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Clival canal and clival foramen development in the fetal and infant basioccipital

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Abstract

Purpose—There is a paucity of research regarding both the development and prevalence of the clival canal or clival foramen in fetuses. Reports that have examined child and adult populations have posited ideas for development of the canal and foramen; however, they have done so in the absence of anatomical data from the fetal population. Therefore, the present study was performed to elucidate the development of the clival canal and foramen through the assessment of perinatal basioccipitals.

Methods—This study analyzed 104 basioccipital bones, 60 from fetuses and 44 from newborns and infants. Dorsal surfaces of basioccipitals were assessed for the presence of anatomical variation with particular attention to the presence of clival canals and foramina. Among cases in which the presence of a clival canal or clival foramen was suspected, cannulation was performed for verification.

Results—Of the 104 basioccipitals analyzed, one (0.96%) had a clival foramen. Clival canals were identified in seven basioccipitals (7:104; 6.73%), four of which were from fetuses. Trends in anatomical variations among basioccipitals were also identified and categorized. These categories were then evaluated relative to age in order to elucidate ontogeny. A model is presented to explain the development of the clival foramen, clival canal, and the basioccipital, in general.

Conclusions—The presence of a clival canal or foramen should be considered even among individuals of fetal age. The findings of this osteological study suggest that the clival canal and foramen develop around vascular structures and, therefore, signify vascular connections among nearby venous plexuses.

Keywords

anatomy; clivus; cranial base; notochord

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Introduction

The clivus is a clinically important cranial base structure situated between the pharynx and endocranium. Because of its location, it is important in transnasal and transoral neurosurgical approaches to the endocranium at the levels of the brain stem and craniocervical junction. In some cases, developmental or acquired defects in the clivus may cause undue communication between pharyngeal and intracranial structures. Occasionally, these pharyngeal-intracranial connections have resulted in cerebrospinal fluid leakage and recurrent meningitis, particularly among children [1–4]. Examples of such connections include the clival canal (CC) (canalis basilaris medianus) and clival foramen (CF), which have been posited as important, but often overlooked causes of recurrent meningitis in children [5].

When present, the CC is located along the dorsal surface of the clivus. Studies of dry or cadaveric crania have reported the CC to occur in as few as 1.61% (2:124) to as many as 7% (6:87) [6,7]. It has also been reported to occur more often in children than adults [8,9]. The canal is typically oriented sagittally or diagonally but has, on occasion, been reported to be oriented transversely [10–13]. Additionally, the clival canal may be bifurcated or trifurcated [6,12].

Details regarding the development of the CC are largely unknown. Some have proposed that the canal is formed by the notochord or a vein [5,8,10,12]. Additionally, the contents of the CC and CF are largely unknown.

Clival canals and clival foramina have clinical significance, particularly with regard to neurosurgery and the spread of infection in children. However, the development of the CC and CF is poorly understood. Also, studies have not assessed clival canals and foramina in the basioccipitals of fetuses. Therefore, this report analyses fetal and infantile basioccipitals in order to elucidate the development and prevalence of the CC and CF in early life.

Materials and Methods

This study analyzed 104 basioccipital bones from the Johns Hopkins collection of perinatal crania housed in the Department of Anthropology at the Cleveland Museum of Natural History. Of the 104 basioccipitals, 59 were male and 45 were female. There were 60 crania were from fetuses. The youngest specimens were from individuals of 5 months fetal age at death. There were 44 crania from neonates/infants, 15 of which were classified as newborns. The oldest specimen was from a 15 month old at death infant. The basioccipitals were from individuals documented as either black (n=58) or white (n=46).

Macrophotography of the dorsal (superior) surfaces of the basioccipitals was performed with a digital camera (Canon PowerShot SX50 HS). Visual inspection was also performed, both unaided and with 2.5X magnification loupes (Rose Micro Solutions). Trends in anatomical configurations of the basioccipital were identified and a classification system was developed. Chi-square tests of independence were performed to examine the relationships between anatomical configurations and both sex and race.

Among cases in which the presence of a clival canal or clival foramen was suspected, cannulation was attempted with thread. Basioccipitals that were cannulated with thread were photographed and counted to determine the prevalence of CCs and CFs.

Results

Of the 104 basioccipitals analyzed, one (0.96%) had a CF (Figure 1A). The basioccipital with the CF was from a two month-old male (1:44 infants/newborns; 2.27%). Clival canals were cannulated in seven basioccipitals (7:104; 6.73%) (Figure 1). Four of the basioccipitals with CCs were from fetuses (three of 9 months fetal age and one of 10 months fetal age) (Figure 1B, C, D, and H), two were from newborns (Figure 1E and F), and one was from a four month-old infant (Figure 1G). Four were found in males and three were found in females.

The CF was located on the right side of the basioccipital, anterior to the plane of the lateral projections (Figure 1A). The CCs were oriented transversely, sagittally, and diagonally (Figure 1). In all cases of sagittal and oblique orientation, there was an opening of the CC intermediate to the lateral projections and another opening near the posterior aspect of the basioccipital. In the case of the transversely oriented CC, both openings of the clival canal were located intermediate to the lateral projections.

Categorization of Basioccipitals

Several common findings were seen along the dorsum of the basioccipitals. Usually, there was a concave fossa that generally spanned from the central aspect to the anterior aspect of the dorsum. There were typically pits in the dorsum, some relatively large and some relatively small. This report refers to these pits as foveae and foveolae, respectively. Occasionally these pits were not cecal in nature, but rather formed clival canals.

The following 11 categories were developed to classify all 104 basioccipitals based upon the aforementioned bony features:

Type A: Two bilateral paramedian foveae located intermediate to the lateral processes of the basioccipital. Rostral to the relatively large foveae are typically smaller foveolae oriented in a rostrally-pointed chevron or triangle. Sometimes the foveolae are absent. Commonly, there is a posterior fovea similar in size to that of the two paramedian fovea that is located toward the basion. The posterior fovea is sometimes absent. Alternatively, there may be two or more posterior foveae. (Figure 2)

Type B: Two bilateral paramedian foveolae are located intermediate to the lateral processes of the basioccipital. Additional foveolae form a rostrally-pointed chevron or triangle. Occasionally, one or more foveae or foveolae are found near the posterior border; however, these pits are often absent. (Figure 3)

Type C: A pronounced dorsal impression that often has a bony strut located at, or very close to, the midline that projects from caudal-and-dorsal to rostral-and-ventral. The bony strut forms a bifid impression which may be devoid of foveae or foveolae but usually contains shallow foveae or foveolae. (Figure 4)

Type D: Confluent and often tortuous foveolae located intermediate to the lateral projections. The impressions may be accompanied by typical round foveae and foveolae. (Figure 5)

Type E: Multiple relatively large foveae are present. In addition to being located intermediate to the lateral projections, foveae may be found rostrally or caudally. The foveae are generally asymmetric, however, there are often two bilateral paramedian foveae located intermediate to the lateral processes of the basioccipital. Otherwise, the foveae are generally bilaterally asymmetrical. (Figure 6)

Type F: One large fovea located along the midline or approximate to the midline and intermediate to the lateral projections. The fovea is usually accompanied by nearby foveolae and another fovea or foveae near the posterior border of the bone. (Figure 7)

Type G: A confluent fovea is located intermediate to the lateral projections, roughly oriented along the coronal plane. The confluent fovea crosses the midline. Foveolae are oftentimes located nearby. The impressions may be accompanied by typical round foveae and foveolae. (Figure 8)

Type H: Multiple foveolae are present. Typically these foveolae are located on or around the midline. One or more foveae are located intermediate to the lateral projections, often midsagittally or near the midline. Occasionally, one or more foveae or foveolae are found near the posterior border of the bone; however, the posterior foveae are often absent. (Figure 9)

Type I: Two roughly bilaterally symmetrical foveolae are located intermediate to the lateral projections in generally the same coronal plane. Oftentimes, other foveolae are located intermediate to the two bilateral paramedian foveolae. Occasionally, one or more foveae or foveolae are found near the posterior border of the bone; however, the posterior foveae are often absent. (Figure 10)

Type J: Absence of the centralized fossa found in the other types. (Figure 11)

Type K: Three roughly equidistant foveae are located intermediate to the lateral processes of the basioccipital. Two bilateral paramedian foveae located intermediate to the lateral processes of the basioccipital are located in roughly the same coronal plane. An additional third fovea is located rostrally, on or near the midline. Occasionally, there are nearby foveolae. (Figure 12)

The prevalence of basioccipitals, sorted among the aforementioned categories, can be found in Figure 13. Additionally, a heat map analyzing frequency distribution according to both age and anatomical category can be seen in Figure 14.

Another common anatomical variation among basioccipitals was that of the inconsistent foveae located at the posterior part of the bone— a location corresponding to the region of the anterior foramen magnum. These foveae were usually visible from the dorsal surface of the bone; however, they were occasionally seen on the ventral surface or the posterior-most part of the bone (i.e., neither dorsal nor ventral). The foveae were singular, septate, doubled, found in numbers greater than two, or absent altogether (Figure 15).

The basioccipital with a CF was categorized as Type E. The seven basioccipitals with CCs were categorized as Type A (3:7; 43%), Type F (2:7; 29%), Type D (1:7; 14%), and Type E (1:7; 14%), respectively. Basioccipital types A, F, D, and E are defined as having foveae as opposed to foveolae. All of the basioccipitals having canals oriented sagittally or diagonally had a posteromedian opening (Figure 1). In one case, the posteromedian opening was divided by a small bony strut (Figure 1H). The transversely oriented CC had no posterior fovea (Figure 1B).

The relationship between sex and basioccipital type was insignificant, $X^2(10, n=104)=11.64$, $p=0.31$. Likewise, the relationship between race and basioccipital type was insignificant, $X^2(10, n=104)=10.25$, $p=0.42$.

Discussion

The CC and CF are clinically relevant structures that have implications for neurosurgical approaches, imaging interpretation, infection spread, and differential diagnosis of lesions near the clivus [5,14,15]. However, few studies have assessed the prevalence of the CC and CF. This study is unique in that it assessed the prevalence of CC and CF in fetuses. Further, this study is the first to document the existence of CCs in fetal crania.

Clival canals and clival foramina have been postulated as causes of recurrent meningitis in children, especially after episodes of paranasal sinus infections [5]. This study identified CCs in two newborns and a four month-old infant (3:44 infants/newborns; 6.82%). Four fetuses also exhibited CCs (4:60 fetuses; 6.67%). This study also identified a CF in a two month-old male (1:44 infants/newborns; 2.27%). When compared to studies among adults, these findings suggest a similar, if not increased, prevalence of CCs and CFs in the fetal and infant populations. These findings support the idea that, because these variations exist in the perinatal population, CCs and CFs may cause recurrent meningitis in very young children. Because many microorganisms that are known to cause neonatal meningitis (e.g., Group B streptococci) may be introduced to the neonatal pharynx by way of the nose and mouth, a bony communication between the retropharyngeal and endocranial regions should be considered in the etiology of neonatal meningitis.

Development of the Clival Canal and Clival Foramen

Some have speculated that the CC and CF are formed by the notochord [9,16,17]. The notion that the CC arises from the notochord has even spurred the use of the terms “canalis chordae” and “canalis basilaris chordae” to describe the canal [9,16]. However, the path of the notochord is inconsistent with the path of the clival canal.

The portion of the notochord located at the inferior clivus courses from the rostral-and-ventral to the caudal-and-dorsal aspect of the basioccipital. However, the clival canal is located exclusively at the dorsum of the basioccipital, a location that is inconsistent with the path of the notochord. Some have referred to distinctly different variations of the basioccipital as clival canals or, alternatively, *canalis basilaris medianus* (CBM), which has likely added to confusion regarding the nature of the bony variation. For example, the

pharyngeal fossa, located on the ventral surface of the clivus, and the “keyhole” defect have been referred to as CCs/CBM [18].

The notochord is a midline structure. Embryologically, it arises from the basioccipital at roughly the same location as the posterior foveae described in this study. However, as illustrated in Figure 15, the posterior foveae are oftentimes multiple and distant from the midline. Because the notochord is a singular midline structure, and the posterior foveae are frequently multiple and exist away from the midline, it is doubtful that the clival canal is formed from the notochord. Otherwise, posterior foveae, if formed by the notochord, would always be in the midline and would not be paired. Further, clival canals such as those seen in Figure 1C may course transversely—perpendicular to the course of the notochord, which also casts doubt upon CC development from the notochord. Moreover, this report notes that the earliest presence of clival canals occurred in fetuses of 9 months development— well beyond the timeframe in which the notochord exists (i.e., the 16th fetal week) [19].

The CF illustrated in Figure 1A was located on the right side of the basioccipital and coursed from dorsomedial to ventrolateral. Because the CF was not located in the midline, these findings dispute the notion that the CF is formed by the notochord. Based upon its location, the CF may have a developmental relationship with the transverse basilar cleft.

It has also been proposed that the CC and CF are formed by veins [10,17]. Tubbs et al. [12] noted that the contents of the clival canals exhibit neither pituitary nor notochordal tissue, but rather demonstrate the presence of vascular tissues consistent with veins. Additionally, Nayak et al. [11] noted that the clival canal may continue bilaterally with the grooves for inferior petrosal sinuses and, therefore, represent a venous connection between inferior petrosal sinuses.

In this study, a CF was identified in a location similar to the location of the grooves described by Nayak et al. [11]. The CF may indicate a venous connection between the basilar plexus and pharyngeal venous plexus— a notion consistent with that of other reports [17].

The findings of this study support the idea that the CC is vascular in nature, an idea that is clarified in the following proposed model of ontogeny:

The early basioccipital begins with a smooth dorsal surface that develops a relatively deep fossa containing soft tissue structures including vasculature. Midline bony growth occurs from posterior to anterior and separates the early fossa into right and left parts (e.g., Type C; Figure 4) in which soft tissue, primarily vasculature, has reserved its location. Within these two parts of the fossa, typically two paramedian pits of varied size are formed. At first these pits are shallow, but later become more deeply situated within the bone. The size and depth of the pits are likely dependent upon the rate of bone growth, the growth of the vascular tissue, and pressure within the vasculature. The paramedian foveae intermediate to the lateral projections may join vascular tissues across the midline via a confluence (e.g., Type G basioccipital; Figure 8) or a transverse clival canal (e.g., Figure 1B). Likewise, the paramedian foveae intermediate to the lateral projections and the

posterior fovea(e) may join vascular tissues via sagittal or diagonal clival canals (e.g., Figure 1C–H). During infancy, the cancellous appearance of the dorsal osseous tissue becomes smoothed with the superficial accretion of cortical bone (e.g., Type J; Figure 1I). If the vasculature does not undergo involution or is not covered entirely by cortical bone, a clival canal may persist (e.g., Figure 1G).

As an aside, the notion that midline bony growth occurs from posterior to anterior and separates the early fossa into right and left parts as seen, for example in Figure 4 (Type C basioccipitals), has been demonstrated in a porcine model of basioccipital development [20]. Further, the concept that bone accretion occurs atop of a venous structure is supported in part by the description of CCs by Zhang and Yen [10] which noted that CCs are associated with midline bony elevations found overlying the canals.

Prior reports have noted bifurcated and trifurcated CCs [12]. Based upon the aforementioned model of ontogeny, it is likely that other combinations of vascular connections may occur as well. Hypothetically, because the posterior foveae are often paramedian, it may be possible for the existence of a unilateral CC, bilateral parallel paramedian CCs, or CCs that form an X-shaped pattern.

In conclusion, the CC can be found in the fetal basioccipital. The development of the canal likely occurs around the vasculature of the basilar plexus or vasculature joining the basilar and the internal vertebral venous plexuses. The clival foramen may also be found in early life and, like the CC, might transmit vascular tissues. The CF may represent a communication between the basilar plexus and the pharyngeal plexus of veins. In a clinical setting, the presence of a CC or CF should be taken into consideration even among individuals of fetal age.

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Figure 1.

A clival foramen and seven clival canals cannulated by thread. The clival foramen (A) opened to the ventral surface of the basioccipital. *In vivo*, it would represent a connection between the retropharyngeal and intracranial regions and may predispose herniation of tissues from the pharynx to the endocranium and vice-versa. Likewise, it would represent a potential path of ingress for pharyngeal infection to spread into the cranium. The clival canals were oriented transversely (B), sagittally (C,D,E), and diagonally (F,G,H).

Figure 2.

Type A basioccipitals possessing two relatively large paramedian foveae intermediate to the lateral projections. **A:** 8 month-old black female fetus; **B:** 8 month-old black male fetus; **C:** 9 month-old white female fetus; **D:** 9 month-old white male fetus; **E:** newborn white female; **F:** newborn black male; **G:** newborn white female; **H:** 3 month-old black male infant; **I:** 4 month-old white female infant.

Figure 3.

Type B basioccipitals possessing two relatively small paramedian foveolae intermediate to the lateral projections. **A:** 6 month-old white male fetus; **B:** 7 month-old black female fetus; **C:** 8 month-old black male fetus; **D:** 8 month-old black female fetus; **E:** 10 month-old white female fetus; **F:** 10 month-old white male fetus; **G:** newborn black male; **H:** newborn black female; **I:** 2 month-old black female infant.

Figure 4.
Type C basioccipitals having pronounced dorsal impression that usually often has a bony strut **A:** 6 month-old white male fetus; **B:** 9 month-old black male fetus; **C:** 2 month-old white female infant.

Figure 5.

Type D basioccipitals having confluent and often tortuous foveae located intermediate to the lateral projections. **A:** 6 month-old black male fetus; **B:** 8 month-old white female fetus; **C:** 10 month-old black female fetus; **D:** newborn black male; **E:** newborn black female; **F:** 3 month-old black female fetus.

Figure 6.

Type E basioccipitals' multiple relatively large foveae are present oftentimes in addition to two paramedian foveae located intermediate to the lateral projections. **A:** 5 month-old white female fetus; **B:** 8 month-old black female fetus; **C:** newborn black female; **D:** newborn black male; **E:** 2 month-old black female infant; **F:** 2 month-old black male infant

Figure 7.

Type F basioccipitals having one large fovea located along the midline or approximate to the midline and intermediate to the lateral projections usually accompanied by an additional fovea or foveae near the basion. **A:** 8 month-old black female fetus; **B:** 9 month-old white male fetus; **C:** 10 month-old black male fetus

Figure 8.
Type G basioccipitals having a confluent fovea located intermediate to the lateral projections, roughly oriented along the coronal plane. **A:** 9 month-old white male fetus; **B:** 10 month-old black female fetus; **C:** 1 month-old white male infant

Figure 9.

Type H basioccipitals having multiple foveolae located on or around the midline. One or more foveolae are located intermediate to the lateral projections. **A:** 8 month-old black male fetus; **B:** 10 month-old black male fetus; **C:** newborn black male

Figure 10.

Type I basioccipitals having two roughly bilaterally symmetrical foveolae are located intermediate to the lateral projections in roughly the same coronal plane. Oftentimes, other foveolae are located intermediate to the two bilateral paramedian foveolae. **A:** 8 month-old white female fetus; **B:** 2 month-old black female infant; **C:** 3 month-old black male infant.

Figure 11.

Type J basioccipitals having no centralized fossa found in the other types. **A:** 12 month-old black female infant; **B:** 14 month-old black female infant; **C:** 15 month-old black male infant.

Figure 12.

Type K basioccipitals having three roughly equidistant foveae located intermediate to the lateral processes of the basioccipital. **A:** 6 month-old black female fetus; **B:** 10 month-old black male fetus; **C:** 10 month-old black male fetus.

Figure 13.

Prevalence of basioccipital categories from a total of 104 basioccipitals.

			<i>n</i>	BASIOCCIPITAL TYPE										
				A	B	C	D	E	F	G	H	I	J	K
AGE (months)	FETAL	1	0											
		2	0											
		3	0											
		4	0											
		5	5			60			20				20	
		6	5		20	20	20		20					20
		7	7	14	14	29		14	14					14
		8	17	29	12	12	6	12	12		12	6		
		9	12	25		17	17	8	17	17				
		10	14		21	7	7	7	14	21	7			14
	INFANTILE	Newborn	15	27	20		20	13		7	13			
		1	2	50						50				
		2	10	20	10	10	20	20				20		
		3	6	33		33	17					17		
		4	4	25			25	25				25		
		5	2		100									
		6	0											
		7	0											
		8	0											
		9	0											
		10	0											
		11	1		100									
		12	2										50	50
		13	0											
		14	1											100
		15	1											100

Figure 14.

Heat map relating the relative frequency (expressed as a percentage) of basioccipital type to age grouping. To identify anatomical changes during development, relative frequencies were examined with regard to sequential age groupings. Trends were identified by assessing the most common basioccipital type in each age group and, when these types were the same or particularly similar (i.e., Type A and Type B) to the subsequent age group, they were clustered into a contiguous group outlined with **thick black lines**. During the 5th through 7th months of intrauterine development the basioccipital tended to have pronounced dorsal

impression that usually often has a bony strut located at, or very close to, the midline forming a bifid impression which may be devoid of foveae or foveolae but usually contains shallow foveae or foveolae. Then, from the 8th month of intrauterine development to at least the 5th postnatal month, the basioccipitals tend to exhibit two paramedian foveae or foveolae intermediate to the lateral projections. Later, from the age of one year, the basioccipital resembles that of the homologous aspect of the clivus in the adult occipital bone.

Figure 15.

Examples of variations among the foveae located at the posterior basioccipital. These fovea may occur as unilateral or bilateral rather than median structures. **A:** 5 month-old black female fetus with three foveae, one on the left side and two on the right side; **B:** 7 month-old white female fetus with multiple foveolae; **C:** 7 month-old white male fetus with five foveae; **D:** 8 month-old white female fetus with two bilateral poorly demarcated impressions; **E:** 8 month-old black female fetus with one fovea located on the left; **F:** 9 month-old white male fetus with three foveae- one median and two paramedian; **G:** 10 month-old white male fetus with two fovea located on the left side and one on the right side; **H:** newborn white male with two foveae separated by a thin bony septum; **I:** 3 month-old white male infant with three foveae- one approximately median and two paramedian.