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Effect of nutritional status on dental maturation and mandibular bone density among Indonesian children aged 6–9 Years in Yogyakarta

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ABSTRACT

Introduction: Growth and development in children depend significantly on their nutritional status; therefore, nutritional deficiencies can greatly influence dental and bone maturity. The level of dental maturation can be used to measure dental development. Mandibular bone density (MBD) can directly impact certain invasive procedures, such as extractions and dental trauma management. This study aimed to determine the influence of nutritional status on dental maturation and MBD in children aged 6–9 years.

Materials and methods: The study used 108 panoramic radiographs from children in this age and divided them into three groups: low, moderate, and high nutritional status. The nutritional status was determined on the basis of height-for-age (H/A) z-scores using the WHO H/A chart. The dental maturity score was calculated as the total score of the seven mandibular teeth in the left region using the Nolla method. Using fractal analysis, MBD was measured as the average fractal dimension values from three regions of interest (ROI): the condyle, angle, and below the second premolar and first permanent molar of the left mandible. Data were analyzed using one-way ANOVA for dental maturation levels and the Kruskal-Wallis test for MBD (95 % CI).

Results: The results showed significant differences in dental maturation levels between the nutritional status groups, with dental maturation in the low-nutrition group being significantly slower than in the other groups. The MBD showed no significant differences between the nutritional status groups.

Conclusion: This study concluded that nutritional status influences the level of dental maturation, but not MBD.

1. Introduction

Nutritional problems are a major public health concern in Indonesia. According to the Ministry of Health of Indonesia (2021), 24.4 % of childhood malnutrition leads to stunting.[1] Nutritional intake plays a crucial role in the formation, development, and maturation of dental hard tissues, such as teeth and jawbones. Therefore, nutritional deficiencies can significantly affect children's growth and development. Moreover, dental and bone condition need to be considered while planning dental treatment and prognoses in children according to their developmental stage.

Various studies have demonstrated nutrition directly impacting growth and development, with undernutrition or overnutrition potentially causing developmental milestones that otherwise do not align with the age progression. Children under 5 years of age with good nutritional status are 3.3 times more likely to experience age-appropriate development.[2] Dental maturation serves as a marker for assessing developmental stages, and can be observed clinically through tooth eruption timing or radiographically using panoramic radiographs. Radiographs provides more precise details of tooth crown development and root calcification, offering greater accuracy than clinical methods.[3] A study on Hispanics using panoramic radiographs demonstrated that those with overnutrition exhibited accelerated tooth development.[4]

Dental maturation analysis can be conducted during the mixed dentition period, starting at 6 years of age, when the first permanent tooth erupts. By the age of 9 years, third molar buds begin to form and calcify. Panoramic radiographs of children aged 6–9 years provide a complete view of the permanent teeth and jawbone structure, enabling the assessment of dental maturation and mandibular bone density (MBD).[5] Several methods are available to measure dental maturation, including the Demirjian, Willem, Nolla, and AlQahtani methods. The Nolla method is more frequently used than the other methods as it

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provides more accurate results in Asian populations than other methods.[6] Nolla method divides the development of permanent teeth into ten detailed stages, offering greater precision.

Tooth and bone mineralization require collagen, which is supported by nutrients such as vitamins C, D, and inorganic minerals such as calcium and phosphorus, to form hydroxyapatite in teeth and bones. Nutritional deficiencies can hinder growth and affect the size, composition, quality, and texture of dental and bone tissues.[7] Studies in adults have suggested that bone density is correlated with body mass index (BMI), with the lowest bone density observed in the group with low body mass.[8] However, this finding varies across studies due to multiple influencing factors.

Understanding the link between nutritional status, dental maturation, and MBD in children is crucial for clinicians to plan effective treatments, as it can significantly impact the prognoses. Orthodontic treatment is the most effective modality for dental development. Certain root canal techniques are required in cases of delayed tooth development. Tooth extraction also depend on eruption timing, and surgical precautions are needed for children with low bone density. This study aimed to investigate the relationship between nutritional status and the level of dental maturation, using the Nolla method, as well as MBD, through fractal analysis in children between 6–9-years.

2. Methods

2.1. Study design and participants

This cross-sectional study used 108 panoramic radiographs of pediatric patients aged 6–9 years at a university dental hospital, between January and October 2023. Ethical approval was obtained from the Ethics Committee of the Faculty of Dentistry and Prof. Soedomo Dental Hospital (Ref. no. 6/UN1/KEP/FKG-RSGM/EC/2024). Nutritional status was assessed using the height-for-age (H/A) parameter, where the height was measured in centimeters and age in years, from electronic medical records. The WHO H/A chart, specific to boys and girls, provided z-scores, that were then used to determine their nutritional status.[9]

Digital panoramic radiographs were selected based on the following inclusion criteria: (1) radiographs meeting the quality standards, (2) radiographs from children categorized by nutritional status based on H/A z-scores: high (>1), moderate (between −1 and 1), and low (<−1), and (3) radiographs taken within 3 months of height measurement. Children with developmental disorders, systemic diseases, history of dental trauma, or periapical abnormalities were excluded from this study. These conditions can result in delayed or accelerated growth and development in children, thereby influencing bone density and dental maturation. Children with agenesis were excluded because their levels of dental maturation could not be assessed.

2.2. Measurement of dental maturation level

Dental maturation was assessed by observing the developmental phase of each tooth on radiographs. Seven left mandibular teeth (excluding the third molar) were evaluated using Nolla's method, which categorizes tooth maturation into 10 stages (Fig. 1). Each tooth was scored based on its stage. If the radiograph showed an intermediate stage between the two phases, the score was adjusted by adding 0.2, 0.5, or 0.7 points, depending on the degree of development. The scores for each tooth were summed to obtain the overall dental maturation score for each sample.

2.3. Measurement of MBD

Each digital panoramic radiograph was preserved in a high-resolution Tagged Image File Format (TIFF) without alterations. The MBD was assessed using fractal analysis with ImageJ v1.52 (64-bit Java-based software for Windows). Fractal analysis describes the complex shapes and microstructures of the bones, making it a valuable tool for assessing bone density.[10] It characterizes the morphology, patterns, and structure of the bone using computer-based programs. Three 50 × 50-pixel regions of interest (ROIs) were defined in the left mandible: one at the center of the condyle, another at the mandibular angle below the mandibular canal, and the third in the dentate area between the second premolar and first molar (Fig. 2).

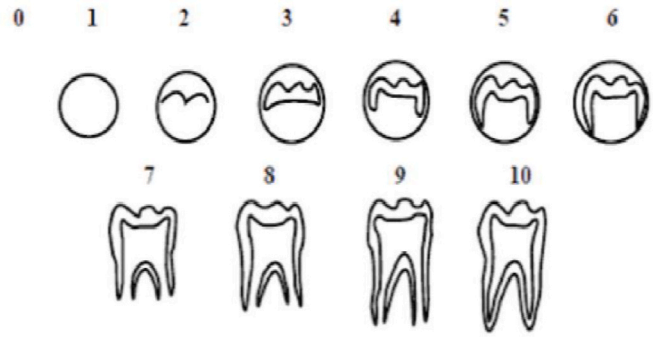

Fig. 1. Dental development stage by Nolla Method.

The fractal analysis followed the method described by White and Rudolph,[11] wherein an ROI was selected and duplicated twice. A Gaussian filter (sigma = 10) was applied to the second duplicate to reduce light-dark fluctuations in the image caused by tissue overlap. The blurred image is then subtracted from the original image to obtain an undistorted representation. An RGB (Red Green Blue) value of 128 was added to highlight the bone marrow cavities and trabeculae. The image was then converted into a binary image to emphasize the trabeculae and bone marrow, with noise reduced through erosion and dilation operations. In the final stage of image processing, inversion and skeletonization were applied to generate a skeletal pattern representing the bone density (Fig. 3).

The fractal dimension value was calculated using the 'Fractal Box Counter' tool in ImageJ's 'Analyze' menu. This tool divides an image into boxes of varying sizes (2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels) to compute fractal dimensions. The calculated values are then displayed graphically on a logarithmic scale, showing the fractal dimension values that characterize bone density.

2.4. Statistical analysis

Interobserver reliability was assessed by two observers one week prior to the main measurements, demonstrating strong agreement (Cronbach's alpha >0.6). According to the results of homogeneity

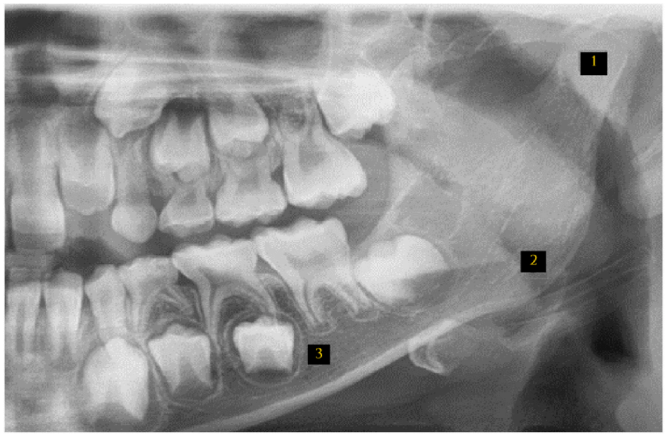

Fig. 2. ROI location to measure MBD.

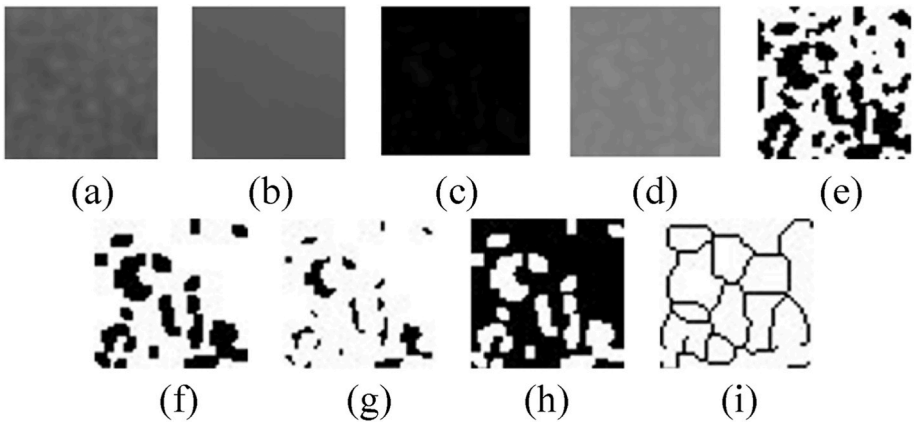

Fig. 3. Image processing from radiograph to fractal representation: (a) Original ROI Image. (b) Gaussian Blur applied. (c) Subtracted Gaussian Blur from the original image. (d) Added 128 Gy filter. (e) Converted to binary. (f) Reduced noise (g) Clarified structure expansion. (h) Reconverted image color. (i) Transformed to skeletal structure.

(Levene's test) and normality (Kolmogorov-Smirnov test), the dental maturation level exhibited homogenous data with a normal distribution, whereas the bone density data showed a non-homogenous distribution that did not follow a normal distribution. The impact of nutritional status on the dental maturation level across the three nutritional status groups was analyzed using parametric ANOVA, followed by post-hoc tests to identify the most affected group. The effect of nutritional status on MBD was evaluated using non-parametric Kruskal-Wallis analysis. Additional analyses were conducted to explore the influence of gender and age on dental maturation and MBD. Sex differences in dental maturation levels were examined using independent t-tests, whereas Mann-Whitney U tests were used to assess sex differences in MBD. All analyses were performed using SPSS (version 26.0; SPSS, Chicago, IL, USA) with a 95 % confidence interval ($p < 0.05$).

3. Results

A total of 108 panoramic radiographs from 108 children (50 % males and 50 % females) aged 6–9 years were evaluated. The results showed mean dental maturation scores as 49.74 ± 5.03, 53.12 ± 3.71, and 52.70 ± 4.91 in the low, moderate, and high-nutrition group, respectively. The mean MBD scores did not exhibit significant differences across groups: 1.49 ± 0.04 in the low, 1.50 ± 0.03 in the moderate, and 1.49 ± 0.03 in the high-nutrition groups (Table 1). Across the groups, the results revealed a significant difference in dental maturation levels ($p = 0.004$), unlike in the MBD values ($p = 0.380$). Further analysis examining the influence of sex and age on dental maturation and MBD showed statistically significant differences in dental maturation levels ($p = 0.000$), with no significant differences in MBD across the age groups ($p = 0.988$). Additionally, there were no significant differences in dental maturation level or MBD between the sexes groups (Table 2).

Tukey's post-hoc ANOVA was used to identify significant differences in dental maturation between groups. The dental maturation level in the low-nutrition group was significantly lower than that in both the moderate and high-nutrition groups ($p < 0.05$), except for the moderate- and high-nutrition groups (Table 3). Similar tests within the age groups showed significant differences ($p < 0.05$) while comparing among all, except between the 8 and 9-year-old groups ($p > 0.05$) (Table 4).

4. Discussion

This study highlights the impact of nutritional status on dental maturation. The low-nutrition group demonstrated slower dental maturation than the other two groups. This delay can be attributed to inadequate nutrition availability for optimal growth and development relative to age. Similar findings have been reported in other studies, indicating that children with inadequate nutrition often experience growth delays. Previous research using the Demirjian method showed that children with poor nutritional status tend to exhibit delayed dental development and tooth eruption.[12] Apart from nutritional factors, children with low nutritional status frequently experience delayed tooth growth attributable to disrupted alveolar bone development and frequent oral infections.[13]

The dental maturation levels in the moderate and high-nutrition groups did not differ significantly, suggesting a higher nutritional status does not necessarily accelerate growth as compared to moderate nutrition. The body regulates nutrient absorption according to its physiological needs,[14] with excess calcium stored rather than absorbed due to the action of the parathyroid hormone. Therefore, excess calcium does not accelerate the growth of hard tissues, including teeth.[15] Genetics also plays a significant role in biological regulation, influencing nutrient absorption and tissue growth timing.[14] These factors may explain the similar dental maturation rates observed in the moderate and high-nutrition groups.[16] A study in the United States using the Demirjian method, BMI measurement, and Food Frequency Questionnaire found accelerated dental maturation among children with a high nutritional status compared to those with a normal one. Variations in the study populations, measurement techniques, and instruments have contributed to different research outcomes.

MBD values did not differ significantly among the nutritional status groups. The panoramic radiographs used in this study were obtained from healthy children who did not present with systemic abnormalities that could interfere with bone development. Consequently, their MBD was consistent across the sample population. Thus, no significant variation in bone density was observed among children with comparable nutritional status. Supporting this finding, research utilizing dual-energy X-ray absorptiometry (DEXA) to assess bone density in children with adequate, normal, and inadequate nutritional status also reported no significant differences in bone density values. However, a separate study that assessed muscle mass revealed that children with a higher nutritional status exhibited higher bone density values than those with a lower nutritional status.[17]

Genetics significantly influence bone development, with 40–80 % of bone density characteristics inherited from parents. Inherited genes, such as *COL1A1, LRP5,* and *VDR* regulate bone formation, calcium absorption, and vitamin D metabolism.[18] Essential nutrients such as calcium and vitamin D are crucial for bone and tooth mineralization, and their deficiency can disrupt these processes.[19,20] Physical activity affects bone density, with higher values observed in children who participate in high-mobility sports, such as running and other field sports.[8] Bones are more effectively stimulated by dynamic muscle pressure than by static fat pressure. Dynamic muscle movement during high-intensity exercise

Table 1
Mean, SD, of dental maturation and MBD between each nutritional status groups based on age and gender.

Nutritional status	Age	Dental maturation (Mean ± SD)			MBD (Mean ± SD)		
		Boys	Girls	Boys and girls	Boys	Girls	Boys and Girls
Low	6	46,37 ± 0,76	44,23 ± 2,03	44,77 ± 2,06	1,48 ± 0,02	1,50 ± 0,03	1,49 ± 0,03
	7	51,33 ± 4,06	48,25 ± 0,07	50,56 ± 3,71	1,50 ± 0,05	1,45 ± 0,04	1,49 ± 0,05
	8	51,03 ± 2,48	54,03 ± 5,81	52,53 ± 4,44	1,51 ± 0,04	1,46 ± 0,06	1,49 ± 0,05
	9	54,48 ± 2,58	55,80 ± 0,85	54,86 ± 2,23	1,49 ± 0,04	1,49 ± 0,08	1,49 ± 0,05
	Total	51,34 ± 3,81	48,14 ± 5,68	49,74 ± 5,03	1,50 ± 0,04	1,49 ± 0,04	1,49 ± 0,04
Moderate	6	47,03 ± 2,14	49,47 ± 1,37	48,25 ± 2,08	1,49 ± 0,03	1,49 ± 0,01	1,49 ± 0,02
	7	51,44 ± 3,13	52,30 ± 2,31	51,91 ± 2,61	1,51 ± 0,03	1,50 ± 0,03	1,51 ± 0,03
	8	55,48 ± 2,10	54,92 ± 3,60	55,21 ± 2,80	1,48 ± 0,04	1,50 ± 0,03	1,49 ± 0,03
	9	56,06 ± 3,04	55,80 ± 4,10	55,93 ± 2,95	1,52 ± 0,02	1,49 ± 0,01	1,50 ± 0,02
	Total	53,01 ± 4,02	53,23 ± 3,48	53,12 ± 3,71	1,49 ± 0,03	1,50 ± 0,01	1,50 ± 0,03
High	6	47,53 ± 2,76	51,36 ± 4,92	48,90 ± 3,97	1,50 ± 0,03	1,47 ± 0,04	1,49 ± 0,04
	7	50,20 ± 3,56	52,40 ± 2,86	51,58 ± 3,10	1,48 ± 0,00	1,47 ± 0,02	1,48 ± 0,02
	8	54,65 ± 2,03	57,63 ± 0,06	55,93 ± 2,15	1,50 ± 0,03	1,50 ± 0,01	1,50 ± 0,02
	9	56,05 ± 0,50	59,28 ± 2,22	58,36 ± 2,41	1,51 ± 0,03	1,47 ± 0,01	1,48 ± 0,02
	Total	50,51 ± 4,26	54,89 ± 4,61	52,70 ± 4,91	1,50 ± 0,03	1,48 ± 0,03	1,49 ± 0,03

SD- Standard Deviation.

promotes bone development, thereby increasing the bone density.[17] This study, however, lacked data on the children's nutritional intake and physical activity, leaving room for uncertainty regarding the causes of irregular MBD patterns.

Furthermore, gender had no affect on dental maturation or MBD in children aged between 6 and 9 years. Before puberty, growth is primarily influenced by growth hormones (GH) and Insulin-Like Growth Factor 1 (IGF-1) rather than by sex hormones such as estrogen and testosterone.[21] Generally, girls may experience pubertal growth spurts about 2 years earlier than boys.[22] Previous studies have found no significant influence of sex on trabecular or cortical bone quality,[23] consistent with the findings of the present study. However, during puberty, bone density values may differ between boys and girls. Boys typically exhibit more complex trabecular bone structures and larger bone sizes owing to the effects of steroids on bone development, whereas in girls trabecular structures tend to be more porous with fewer trabeculae.[24]

The dental maturation scores observed in the present study increased

Table 2
Inferential analysis of each variable.

Variable	n	Dental maturation			MBD		
		Statistic test	df	p-value	Statistic test	df	p-value
Nutritional status							
Low	36	5.798	2	0.004[a,e]	1.934	2	0.380[d]
Moderate	36						
High	36						
Gender							
Boys	54	4.050	1	0.614[b]	1241.0	1	0.182[c]
Girls	54						
Age							
6	33	42.446	3	0.000[a,e]	0.133	3	0.988[d]
7	27						
8	30						
9	18						

[a] Analysis using *one-way ANOVA*.
[b] Analysis using *independent sample t-test*.
[c] Analysis using *mann-whitney u-test*.
[d] Analysis using *kruskal wallis*.
[e] Analysis results indicate a significant difference ($p < 0,05$).

Table 3
Tukey's post-hoc Anova analysis on dental maturation between each nutritional status group.

Nutritional status (I)	Nutritional status (J)	Mean differences (I-J)	Sig
Low	Moderate	−3.5000	0.005[a]
	High	−2.9583	0.020[a]
Moderate	Low	3.5000	0.005[a]
	High	0.5417	0.872
High	Low	2.9583	0.020[a]
	Moderate	−0.5417	0.872

[a] Analysis results indicate a significant difference ($p < 0,05$).

Table 4
Tukey's post-hoc Anova analysis on dental maturation between each age group.

(I) Age	(J) Age	Mean Difference (I-J)	Sig
6	7	−4.2566	0.000[a]
	8	−7.5088	0.000[a]
	9	−9.3010	0.000[a]
7	6	4.2566	0.000[a]
	8	−3.2522	0.002[a]
	9	−5.0444	0.000[a]
8	6	7.5088	0.000[a]
	7	3.2522	0.002[a]
	9	−1.7922	0.258
9	6	9.3010	0.000[a]
	7	5.0444	0.000[a]
	8	1.7922	0.258

[a] Analysis results indicate a significant difference ($p < 0,05$).

with age. The participants included in the study did not present with systemic conditions or developmental abnormalities, thus ensuring age-appropriate dental development. Significant differences in dental maturation scores were noted across most age groups except for 8- and 9-year-olds. This similarity in scores is due to comparable dental calcification stages; 8-year-olds had first premolars at one-third root length, whereas 9-year-olds had them at two-thirds root length. The second permanent molar crown was incompletely formed in 8-year-olds but fully formed in 9-year-olds, leading to minimal score differences between these groups.[25]

There was no significant difference in MBD across age groups in this study. An 8-year-old girl may exhibit MBD similar to that of a 6-year-old girl as both are in the pre-pubertal stage, unaffected by the hormonal changes influencing bone density. During puberty, bones undergo rapid growth stimulated by estrogen and testosterone. These hormones enhance the osteoblast activity and bone synthesis, resulting in

increased bone size and density.[26] An earlier study showed that children in the early and late mixed dentition phases did not differ significantly in MBD, whereas there was a notable difference between children in the early mixed and permanent dentition phases.[27] The 6–9 year age range in this study corresponded to the mixed dentition period, explaining the lack of significant MBD differences.

The nutritional status of children is vital for planning treatments for dental maturation and MBD. Understanding the level of dental maturation is crucial, particularly in orthodontic treatment, because treatment must align with the developmental stage. Clinicians should educate parents on how nutritional status relates to the timing of tooth development, particularly in cases of delayed eruptions. MBD influences the quality and stability of tooth support, affecting the duration needed for post-trauma treatments such as orthodontic adjustments or tooth fixation.[28]

In addition to the presented results, this study has several limitations. It relied on secondary data and lacked access to additional supporting information such as nutritional intake, physical activity levels, and parental socio-economic history. Further research is necessary to explore the underlying causes of these findings observed in the study.

5. Conclusion

Nutritional status influences dental maturation but does not affect MBD in children aged 6–9 years. Children with lower nutritional status exhibit slower dental maturation than those with better nutritional status. Age affects dental maturation but does not influence MBD. Sex did not affect dental maturation or MBD in the present study.

Patient's consent

This research utilizes secondary data available from the hospital, so we did not asked direct consent from the patients.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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