Assessing the impact of structured teaching on dental age estimation using the Demirjian staging system among undergraduate dental students

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KEYWORDS

Dental age estimation, Dental education, Forensic Odontology, Demirjian Method

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ABSTRACT

Background: Training in dental age estimation (DAE) is inconsistent in undergraduate dental curricula. This study aimed to assess the impact of a structured teaching intervention on the inter-rater agreement and accuracy of undergraduate students using the Demirjian staging method.

Material and Methods: Eighteen dental students with no prior training in forensic odontology assessed seven panoramic radiographs using Demirjian's method during a pre-teaching session. This was followed by a 90-minute lecture led by a qualified forensic odontologist, which included a presentation, interactive discussion, and practical demonstration of the Demirjian staging system. The same radiographs were re-evaluated by the students two weeks later. Inter-observer agreement was assessed using Fleiss' Kappa, while accuracy was determined by comparing the students' staging results to those of the primary observer.

Results: Initial inter-observer agreement was moderate (κ = 0.45), increasing to substantial agreement (κ = 0.76) after the teaching session. Overall, accuracy improved from 46% to 73% post-teaching. The highest improvement was seen in the incisors, which improved from 48% to 92%.

Conclusion: A brief, structured teaching session substantially improved dental students' reliability and accuracy in DAE. Integrating targeted forensic odontology education into the undergraduate dental curriculum is essential, as even brief instructional interventions can yield notable improvements in both staging consistency and accuracy.

INTRODUCTION

Dental age estimation (DAE) is a fundamental component of forensic odontology (FO), involving the assessment of an individual's chronological age through the analysis of age-related changes in the dentition. DAE is an essential tool in legal and migration contexts.[1] For example, when unaccompanied minors seek asylum without reliable documentation, authorities often rely on DAE to verify age.[2] Similarly, DAE is routinely applied in investigations involving suspected juvenile pornography as well as in the identification of unknown juvenile skeletal remains. [3, 4]

For children and adolescents, most DAE techniques are non-invasive and rely on radiological assessment, making them suitable for both antemortem and postmortem examinations.

These techniques evaluate tooth development, which is less affected by external factors than the morphological changes commonly used in adults. [5] Numerous teeth development-based DAE methodologies have been proposed, including atlas-based references,[6] staging systems,[7] and metric measurements.[8]

Among these approaches, staging systems have been widely used.[9] A staging-based DAE assessment generally involves two sequential steps: (1) assigning a developmental stage to one or more teeth and (2) converting that stage into an estimated chronological age. While the second step requires a robust statistical modelling,[10] the first can be susceptible to observer subjectivity,[11] creating the need for systematic training to ensure consistent results.

Recent work by Al Ghazi et al. (2024) highlights the importance of standardised training for forensic odontologists and supports the incorporation of DAE into dental curricula.[12] In line with this finding, the latest revision of Indonesia's National Dental Curriculum mandates that graduating dentists should be able to demonstrate basic competence in FO, including on DAE.[13] This policy is partly driven by the country's geographic vulnerability to natural disasters, which often necessitate large-scale Disaster Victim Identification (DVI) efforts.[14] Therefore, enhancing DAE skills among general dentists is expected to streamline victim identification and professional dental identification efforts across Indonesia. However, meeting these new curricular requirements presents a pedagogical challenge: selecting an appropriate staging methodology and delivering it effectively within the constraints of undergraduate dental education.

The primary objective of teaching DAE staging is to ensure that the students perform the two-step staging process, previously described, consistently and reproducibly. Demirjian method has been widely applied for over five decades,[15] and although several studies have evaluated the reliability of the Demirjian system among experienced practitioners in Europe,[16, 17] Asia,[18] and Africa,[19] its educational impact on inexperienced undergraduate observers remains largely underexplored. Accordingly, this study aimed to evaluate the difference in staging agreement and performance among undergraduate dental students before and after receiving structured teaching and instructions in the Demirjian staging system using panoramic radiographs (PAN).[15] This study was conducted as a pilot study to gather preliminary data on the effectiveness of targeted teaching intervention.

MATERIALS AND METHOD

Participants

A total of 18 undergraduate students participated in the study. Each student was presented with seven PANs, which they were tasked with evaluating the seven primary teeth in the third quadrant using Demirjian's staging system namely FDI 31 to FDI 37. [15]

Samples

The PANs were selected according to the following criteria: healthy children aged between 3 and 10 years, with accessible parental or caregiver contact information to retrieve the child's medical history if needed, and both date of birth and date of radiograph exposure clearly documented. The PAN were retrieved from the archived medical records of patients who attended Universitas Mahasaraswati Educational Dental Hospital, Denpasar, between January and February 2025. Patient anonymity was strictly maintained; students received only the images without any accompanying metadata (e.g., name, sex, date of birth, or date of exposure). None of the PANs were taken specifically for this research.

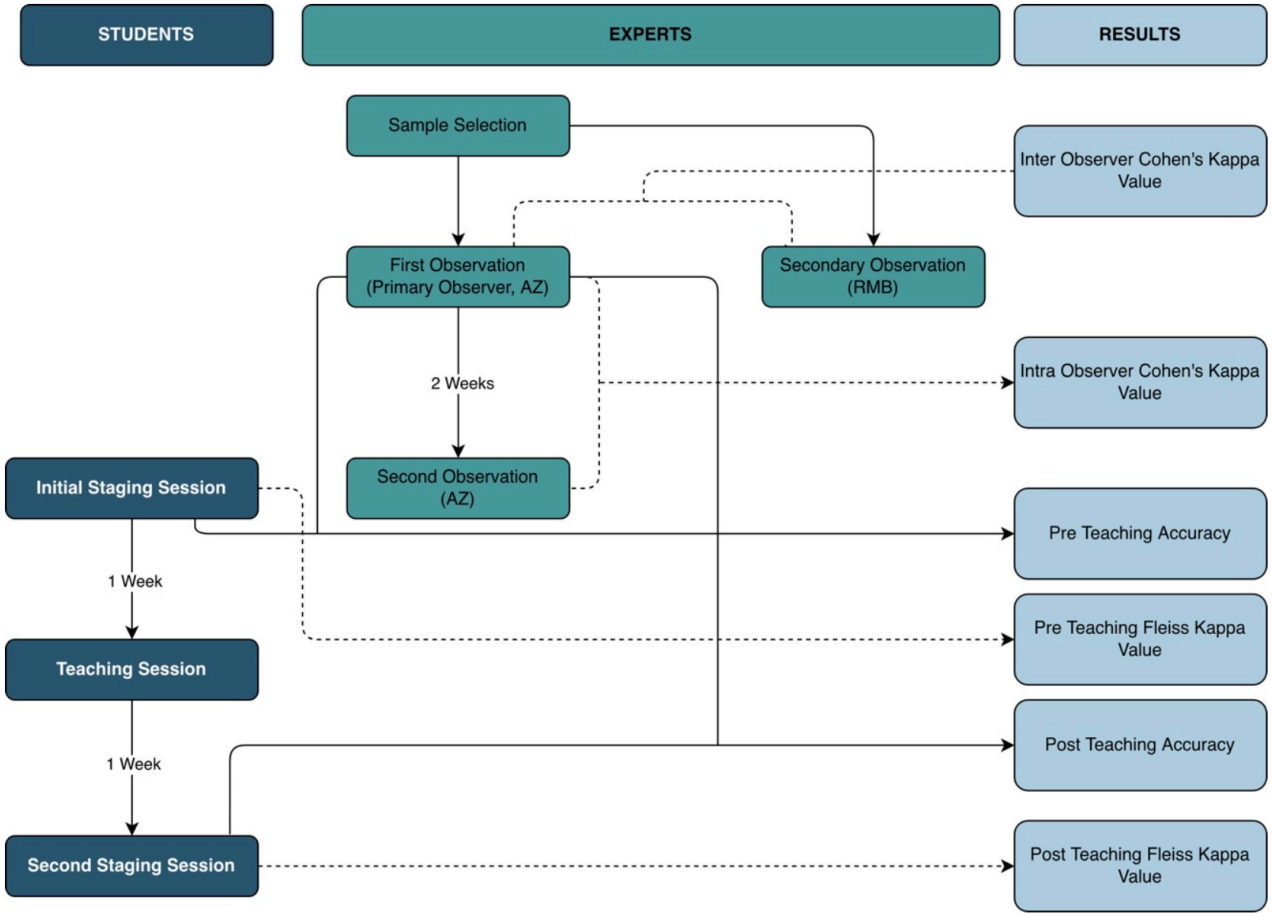
Children presenting with systemic diseases, genetic disorders, localized oral pathologies, severe malocclusion, or a history of orthodontic treatment were excluded from the study. All datasets were collected by the first author.

Students were eligible as participants if they had successfully completed and passed the Anatomy and Radiology module with a minimum grade of 65 and had not yet commenced the FO module. Students who were absent or did not fully attend the DAE course were excluded from the study. This study was conducted as part of a class-based evaluation for internal educational purposes and involved no to minimal risk, ethical clearance was given by the local ethical committee Number: K.541/A.17.01/FKG-Unmas/V/2025. All participants were informed about the purpose of the study and provided written consent prior to participation.

Rationale behind the selection of the staging system
Several tooth staging techniques exist in DAE, including Nolla's foundational work on the development of permanent teeth in 1960,[7] followed by the standards for tooth formation and emergence developed by Moorrees et al., in 1963.[20] Even so, the Demirjian system was chosen for this research as it is one of the most popular staging systems used [15] and it has been used as the staging approach not only to estimate age according to original Demirjian's study, but also in subsequent research that considered the developmental stages to propose new individual dental age scores.[21,22] Additionally, the Demirjian method has fewer developmental stages when compared to other staging systems,[9] which may facilitate easier learning and application. [23,24]

Teaching session and evaluation
The full timeline of the current research is illustrated in Fig. 1. The staging process was conducted in two separate sessions: one before and one after a dedicated DAE lecture session. The initial staging session (Pre-teaching) occurred prior to any formal DAE instruction; students were only provided with the original Demirjian publication via email, and the corresponding staging diagrams were displayed on-screen during the session. The second session took place two weeks later, following the teaching intervention.

Figure 1. Timeline between observation and teaching for the Primary Observers and Students



The lecture sessions were delivered by the primary author (APZ), a forensic odontologist with four years of professional experience, through three separate 90-minute lectures. Each session included a presentation, discussion, and a live demonstration of the Demirjian staging system.[15] Each of the stages (i.e., Stage A, B) was thoroughly examined and explained in detail to enhance students' understanding, until consensus was achieved. Additionally, participants were provided with a standardised calibration guide. For example: (1) when there is an uncertainty regarding which stage to choose, or a tooth fell between two stages, the students were instructed to select the lower stage, (2) when a tooth has two different stages, especially in multi-rooted teeth

(i.e., distal root of FDI 36 was at stage G and the mesial root was at stage H), the lower stage was taken into consideration, and (3) students were allowed to use any image processing software to aid with the staging process, but only limited to adjusting contrast and brightness based on their own preferences. After the session, students were provided with the same seven PANs for which they were asked to complete the staging in a newly randomized order. All observers were blinded to all PANs metadata during all evaluation periods.

Data analysis

Three distinct types of agreement were assessed in this study: Primary observer, pre-teaching, and post-teaching agreement. First, the intra- and inter-rater agreement of the primary observer (APZ) was assessed using Weighted Cohen's Kappa. The intra-rater agreement was calculated based on two observations taken two weeks apart, and the inter-rater agreement was calculated by comparing the initial measurements of the primary observer to those of a second observer (RMB), a forensic odontologist with eight years of experience in DAE research and clinical practice.

Second, the pre-teaching agreement was assessed in intra-rater reliability using Fleiss' Kappa between the students. Lastly, the resulting kappa values were compared to evaluate the improvement in agreement in the post-teaching session. An additional evaluation of staging accuracy was conducted by calculating the average number of correct answers per session, as determined by comparison to the primary observer. To determine the precision of these estimates, 95% confidence intervals (CI) for both Kappa and Accuracy measures were generated using the bootstrapping method with 2000 replications with set.seed of 33. All statistical analysis were performed using RStudio version 4.3.1 with irr and boot packages.

RESULTS

A total of 49 teeth from seven PANs were evaluated by 18 students. The primary observer intra-rater agreement Kappa was 0.95 [95% CI 0.88-1], and the intra-observer agreement Kappa was 0.7 [95%CI 0.55 – 0.85].

The overall result of the Fleiss' Kappa Agreement was reported in Table 1. In the initial staging session, the students' overall inter-observer reliability was 0.45 (95%CI 0.42 – 0.5). An improvement in inter-observer reliability was observed in the post-teaching staging session, with the Fleiss' Kappa value improved to 0.76 (95%CI 0.69 – 0.84).

In terms of tooth regions (i.e., Anterior and Posterior), the highest improvement of staging agreement was observed in the anterior region (Δk = +0.38) compared to the posterior region (Δk = +0.34). Regarding the tooth type (i.e., Incisors, Canine, Premolars, Molars), the lowest inter-observer agreement was in Incisors (k = 0.13), and the highest inter-observer agreement was in Molars (k = 0.53). In terms of improvement, the highest improvement was observed in Incisors (Δk = +0.73) and the lowest improvement was in Canine (Δk = +0.11). In each FDI tooth (i.e., FDI 31, FDI 32), the lowest improvement was in FDI 33 (Δk = +0.11), and the highest improvement was in FDI 31 (Δk = +0.55).

The overall accuracy was reported in Table 1. The initial accuracy of the students was 0.46 (95% CI 0.43 – 0.5) which then later improved to 0.73 (95% CI 0.7 – 0.77) after the teaching session. Similar to the kappa improvement, the tooth region accuracy improvement was observed in the anterior tooth (ΔAcc = +0.37). Regarding the tooth type, the highest improvement was also observed in the Incisors (ΔAcc = +0.44), and the lowest improvement was in the premolar region (ΔAcc = +0.07). In each FDI tooth, the highest improvement of accuracy was observed in FDI 37 (ΔAcc = +0.42), and the lowest improvement of accuracy was in FDI 34 (ΔAcc = +0.01).

DISCUSSION

The current study observed an overall improvement, both in terms of observer agreement and accuracy among undergraduate dental students using the Demirjian staging method.[15] These findings demonstrate a clear improvement following the educational intervention delivered by a trained forensic odontologist, supporting the hypothesis that formal instruction, demonstration, and calibration improve students' ability to perform dental staging reliably.

Table 1. Student's Fleiss Kappa and Accuracy in using Demirjian Staging.

Observations	Fleiss' Kappa (95% CI)		Accuracy (95% CI)	
	Pre-Teaching	Post-Teaching	Pre-Teaching	Post-Teaching
Overall	0.45 (0.42 – 0.5)	0.76 (0.69 – 0.84)	0.46 (0.43 – 0.5)	0.73 (0.7 – 0.77)
Tooth Regions				
Anterior	0.43 (0.28 – 0.57)	0.81 (0.5 – 1)	0.45 (0.37 – 0.47)	0.82 (0.77 – 0.85)
Posterior	0.4 (0.11 – 0.49)	0.74 (0.41 – 1)	0.5 (0.45 – 0.54)	0.67 (0.63 – 0.71)
Tooth Type				
Incisors	0.13 (0.04 – 0.24)	0.86 (0.29 – 1)	0.48 (0.44 – 0.56)	0.92 (0.87 – 0.94)
Canine	0.42 (0.26 – 0.59)	0.53 (0.27 – 0.8)	0.25 (0.17 – 0.32)	0.62 (0.54 – 0.71)
Premolars	0.38 (0.28 – 0.47)	0.76 (0.61 – 0.93)	0.45 (0.43 – 0.55)	0.52 (0.45 – 0.57)
Molars	0.53 (0.38 – 0.66)	0.78 (0.41 – 1)	0.52 (0.43 – 0.56)	0.81 (0.78 – 0.88)
Tooth FDI				
31	0.23 (-0.01 – 0.39)	0.78 (0.33 – 1)	0.6 (0.52 – 0.69)	0.92 (0.86 – 0.95)
32	0.28 (0.06 – 0.43)	0.8 (0.38 – 1)	0.41 (033 – 0.49)	0.91 (0.85 – 0.95)
33	0.42 (0.26 – 0.59)	0.53 (0.27 – 0.8)	0.25 (0.17 – 0.33)	0.62 (0.54 – 0.7)
34	0.34 (0.18 – 0.43)	0.58 (0.4 – 0.83)	0.54 (0.45 – 0.62)	0.55 (0.46 – 0.63)
35	0.35 (0.18 – 0.5)	0.59 (0.41 – 0.78)	0.44 (0.35 – 0.52)	0.48 (0.39 – 0.56)
36	0.14 (0.03 – 0.3)	0.58 (0.26 – 1)	0.45 (0.36 – 0.53)	0.69 (0.61 – 0.78)
37	0.37 (0.11 – 0.55)	0.9 (0.6 – 1)	0.55 (0.45 – 0.73)	0.97 (0.9 – 0.98)

Tooth Numbering Follows Federation Dentaire International (FDI) Tooth Numbering. CI = Confidence Interval

The increase in Fleiss' Kappa from 0.45 to 0.76 post-teaching reflects a substantial improvement in inter-rater agreement among the students, shifting from moderate to substantial agreement according to Landis and Koch's benchmark scale.[25] This suggests that even a brief, structured teaching session, when supported by interactive review and group discussion, can substantially improve staging consistency even with inexperienced dental students. However, it should be noted that the students had prior exposure to radiographic assessment in their previous semester, and different results are expected when no previous lessons in oral radiography have been taken by the students.

The results of our study suggest that enhancements in staging consistency and accuracy differed based on the specific parameters examined, which give specific patterns of error among the students. For this context, distinct pairs of observations need to be evaluated carefully. First, a high agreement with low accuracy suggests consistent misinterpretation of developmental stages. For example, in FDI 33 the students' Fleiss' Kappa was 0.42 and the accuracy was 0.25. This pattern of consistent but incorrect staging was also observed at a group level for the molars, which had the highest pre-teaching agreement of any tooth type ($\kappa = 0.53$) yet only achieved a moderate accuracy of 0.52. Secondly, a lower Fleiss' Kappa value paired with a high accuracy may indicate that students are randomly guessing and arriving at the correct answer by chance. This was observed in tooth 31 with 0.23 Kappa and 0.6 accuracy. The pattern was also observed for the incisors group, where a very low agreement ($\kappa = 0.13$) was paired with an accuracy of 0.48. Such variations were markedly reduced following the instructional intervention, as both types of

inconsistencies were frequently observed during the pre-teaching sessions.

The undergraduate dental education aims to provide students with a solid foundation to become competent dentists to provide societal needs, in this case, to be proficient in FO with the basic skill in DAE.[26] Although the current focus of the dental staging was to be used as a forensic tool for age identification, DAE can also be useful in other parts of dentistry. For example, assessment of dental growth can influence diagnosis, objectives, treatment planning, and the eventual outcome of orthodontic treatment.[27] Additionally, assessment of dental maturation can detect the peak of pubertal growth spurt.[28] Therefore, the study of DAE not only enhances a dentists' understanding of FO but also has practical applications across various other fields of dentistry. Introducing this knowledge early in dental education can foster professional versatility and may inspire students to pursue FO as a career path.[29]

Despite the importance of teaching DAE, a recent pilot demographic study found that a substantial percentage of respondents — specifically, 50% of active forensic odontologists and FO students worldwide— reported that FO was either not included in their undergraduate education or had been removed from the dental curriculum.[29] Integration of FO into undergraduate curricula often remains limited, resulting in overall lower awareness of the field, especially in developing countries.[30,31] This lack of exposure to FO may contribute to insufficient training in DAE and limited familiarity with forensic procedures, potentially compromising the reliability of forensic assessments in legal, humanitarian, and, most critically, disaster preparedness contexts. In the event of a mass disaster, dentists and dental professionals should be prepared to assist with dental identification.[32] Dental students or recent graduates with specialized training may be deployed in DVI efforts to assist in the collection, organization, and transcription of antemortem and postmortem data. They may also serve in a consultative capacity, supporting forensic odontologists during the comparative analysis phase. Formal training allows general dentists to contribute more effectively to the overall response, thereby reducing challenges related to professional coordination in the field.[33]

A recent example of FO in undergraduate dental education can be found at the European University Cyprus School of Dentistry.[34] Despite being a relatively new dental programme, FO has been successfully integrated into the undergraduate curriculum, where students engage in anthropological analysis and learn to create biological profiles for unidentified individuals. This highlights how early, structured exposure to FO can improve students' skills and better prepare them for their professional careers.

Several limitations must be acknowledged. First, as a pilot study, the primary small sample size (18 students) and limited number of PANs (n = 7) may restrict the generalizability of the findings, and the marked improvements observed may not be fully representative of the broader undergraduate dental student population. Secondly, the short interval between two staging sessions may also introduce recall bias, although the anonymised nature of the images and random sequences of the PANs were designed to minimize this risk. Thirdly, only the mandibular left region —as proposed originally by Demirjian et al., in 1973 — was observed in this study. It has been reported by previous studies that maxillary teeth are harder to stage, even by the experts.[11] Finally, this study lacked a long-term follow-up to assess whether the observed improvement in skill was retained over time. Even so, greater variability in agreement was anticipated among inexperienced observers, such as undergraduate dental students.

Future research should investigate long-term outcomes and assess the impact of various teaching strategies, such as simulations and case-based learning. Additionally, further studies evaluating alternative staging methods that incorporate more developmental stages than the Demirjian system are warranted.[15] Such approaches could help identify the most suitable methodologies for educating undergraduate dental students, with the goal of effectively introducing them to the principles of FO.

CONCLUSION

Structured teaching substantially enhances dental students' inter-rater reliability and accuracy in applying the Demirjian staging method compared to an experienced observer. Given the increasing forensic and legal reliance

on DAE, it is crucial to equip dental students with these skills. The integration of targeted FO education into undergraduate dental curriculum is essential, as brief instructional interventions can lead to meaningful improvements in both staging consistency and accuracy, while also potentially inspiring new generations of prospective forensic odontologists.

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