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Relation of gubernacular canal and permanent dentition by Nolla stage: Cone-beam computed tomography analysis

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SUMMARY

Background. The aim of the study was to evaluate an association between the stages of permanent dentition development, based on Nolla stages, and the characteristics of the gubernacular canal (GC), and to investigate the correlation between eruption process failures and the GC.

Material and methods. This observational, cross-sectional, and retrospective study analyzed tomographic scans from 164 patients, encompassing 244 included teeth. The teeth were categorized into ten and three stages according to Nolla stages and were evaluated the position of the GC relative to the dental follicle, the alignment of the GC relative to the tooth and the direction of the GC relative to the bone cortices. The teeth were also classified as: normal impacted, normal non-impacted, delayed impacted, and delayed non-impacted.

Results. Of the total sample, 162 exhibited GC (71.1%). Statistical significance was noted when exploring the association between Nolla stage, categorized into ten and three stages, and the position of GC in relation to the follicle (p=0.023 and p=0.005, respectively). Furthermore, an association was identified between teeth with delayed (Nolla stage equal to or greater than 8) and impacted eruption and the position of GC in relation to the follicle (p=0.004) showing a shifting of the canal's position as the root develops, from the occlusal position to other positions.

Conclusions. The findings of this study suggest that displacement of the GC from its typical occlusal position to other directions may be associated with tooth impaction or delayed eruption and highlight the potential of GC position as an early radiographic marker for eruption disturbances.

Keywords: permanent dentition, tooth eruption, gubernaculum, cone beam computed tomography.

INTRODUCTION

The gubernaculum dentis or gubernacular cord (GCo) is a structure composed of fibrous connective tissue, blood and lymphatic vessels, nerves, and clusters of epithelial cells (1). After the establishment of the dental germs, these remnants of the dental lamina fragment and organize into islands or epithelial cords. The adjacent mesenchyme originates the bone tissue that forms around the gubernacular cords, establishing a bony canal known as the gubernacular canal (GC) (2). The GC is present in permanent teeth before their eruption, extending from the dental follicle to the dental lamina of the underlying gingiva (3), reaching the surface of the alveolar process (4). Some studies suggest that the GC is related to the presence of a corresponding deciduous tooth, although it has also been observed in molar teeth, which do not have corresponding deciduous counterparts (3).

Although the function of the GCo and GC are not completely elucidated, it is known that these structures are responsible for guiding the permanent teeth during the eruption process (4). The cord produces chemical mediators, e.g. epidermal growth factors, which activate osteoclasts, promoting bone resorption directed towards the eruption of the tooth (2, 5). Therefore, the canal can only be observed in

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complementary exams of teeth that are still in the eruption process, as the GCo and the GC are completely resorbed once this process is completed. The remnants of the GCo may serve as a basis for the development of cysts and odontogenic tumors (5). Some characteristics of the cord and canal may be associated with tooth impaction, changes in the eruption process, and the presence of supernumerary teeth, as these structures and their modifications are identified in several odontogenic pathological processes (1).

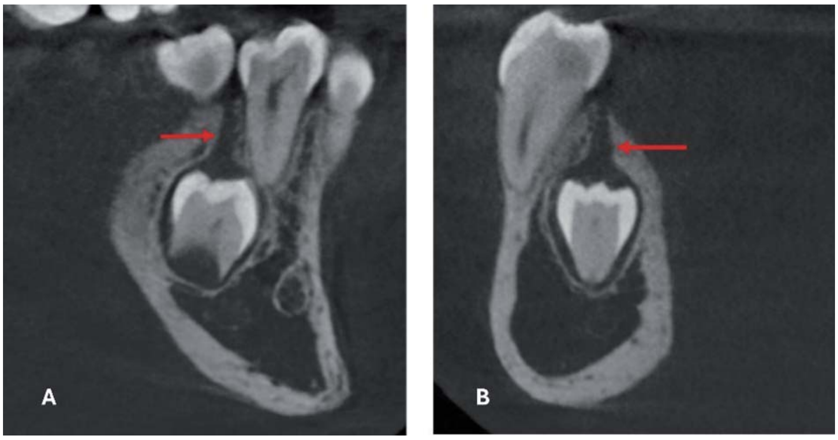

Fig. Sagittal (A) and coronal (B) tomographic sections showing the trajectory of the gubernacular canal from the dental follicle to the alveolar bone crest

In radiographic images, the GC is visible as a radiolucent canal with a diameter of 2 to 3 mm, surrounded by bone cortices, and connected to the dental follicle (6). In two-dimensional imaging exams, such as panoramic radiographs, the CG is rarely identified due to its narrow anatomical structure. This is because, in addition to the characteristics of the structure itself, this type of exam presents image superposition and distortions, limiting the recognition of the canal. Thus, the most suitable complementary exam for recognizing the GC is the cone-beam computed tomography (CBCT), which allows the visualization of high-quality three-dimensional images with clarity, high resolution, and no image superposition (Figure) (7, 8).

Some authors have studied the development of permanent teeth and proposed different classifications based on the mineralization stages observed in radiographic images (9). The classification proposed by Nolla (1960) is divided into ten stages, starting from the presence of the crypt to the complete formation of the root and apex closure (10). In Nolla stage 8, the tooth has two-thirds of its root formed and should reach the alveolar bone crest erupting into the oral cavity. Therefore, teeth that are in stage 8, 9 or 10 of Nolla but are not exposed to the oral cavity exhibit a delay in the eruption process (11).

The identification and analysis of the characteristics of the GC using CBCT can play a key role in understanding the development process of permanent dentition. This structure can present challenges in radiographic interpretation regarding its existence and position because it can be confused with the nutrient canal, an accessory branch of the inferior alveolar canal, or even the fistulous tract (12). Therefore, the use of CBCT becomes crucial, facilitating the identification of the canal and its characteristics by allowing the visualization of three-dimensional images.

Therefore, the study and understanding of the characteristics of the GC in CBCT scans could allow the identification of potential abnormalities in the dental eruption process. This early detection capability could enable early diagnosis and appropriate interventions, contributing to the effectiveness of treatments and the efficient management of disturbances associated with tooth eruption. Thus, the investigation of GC characteristics in CBCT can be a valuable tool for clinical practice.

There are no studies in literature that have evaluated the characteristics of the GC in relation to the Nolla stages across the entire arch. The hypothesis of this study is that teeth with an abnormal eruption pattern may present specific characteristics or the absence of the GC. Thus, identifying characteristics of the GC in CBCT may assist dentists in the early detection of eruption disorders, enabling early diagnosis and intervention. The aim of the study was to evaluate the correlation between the stages of permanent dentition development according to Nolla`s classification and the characteristics of the gubernacular canal using CBCT. The secondary objective was to evaluate the association between gubernacular canal and eruption process failures.

Table 1. Nolla's stages of tooth calcification

Nolla's Stage	Characteristic
0	Absence of a crypt
1	Presence of a crypt
2	Initial calcification
3	One-third of the crown completed
4	Two-thirds of the crown completed
5	Crown almost completed
6	Crown completed, root formation begins
7	One-third of the root completed
8	Two-thirds of the root completed
9	Root almost completed, apex open
10	Root completed, apical end closed

Source: Nolla (1960)

MATERIAL AND METHODS

This observational, cross-sectional, retrospective study was approved by the Research Ethics Committee of the Universidade Federal de Minas Gerais (UFMG) (CAAE 62546316.5.0000.5149). Tomographic images from the database of the Oral and Maxillofacial Radiology Service at the School of Dentistry of Universidade Federal de Minas Gerais (UFMG) taken from June 2018 to June 2023 were evaluated.

Tomographic images were acquired using two different devices with the following exposure parameters:

I. KODAK 9000 3D® (Kodak Dental Systems, Carestream Health, USA), employing the following exposure factors: 0.2 mm voxel, 50 mm x 37 mm field of view, 70 kVp tube voltage, 10 mA tube current, and 32 seconds of exposure.

II. SIRONA ORTOPHOS SL 3D® (Sirona Dental Systems, Charlotte, USA), with the following exposure parameters: 0.2 mm voxel, 110 mm x 100 mm field of view, 85 kVp tube voltage, 10 mA tube current, and 14 seconds of exposure.

The images were saved in DICOM format (Digital Imaging and Communications in Medicine) and analyzed using the Implant Viewer® software (Anne Solutions, São Paulo, Brazil) with a slice thickness of 0.2 mm, on a Samsung® monitor with a resolution of 1366×768 pixels.

Data collection was performed by two trained and calibrated examiners (A.L.M.B. and C.B.B.). CBCT exams containing one or more intraosseous teeth were included in the study. Exams with artifacts and teeth in advanced eruption stages, with cusps above the level of the alveolar bone crest were excluded. To determine the position of the tooth in relation to the bone, the tomographic images were analyzed in the three orthogonal planes (sagittal, coronal, and axial), and only exams showing bone overlying the tooth in at least two of these planes were included.

The sample was classified for descriptive and statistical analysis. For the descriptive analysis, individuals were categorized according to sex (female or male) and age (by decade of life). For the descriptive analysis of the eruption process, supernumerary teeth were excluded, as they do not follow a well-defined eruption process, hindering to classify them.

For the statistical analysis, the teeth were classified according to each analysis performed. Initially, the existence of an association between the Nolla stage and the characteristics of the GC was evaluated. For this, the teeth were divided into two categories based on their developmental stage. In the first, the teeth were classified from 1 to 10 according to their Nolla stage (Table 1), and an analysis was conducted based on: the position of the GC relative to the dental follicle (occlusal/incisal, distal, mesial, palatal/lingual), the alignment of the GC relative to the tooth (non-aligned and aligned along the long axis), and the direction of the GC relative to the bone cortices (bone crest, palatal/lingual, vestibular). In the second analysis, the teeth were divided into subgroups considering the following developmental phases: teeth with complete crown formation (Nolla stages 0, 1, 2, 3, 4, 5, or 6); teeth with less than two-thirds of the root formed (Nolla stage 7); and teeth with two-thirds or more of the root formed (Nolla stages 8, 9, or 10). These three subgroups were also analyzed according to the position of the GC relative to the follicle, the alignment of the GC relative to the tooth, and the direction of the GC relative to the bone cortices.

For the evaluation of the association between the GC and eruption process failures, supernumerary teeth were excluded as they do not have an eruption pattern. Considering the eruption status, the teeth were classified as: normal impacted, normal non-impacted, delayed impacted, and delayed non-impacted. Teeth with a Nolla stage equal to or greater than 8 that had not yet erupted were classified as delayed. Teeth that exhibited obstruction in the eruption process, abnormal eruption direction, or dilaceration were classified as impacted. The eruption process was analyzed according to the position of the GC relative to the follicle, the alignment of the GC relative to the tooth, and the direction of the GC relative to the cortical bone.

RESULTS

Tomographic images of 164 patients were analyzed, being 61 (37.2%) male patients and 103 (62.8%) female patients. The majority (81.7%) was between the second and fourth decades of life. A total of 228 impacted teeth were analyzed: 9 incisors (3.9%), 64 canines (28.1%), 14 premolars (6.1%), 87 molars (38.2%), of which 86 were third molars, and 54 supernumerary teeth (23.7%). The GC was identified in 162 of these teeth (71.1%).

For the evaluation of the eruption status (normal, delayed, and impacted), the supernumerary teeth were excluded from the sample as they do not follow a well-defined eruption process. In addition to the 54 supernumerary teeth, 01 tooth with missing data was also excluded, resulting in a total of 173 teeth evaluated. Of these, 143 (82.7%) showed delayed eruption, 30 (17.3%) had a normal eruption process, and 163

(94.2%) were impacted, meaning they had some obstruction in the eruption process, abnormal eruption direction, or dilaceration (Table 2).

The status of dental eruption was associated with the position of the GC relative to the dental follicle (p=0.004). In the delayed impacted group, 61.3% showed the GC positioned toward the occlusal/incisal surface, 30.6% toward the distal surface, 2% toward the mesial surface, and 6.1% toward the palatal surface. In the normal impacted, normal non-impacted and delayed non-impacted groups, all teeth (100%) exhibited the GC directed toward the occlusal/incisal surface in relation to the follicle. In contrast, there is no association between the eruption status and the alignment of the GC relative to the tooth (p=0.231) or between the eruption status and the direction of the GC relative to the bone cortices (p=0.301) (Table 3).

To evaluate the association between Nolla stages and the characteristics of the GC, supernumerary teeth were included. Considering the Nolla stages divided into three categories, an association was found between these stages and the position of the GC relative to the dental follicle (p=0.005. In teeth with a fully formed crown or less than two-thirds of the root formed, a high frequency of the canal in the occlusal/incisal position relative to the follicle was observed (96.8% and 92.9%, respectively). However, in teeth with two-thirds or more of the root formed, the frequency of the canal in the occlusal/incisal position decreased to 63.8%, while there was an increase in the frequency of the canal in the distal, mesial, and palatal positions (36.2%). No association was found between Nolla stage and the alignment of the GC relative to the tooth (p=0.066), or between the Nolla stage and the direction of the GC relative to the bone cortices (p=0.471) (Table 4).

In the analysis, where the teeth were categorized according to the 10 stages of Nolla, was observed an association between the stages and the position of the GC relative to the dental follicle (p=0.023). No association was found between these stages and the alignment of the canal relative to the tooth (p=0.285) or the direction of the canal relative to the bone cortices (p=0.328) (Table 5).

DISCUSSION

The high prevalence of GC in studies that employed CBCT reinforces the importance of investigating the relationship between this structure and eruption disorders. In this study, the presence of the GC was identified in 71.1% of the teeth, a prevalence comparable to the 72.8%, observed by Nishida *et al.* (2015) (13), and 77.8%, revealed by Dogan et al (2023) (6). However, other studies have found higher prevalences such as the study of Gaêta-Araújo *et al.* (2019) (14), that identified the GC in 90.6% of their sample, and Behrouzi *et al.* (2024) (15) that observed a prevalence of 88.7%.

Although some studies suggest that the GC may derive from a deciduous predecessor (Ferreira *et al.*, 2013) (3), the findings of this study contradict this hypothesis, aligning with the conclusions of Nishida *et al.* (2015) (13), Gaêta-Araújo *et al.* (2019) (14) and Zengin *et al.*, (2023) (16). This is evidenced by the identification of the GC in supernumerary teeth and molars, which do not have deciduous predecessors.

Gaêta-Araújo *et al.* (2019) (14) and Behrouzi *et al.* (2024) (15) found that the prevalence of the GC is predominant in the occlusal position relative to the follicle, a disposition they classified as usual.

Table 2. Descriptive values of tooth eruption status

Eruption status	N (%)
Normal	
No	143 (82.7)
Yes	30 (17.3)
Delayed	
No	30 (17.3)
Yes	143 (82.7)
Impacted	
No	10 (5.8)
Yes	163 (94.2)

Table 3. Association between tooth eruption status and the position of the gubernacular canal (GC) in relation to the dental follicle, its alignment in relation to the tooth, and its direction relative to cortical bone

	Normal impacted N (%)	Normal non-impacted N (%)	Delayed Impacted N (%)	Delayed non-impacted N (%)	p*
Position of GC					
Occlusal/incisal	28 (100.0)	02 (100.0)	60 (61.3)	03 (100.0)	0.004
Distal	00 (0.0)	00 (0.0)	30 (30.6)	00 (0.0)	
Mesial	00 (0.0)	00 (0.0)	02 (2.0)	00 (0.0)	
Palatal/lingual	00 (0.0)	00 (0.0)	06 (6.1)	00 (0.0)	
Alignment of GC					
Non-aligned	11 (39.3)	01 (50.0)	57 (58.2)	01 (33.3)	0.231
Aligned	17 (60.7)	01 (50.0)	41 (41.8)	02 (66.7)	
Direction of GC					
Bone Crest	20 (71.4)	00 (0.0)	68 (68.7)	03 (100.0)	0.301
Palatal/Lingual	08 (28.6)	02 (100.0)	27 (27.3)	00 (0.0)	
Vestibular	00 (0.0)	00 (0.0)	04	(4.0)	0.0 (0.0)

*Fisher's exact test

In addition, there was an increased incidence of the GC in non-usual positions, especially in teeth with abnormal eruption processes. These results are aligned with those found in this study, where, in the group of delayed and impacted teeth, 61.3% of the GC were in occlusal position and 38.7% of the GC were identified in non-usual positions. Teeth with another eruption status (normal impacted and non-impacted and delayed non-impacted) didn't present non-usual positions. However, these findings contrast with those of Khouri *et al.* (2023) (17), who identified the GC on the occlusal surface of 100% of the teeth evaluated. It is essential to highlight that Khouri *et al.* (2023) (17) excluded from their sample teeth with Nolla stages equal to or greater than 8, which may explain the total prevalence of the GC in the occlusal position. This study noted a variation in the prevalence of the GC position as dental development progressed. In the early Nolla stages, most teeth (more than 90%) had the GC predominantly in the occlusal position relative to the follicle, while in the more advanced Nolla stages, there was an increase in the prevalence of the GC in other positions. These results indicate a progressive change in the position of the canal as the root develops in both groupings, with three and ten categories, especially in impacted teeth and with a delayed eruptive process (Nolla stage equal to or greater than 8). The positional change of the GC in such cases may represent a dental adaptation in an attempt to establish an alternative eruption pathway.

Clinically, the progressive change in the GC position observed in advanced developmental stages may serve as a predictive marker for altered eruption pathways, supporting early interventions in cases of suspected dental impaction or delayed eruption.

However, it is crucial to emphasize that this study was conducted on a single population; therefore, further research involving other samples is imperative to reinforce these findings and extend the conclusions to different population groups. This approach will contribute to a more comprehensive understanding of the clinical implications and enable more precise application of these findings in dental practice.

Table 4. Association between Nolla's stage divided into three categories and the position of the gubernacular canal (GC) in relation to the dental follicle, its alignment in relation to the tooth, and its direction relative to cortical bone

	Complete crown formation N (%)	Less than two-thirds of the root completed N (%)	Two-thirds or more of the root formed N (%)	p*
Position of GC				
Occlusal/incisal	30 (96.8)	13 (92.9)	74 (63.8)	0.005
Distal	01 (3.2)	01 (7.1)	34 (29.3)	
Mesial	00 (0.0)	00 (0.0)	02 (1.7)	
Palatal/lingual	00 (0.0)	00 (0.0)	06 (5.2)	
Alignment of GC				
Non-aligned	12 (38.7)	05 (35.7)	68 (58.1)	0.066
Aligned	19 (61.3)	09 (64.3)	49 (41.9)	
Direction of GC				
Bone Crest	22 (71.0)	08 (57.1)	84 (71.8)	0.471
Palatal/Lingual	09 (29.0)	06 (42.9)	28 (23.9)	
Vestibular	00 (0.0)	00 (0.0)	05 (4.3)	

*Fisher's exact test

Table 5. Association between tooth eruption status and the position of the gubernacular canal (GC) in relation to the dental follicle, its alignment in relation to the tooth, and its direction relative to cortical bone

	One-third of the crown completed N (%)	Two-thirds of the crown completed N (%)	Crown almost completed N (%)	Crown completed N (%)	One-third of the root completed N (%)	Two-thirds of the root completed N (%)	Root almost completed, apex open N (%)	Root completed, apical end closed N (%)	p*
Position of GC									
Occlusal/incisal	03 (100.0)	04 (100.0)	13 (100.0)	10 (90.9)	13 (92.9)	11 (78.7)	19 (82.7)	44 (55.6)	0.023
Distal	00 (0.0)	00 (0.0)	00 (0.0)	01 (9.1)	01 (7.1)	01 (7.1)	03 (13.0)	30 (38.0)	
Mesial	00 (0.0)	00 (0.0)	00 (0.0)	00 (0.0)	00 (0.0)	01 (7.1)	00 (0.0)	01 (1.3)	
Palatal/lingual	00 (0.0)	00 (0.0)	00 (0.0)	00 (0.0)	00 (0.0)	01 (7.1)	01 (4.3)	04 (5.1)	
Alignment of GC									
Non-aligned	01 (33.3)	01 (25.0)	05 (38.5)	05 (45.5)	05 (35.7)	09 (64.3)	10 (43.5)	49 (61.3)	0.285
Aligned	02 (66.7)	03 (75.0)	08 (61.5)	06 (54.5)	09 (64.3)	05 (35.7)	13 (56.5)	31 (38.7)	
Direction of GC									
Bone Crest	03 (100.0)	02 (50.0)	11 (84.6)	06 (54.5)	08 (57.1)	07 (50.0)	18 (78.3)	59 (73.7)	0.382
Palatal/Lingual	00 (0.0)	02 (50.0)	02 (15.4)	05 (45.5)	06 (42.9)	06 (42.9)	05 (21.7)	17 (21.3)	
Vestibular	00 (0.0)	00 (0.0)	00 (0.0)	00 (0.0)	00 (0.0)	01 (7.1)	00 (0.0)	04 (5.0)	

*Fisher's exact test

CONCLUSION

The displacement of the gubernacular canal from the typical occlusal position relative to the follicle to other positions, particularly observed in impacted or delayed teeth, suggests that this feature of GC may highlight its potential as a diagnostic marker in the early detection of eruption disturbances.

STATEMENT OF CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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