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ORIGINAL ARTICLE

Analysis of the Internal Morphology of Root Canals in Teeth with Molar-Incisor Hypomineralization Using Cone Beam Tomography

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ABSTRACT

Objective: To analyze the internal morphology of root canals in hypomineralized molars and compare them with healthy teeth and different lesion discolorations using cone-beam computed tomography (CBCT). **Material and Methods:** CBCT scans of Nineteen teeth were collected: five hypomineralized teeth with a creamy-white color (maxilla=2; mandible=3); eight hypomineralized teeth with a brownish-yellow color (maxilla=3; mandible=5); six healthy teeth (maxilla=4; mandible=2). Parameters such as the number of canals, foramina, accessory canals, relevant distances, and linear measurements were evaluated. The Kruskal-Wallis test and descriptive analysis were performed to assess differences between the groups, with a 5% margin of error. **Results:** The number of major foramina was higher in hypomineralized teeth with yellow-brown discoloration in the lower arch (p=0.029) compared to the other groups. Hypomineralized teeth exhibited smaller linear measurements when compared to healthy teeth. **Conclusion:** Hypomineralized teeth tended to have more complex root canal systems when compared to healthy teeth. Further research should be conducted to evaluate these parameters in larger samples.

Keywords: Molar Hypomineralization; Endodontics; Cone-Beam Computed Tomography; Child.

Introduction

Molar-Incisor Hypomineralization (MIH) is a dental condition determined by a qualitative defect in tooth enamel [1]. The etiology of MIH is believed to be uncertain [2]. In hypomineralized teeth, enamel and dentin become less dense [3] and reduced mechanical properties can be observed, predisposing to post-eruptive breakage [4]. This effect is associated with the degradation of the color of the hypomineralized lesion. Thus, the darker it is, the greater the structural damage to the development of the tissue matrix [5].

Porous enamel and dentin exposure in teeth with MIH can lead to increased biofilm adhesion (a necessary factor) for the development of caries, ultimately inciting [6] pulpal inflammation [7]. This results in exacerbated sensitivity [8], especially to heat [7]. This hypersensitivity can be attributed to increased expression of the noxious pain stimulus receptor, TRPV1, indicating pulpal inflammation [7]. Pulp inflammation can also be attributed to damage to the extensions of odontoblasts [9,10] due to a poorly developed collagen network structure, which ultimately impairs their ability to respond to mechanical and thermal stimuli [7,10].

In addition, the internal anatomy of the root canals of teeth affected by MIH has a predisposition to be morphologically distinct and more complex, especially the greater the tone of the discoloration, when compared to healthy teeth [11]. Teeth affected by MIH have root canals that do not narrow occlusally-apically due to the dilation of blood vessels following pulpal inflammation [10,11]. On the other hand, accessory canals are found more often [11,12], and are not completely filled with dentin, thus these canals remain with open apices [11].

Most studies that analyze this relationship between hypomineralization and root canal morphology are carried out using micro-CT scanning, a technology that is unavailable for clinical use. To the best of our knowledge, this is the first study to analyze this morphological context regarding the complexity of the internal anatomy of molars with hypomineralization in different staining gradations compared to healthy teeth using cone beam computed tomography (CBCT), an accessible technology that can be useful in the processes of diagnosis, planning and endodontic therapy [13].

The null hypothesis to be tested is that there is no difference between the internal morphological parameters of root canals of teeth with hypomineralization, regardless of their clinical color, when compared to healthy teeth.

Material and Methods

Study Design and Ethical Clearance

This is an observational, cross-sectional study. This study was approved by the Research Ethics Committee of the Federal University of Alagoas (UFAL) under Opinion No. 6.193.354.

Data Collection

Using the database of a radiology clinic in the city of Maceió, State of Alagoas, Brazil, signs of molar hypomineralization were assessed through an active search using intraoral photographs taken for orthodontic purposes of children aged 8 to 10 years. The existence of hypomineralization in permanent first molars had been verified according to the criteria of the European Academy of Pediatric Dentistry (EAPD) [14]. These parameters were based on the presence of demarcated creamy-white and brownish-yellow opacities.

After analyzing the intraoral photographs, the authors verified the existence of a cone beam CT scan in their radiological records. In addition, healthy teeth were those that did not show any damage to their integrity. The collection period began in April/2023 until August/2023.

Based on the clinical presentations found, the permanent first molars were divided into the following groups:

- Group 1: Hypomineralized upper first molars with a yellow-brown color;
- Group 2: Hypomineralized lower first molars with a yellow-brown color;
- Group 3: Hypomineralized maxillary first molars with creamy white staining;
- Group 4: Hypomineralized lower first molars with a creamy white color;
- Group 5: Healthy upper first molars;
- Group 6: Healthy lower first molars.

Nineteen teeth were collected: five hypomineralized teeth with a creamy-white color (maxilla= 2; mandible= 3); eight hypomineralized teeth with a brownish-yellow color (maxilla= 3; mandible= 5); six healthy teeth (maxilla= 4; mandible= 2).

A KaVo OP 3D Pro cone beam tomograph (KaVo do Brasil Ind. Com. Ltda., Joinville, SC, Brazil) was used to assess the internal morphology of the root canals in the tomographic examinations. The acquisition protocol used for the CT scans ranged from 5 to 10 mA, at 90 Kv; the field of view ranged from 5x5, 8x8 and 8x15; the voxel size ranged from 0.125 mm to 0.250 mm and the exposure time ranged from 6.09 sec to 8.14 sec. The images were exported in DICOM format and evaluated in the InVivo Dental Software, version 6.0 (Anatomage Inc., Santa Clara, CA, USA) by a previously calibrated radiologist (Kappa=0.94). The analysis was established in the three main planes: sagittal, coronal and axial.

According to studies carried out by Briseño-Marroquín et al. [15] and Johnsen et al. [16] the following parameters were analyzed:

I. The number of canals in each root was divided into thirds, with the number of root canals present for each coronal limit being evaluated, and the root canal configuration of each root determined;

II. Number of main foramina - all foramina with a diameter greater than or equal to 0.25mm are considered main foramina. Foramina smaller than 0.25mm are considered accessory foramina;

III. Presence of accessory canals.

IV. Distances will be measured for all roots (Figure 1):

IV.1. From the cusp to the pulp horn;

IV.2. From cusp to apex;

IV.3. From the cemento-enamel junction to the apex;

IV.4. Root canal thickness

A. Mesiodistal

B. Buccal-lingual

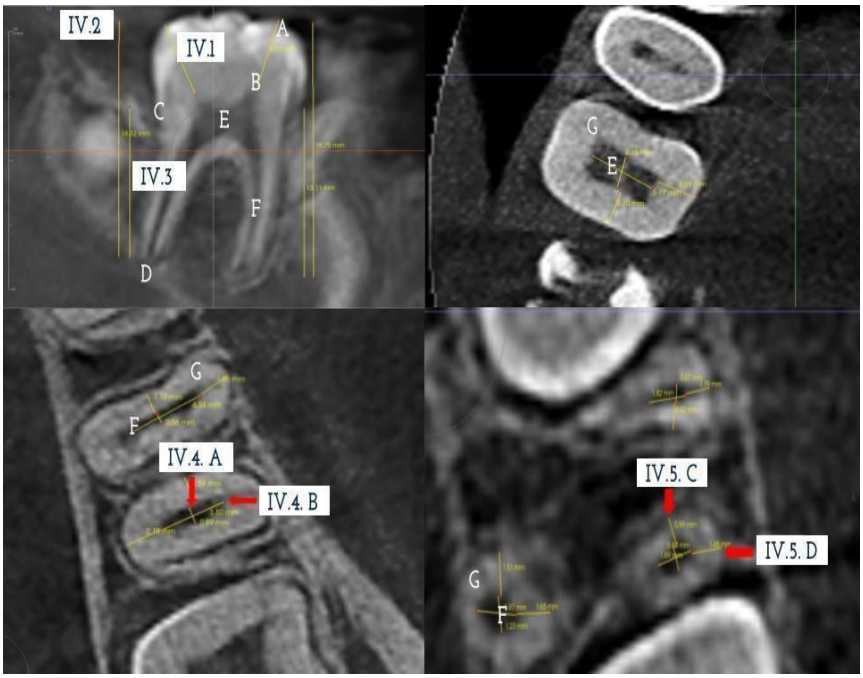
IV.5. Less dentin thickness in

C. Mesiodistal

D. Buccal-lingual

Parameters IV.4 and IV.5 were measured at 3 levels:

1. In the pulp chambe.
2. Halfway between the cemento-enamel junction (CEJ) and the apex.
3. 2mm before the apex.



Linear measurements of the molars including lengths: Cusp to pulp horn (IV.1), Cusp to apex (IV.2), JCE to apex (IV.3). Thickness of the root canals in the following directions: Mesiodistal (IV.4.A) and Buccal-lingual (IV.4.B) at half the distance between the OHC and the apex. Lower dentin thickness in the following directions: Mesiodistal (IV.5.C) and Buccal-lingual (IV.5.D) at 2 mm before the apex.

Figure 1. A: Cusp tip; B: Pulp horn; C: Cemento-enamel junction (CEJ); D: Root apex; E: Pulp chamber; F: Root canal; and G: Dentin thickness.

Data Analysis

After collecting the data and categorizing the variables, a database was created for statistical analysis using SPSS (Statistical Package for the Social Science) version 21 (IBM Corp., Armonk, NY, USA). To test the association between two categorical variables, the Kruskal-Wallis non-parametric test was used to determine whether there were statistically significant differences between the independent groups. The margin of error adopted was of 5%. Descriptive statistics were also presented.

Results

To analyze the configuration of the root canals, 19 first molars were selected, 6 of which were healthy, 5 were hypomineralized with a creamy white color, and 8 were hypomineralized with a brownish-yellow color, making up a total of 48 roots analyzed. The mesio-buccal root of the mandibular molars showed the greatest variation in possible root canal configurations, followed by the mesio-buccal roots of the maxillary molars and the distal roots of the mandibular molars. All palatal roots had a 1-1-1/1 configuration.

It was possible to observe the 1-1-1/1 configuration, i.e. only one main canal in the entire root canal and only one main foramen, in 76.47% of the roots of healthy teeth, 91.66% of the roots of hypomineralized teeth with a creamy-white color, and 52.63% of the roots of hypomineralized teeth with a brownish-yellow color, showing a prevalence of 70.83% when considering all the roots analyzed. The 1-1-2/2 and 1-1-1/2 configurations were the second and third most prevalent, respectively, found in 10.41% and 8.33% of the roots analyzed.

Of the roots analyzed, 11 had configurations with 2 foramina: 2 roots of healthy teeth in the 2-2-2/2 configuration, 1 root of a creamy-white hypomineralized tooth in the 1-1-2/2 configuration, and 8 roots of yellow-brown hypomineralized teeth in the 1-1-1/2 configuration in 4 roots, and 1-1-2/2 in 4 roots.

Based on the analysis conducted using the Kruskal-Wallis non-parametric test, when comparing the frequency of main canals for the yellow-brown and creamy-white hypomineralized molars and those considered healthy, no statistically significant difference was found (p>0.05). This result was verified for both arches.

No accessory canals were identified in the groups of healthy and hypomineralized teeth with a creamy white color. However, in the group of hypomineralized teeth with a brownish-yellow color, 2 accessory canals were recognized, both in mandibular teeth, 1 of which was adventitious and 1 collateral, representing an incidence of 33.33% of the mandibular teeth belonging to this group. In this study, there was no statistically significant difference (p>0.05) in the frequency of accessory canals when comparing the groups of hypomineralized and healthy teeth in the upper and lower arches.

When evaluating the hypomineralized molars and the molars considered healthy in the upper arch, no statistically significant difference was observed in relation to the number of main foramina (p>0.05). However, in the lower arch, it was observed that the number of main foramina in the brownish-yellow hypomineralized teeth was higher (p=0.029) compared to the creamy-white hypomineralized teeth. While the number of accessory foramina showed no statistically significant difference (p>0.05) in all groups.

When comparing the measurement of the pulp chamber in the Cemento-Enamel Junction (CEJ) in the medial-vestibular and vestibular-lingual directions in all the upper and lower arch groups, there was no statistically significant difference (p>0.05). Similarly, no statistically significant differences (p>0.05) were found when considering the smaller dentin thickness of the pulp chamber in the CEJ in the medial-vestibular and buccal-lingual directions in all the upper and lower arch groups.

A significant discrepancy was observed between the measurements of the mesio-vestibular roots of the mandibular and maxillary molars. The teeth considered healthy had a greater distance between the cusp and the root apex, between the cusp and the pulp horn, as well as between the cemento-enamel junction and the root apex. In the mesio-buccal canal, in the buccal-lingual direction, at a distance of 2 mm before the apex, in both maxillary and mandibular teeth, there was a greater measurement in hypomineralized teeth compared to healthy teeth (Table 1).

Table 1. Linear measurements, in millimeters, of the MV canals of maxillary and mandibular first permanent molars.

Measurement	MV Canal - Maxilla						MV Canal - Jaw					
	Yellow-Brown Color		Creamy White Color		Healthy Teeth		Yellow-Brown Color		Creamy White Color		Healthy Teeth	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Distance from Cusp to Pulp Horn	4.28	0.94	5.13	0.38	4.51	0.39	4.5	0.79	4.06	0.44	6.00	0.09
Distance from cusp to apex	17.53	3.52	17.06	0.04	20.56	0.82	17.36	1.30	19.76	0.25	21.46	0.77
Distance from JCE at its peak	11.87	2.05	10.44	0.58	13.79	1.02	11.73	0.82	12.65	0.22	14.5	2.03
MD Canal Thickness at ½ the distance from the CEJ to the Apex	0.67	0.12	0.93	0.81	1.11	0.64	0.48	0.14	0.66	0.35	0.83	0.03
VL Canal Thickness at ½ the distance from the CEJ to the Apex	2.25	0.77	2.04	1.49	1.79	0.88	5.63	1.73	5.72	1.39	1.50	0.26
Canal MD thickness 2mm before apex	0.66	0.11	0.61	0.16	0.86	0.17	0.62	0.21	0.5	0.08	0.49	0.19
VL Canal Thickness 2mm before apex	2.96	0.99	1.12	0.01	1.23	0.18	2.05	1.26	6	2.06	0.79	0.01

Less dentin thickness in MD at ½ the distance from the CEJ to the apex	0.92	0.37	0.88	0.01	1.23	0.14	1.05	0.20	1.32	0.28	0.91	0.16
Less dentin thickness in VL at ½ the distance from the CEJ to the apex	1.28	0.08	1.25	0.39	1.66	0.23	1.48	0.37	1.53	0.20	1.37	0.12
Less dentin thickness in MD 2mm before the apex	0.83	0.15	0.82	0.04	1.02	0.13	0.82	0.17	0.85	0.02	0.97	0.21
Less dentin thickness in VL 2mm before the apex	1.14	0.14	1.24	0.18	1.04	0.17	1.02	0.40	1.01	0.36	1.05	0.42

Additionally, in the disto-vestibular, palatal and distal roots, there was a greater distance between the OHC and the apex in healthy teeth when compared to hypomineralized teeth (Tables 2 and 3). In the palatine canal, there was a significant disparity in the lowest dentin thickness in the region between the mid-CEJ and the apex, with healthy teeth showing higher thickness values than those observed in hypomineralized teeth (Table 3). The distance from the palatal cusp to the pulp horn was greater among healthy teeth than those with hypomineralization, regardless of tooth color (Table 3). All distances between the cusps and the apex showed a lower value when the tooth was affected by hypomineralization, showing less development (Tables 1 to 3).

Table 2. Linear measurements, in millimeters, of the DV and ML canals of maxillary and mandibular first permanent molars.

Measurement	DV Canal - Maxilla						ML Canal - Mandible					
	Yellow-Brown Color		Creamy White Color		Healthy Teeth		Yellow-Brown Color		Creamy White Color		Healthy Teeth	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Distance from Cusp to Pulp Horn	6.14	0.37	5.00	0.53	5.52	0.92	4.73	-	-	-	-	-
Distance from cusp to apex	17.17	2.54	16.80	1.08	20.47	1.14	17.92	-	-	-	-	-
Distance from JCE at its peak	10.74	1.92	10.69	0.53	13.75	0.08	12.83	-	-	-	-	-
MD Canal Thickness at ½ the distance from the CEJ to the Apex	0.84	1.91	1.02	0.24	0.92	0.32	0.51	-	-	-	0.76	0.19
VL Canal Thickness at ½ the distance from the CEJ to the Apex	1.67	0.50	1.33	0.16	2.18	0.65	1.86	-	-	-	1.18	0.22
Canal MD thickness 2mm before apex	0.49	0.20	0.64	0.28	0.71	0.25	0.54	0.02	-	-	0.45	0.07
VL Canal Thickness 2mm before apex	1.53	0.25	1.42	0.17	0.86	0.35	1.1	0.14	-	-	0.99	0.06
Less dentin thickness in MD at ½ the distance from the CEJ to the apex	0.99	0.11	0.96	0.03	1.21	0.29	1.04	-	-	-	1.29	0.46
Less dentin thickness in VL at ½ the distance from the CEJ to the apex	1.09	0.26	1.38	0.61	1.66	0.20	1.36	-	-	-	1.54	0.62
Less dentin thickness in MD 2mm before the apex	0.65	0.02	0.73	0.007	0.84	0.32	0.9	0.32	-	-	0.82	0.27
Less dentin thickness in VL 2mm before the apex	0.81	0.05	0.81	0.27	1.21	0.16	1.01	0.28	-	-	1.06	0.41

Table 3. Linear measurements, in millimeters, of the DV and ML canals of maxillary and mandibular first permanent molars.

Measurement	DV Canal - Maxilla						ML Canal - Mandible					
	Yellow-Brown Color		Creamy White Color		Healthy Teeth		Yellow-Brown Color		Creamy White Color		Healthy Teeth	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Distance from Cusp to Pulp Horn	6.14	0.37	5.00	0.53	5.52	0.92	4.73	-	-	-	-	-
Distance from cusp to apex	17.17	2.54	16.80	1.08	20.47	1.14	17.92	-	-	-	-	-
Distance from JCE at its peak	10.74	1.92	10.69	0.53	13.75	0.08	12.83	-	-	-	-	-
MD Canal Thickness at ½ the distance from the CEJ to the Apex	0.84	1.91	1.02	0.24	0.92	0.32	0.51	-	-	-	0.76	0.19
VL Canal Thickness at ½ the distance from the CEJ to the Apex	1.67	0.50	1.33	0.16	2.18	0.65	1.86	-	-	-	1.18	0.22
Canal MD thickness 2mm before apex	0.49	0.20	0.64	0.28	0.71	0.25	0.54	0.02	-	-	0.45	0.07
VL Canal Thickness 2mm before apex	1.53	0.25	1.42	0.17	0.86	0.35	1.1	0.14	-	-	0.99	0.06
Less dentin thickness in MD at ½ the distance from the CEJ to the apex	0.99	0.11	0.96	0.03	1.21	0.29	1.04	-	-	-	1.29	0.46
Less dentin thickness in VL at ½ the distance from the CEJ to the apex	1.09	0.26	1.38	0.61	1.66	0.20	1.36	-	-	-	1.54	0.62
Less dentin thickness in MD 2mm before the apex	0.65	0.02	0.73	0.007	0.84	0.32	0.9	0.32	-	-	0.82	0.27
Less dentin thickness in VL 2mm before the apex	0.81	0.05	0.81	0.27	1.21	0.16	1.01	0.28	-	-	1.06	0.41

Discussion

Molar-incisor hypomineralization (MIH) originates from defects in tooth enamel [1]. However, its influence is not solely limited to abnormalities in this tissue [11]. MIH is also associated with immunohistochemical alterations in pulp innervation and vascularization [7]. Thus, the impact of MIH goes beyond enamel structure to include immunological and microstructural alterations, as evidenced by the morphological changes found in the analyses carried out in this study. Therefore, the null hypothesis of this study (that there is no difference between the internal morphological parameters of root canals of teeth with hypomineralization, regardless of their clinical color, when compared to healthy teeth) was rejected partly due to the descriptive and inferential statistical data obtained in this study.

There was a greater number of main foramina in the lower teeth with yellow-brown hypomineralization, corroborating the findings of Neboda et al. [12] However, by analyzing the number of main and accessory canals, accessory foramina, thickness in the MD and VL directions of the pulp chambers at the level of the OHC, it was noted that there was no difference between teeth with hypomineralization of different stains or healthy teeth.

Neboda et al. [12] found no significant differences in the linear measurements of the elements evaluated in their analysis. In contrast to these findings, the present study observed a possible underdevelopment of the hypomineralized teeth groups when compared to the healthy teeth group, evidenced by the lower mean distances between the OHC and the root apex in the disto-vestibular, palatal and distal roots, as well as a lower dentin thickness in the palatal roots.

Observations have shown that hypomineralized teeth with post-eruptive destruction have a reduced pulp volume compared to hypomineralized teeth without post-eruptive destruction and healthy teeth, which can be attributed to harmful stimuli to the pulp, possibly promoting the formation of reactive/tertiary dentin [12]. Based on these findings, this study measured the width of the pulp chamber and lower dentin thickness in the mesio-distal and buccal-lingual directions in all groups. No statistically significant difference was found for these variables. Therefore, there was no significant increase in dentin thickness in yellow-brown and creamy-white hypomineralized teeth when compared to healthy teeth. This could be attributed to the age of the children in the sample (8-10 years) and the non-overlapping of carious lesions or breaks on the hypomineralized teeth.

Özükoç [11] found a higher prevalence of accessory canals in hypomineralized teeth, associated with a failure in canal obliteration, which is more common in young teeth but is obliterated by dentin throughout life. According to Rodd et al. [7], this failure in obliteration can be explained by the increase in vascular activity due to the chronic inflammatory process found in hypomineralized teeth. The CBCT scans carried out in this study showed no significant changes in the number of these canals, diverging from the findings of Özükoç [11]. This divergence may be related to the use of micro-CT in the study - a more precise examination than CBCT, capable of recording dental structures in greater detail, but which can only be performed on ex-vivo teeth [17]. Regarding the main canals, it was not possible to observe any changes in their quantity, as in the studies carried out by Özükoç [11] and Neboda et al. [12].

Briseño-Marroquín et al. [15] carried out a study in which major foramina were considered to be those with a diameter of 0.25 mm or more. In the context of the present study, a higher prevalence of major foramina was observed in hypomineralized teeth with a brownish-yellow color, specifically in the lower arch. Among the lower healthy teeth, the present study identified more than 1 main foramen in 2 roots, representing a frequency of 11.76%. In contrast, none of the roots of the lower hypomineralized teeth with a creamy white color had more than 1 main foramen. However, a total of 8 roots with more than 1 main foramen were observed in the lower hypomineralized teeth with yellow-brown staining, with an occurrence rate of 42.10%. This variation is of great clinical importance, hindering the precision and effectiveness of instrumentation, disinfection and proper obturation of the root canal system, leading to endodontic treatment failures [18,19]. In view of this, the clinician must carefully consider the anatomical variations of teeth with such staining due to MIH.

There are many techniques for analyzing the internal morphology of root canals, such as sectioning, periapical radiographs, micro-CT and cone beam computed tomography (CBCT). Some of these techniques have limited applications and their use is restricted to extracted teeth. Periapical radiographs and cone-beam CT scans are the preferred choice for clinical assessment. However, radiographs generate two-dimensional images of three-dimensional structures, being thus less accurate than CBCT [17]. Therefore, although CBCT is not capable of detecting all morphological parameters in detail, Borges et al. [20] and Zhang et al. [17] concluded that the accuracy of CBCT is similar to that of micro-CT, and it is considered the best test to help the endodontist understand the root canal system before treatment. Although significant differences were found between the groups analyzed using CBCT, confirming the hypothesis of greater variation in the morphological complexity of the root canal system of hypomineralized teeth of different stains, as well as in relation to healthy teeth.

In this regard, hypomineralized teeth tended to have more complex root canal systems when compared to healthy teeth. However, future research should be conducted in order to prioritize the evaluation of these parameters in larger samples.

Conclusion

Hypomineralized teeth tend to have more complex root canal systems when compared to healthy teeth. Yellow-brown teeth tend to have greater complexities in the internal anatomy of the root canals.

Authors' Contributions

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All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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