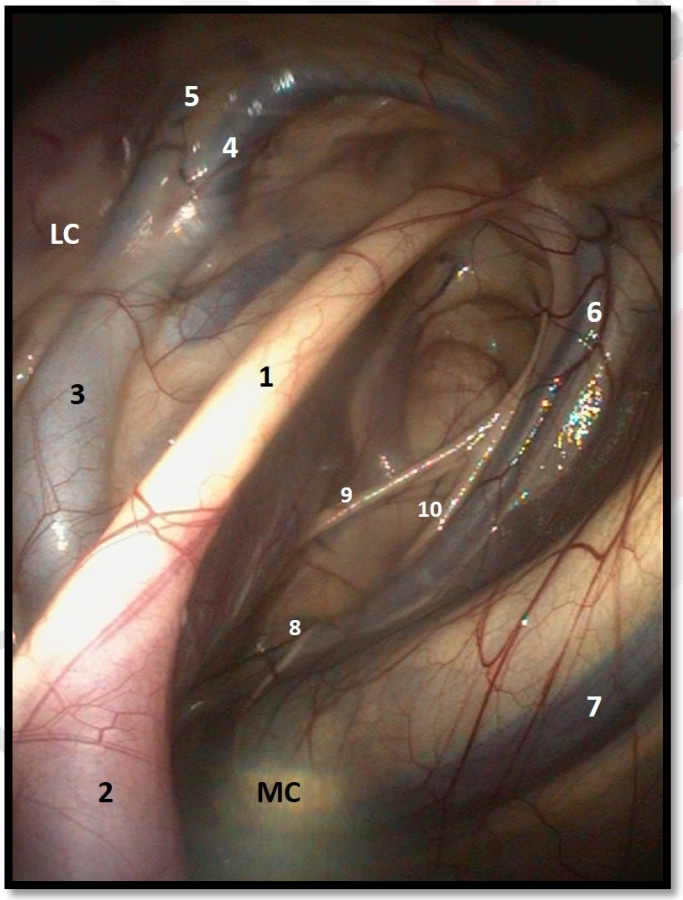


Figure 4: Endoscopic Image of Right Guttural Pouch of a Horse

1. *Stylohyoid bone*
2. *Stylopharyngeus muscle*
3. *External carotid artery*
4. *Maxillary artery*
5. *Superficial temporal artery*
6. *Internal carotid artery*
7. *Longus capitis muscle*
8. *Cranial nerve XII (Hypoglossal)*
9. *Cranial nerve IX (Glossopharyngeal)*
10. *Cranial Nerve X (Vagus)*

LC *Lateral compartment*
MC *Medial compartment*

4.2 Computed Tomography Angiography (CTA)

Both horses used in this study shows similar common anatomic pattern (see Figure 1). In the CTA, we can observe several important arteries that associate with the guttural pouch in three different plane, which are the transverse plane, the sagittal plane, and the dorsal plane.

The common trunk, which is the common carotid arteries give arise to three blood vessels, which are the internal carotid arteries, occipital arteries, and external carotid arteries (Figure 5, 6, and 7). The end of the common carotid arteries and beginning of these three arteries create the term of equine carotid trifurcation (Hayah, 2012). The internal carotid and occipital arteries branches dorsally, while the external carotid artery branches rostrally (Figure 7).

As the internal carotid arteries continue its course rostro-dorsally, the artery will pass closely dorsal to the guttural pouch and deviate laterally and later it will deviate again medially and goes dorsally to the basisphenoid bone (Figure 8 and 10). The internal carotid arteries will form a characteristic of S-shaped or sigmoid flexure at the base of the skull before vascularizing the brain (Figure 9).

The occipital artery passes dorsally and divides into cranial and caudal branch. The cranial branch goes dorsally and it also known as cerebrospinal artery, which will later form basilar artery. While the caudal branch of the occipital artery goes caudo-dorsally and later it contributes in the formation of the vertebral artery (Figure 6).

After arising from the common carotid artery, the external carotid arteries will go rostrally and laterally (Figure 7) before it gives rise to another blood vessel, which is the linguofacial trunks, which will go rostro-ventrally (Figure 9). The main external

carotid arteries continue to go dorsally before it branches into several arteries, which are maxillary arteries, superficial temporal arteries, and caudal auricular arteries (Figure 11, 12, and 13). In Figure 14, the image shows the branch of transverse facial artery, which arise from the superficial temporal artery.

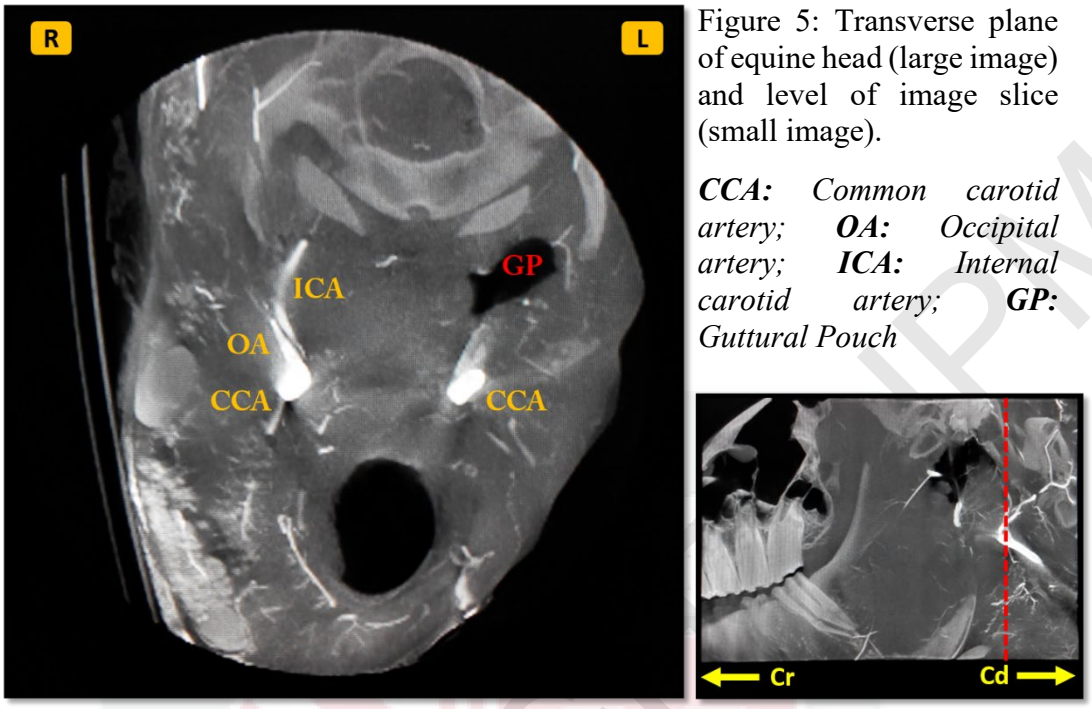


Figure 5: Transverse plane of equine head (large image) and level of image slice (small image).

CCA: *Common carotid artery;* ***OA:*** *Occipital artery;* ***ICA:*** *Internal carotid artery;* ***GP:*** *Guttural Pouch*

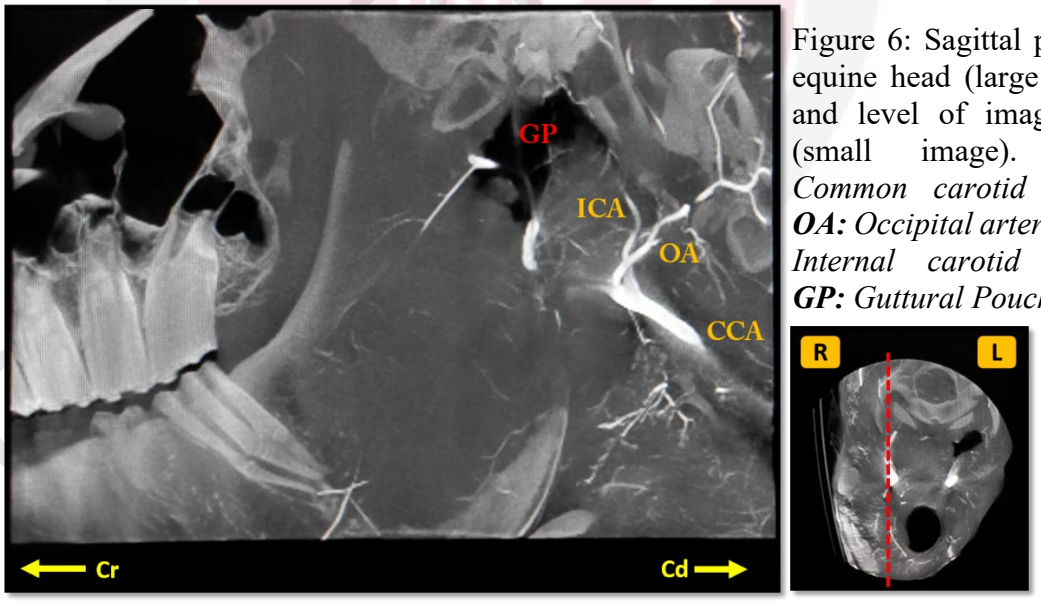


Figure 6: Sagittal plane of equine head (large image) and level of image slice (small image). ***CCA:*** *Common carotid artery;* ***OA:*** *Occipital artery;* ***ICA:*** *Internal carotid artery;* ***GP:*** *Guttural Pouch*

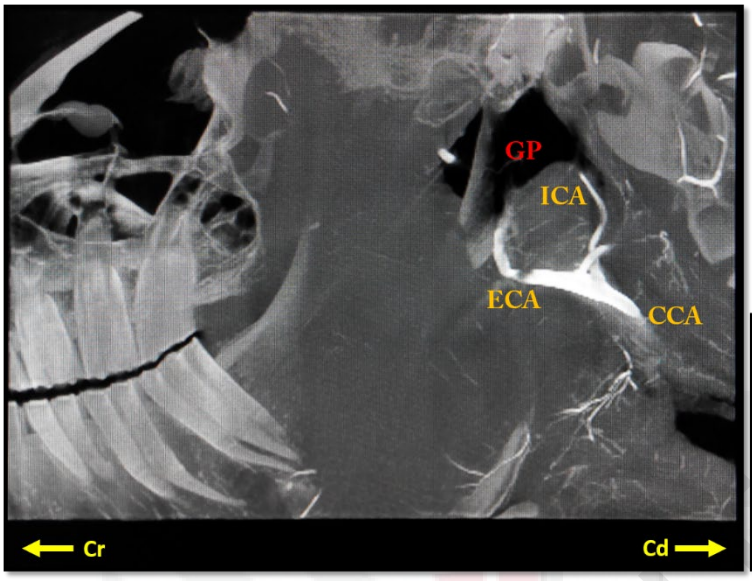


Figure 7: Sagittal plane of equine head (large image) and level of image slice (small image). ***CCA:*** *Common carotid artery;* ***ECA:*** *External carotid artery;* ***ICA:*** *Internal carotid artery;* ***GP:*** *Guttural Pouch*

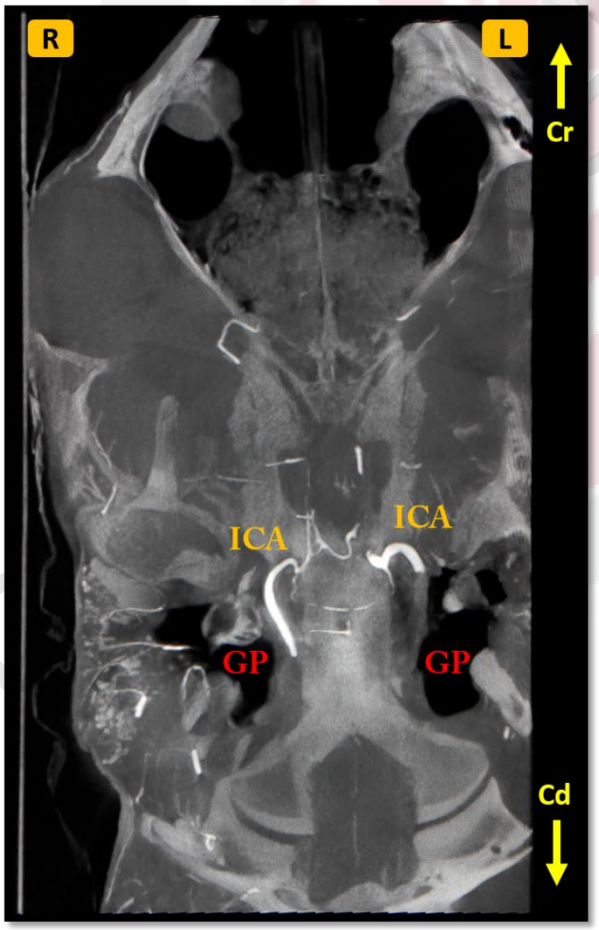
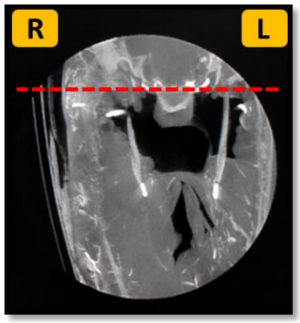


Figure 8: Dorsal plane of equine head (large image) and level of image slice (small image). ***ICA:*** *Internal carotid artery;* ***GP:*** *Guttural pouch*



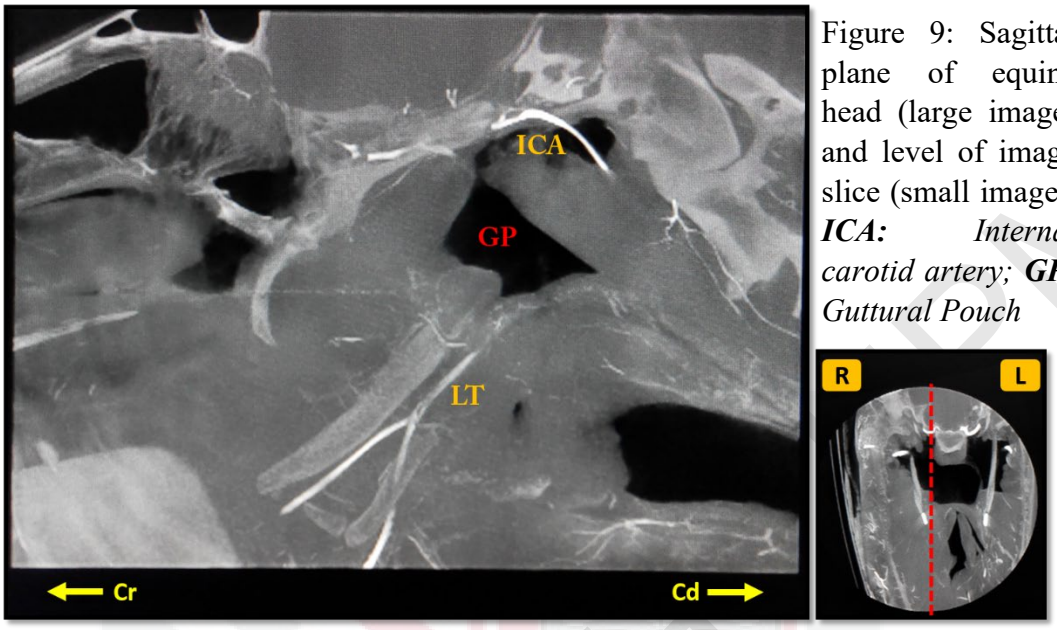


Figure 9: Sagittal plane of equine head (large image) and level of image slice (small image). ***ICA:*** *Internal carotid artery;* ***GP:*** *Guttural Pouch*

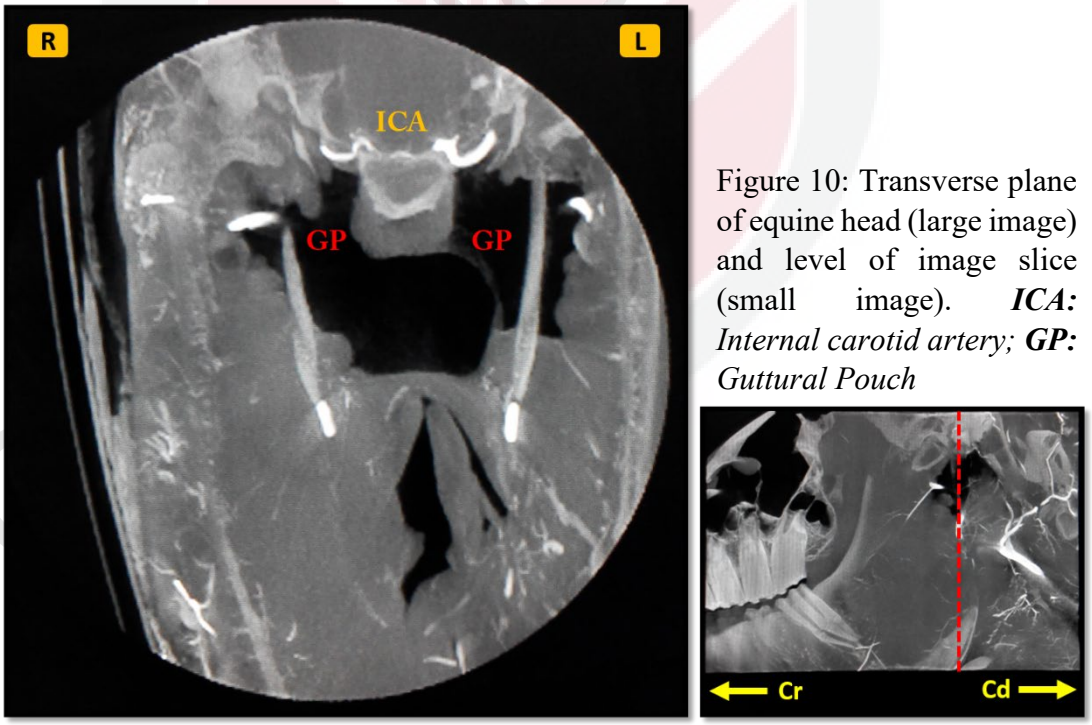


Figure 10: Transverse plane of equine head (large image) and level of image slice (small image). ***ICA:*** *Internal carotid artery;* ***GP:*** *Guttural Pouch*

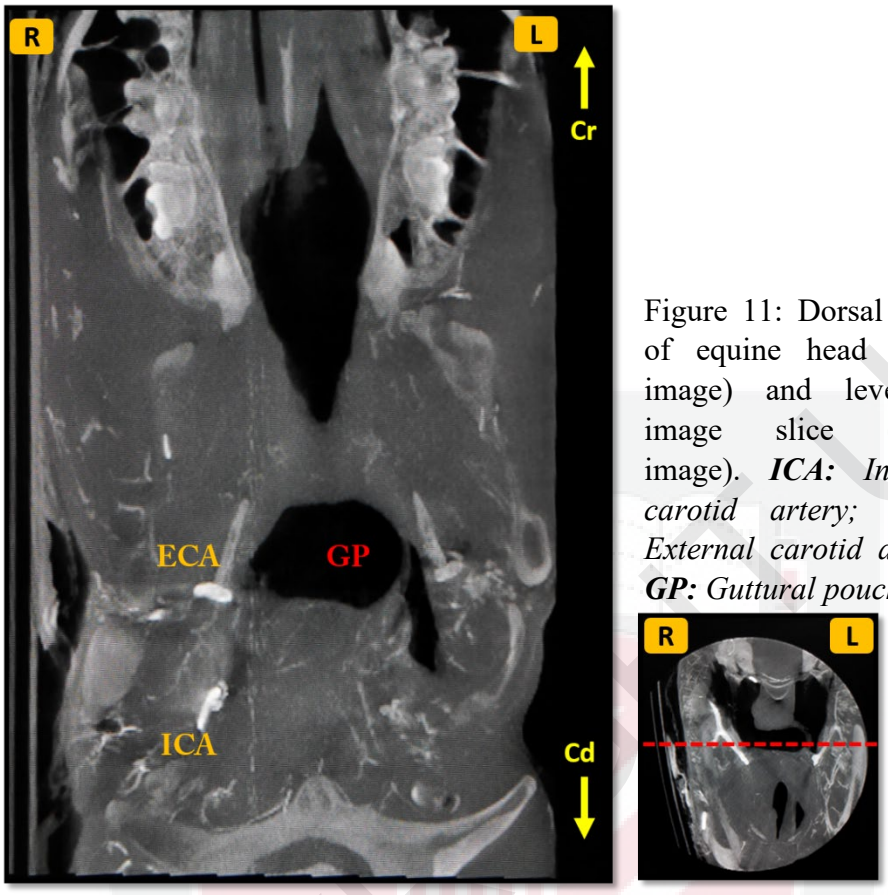


Figure 11: Dorsal plane of equine head (large image) and level of image slice (small image). ***ICA:*** *Internal carotid artery;* ***ECA:*** *External carotid artery;* ***GP:*** *Guttural pouch*

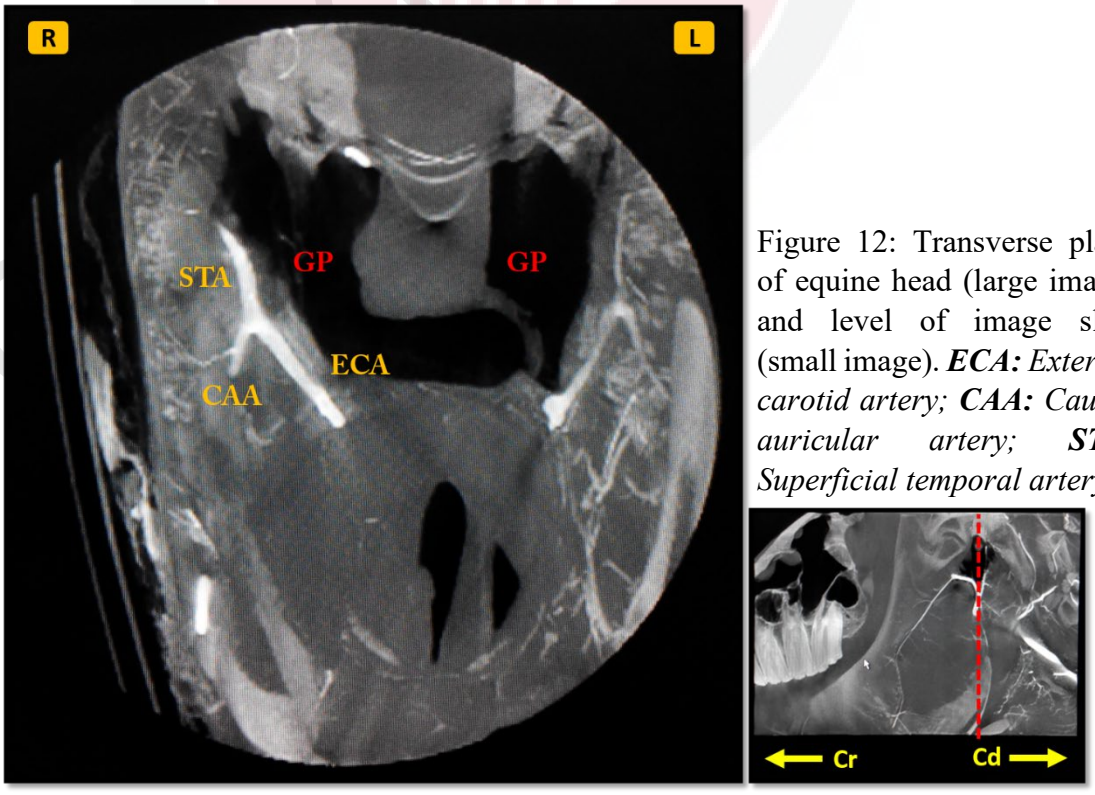


Figure 12: Transverse plane of equine head (large image) and level of image slice (small image). ***ECA:*** *External carotid artery;* ***CAA:*** *Caudal auricular artery;* ***STA:*** *Superficial temporal artery*

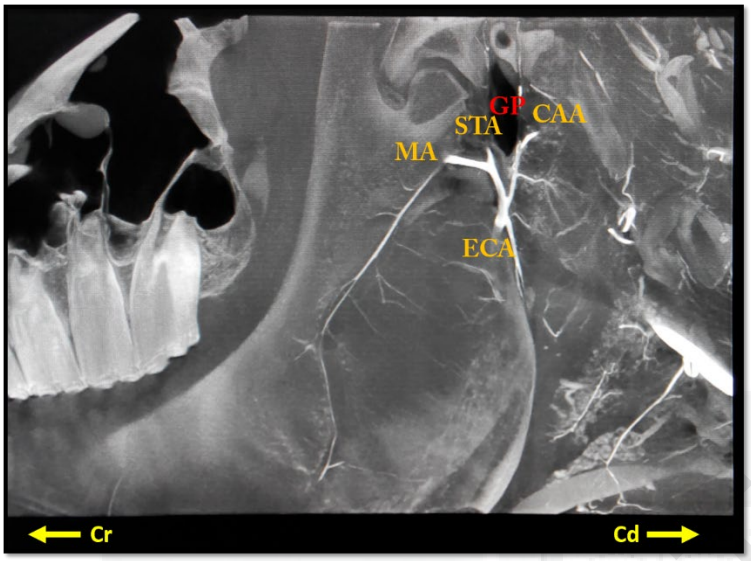


Figure 13: Sagittal plane of equine head (large image) and level of image slice (small image). ***ECA:*** *External carotid artery;* ***CAA:*** *Caudal auricular artery;* ***MA:*** *Maxillary artery;* ***GP:*** *Guttural Pouch*

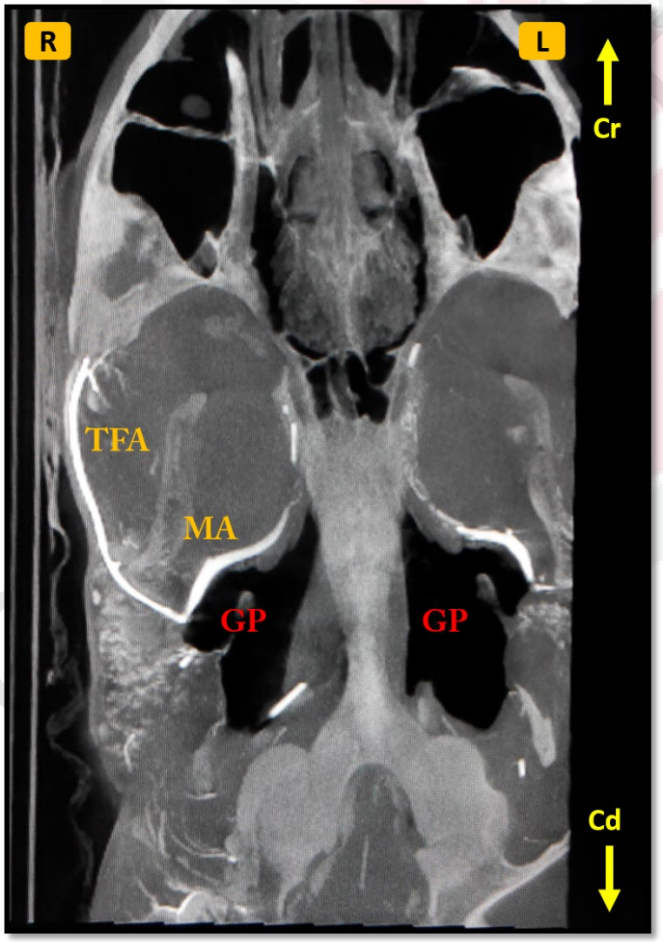
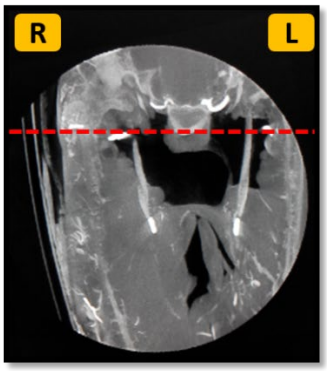


Figure 14: Dorsal plane of equine head (large image) and level of image slice (small image). ***MA:*** *Maxillary artery;* ***TFA:*** *Transverse facial artery;* ***GP:*** *Guttural pouch*



CHAPTER 5

DISCUSSION

The anatomy of the arterial system is important in studying the aetiology of the guttural pouch mycosis, especially on the question as in why does it mostly reside at the internal carotid artery rather than external carotid and maxillary artery (Markus *et al*., 2005; Allison *et al*., 2008; Pollock, 2007). When the mycotic plaque resides at the artery, it may cause erosion of the blood vessel and cause hemorrhage in the guttural pouch, which will lead to the clinical sign of epistaxis in horse (Hardy and Léveillé, 2003). Hence, a computed tomography angiography was done to determine its value in studying the arterial system in relation to guttural pouch mycosis.

Based on the computed tomography angiography images, the important arteries in vicinity to the guttural pouch can be appreciated and recognized. It shows that the use of cone beam computed tomography with contrast media (Iomeron®, Iomeprol, 300mg/ml), is helpful in identifying the blood vessels. Furthermore, we can observe several important arteries that associate with the guttural pouch in three different plane, which are the transverse plane, the sagittal plane, and the dorsal plane. Other than that, we can view the flow of contrast media through the slice of images and determine how the branching of the arteries. Not only that, we can also relate the vascular anatomy with the skeletal anatomy and soft tissue structure of the equine head.

However, there are several limitations in using this method. Presence of blood clots in the arterial system block the flow of contrast media throughout the artery and this limits the flow of the contrast media until the end of the arteries or the micro

vessels. Other than that, gas bubbles were also present due to introduction of air into the blood vessel, which will cause the appearance of shade of grey in the blood vessel in the computed tomography angiography images (see Figure 9). The position of the cadaveric head of the horse is important while using the cone beam computed tomography as the machine has a limit area of beam. As in our case, we need to position the cadaveric head on right lateral recumbency to obtain the images of area of interest, which is the guttural pouch. Other problem that we encountered while carrying out the procedure was that the contrast media seems to flow out from other smaller arteries that are difficult to identified and clamped, which later may cause the insufficient amount of contrast media to fill up the whole arterial system of the cadaveric head.

Therefore, it is recommended to use this method for future study in studying the arterial system in vicinity to the guttural pouch with some improvement applied. The presence of blood clots in the arterial system during contrast study can be avoided by flushing the arterial system using normal saline with high pressure. As for the contrast media, we suggested the use of gelatin mix with contrast agent and normal saline. The use of this media will form a solid gel when it is cooled (Echol, 2016), which will reduce the risk of it to flow out from the arterial system.

The study was initially done to relate the vascular anatomy to the incidence of guttural pouch mycosis in horse. However, there are no diseased horses included in our study. Hence, in future study, this can be taken into consideration to include diseased horses to study the arterial system in relation to guttural pouch mycosis.

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APPENDICES

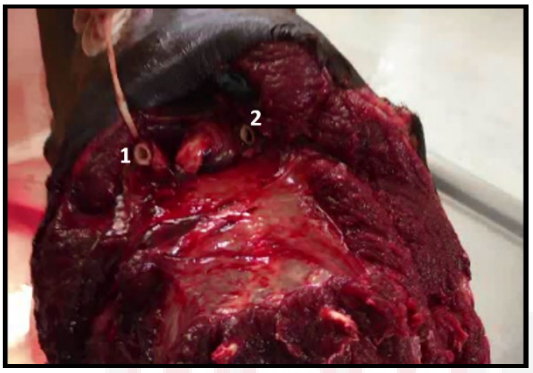

Figure 15:

Cadaveric head on dorsal recumbency

1 *Right common carotid artery*

2 *Left common carotid artery*

Figure 16:

Endoscopic examination on a horse

Figure 17:

The cadaveric head was placed on the table of FIDEX cone beam computed tomography machine on right lateral recumbency.

Figure 18:

Iomeprol, 300 mg/ml was infused into both left and right common carotid arteries with approximately 80 ml for each side.