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ANOMALOUS CANALS OF THE CLIVUS: ANATOMICAL CONSIDERATIONS AND THE ROLE OF CONE BEAM COMPUTED TOMOGRAPHY IN DIAGNOSTIC EVALUATION

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ABSTRACT
The Clivus is a bony structure of the central skull base that supports some vital structures in the skull. Although CT and MRI are traditionally used for evaluation of this area, recent studies suggest that Cone-Beam Computed Tomography (CBCT), due to its high spatial resolution, lower radiation dose and routine use in dentistry may also serve as a potential tool for detecting anomalous canals of the Clivus. This review highlights the significance of accurate diagnosis of some key anomalous canals found in the clival region such as Fossa Navicularis Magna, Canalis Basilaris Medianus, and Craniopharyngeal Canal. These anatomically variant foramina, although often found incidentally, may be misinterpreted as fractures or pathological lesions or serve as pathways for infection. Hence, an in-depth understanding of the anatomy, embryological development, neural and vascular relationships of the Clivus and potential anatomical variations in the area becomes imperative. This review highlights the clinical significance of such anomalous clival canals and how Cone-Beam Computed Tomography (CBCT) can aid oral radiologists and dental professionals recognise these canals during routine imaging.

KEYWORDS: Clivus; Fossa Navicularis Magna; Canalis Basilaris Medianus; Craniopharyngeal Canal; Anomalous canals

INTRODUCTION
The Clivus is a bone in the skull base situated in the central portion of the skull base. Several studies in literature studies show that the Clivus and its surrounding structures may be associated with presence of anatomical variations in the form of anomalous foramina that may be associated with pathological conditions and infections[1–5]. Therefore, it is crucial for oral radiologists and clinicians to have a thorough understanding of normal and variant skull-base anatomy in order to diagnose certain pathologies and distinguish anatomical variations from pathology, so as to prevent misdiagnosis and plan surgical approach in the area[6,7].
Since the area is not easily accessible for clinical assessment, the clinicians are heavily dependent on radiographic imaging to study the area. Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are the imaging methods that are traditionally used to study the skull base and clival region. However, in routine dental practice, Cone-Beam Computed Tomography (CBCT) is an imaging modality that is commonly used, owing to its lower radiation dose, ability to perform multiplanar imaging, ease of use and wider availability compared to traditional CT.
Many of these CBCT scans, especially those with large field of view (FOV), record structures beyond the area of primary indication for the scan, like the skull base and clivus regions. This opens up the prospect of identifying incidental findings outside the area of interest that could otherwise go unnoticed by the inexperienced eye. However, the knowledge regarding these anomalous canals is limited among dental practitioners, leading to diagnostic confusion and unnecessary intervention.
In order to address this knowledge gap, this review focusses on the different anomalous foramina in the Clivus and the potential role of CBCT in the assessment of such variations.

2. Anatomy of the Clivus
The term Clivus, that translates to "slope" in Latin, is a bony structure in the central skull base. This structure is otherwise called as the Clivus Blumenbachii, named after the German physiologist and anthropologist, Johann Friedrich Blumenbach who first described it [7]. It forms an integral part of the skull base and plays a pivotal role in providing structural support to several neurovascular structures[1]. It is bordered superiorly by the dorsum sellae and inferiorly by the foramen magnum. Anteriorly, the sphenoid bone and the sphenoid sinus blends in to

the Clivus, while posteriorly, it is related to the foramen magnum [3,8].On either side, the Clivus is separated from the petrous part of the temporal bone by a petro-occipital (or petroclival) fissure, which contains a thin cartilage plate. This fissure extends from the foramen lacerum (externally) and the cavernous sinus (internally) to the jugular foramen. The intracranial edges of the fissure are marked by grooves for the inferior petrosal sinus[3,9].While the petro-occipital fissure serves as a passage for nerves like the greater petrosal nerve and lesser petrosal nerve, the Clivus provides crucial structural support for the brainstem.

3. Neural and Vascular Relations to the Clivus

The Clivus is closely related to several cranial nerves, arteries, and venous systems. The cavernous sinus that contains cranial nerves III, IV, V1, V2, and VI, and the internal carotid artery (ICA), lies lateral and superior to the Clivus [10,11]. The brainstem, including the pons and medulla oblongata, lies posterior to the Clivus. The vertebral arteries contribute to the formation of the basilar artery. This courses along the Clivus and supplies the brainstem and cerebellum. The inferior petrosal sinus, which drains venous blood from the brainstem, passes along the inferior border of the Clivus and empties into the internal jugular vein[12]. The abducens nerve (CN VI), responsible for eye movement, runs near the Clivus, piercing the outer layer of the duramater covering the clivus. It ascends the clivus slope through the dorello canal and enters the cavernous sinus[8]. The trochlear nerve (CN IV), which controls the superior oblique muscle of the eye, travels over the tentorium cerebelli in close relation to the Clivus[8].

4. Embryology of the Clivus

The Clivus is derived from the first and second occipital sclerotomes, with contributions from the proatlas. It is a cartilaginous structure in fetal life, that gradually ossifies from the basisphenoidal and basioccipital regions. These ossification centers gradually grow towards and form a cartilaginous junction known as the spheno-occipital synchondrosis. The spheno-occipital synchondrosis generally fuses by the age of 25 years. Postnatally, the notochord, which is closely related to the Clivus, regresses. [8,13].

5. Anatomical Variations of the Clivus

5.1. Fossa Navicularis Magna (FNM)

The Fossa Navicularis Magna (FNM) is one of the anomalous canals found in the Clivus. It usually presents as a small osseous notch-like or saucer shaped defect in the basio-occiput region(16–18) (Figure. 1). It was first described by Testut in 1921 and is known by several other names such as fossa pharyngea, large pharyngeal fossa, fossa navicularis, keyhole defect, and longitudinal or transverse segmentations[15].

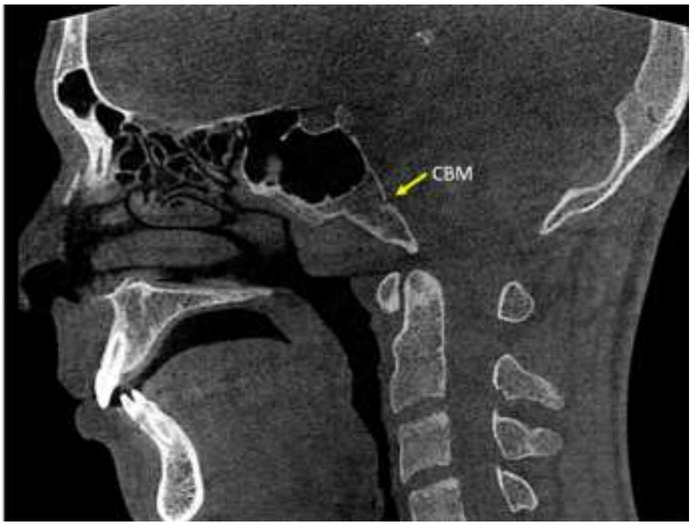
Figure. 1: CBCT image showing Fossa Navicularis Magna (FNM) as a notch-like defect in the clival region

It has been hypothesised that this anatomical variant is a result of either enlarged emissary veins or due to persistent remnants of the notochord[14,16,17]. Although it is usually asymptomatic, the presence of this anatomical variation may sometimes lead to infection in the skull base, recurrent fever, neck pain and even clival osteomyelitis[17–19]. It may also contain lymphoid tissue from the pharyngeal tonsils and serve as a potential pathway for spread of intracranial infections from the pharynx [18–20]. Due to its anatomical location and proximity to the nasopharynx and sphenoid sinus, FNM may also be associated with certain other pathologies such as local and metastatic tumours, adenoid retention cyst, Rathke pouch cyst, Tornwaldt's cyst, sphenoidal sinus mucocele, etc[18]. This structure may also be easily confused with pathological lesions, such as tumors or cysts, if not accurately identified on imaging studies.

5.2. Canalis Basilaris Medianus (CBM)

Canalis Basilaris Medianus (CBM) is another anatomical variation observed in the clival region, first described by Gruber in 1880[21]. This canal is usually identified as an incidental finding during routine imaging studies, especially in the basilar region of the occipital bone [21,22] (Figure. 2).

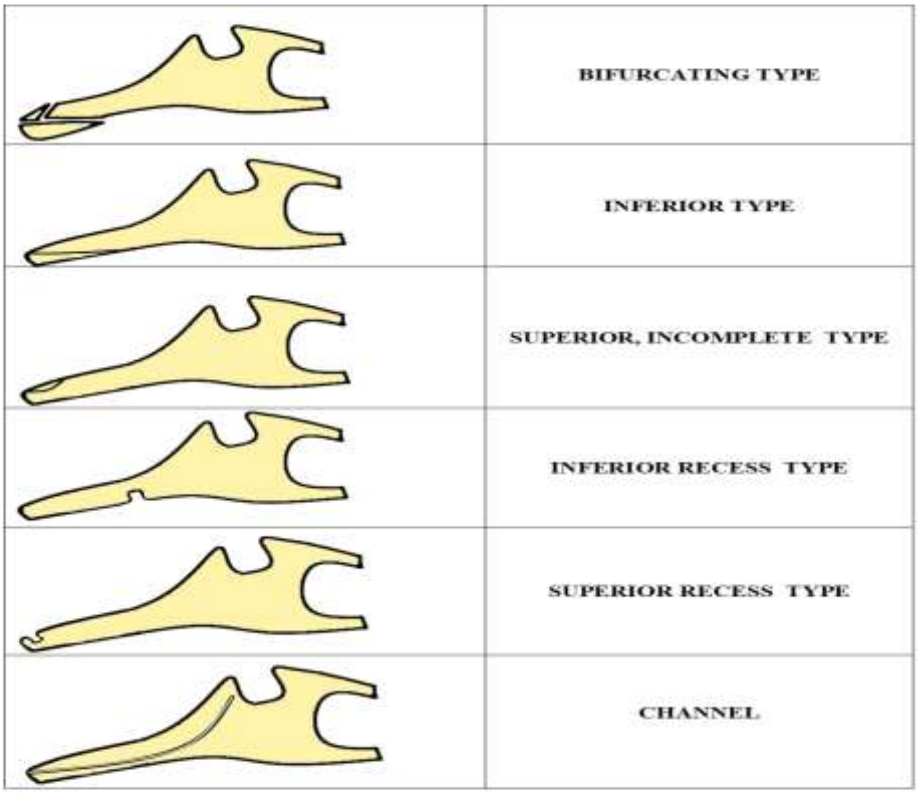
Figure. 2: CBCT image showing Canalis Basilaris Medianus (CBM) in the basiocciput



This anomaly is usually not clinically significant. However, it may at times be associated with several pathological conditions such as recurrent meningitis, Tornwaldt's cysts, meningocele, Cerebrospinal Fluid leaks, nasal congestion, headache, and vision defects [5,23,24].

CBM may be of complete type (with two open ends) or incomplete type (with an open end on one side and blind end on the other). The complete CBM may be of three types, viz., bifurcating type (Type 1), inferior type (Type 2) and superior (Type 3). Incomplete CBM variants are inferior recess (Type 4), Superior recess (Type 5) and Channel (Type 6) [25,26]

Figure. 3 Types of Canalis Basilaris Medianus



5.3. Craniopharyngeal Canal (CPC)

Another anomalous canal encountered in this region is a persistent Craniopharyngeal Canal (CPC). This canal was first recorded by Virchow in 1857[27]. The CPC is a canalicular structure that usually forms due to persistence of the embryological stalk of Rathke's pouch[1,28]. If present, it may be associated with many different complications like recurrent infections, cerebrospinal fluid (CSF) leaks and meningitis[29,30]. On imaging, the Craniopharyngeal Canal typically appears as a tubular, well corticated structure extending from the base of the Sella Turcica to the nasopharyngeal roof[31]. These anomalous structures may present as small, medium or large canals that may be associated with tumours and/or cephaloceles[32].

The clinical implications of anatomical variants of the Clivus have profound significance in the fields of Neurosurgery, Otolaryngology, and Dentistry. Therefore, an in-depth understanding of these variations becomes imperative as it can greatly improve patient outcomes by preventing unnecessary interventions and treatment procedures [15]. In order to understand the clinical significance of these anatomical variants, a summary has been presented in the table below.

Table 1. Anatomical variants of the clivus, their radiographic appearance, clinical significance, and management

Variant foramen	Radiographic Appearance	Clinical Significance	Management
Fossa Navicularis Magna	Small, corticated notch like or saucer shaped defect on the inferior aspect of the clivus[14]	May cause spread of infection between the nasopharynx and intracranial structures[17,19,33].	Usually asymptomatic, No treatment required,
Canalis Basilaris Medianus	Radiolucent canal in the basioocciput[26]	Infection,CSF leak risk, Meningitis[34]	Conservative/surgical approach if symptomatic
Craniopharyngeal Canal	Radiolucent, corticated canal usually extending from the roof of the nasopharynx to the base of the sella	CSF leak, infection[35]	Rarely intervention

6. Imaging Techniques in Diagnosing Clivus Variations

Due to its anatomical location, the Clivus is inaccessible to direct clinical assessment. Therefore, advanced imaging methods would be required to diagnose anatomical variations and pathological conditions involving this region as well as for effective surgical and treatment planning. Three imaging modalities are relevant to this region: Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Cone-Beam Computed Tomography (CBCT), each offering distinct and complementary capabilities. Athough Computed Tomography (CT) is the conventional imaging modality used for the skull base, recent literature demonstrates the potential use of Cone-Beam Computed Tomography (CBCT) as an effective tool for visualizing the Clivus and the skull base region[1].

6.1. Cone-Beam Computed Tomography (CBCT)

Cone-Beam Computed Tomography (CBCT) has emerged as one of the most widely used radiographic imaging technique over the past few decades, particularly in the field of dentistry. This may be largely attributed to its ability to produce high-resolution, three-dimensional multiplanar images with relatively low radiation doses[36]. Large FOV CBCT scans, with a diameter of > 16 cms, that are routinely acquired for dental indications such as implant planning, orthognathic surgery assessments and Temporomandibular joint evaluation, often cover almost the entire oral and maxillofacial region, including the clivus[37].These high resolution CBCT images facilitates accurate assessment of the Clivus, including its shape, size, and potential anatomical variations such as Fossa Navicularis Magna, Canalis Basilaris Medianus, and Craniopharyngeal Canal[14,15]. In addition, CBCT provides enhanced multiplanar imaging, which can be instrumental to accurate diagnosis of the subtle anatomic variations in the clival region which could otherwise be mistaken for pathology. Multiplanar imaging also enables clinicians to determine the exact location and extent of anatomical anomalies and plan treatment and surgical procedures in the skull base more effectively[5] . In case a clival variant is identified incidentally on CBCT, it is recommended that the patient may be referred for CT or MRI if the variant is large, associated with symptoms, or in proximity to planned surgical sites.

6.2. Computed Tomography (CT)

Computed Tomography (CT) is an indispensable imaging modality that remains a gold standard for evaluation of osseous structures of the skull base, especially for the evaluation of deeper cranial structures such as the Clivus and cranial fossae where precise view of bone structures are required. High-resolution CT with thin slices (≤1 mm) and multiplanar reconstruction allows precise identification basilaris of bony architecture and foraminal anatomy. With regard to clival variants, the Canalis Basilaris Medianus may be visualised as a well-defined radiolucent channel in the midline of the basiocciput, Fossa Navicularis Magna may be seen as an osseous concavity in the inferior surface of the clivus, and the Craniopharyngeal canal is seen as a well-defined tubular structure extending from the sellar base to the nasopharynx. It is also the modality of choice for identification of pathological lesions in the clival region such as chordomas, tumours, or cystic lesions[38].

6.3. Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is another important tool in evaluating the Clivus region, particularly for the assessment of soft tissues and determining the relation of the Clivus with closely related anatomic structures such as brainstem and cranial nerves. MRI is extremely useful in identifying lesions that affect both soft tissues and bone, such as neoplasms or inflammation, although it does not offer the same level of detail for bone as CT or CBCT (2). Since MRI offers high contrast resolution for soft tissue structures, it is especially helpful for evaluating the craniopharyngeal canal of the Clivus(27). However, due to the relatively lower spatial resolution for fine osseous detail, higher cost and reduced availability in the dental setting, MRI has limited role as a primary tool for detecting clival variants incidentally.

7. CONCLUSION

With growing clinical evidence, it is becoming exceedingly clear that anatomical variations of the Clivus, whether congenital, developmental, or pathological, have clinical significance and accurate diagnosis is important for clinicians to be aware of its clinical implications. Due to its anatomical position, correct diagnosis of such subtle anatomical variations in the clivus and its surrounding area would only be possible with the use of advanced imaging techniques such as CBCT, CT and MRI. Since oral health practitioners routinely take large field of view CBCT scans for other indications that often include the clival region, it is important that they have knowledge about the possible presence of anatomically variant foramina in this region in order to avoid misinterpretation of normal anatomically variant foramina as pathology and avoid unnecessary probing and intervention. It also opens up the possibility for timely communication to clinicians and surgeons who are planning treatment or surgery in the clivus region. As more studies continue to explore these anatomic variations, it is expected that a more comprehensive understanding of the anatomy of the Clivus and the clinical implications of the presence of anomalous canals in this area will develop and CBCT scans would eventually play a meaningful role in the diagnosis of these anomalous canals.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The authors were involved in the conceptualization of the review, literature search, data interpretation, manuscript drafting, and final approval of the submitted version.

Data Availability Statement

No new data were generated or analyzed in this study. Data sharing is not applicable as this article is a review of previously published literature.

Institutional Review Board Statement

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Informed Consent Statement

Not applicable.

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