Permanent tooth stages assessment of panoramic radiographs and lateral cephalograms

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ABSTRACT

Background Several classic craniofacial growth studies used lateral cephalograms (LCs) before the availability of panoramic radiographs (PRs). Are tooth stages comparable in these types of radiographs?

Aim To compare tooth developmental stages of left side teeth in PR and LC using the methods of Moorrees Fanning and Hunt (1963) and Demirjian Goldstein and Tanner (1973).

Design Three hundred date-matched dental radiographs [n = 300, 150 PRs and 150 LCs, 69 males and 81 females] from children aged 6 to 20 years old were obtained from the online Maxwell Museum of Anthropology's orthodontic collection, Albuquerque, USA. Maxillary and mandibular left side teeth, including incisors, canines, premolars, and molars, were scored on the two types of radiographs (number of teeth = 1600) using Moorrees and Demirjian methods. The developmental stages of left side permanent teeth were compared in PRs and LCs using weighted kappa.

Results Analysis of the developmental stages for left side teeth in the PRs compared with LCs showed that kappa values were excellent for both Moorrees and Demirjian methods ($\kappa > 0.9$). Percentage of agreement between LC and PR for Moorrees was 92.7% and 96.16% for Demirjian method.

Introduction

The American Association of Orthodontics Foundation hosts the Growth Legacy Collection of archived radiographs that make up the six Craniofacial Growth Consortium Studies (American Association of Orthodontics Foundation, 2022). This consists of six historic, longitudinal growth studies in USA from 1929 to 1984 made up of the Denver Growth Study, the Iowa Growth Study, the Michigan Growth Study, the Fels Longitudinal Study, the Bolton-Brush Growth Study, and the Child Health Study at Oregon Health & Science University (Sherwood et al., 2021, Hardin et al., 2022). The early radiographs were lateral skull, anterior skull, cephalogram, oblique lateral of the jaw and intraoral views before the widespread use of the dental panoramic radiograph. Classic dental reference data and permanent tooth staging methods (Gleiser and Hunt Jr., 1955, Anderson et al., 1976) relied on lateral skull views or cephalograms, oblique laterals (Moorrees et al., 1963a, Moorrees et al., 1963b) or a combination of these types of radiographs (Garn et al., 1959, Fanning, 1961). Most recent dental reference data use panoramic radiographs (Haavikko, 1970, Demirjian et al., 1973, Nyström et al., 2007, Liversidge, 2011). The consortium studies remain an important resource as longitudinal radiographic studies are no longer considered ethical. Such collections are of great value as new statistical approaches are developed and recent studies include the longitudinal development of the dentition (Šešelj et al., 2019) and longitudinal analysis of craniofacial growth (Sherwood et al., 2021, Hardin et al., 2022).

Knowledge of the limitations of each type of radiograph is essential to prevent misinterpretation of tooth stages. Misinterpretation of tooth stages can have significant implications in various contexts, such as forensic science, bioarchaeology, and odontology. In forensic science, accurate age estimation is crucial for identifying unknown individuals and assisting in legal proceedings (Mohammed et al., 2019). Bioarchaeologists rely on

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precise tooth stage assessments to reconstruct past populations' demographics and health (Hillson, 2023). In odontology, correct interpretation of dental development stages is essential for treatment planning and understanding growth patterns (Koch et al., 2017).

In a lateral skull or cephalometric radiograph, the left and right-side teeth are superimposed and if the patient is not positioned correctly, the overlapping teeth of left and right side can make stage assessment difficult. In the lateral oblique, the anterior teeth of the mandible, if visible, can be distorted. Reliability of tooth staging affects the assessment of maturity and age estimation. Visualising developing teeth from different types of radiographs has not been well studied and the effect of the type of radiographs on the assessment of developing permanent teeth is unknown. Given the crucial roles these assessments play in various fields, the need to ensure accurate and comparable results between different radiographic methods is imperative.

The aim of our study was to compare permanent tooth staging in cephalograms (LC) and panoramic radiographs (PR) using the two most widely used tooth staging methods.

Materials and methods

Study Sample

Three hundred date-matched dental radiographs [n = 300, 150 PR and 150 LC, 69 males and 81 females] from children aged 6 to 20 years old (mean age = 13.28 years; standard deviation [SD] = 4.32) were obtained from the online open access resource of the Maxwell Museum of Anthropology's orthodontic collection, Albuquerque, USA . The PR and LC were taken on the same day and have been de-identified except for age and sex. The age and sex distribution of the study sample was summarised in Table 1. Inclusion criteria for the sample were a chronological age of 6 to 20 years and presence of all permanent teeth. Exclusion criteria were a record of any disturbances affecting normal dental development, presence of supernumerary teeth, bilateral hypodontia and evidence of previous extraction of a permanent tooth. Each radiograph was coded so that the first author was blinded to the age and sex of the children.

Tooth Staging Methods

Moorrees and Demirjian stages (Moorrees et al., 1963a, Demirjian et al., 1973) were used for assessment of tooth development with the addition of 'not developed' and 'crypt' stages. All radiographs were assessed in a random order, determined by pseudo-random numbers generated using the "RANDBETWEEN" function in Microsoft Excel, which selects a value between a specified bottom and top range. First, tooth stages were assigned to the maxillary left side teeth, from the central incisor to the third molar, on the PRs and then left side mandibular teeth were assessed accordingly. The same steps were repeated for maxillary and mandibular teeth on the LCs. Examples of PR and LC radiographs of individuals of various age groups are illustrated in Figures 1 and 2.

Tooth stages were assigned numbers and recorded into a Microsoft Excel 2019 version 16.28 spreadsheet for non-parametric statistical analysis.

Statistical Analysis

Observations were repeated at a week's interval for 60 radiographs (30 PRs, 30 LCs) by the first and second authors and weighted kappa was calculated to determine the inter and intra-observer agreements.

All statistics were performed using the Statistical Package for Social Science statistical software (version 26; SPSS Inc., Chicago, Illinois). The statistical analysis compared the developmental stages of the maxillary and mandibular left-side teeth on PR) and LC using Demirjian and Moorrees stages. Weighted kappa statistics were applied to meas-

Table 1. Distribution of the sample by age and sex

Age in years	Female	Male	Total
6	7	4	11
7	5	3	8
8	7	4	11
9	4	6	10
10	4	5	9
11	1	0	1
12	4	5	9
13	6	3	9
14	8	5	13
15	7	12	19
16	2	8	10
17	7	3	10
18	8	2	10
19	5	5	10
20	6	4	10
Total	81	69	150

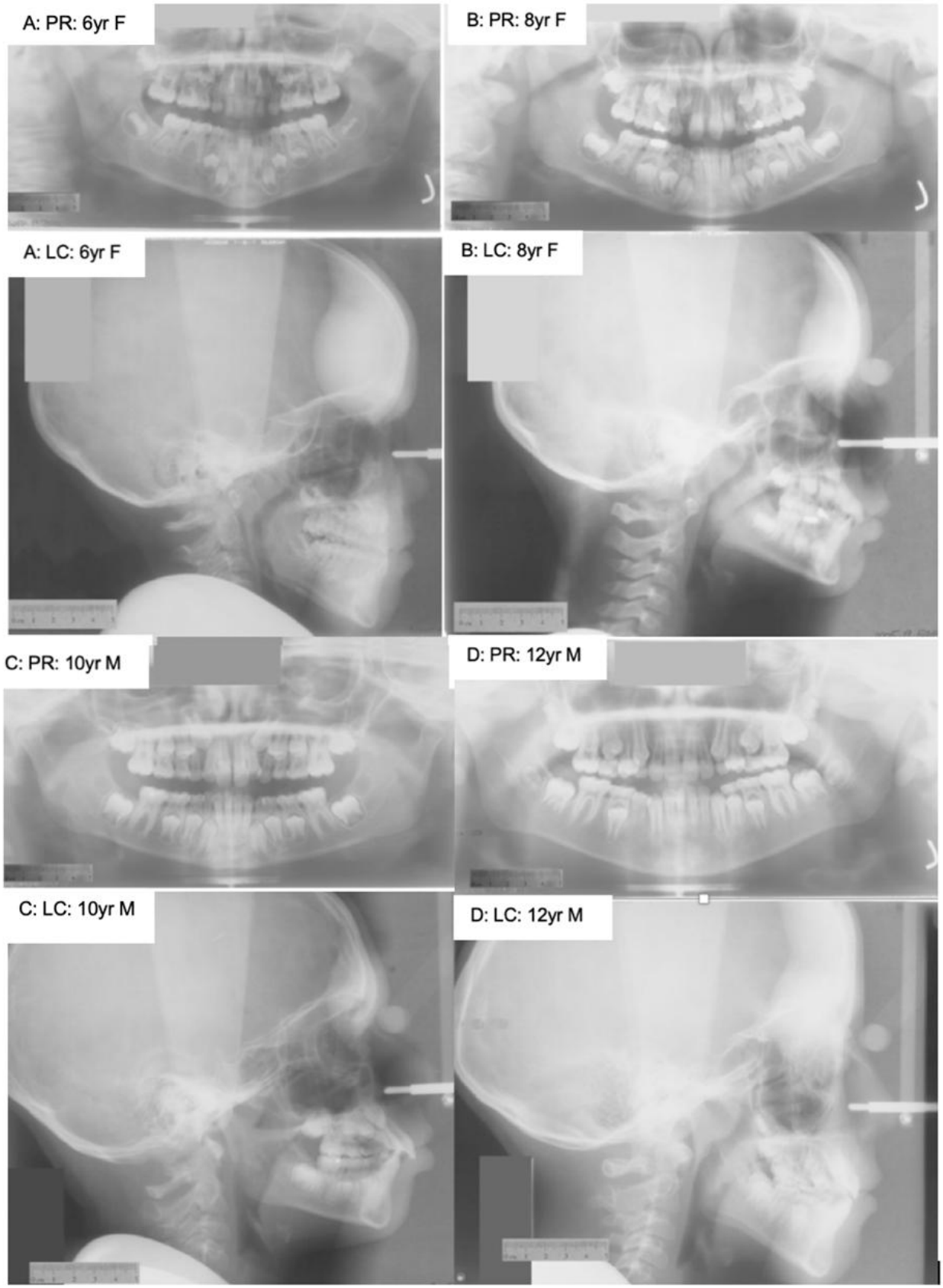

Figure 1. Example of PR and LC radiographs of individuals aged 6 to 12 years, *A: 6yr F, B: 8yr F, C: 10yr M, D: 12yr M.*

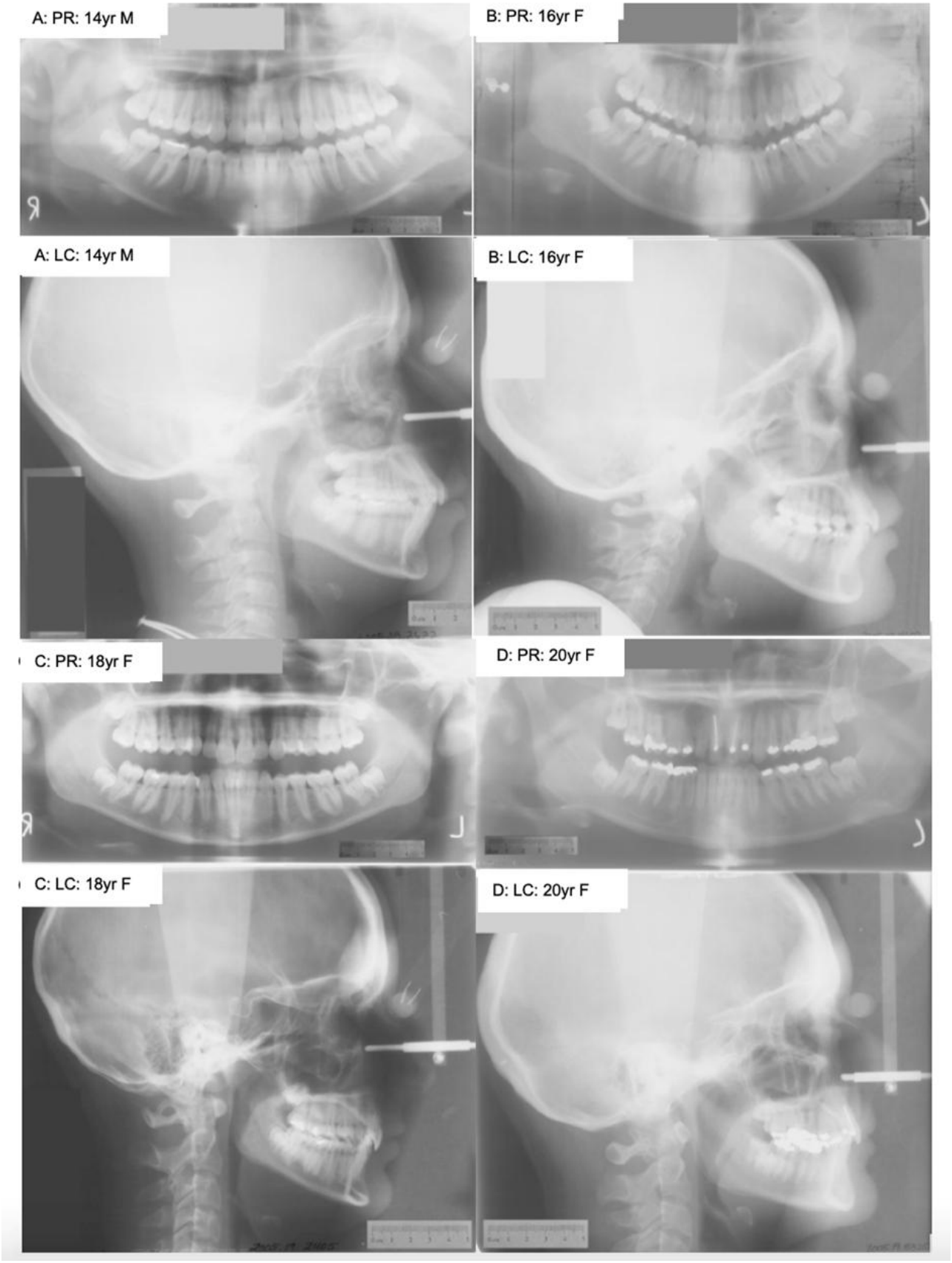

Figure 2. Example of PR and LC radiographs of individuals afed 12 to 20 years, *A: 14yr M, B: 16yr F, C: 18yr F, D: 20yr F.*

ure the agreement between the methods (Cohen, 1960). Data were also cross tabulated.

Results

High inter- and intra-observer agreements were found for each radiograph type between the two readings (inter-observer κ=0.875 PR and κ=0.8 LC, intra-observer κ=0.995 PR and κ=0.948 LC). This demonstrated excellent reliability even though LC was slightly lower.

The weighted kappa values of the individual maxillary and mandibular teeth, as all maxillary teeth, all mandibular teeth, and all teeth are shown in Table 2. Kappa values were excellent for both Moorrees and Demirjian staging methods comparing PR and LC (κ > 0.9).

Kappa values for all tooth stages for both staging methods were excellent with values ranging from 0.893 to 1.000 (Table 2). Slightly lower values were seen using Moorrees except for the second premolar. The lower 2nd incisor had the lowest kappa values for both Moorrees (0.893) and Demirjian (0.916)

Table 2. Weighted kappa comparing tooth stage assessment in PR and LC using Moorrees and Demirjian tooth staging

Tooth	N teeth	Kappa	95% CI	Kappa	95% CI
		Moorrees		Demirjian	
U1	150	0.955	0.930-0.979	0.986	0.981-0.991
U2	150	0.969	0.949-0.990	0.979	0.958-1.000
U3	150	0.971	0.957-0.985	0.980	0.965-0.995
U4	150	0.983	0.973-0.994	0.990	0.978-1.001
U5	150	0.976	0.962-0.990	0.955	0.927-0.982
U6	150	0.991	0.974-1.008	1.000	1.000-1.000
U7	150	0.988	0.978-0.998	0.989	0.977-1.000
U8	150	0.979	0.965-0.993	0.978	0.960-0.995
All maxillary teeth	1200	0.983	0.978-0.987	0.986	0.981-0.991
L1	150	0.974	0.968-0.979	0.976	0.969-0.982
L2	150	0.893	0.828-0.958	0.916	0.849-0.983
L3	150	0.961	0.941-0.981	0.975	0.955-0.996
L4	150	0.979	0.967-0.990	0.980	0.964-0.995
L5	150	0.980	0.970-0.991	0.973	0.956-0.990
L6	150	0.933	0.880-0.986	0.932	0.866-0.999
L7	150	0.970	0.953-0.986	0.967	0.945-0.988
L8	150	0.961	0.944-0.978	0.961	0.937-0.985
All mandibular teeth	1200	0.974	0.968-0.979	0.976	0.969-0.982
All teeth	2400	0.978	0.975-0.982	0.981	0.977-0.985

staging, although they were still excellent. Visualisation of lower incisor roots in both LC and PR can be difficult.

Pivot tables and percentage agreement for developmental stages of left side teeth between LC and PR using both Moorrees and Demirjian are shown in Table 3 and 4, respectively. Percentage agreement between LC and PR for Moorrees was 92.7% and 96.16% for Demirjian method. Very few teeth were staged more than 1 stage different between the radiographs. The outliers for both Moorrees (LC: crown-coalescence (Cco) and crown-complete (Coc); PR: crypt stage) and Demirjian (LC: stage B; PR: crypt stage) occurred in the same two individuals. These individuals had maxillary right third molars in the crown stages, while the corresponding teeth on the left side were not developed. On the PR, the difference between the left and right sides is evident. However, on the LC, due to superimposition, the left-side teeth are misinterpreted as being in the crown stage.

Table 3. Pivot table of left side teeth stages on the LC & PR using Moorrees method

		Moorrees-LC																
		Not developed	Crypt	Ci	Cco	Coc	Cr1/2	Cr3/4	Crc	Ri	Rcl	R1/4	R1/2	R3/4	Rc	A1/2	Ac	Total
Moorrees-PR	Not developed	78	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	80
	Crypt	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
	Ci	0	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	7
	Cco	0	0	0	17	2	1	0	0	0	0	0	0	0	0	0	0	20
	Coc	2	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	8
	Cr1/2	0	0	0	0	0	33	7	0	0	0	0	0	0	0	0	0	40
	Cr3/4	0	0	0	0	0	5	121	6	0	0	0	0	0	0	0	0	132
	Crc	0	0	0	0	0	0	16	113	5	0	0	0	0	0	0	0	134
	Ri	0	0	0	0	0	0	0	27	55	1	0	0	0	0	0	0	83
	Rcl	0	0	0	0	0	0	0	2	7	23	3	0	0	0	0	0	35
	R1/4	0	0	0	0	0	0	1	0	1	2	83	5	0	0	0	0	92
	R1/2	0	0	0	0	0	0	0	0	0	0	12	65	8	1	0	0	86
	R3/4	0	0	0	0	0	0	0	0	0	0	1	7	46	14	0	01	69
	Rc	0	0	0	0	0	0	0	0	0	0	0	1	12	122	1	8	144
	A1/2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	7	9
	Ac	0	0	0	0	0	0	0	0	0	0	1	0	0	5	0	1450	1455
	Total	79	6	6	18	11	39	145	148	68	26	99	78	66	144	1	1455	2400

Table 4. Pivot table of left side teeth stages on the LC & PR using Demirjian method

		Demirjian-LC										
		Not developed	**Crypt**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total**
Demirjian-PR	**Not developed**	78	0	0	2	0	0	0	0	0	0	80
	Crypt	1	5	0	0	0	0	0	0	0	0	6
	A	0	1	6	0	0	0	0	0	0	0	7
	B	0	0	0	27	1	0	0	0	0	0	28
	C	0	0	0	0	166	6	0	0	0	0	172
	D	0	0	0	0	16	200	1	0	0	0	217
	E	0	0	0	0	1	10	110	5	1	0	127
	F	0	0	0	0	0	0	12	65	9	0	86
	G	0	0	0	0	0	0	1	8	194	10	213
	H	0	0	0	0	0	0	0	0	7	1457	1464
	Total	79	6	6	29	184	216	124	78	211	1467	2400

Discussion

Summary of Findings

This study compared tooth developmental stages of maxillary and mandibular left side permanent teeth between two types of dental radiographs (PRs and LCs) using Moorrees and Demirjian methods and demonstrated using weighted kappa and pivot tables that there was very little difference in staging. The percentage agreement for both staging methods exceeded 90%.

Comparison with Previous Research

Even though there have been many studies on tooth development and dental age estimation, there have been few studies specifically comparing tooth developmental stages between different types of radiographs. Previous studies relied on lateral skull views or cephalograms, oblique laterals, or a combination of these types of radiographs, but recent dental reference data use panoramic radiographs. This study fills the gap by providing evidence that PRs and LCs are comparable when determining tooth developmental stages for permanent teeth using these methods. These results would suggest that both PRs and LCs are equally valid for tooth staging and therefore dental aging. The advantage of LCs is that they are standardised, reproducible radiographs whereas panoramic radiographs rely on correct positioning of the patient to avoid distortion. In addition, magnification differs between machines and PRs cannot be compared. When examining other variables related to growth, LCs have greater accuracy. The archived radiographs of the Growth Legacy Collection, therefore, have potential for reanalysis using updated statistical methods, particularly for studying the relationship between growth and tooth staging.

Importance of Accurate Tooth Stage Assessment

Reliability of tooth staging affects the assessment of maturity and age estimation. Misinterpretation of tooth stages can affect contexts such as forensic science, bioarchaeology, and odontology. For instance, in a lateral skull or cephalogram, the left and right-side teeth are superimposed, and if the patient is not positioned correctly, the overlapping teeth of the left and right side can make stage assessment difficult. In the lateral oblique, the anterior teeth of the mandible, if visible, can be distorted.

Comparison of Radiographic Methods

The most widely used staging of developing permanent teeth are Moorrees, Fanning, and Hunt (Moorrees et al., 1963a) and Demirjian, Goldstein, and Tanner (Demirjian et al., 1973). Moorrees stages follow Gleiser and Hunt (1955) who assessed longitudinal radiographs where the crown and

root were divided into 13 and 14 crown, root and apical stages for single rooted and multiple rooted teeth, respectively (Moorrees et al., 1963a). The developing crown and root are divided into fractions of a quarter, half and three-quarter lengths. One of the major difficulties with this subjective approach is that the length of the mature crown or root has to be estimated, unless one is lucky enough to have a subsequent radiograph showing the mature tooth.

Demirjian, Goldstein, and Tanner (1973) described a new tooth staging approach based on qualitative morphologic features rather than subjective fractions of the crown and root. Demirjian method classified tooth formation into eight stages from A to H, beginning at initial mineralisation and finishing at the radiographic closure of the root apex (Demirjian et al., 1973). Each tooth stage has three of four specific morphologic features that are identified making identification of tooth stages easier and less subjective.

Moorrees has more stages than Demirjian which makes differentiation between stages more difficult, but it seems to be a logical way to overcome a challenge classifying a tooth when it appears between two stages. While increasing tooth formation stages might improve reliability of stage assignment, too many reduces precision (Fanning, 1961). Demirjian recommends that if a tooth is between stages, the less developed stage should be chosen (Demirjian et al., 1973).

Clinical and Research Implications

Posterior teeth (permanent molars) had high agreement values compared to anterior teeth. This reflects the clarity of molars on LC compared to anterior teeth where the palate and anterior mandibular bone overlaps with the teeth.

Several studies have shown that tooth stages on the left and right side are not significantly different (Demirjian et al., 1973, Haavikko, 1974, Kullman et al., 1992, Vidisdottir and Richter, 2015, Kuremoto et al., 2022). The homologous tooth can be used in cases when the tooth on the studied quadrant is missing or been extracted. These studies support the use of LCs for tooth staging as the teeth are not always clear. Mandibular teeth are easier for assessing tooth stages than maxillary teeth on PR. This is due to superimposition of bony structures of the midface (nasal cavity) and palate over maxillary teeth which create a radiopaque shadow. Also, the radiolucency of the oral cavity may obscure the roots of the anterior teeth due to overexposure (Perschbacher, 2012).

Challenges and Limitations

The main limitations of this study arise from the quality of radiographs. In 2005, the University of New Mexico's Maxwell Museum of Anthropology acquired the James Economides Orthodontic Collection. The collection was compiled from 1972 through 1999. The radiographs were originally wet film which have been digitized so a loss of quality is to be expected. In addition, the study was limited to the available radiographs, some of which had issues with low contrast, superimposition, distortion and positioning errors. To verify this data, the study could be repeated with contemporary digital radiographs taken for orthodontic purposes.

Future Research Directions

Despite the limitations, the result of this study shows no statistically significant difference in maxillary and mandibular left side tooth development between PR and LC using Moorrees and Demirjian methods. Further studies could explore the application of these findings to a larger population and incorporate contemporary digital radiographs to mitigate quality issues.

Conclusion

This study provides evidence of similarity in tooth stage assessment using PR and LC. Permanent tooth staging from these two types of radiographs is comparable and that data from the archived growth studies of LC are valid and can be combined with more recent results from PR. The high kappa values and percentage agreements demonstrate that both types of radiographs can be reliably used for tooth staging, which is crucial for several practical applications.

Applications in Forensic Anthropology

Accurate tooth stage assessment is essential in forensic anthropology for age estimation of unidentified human remains. The comparability of PRs and LCs means that forensic experts can confidently use either type of radiograph, depending on availability, to assist in the identification process and provide critical information in legal contexts.

Implications for Odontology

In clinical dentistry, determining the developmental stages of teeth is vital for diagnosing and planning treatments, especially in paediatric dentistry and orthodontics. The findings of this study sug-

gest that both PRs and LCs can be effectively used for such assessments, ensuring that practitioners can make informed decisions even when only one type of radiograph is available.

Benefits for Bioarchaeology and Osteoarchaeology

Bioarchaeologists and osteoarchaeologists rely on accurate tooth stage assessments to reconstruct the life histories of past populations. The demonstrated comparability of PRs and LCs allows researchers to utilize archived radiographs, enhancing the analysis of skeletal remains and contributing to a better understanding of historical health and demographics.

Future Research Directions

This study highlights the need for further research to explore the use of additional radiograph types in tooth stage assessment and to investigate potential advancements in radiographic technology. Future studies could also focus on refining statistical methods to improve the accuracy and reliability of tooth stage interpretation across different radiographic modalities.

In conclusion, the findings of this study have significant implications for improving practices in forensic anthropology, clinical dentistry, bioarchaeology, and osteoarchaeology. By demonstrating the reliability of both PRs and LCs for tooth staging, this research supports the broader application of these radiographs in various fields, ultimately contributing to more accurate age estimations, better clinical outcomes, and enhanced understanding of past populations. This manuscript not only addresses an important topic but also provides a robust and reliable approach that can inform and improve practices across multiple disciplines.

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