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**ASSOCIATION BETWEEN BODY MASS INDEX AND DEMIRJIAN-BASED
 DENTAL AGE ESTIMATION IN CHILDREN: EVIDENCE FROM PANORAMIC
 RADIOGRAPHS**

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ABSTRACT

Background: Age estimation is a crucial aspect of forensic dentistry, particularly in identifying children whose chronological age is uncertain or undocumented. The Demirjian method is one of the most widely used approaches to determine age by evaluating the mineralization stages of seven mandibular permanent teeth using panoramic radiographs. Body Mass Index (BMI) reflects nutritional status and general growth patterns, which may influence the rate of dental maturation. **Purpose:** This study aimed to analyze the correlation between BMI and dental age estimation based on the Demirjian method in children. **Methods:** This analytical observational study with a cross-sectional design involved 42 children who underwent panoramic radiographic. BMI values were calculated from measurements of body weight and height, while dental age was determined by assessing tooth development stages using the Demirjian method. **Results:** The results of the Spearman test showed that 90.4% of participants had consistent dental and chronological ages, 4.8% showed advanced, and 4.8% delayed dental maturation. Significant correlation was found between BMI and dental age ($p = 0.038$), while a not-significant correlation was observed between BMI and chronological age ($p = 0.117$). There was a significant correlation between dental age and chronological age ($p = 0.000$). The intraclass correlation coefficient ($ICC = 0.997$) indicated excellent inter-examiner reliability. **Conclusion:** These findings suggest that BMI variation is associated with differences in dental development, indicating its potential use as a complementary indicator in biological age estimation within forensic dentistry; however, this association should be interpreted cautiously, as potential confounding factors were not controlled in this study.

Keywords: Body Mass Index, Dental Age, Demirjian Method, Panoramic Radiography, Children

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INTRODUCTION

Determination of an individual's age is important in law, forensics, health, and education. This condition demands accurate methods for identification and decision-making. In Indonesia, age determination faces challenges due to population variations and data limitations. This has been noted in several studies that show the need for local data¹. Anthropometric approaches emerged as a practical alternative. One of the parameters that is often used is Body Mass Index (BMI). BMI is commonly used to assess nutritional status and risk of metabolic disease. However, BMI can also reflect relevant levels of biological maturity in a forensic context².

In forensic situations, age data is often unavailable or unreliable. Dental methods such as Demirjian offer an objective estimate of dental age through panoramic radiography. This method assesses the stages of tooth development and provides a score that can be converted to dental age. The reliability of this method has been reported to be higher than some other methods in specific population studies³. Research on the relationship between BMI and bone or dental maturation has shown mixed results. Some studies have found a correlation between BMI and ossification or molar development, but this correlation often disappears after age adjustment⁴.

However, despite these findings, there is a lack of population-specific evidence examining whether BMI is associated with dental age estimated using the Demirjian method in Indonesian children. Existing studies are predominantly conducted in non-Indonesian populations and often focus on skeletal rather than dental

maturation⁸. Therefore, the specific relationship between BMI and Demirjian-based dental age estimation in this population remains unclear.

From a biological perspective, BMI reflects nutritional status, which plays a role in growth and maturation processes. Nutritional factors influence hormonal regulation, including growth hormone and insulin-like growth factor-1, which are involved in tissue development, including odontogenesis³⁴. Adequate intake of calcium, vitamin D, and protein contributes to tooth mineralization and maturation, while deficiencies may delay these processes^{35,36}. From a forensic perspective, understanding whether BMI is associated with dental maturation is important, as it may affect the accuracy and interpretation of dental age estimation in populations with varying nutritional profiles³.

Comparisons of chronological age, biological age, and dental age help describe an individual's level of maturation. Chronological age does not always correspond to the physiological functions of the body. Bone and dental assessment methods remain an important component for estimating biological age. Therefore, the selection of methods should take into account the forensic objectives and characteristics of the population^{5,6}. This research took place at Brawijaya University Hospital. The study examined the relationship between BMI and dental age estimation based on the Demirjian method in children. The general goal is to analyze the relationship. Specific objectives include the identification of BMI potential as an indicator of biological maturation and the measurement of dental age using Demirjian.

This study contributes by providing population-specific data on the relationship between BMI and Demirjian-based dental age estimation in Indonesian children, which has not been clearly established in previous studies. The findings are expected to support the validation and contextual interpretation of dental age estimation methods in forensic practice, particularly in populations with diverse nutritional and developmental profiles³. The results of the study are expected to add to the anthropometric database of the Indonesian population. These data can help develop locally appropriate forensic identification protocols. In addition, the findings are expected to support decision-making in the fields of law and health. Thus, this research contributes to increasing national forensic capacity^{7,8}.

MATERIALS AND METHODS

Children's growth is influenced by genetic, environmental, nutritional intake, and socioeconomic conditions. All of these factors determine variations in height, weight, and tooth development in children. Therefore, two children of the same chronological age can show different levels of biological maturation. To assess body maturity more accurately, biological age is evaluated through skeletal or dental development⁹.

Body mass index (BMI) is an important indicator in looking at a child's nutritional status. A BMI is too low can lead to calcium and vitamin D deficiencies that inhibit tooth mineralization, while high BMI can accelerate the eruption of the third molar¹⁰. These differences in nutritional status can affect tooth development patterns and need to be considered in biological age analysis.

Chronological age is derived from administrative data and is objective, but does not necessarily reflect biological maturity. Biological age describes the development of the body through changes in teeth, bones, and tissues. In forensics, biological age assessment is important when birth data is not available, so radiographic analysis is the main tool for age assessment^{11,12}.

There are three main indicators of biological age, namely tooth maturation, bone development, and changes in muscle and fat composition. These three indicators complement each other to indicate the level of body maturity¹³. Changes in bone and muscle tissue follow certain biological patterns that can be mapped to estimate age¹³.

Dental age is assessed through the stages of tooth formation, mineralization, and eruption. The Demirjian method is the most commonly used method because the pattern of tooth development is relatively constant even though external factors vary³. In addition to Demirjian, there are the Nolla, Willems, and Cameriere methods, but this study chose Demirjian because of the accuracy and consistency of the score⁶.

The estimation of dental age from the Demirjian method was then compared to chronological age using the Δ Age difference to determine whether dental maturation was appropriate, faster, or slower than actual age¹⁴. This analysis is important because nutritional status through BMI can affect the estimated results⁵.

This study focuses on the relationship between BMI and estimated dental age in children. If BMI is shown to influence the outcome of dental age assessments, these findings are useful in pediatric forensics, especially in cases of identification without official documents³.

Material

1. Meters to measure height.
2. Electric scales to measure weight.
3. Google Forms for recording identity data and research variables.
4. Panoramic radiography of the patient's teeth.
5. Demirjian method score table as an instrument for assessing dental age.

Method

1. Analytical observational research design with a cross-sectional approach. This design allows the assessment of associations between variables at a single point in time; however, it does not permit causal inferences between BMI and dental age estimation.
2. Samples were determined using the Slovin formula and purposive sampling techniques based on inclusion and exclusion criteria. The use of purposive sampling was intended to ensure that only subjects meeting specific clinical and radiographic criteria were included. However, this non-probability sampling approach may introduce selection bias and limit the generalizability of the findings. The Slovin formula was applied due to the relatively small and finite population size. The minimum sample size obtained was 42 subjects. Although this number met the calculated requirement, no formal power analysis was conducted; therefore, the statistical power to detect small or moderate correlations may be limited. However, the sample size is comparable to those used in similar preliminary studies in dental age estimation.
3. The independent variable is BMI, while the dependent variable is dental age based on the Demirjian method. BMI was analyzed as a continuous variable for correlation analysis. In addition, BMI categories (underweight, normal, overweight) were derived based on WHO classification to support descriptive interpretation of the results.
4. Primary data collection was carried out through height, weight, and panoramic radiographic examination.
5. The assessment of the stage of calcification of teeth is carried out using the Demirjian method to calculate a simple maturity score. Prior to data collection, calibration was conducted between the examiners using a set of training radiographs to ensure consistency in assigning Demirjian stages.
6. Data were analyzed using the Shapiro-Wilk normality test and the Spearman correlation test. Spearman correlation was selected due to non-normal data distribution. Correlation coefficients (rho values) were calculated to determine the strength and direction of the association between BMI and dental age, in addition to p-values.

Step Procedure

1. Selecting patients according to the inclusion criteria of 3–16 years and willingness to participate in the study.
2. Measure height and weight using a meter and scale, then calculate BMI.
3. Record identity data and measurement results into Google Forms.
4. Performing panoramic radiography at the Radiology Installation of FKG UB.
5. Assess seven permanent teeth of the left mandible using the Demirjian method, assign an A–H score, and calculate the maturity score.
6. Convert the score to dental age according to the reference table.
7. Calculate the difference between dental age and chronological age using the Δ Age formula.
8. Processing data in SPSS, conducting normality tests, Spearman correlation tests, and ICC tests for reliability between assessors. Inter-examiner reliability was assessed using the intraclass correlation coefficient (ICC) with a two-way random-effects model for absolute agreement, after prior calibration between examiners to ensure scoring consistency.
9. Draw conclusions about the relationship between BMI and dental age estimation.

RESULTS

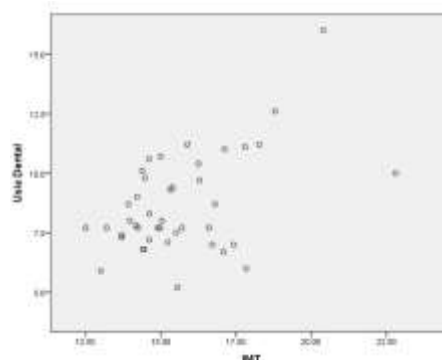


Figure 1. BMI Plot Scatter Diagram with Dental Age

The scatter plot illustrates the relationship between body mass index (BMI) and dental age, showing a relatively wide distribution of data points, which indicates variability among subjects. Spearman correlation analysis revealed a weak positive correlation ($\rho = 0.321$, $p = 0.038$).

This suggests that higher BMI is associated with slightly higher dental age; however, the strength of the relationship is low. Although the correlation is statistically significant ($p < 0.05$), the result should be interpreted cautiously given the marginal p-value and relatively small sample size ($n = 42$). Several outliers were observed, including individuals with higher dental age at lower BMI and opposite condition, which may have influenced the correlation coefficient and contributed to the weak strength of the association.

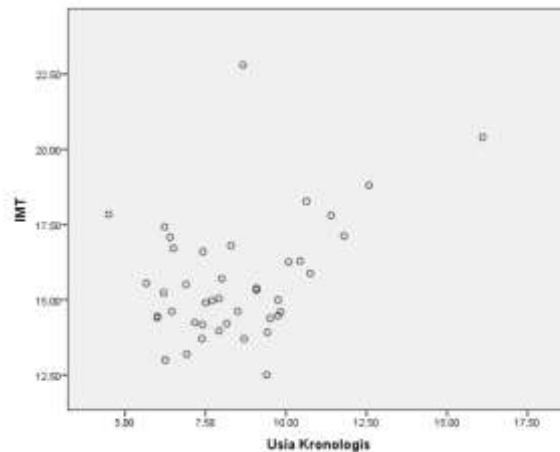


Figure 2. BMI Plot Scatter Chart with Chronological Age

The scatter plot illustrates the relationship between body mass index (BMI) and chronological age, showing a widely dispersed distribution without a clear linear pattern. Spearman correlation analysis revealed a weak and non-significant correlation ($\rho = 0.246$, $p = 0.117$).

This indicates that BMI is not significantly associated with chronological age in this study. Although a weak positive tendency is observed, the relationship is not statistically significant ($p > 0.05$) and therefore should not be interpreted as a meaningful association. The wide variability of data points and the presence of several outliers may have contributed to the weak correlation and lack of statistical significance¹⁵.

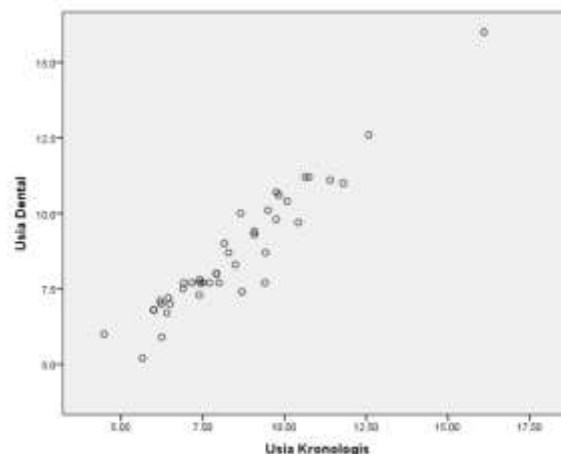


Figure 3. Dental Age and Chronological Age Plot Scatter Chart

The scatter plot illustrates the relationship between dental age and chronological age, showing a clear linear pattern with data points closely distributed along a diagonal trend. Spearman correlation analysis revealed a very strong positive correlation ($\rho = 0.938$, $p < 0.001$).

This indicates that dental age increases proportionally with chronological age, reflecting a very strong and statistically significant association between the two variables. The distribution of data is relatively tight, with only a few outliers observed, which did not substantially affect the overall pattern of the relationship¹⁶⁻¹⁸.

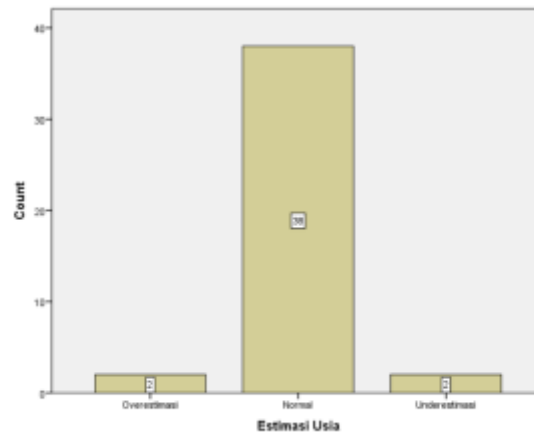


Figure 4. Estimation of Dental Age with the Demirjian Method

Based on the Demirjian dental age estimate distribution chart, it can be seen that most of the respondents, namely 38 people, have dental age estimates that fall into the normal category. This shows that the estimate of dental age based on the Demirjian method corresponds to the actual chronological age in the majority of respondents. In addition, there were 2 people who experienced overestimation, namely an estimate of dental age that was higher than their chronological age, and 2 people who underestimated or had an estimate of dental age that was lower than their chronological age. Overall, these results illustrate that the Demirjian method has a good level of accuracy in estimating the age of the teeth in this study sample.

Table 1. Results of Dental Age Assessment Reliability Test Using ICC

Variabel	ICC Value	95% Confidence Interval	F	df1	df2	Sig.	Interpretasi
Single Measures	0.994	0.989-0.997	331.599	41	41	0.000	Excellent Agreement
Average Measures	0.997	0.994-0.998	331.599	41	41	0.000	Excellent Agreement

The results of the inter-rater reliability test with the Intraclass Correlation Coefficient (ICC) showed an ICC value of 0.994 (95% CI 0.989–0.997, $p < 0.001$) for single measures and 0.997 (95% CI 0.994–0.998, $p < 0.001$) for average measures. ICC value of 0.9 > indicates that there is an excellent agreement between Assessor 1 and Assessor 2 in determining the age of the teeth based on the Demirjian method.

DISCUSSION

1. The Relationship between BMI and Dental Age

The results show a consistent pattern. High BMI tends to cause overestimation of dental age. Low BMI tends to lead to underestimation of dental age. The category is determined when the difference is $> \pm 1$ year^{19,20}.

The difference is visible on radiography. The normal BMI group is generally $\approx \pm 0.3$ years apart. The low BMI group showed a difference of -1.3 to -1.7 years. The high BMI group showed a difference of $+1.34$ to $+1.51$ years¹⁹. However, these findings should be interpreted as an association rather than a causal relationship, given the cross-sectional design of the study.

Biological mechanisms support the findings. Fatty tissues produce adipokines such as leptin that stimulate the odontoblasts. IGF-1 in obese children accelerates ossification and eruption. A lack of calcium, vitamin D, or protein at a low BMI slows down tooth mineralization^{1,21–23}. These biological factors were not directly measured in this study; therefore, the explanation remains theoretical and should be interpreted with caution. Statistical analysis from other studies reinforces this relationship. Some studies reported $p < 0.001$ or a significant positive coefficient between BMI and dental maturation. The findings are consistent that the increase in BMI is related to the acceleration of tooth maturation¹⁶. However, the strength of this association may vary after age adjustment, suggesting potential differences across populations.

2. The Relationship of BMI to Chronological Age

The analysis showed no significant relationship between BMI and chronological age. The p-value in this study was 0.117. This means that BMI does not affect the administrative age increase^{9,10}. The sample data showed a similar chronological age distribution between the BMI categories. Children with low, normal, or high BMI still have the same chronological age according to the document. The forensic

implications are clear. BMI should not be used as a legal indicator to determine chronological age. BMI is only useful as additional biological information when interpreting dental age estimates^{9,10}.

3. Relationship Between Dental Age and Chronological Age

This study found a significant relationship between dental age and chronological age with $p=0.000$, indicating that dental age can be used to estimate an individual's chronological age²⁴. Although the correlation is strong, some children still show discrepancies between the two ages. These variations are influenced by biological factors, especially nutritional status and hormonal regulation. Higher BMI tends to accelerate dental maturation and results in dental age overestimation, while lower BMI is associated with delayed dental development and dental age underestimation²⁵. Other studies also reported significant differences between dental and chronological age, with $p < 0.001$ and $p < 0.05$ ^{26,27}.

BMI is considered an important factor in dental maturation, as it reflects nutritional adequacy, micronutrient availability, and metabolic stability; however, this relationship should be interpreted cautiously, as the current study design does not allow confirmation of a direct causal mechanism. Higher BMI enhances mineralization processes, ameloblast and odontoblast activity, and root development, leading to faster dental maturation⁵. Elevated BMI also increases IGF 1 and growth hormone activity, which accelerates jaw growth and the eruption of permanent teeth²⁴. These mechanisms were not directly measured in this study and should therefore be interpreted cautiously. Literature also identifies other contributing factors, including hormones, sex, skeletal maturity, culture, daily habits, and environmental influences, although these were not analyzed directly in this study²⁸. These variables may act as confounding factors and were not controlled in the present analysis.

Sex-related differences may appear because girls often experience accelerated dental maturation due to earlier estrogen increases, although the effect is weaker than that of BMI²⁴. Skeletal maturity also correlates with dental development but is still strongly influenced by nutrition and BMI²⁹. Genetic factors affect eruption patterns and mineralization, but their impact is not as extensive as BMI²⁹⁻³⁰. Dietary habits, oral hygiene, early childhood caries, socioeconomic status, and sanitation further influence dental development by altering mineralization processes and increasing the risk of periapical inflammation²⁷.

Although many factors contribute to dental age variation, this study focused specifically on BMI. Existing literature consistently shows that BMI, as an indicator of nutritional status, plays a central role in determining differences in dental development among children^{5,28}.

4. Comparison of Dental Maturation Scoring Between Two Examiners

The assessment of dental maturation using the Demirjian method showed a very high level of interobserver agreement, with Intraclass Correlation Coefficient (ICC) values in the excellent category. This indicates that the method is objective and can be reproduced reliably by different examiners³¹. Most differences between examiners involved only a single developmental stage and did not meaningfully affect estimated dental age. Even so, initial training is still required to minimize subjective interpretation³¹.

Variations between examiners are common due to inherent subjectivity in radiographic interpretation, which is influenced by image quality, clinical experience, attention to detail, and differences in identifying structural boundaries. Biological variation among individuals may also contribute, making calibration essential to maintain consistency³¹. In this study, Intraclass Correlation Coefficient (ICC) reached 0.90, indicating excellent agreement and high reliability even when assessed by two different examiners^{21,31-33}.

Other studies support these findings. ³²reported ICC values ranging from 0.60 to 0.80, classified as good agreement. ²¹found inter examiner ICC values of 0.95 for the Demirjian method and 0.94 for the Nolla method, indicating very high reliability. ³³reported an ICC of 0.918, also within the excellent agreement range. Collectively, these results confirm strong reliability in radiographic interpretation for dental age estimation^{21,31-33}.

The consistency demonstrated in these studies reinforces that the Demirjian method can be applied by multiple examiners without significantly reducing accuracy, provided proper training and calibration are conducted^{21,31-33}. This is crucial in forensic settings, where age estimations often require verification by more than one expert, and in clinical practice to ensure consistent diagnosis of dental development across practitioners⁹.

CONCLUSION

Based on the results of the study, nutritional status measured through BMI is associated with variations in the speed and delay of tooth maturation. Children with high BMI tend to have older dental ages, while children with low BMI show delayed dental development. The majority of the samples showed a match between dental age and chronological age, with few cases of overestimation and underestimation. The results of the analysis also showed a significant association between BMI and dental age, while a relationship between BMI and chronological age was not found. In contrast, dental age has been shown to be strongly related to chronological

age. Thus, this study supports the hypothesis that BMI is related to dental age; however, this relationship should be interpreted cautiously and does not imply a direct biological influence due to the cross-sectional design of the study.

Suggestions for future research include using larger sample numbers and wider site coverage to make the results more representative. Further research is also recommended to observe the development of dental age and chronological age in a given period to see patterns of change. Additional biological variables such as growth hormone, leptin, IGF-1, vitamin D, and history of systemic disease need to be considered to understand the biological mechanisms that affect dental maturation.

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