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Concordances and Correlations between Chronological, Dental and Bone Ages: A Retrospective Study in French individuals

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ABSTRACT

Bone and dental maturations are subject to physiological, environmental and pathological variables and are unique to each individual. Numerous methods for age estimation appeared to answer a new demand explained by the contemporary migratory movements and the increase of the crime rates. The objective of this study was to observe the relationships between skeletal and dental maturation stages to estimate which methods can be applied to a French population. This retrospective study was based on panoramic and cephalometric radiographs belonging to 192 (101 females and 91 males) orthodontic patients aged between 9 and 19 years, inhabitants of the Provence-Alpes-Côte d'Azur region. The Demirjian method based on dental calcification was used to estimate dental age. For the assessment of skeletal maturity and bone age, the Cervical Vertebral Maturation (CVM) method (Baccetti et al.) and its computerized version (Decocq et al.) were used. Spearman's correlation tests were performed to estimate the correlation between dental calcification stages and those of cervical vertebral maturation among the study population. The methods of Lin's concordance correlation coefficient and Bland and Altman were used to analyze the concordance between bone, dental and chronological ages. A moderate but statistically significant correlation was obtained between dental and skeletal developmental stages ($R=0.383-0.618$). The tooth showing the highest correlation with vertebral stages was the second molar for both sexes. Earlier vertebral maturation stage affiliation was observed in girls. The results confirmed that bone and dental maturations can be assessed to estimate relevant biological ages for children in orthodontic or forensic contexts.

1. Introduction

Estimating the age of a child is crucial to understanding his or her overall development. Chronological age is the most used age because the subjects' dates of birth are known in most cases. However, it may not be a reliable factor to reflect the maturation of an individual [1]. Moreover, this information is not present in the case of children found without valid identity papers or found deceased without identity [2]. Therefore, the growth of a child can be estimated by evaluating the biological age. Estimation of this age is based on several parameters as height, weight or sexual, skeletal and dental maturations [3].

Thus, evaluating skeletal maturation is useful in several fields treating the living subject, as in orthodontics or in (dentofacial) orthopedics: to take advantage of the patient's growth changes for extra oral tractions, orthodontic retentions and orthognathic surgeries or to treat different types of malocclusions related to maxillofacial growth [4,5,9]. This assessment is also of interest in endocrinology and pediatric medicine [6, 7]: it allows health professionals to anticipate treatment plans and types that are more appropriate to the child's overall development [8].

These assessments are also necessary in the forensic field, where victims are in certain situations found without known identity:

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estimating chronological age from dental and bone age assessments is useful in disaster victim identification (DVI) protocols when natural or man-made disasters occur [2,10-15]. Estimations of bone and dental ages are also made in context of criminal proceedings, leading to reductions in sentence and criminal responsibility when the offender is a minor. These biological ages are also operated in unaccompanied minor migrant's problematic [16]. In addition, new methods of estimation are emerging each year because of the rising level of infanticide crimes [17, 18].

In 2012 and 2018, the SCEPT and EASO reports recommended a multidisciplinary holistic approach for age estimations with a global harmonization through a gradual implementation of non-medical and medical methods [19,20]. In a context of separated child, non-medical methods (albeit subjective) therefore became a priority in age estimation because they should provide the same results as those obtained with bone and dental maturation assessments by medical procedures.

However, while there is some controversy about the accuracy of dental x-ray examinations [21], it is reported that medical methods, although intrusive, result in more reliable and objective findings [22,23]. Psychological tests undertaken as a priority in child assessment have margins of error that are not validated and are subject to environmental or social pressures that influence them. As Cummando *et al.* said, "medical radiological methods [...] have fairly large error ranges but these are better known and quantifiable than those of psychosocial assessments" [24].

Morphological methods based on radiological examinations of skeletal and dental development are then recommended for biological age estimations in immatures [25]. The scientific literature shows anyway that analysis of dental calcification allows to estimate an age more reliably than with dental eruption or with skeleton, because it is less influenced by intrinsic and extrinsic variations (endocrinological disorders or environmental alterations) [26].

Demirjian's is the one most widely used method for dental age estimation [27]. He proposed this method in 1973 based on dental calcification of the seven permanent left mandibular teeth excluding third molars. Each tooth is assigned a stage of bone development, ranging from A (early calcification) to H (complete tooth) with an additional stage of 0 indicating no evidence of mineralization. A score is then assigned to each stage from numerical tables distinguishing girls and boys. The sum of all the

scores obtained results in an estimation of dental age.

During growth, bones undergo changes that can be detected by X-rays. Bone age estimation is then used to assess the growth and maturation of young individuals, and to diagnose and treat pediatric disorders [28]. Previously, there was a preponderance of estimations of skeletal maturation by observation of wrist and hand radiographs, particularly based on the Greulich and Pyle atlas [29]. Only very recently, the assessment of maturation stages of the cervical vertebrae on orthodontic cephalometries has been integrated to estimate bone age without the need for additional radiation of the hand and wrist [5, 26, 30-32]. Since the publication of the Lamparski's atlas, orthodontists have been using changes in vertebral morphology to estimate a child's skeletal age and to predict the most optimal treatment plan [33]. Baccetti *et al.* proposed an improved version of the Cervical Vertebral Maturation (CVM) method to assess skeletal development from the morphology of the C2, C3 and C4 vertebrae. [34]. This method associates a stage of maturation based on the observation of the morphological variations established on these vertebrae over time on lateral cephalometric radiographs [35]. Recently, Decocq *et al.* published a computerized version of this method to overcome the subjective interpretation of vertebral morphology [36].

The aim of the present study was to explore the relationship between cervical maturation stages and those of dental calcification to determine if biological age can be estimated from panoramic and cephalometric radiographs on a French population.

Table 1
Number of subjects, mean and median for each sex.

Sex	Number of subjects	Mean age ±SD (years)	Median age (years)	<i>p</i> *
Females (<i>p</i> =0.002)**	101	12.57 ± 2.44	12.16	0.471
Males (<i>p</i> =0.002)**	91	12.80 ± 2.57	12.40	

SD, standard deviation; IQR, interquartile range;

* χ^2 test; **Shapiro-Wilk test.

2. Materials and methods

2.1 Materials

This retrospective study was based on a sample of 192 randomly selected individuals (101 females and 91 males) aged between 9 to 19 years and treated for dentofacial anomalies (Table 1). For each child, panoramic and lateral cephalometric radiographs taken the same day were digitally retrieved from the Dentofacial Orthodontic Unit of the Timone Hospital (Marseille). Both the radiographs were taken in the Radiology Department between 2014 and 2021 for treatment forecasting and diagnosis. They were selected according to the following exclusion criteria: patients with dental agenesis, pathologies (genetic or systemic) altering the maturation of the cervical vertebrae or the eruption and calcification of teeth, with previous surgeries and orthodontic treatments, patients undergoing treatment and wearing orthodontic appliances and poor-quality radiographs that do not show the teeth and C2, C3 and C4 vertebrae in their entirety. Patients were anonymized: only the sex and the age of each patient at the time of radiographic examinations were recorded (computed from the date of birth and the exam date). The entire sample was analyzed by a forensic science student majoring in odontology and the ethical framework was thus respected and followed the PADS20-342 GDPR's protocol (General Data Protection Regulation).

2.2 Dental age estimation

Dental calcification was evaluated using the Demirjian's method [27] where a score ranging from A to H is assigned to the first seven left mandibular teeth. All panoramics were evaluated and scored in the same order: central and lateral incisors, canine, first and second premolars, first and second molars.

2.3 Skeletal age estimation

Bone development was evaluated on three cervical vertebrae following the Cervical Vertebral Maturation (CVM) method described by Baccetti *et al.* [34] and computerized by Decocq *et al.* [36]. The inferior borders of the C2, C3, and C4 vertebrae were analyzed on lateral cephalometric radiographs in addition to their general shape. The ODRADE® cephalometric analysis extension of the ORTHOKIS® software was used to place the eight points mentioned by Bacetti *et al.* to obtain precise measurements of the three vertebrae.

2.4 Statistical analysis

Statistical analyses were performed with R Studio® software (1.4.1106 version). P-values less than 0.05 were considered as statistically significant. Quantitative variables were tested for a normal distribution using the Shapiro-Wilk test and were expressed as means associated with standard deviations. Qualitative variables were expressed as percentages.

Spearman's correlation coefficient was calculated to statistically assess the relation between chronological age, dental calcification stages and cervical vertebrae's maturation stages. Lin's concordance correlation coefficient and the Bland & Altman' methods were applied to investigate the concordance between estimated and chronological ages. The accuracy of the methods used was assessed by calculating the residuals between dental and bone age estimations and chronological ages.

Reproducibility and repeatability were assessed by forensic sciences students trained by radiologists and orthodontists who analyzed a second time 20% of the total sample within 30 days of the initial analysis. Lin's concordance correlation coefficient (CCC) method was performed to assess the reliability of the methods used and the results were interpreted using the classifications proposed by Partik *et al.* [52].

3. Results

Table 2 shows the repartition of chronological, dental and bone ages in the CVM stages for females and males. It confirms that cervical vertebral maturation stages (CS) and thus bone age were increasing with chronological and dental ages. A higher proportion of females was found in late maturation stages (21.8% for girls in CS5 versus 12.1% for males); girls reached maturation stages earlier than boys (13.18 ± 2.24 years in CS4 for girls versus 14.37 ± 1.50 for boys, 14.85 ± 1.70 in CS5 for girls versus 16.58 ± 2.05 for boys). Overestimations of dental age can be seen in all CS in both girls and boys (mean of differences between CA and DA in girls: 0.72 ± 0.41 years, mean of differences between CA and DA in boys: 0.78 ± 0.84 in boys). On the contrary, bone age was underestimated for both girls and boys for all CS (mean of differences between CA and BA in girls: 1.69 ± 1.2 years, mean of differences between CA and BA in boys: 2.45 ± 1.15 years).

Table 2

Mean chronological, dental and bone ages in each sex and Cervical Vertebral Maturation (CVM) stages.

CVM	Females		Males		
		Number	Mean	Number	Mean
CS0	Chronological age		10.94 ± 1.35		10.95 ± 1.23
	Dental age	6 (5.9%)	11.57 ± 1.13	12 (13.2%)	12.15 ± 2.22
	Bone age		7.71 ± 0.22		7.58 ± 0.77
CS1	Chronological age		10.44 ± 1.47		11.07 ± 1.28
	Dental age	9 (8.9%)	11.22 ± 1.81	11 (12.1%)	11.97 ± 1.96
	Bone age		8.94 ± 0.18		8.90 ± 0.23
CS2	Chronological age		11 ± 1.58		11.07 ± 1.35
	Dental age	15 (14.9%)	11.93 ± 1.82	19 (20.9%)	12.24 ± 2.28
	Bone age		9.89 ± 0.30		9.60 ± 0.25
CS3	Chronological age		11.21 ± 1.32		12.20 ± 1.70
	Dental age	23 (22.8%)	12.33 ± 1.64	14 (15.4%)	11.88 ± 1.74
	Bone age		10.84 ± 0.33		10.80 ± 0.36
CS4	Chronological age		13.18 ± 2.24		14.37 ± 1.50
	Dental age	20 (19.8%)	13.47 ± 1.51	20 (22%)	15.09 ± 1.19
	Bone age		11.81 ± 0.31		11.76 ± 0.33
CS5	Chronological age		14.85 ± 1.70		16.58 ± 2.05
	Dental age	22 (21.8%)	14.50 ± 0.88	11 (12.1%)	15.95 ± 0.18
	Bone age		12.79 ± 0.31		12.83 ± 0.30
CS6	Chronological age		16.20 ± 0.66		16.25 ± 1.70
	Dental age	6 (5.9%)	15.22 ± 0.88	4 (4.4%)	15.68 ± 0.65
	Bone age		13.98 ± 0.27		13.85 ± 0.46

CVM: Cervical Vertebral Maturation; CS: Cervical Stage.

The relative distributions of each dental development stages in each CS for females and males are presented in [Table 3](#) and [Table 4](#). It indicates that the relative frequencies of teeth belonging to high dental maturation stages increased when the maturation stages of the cervical vertebrae increased.

The correlation coefficients between dental development and cervical vertebral maturation stages are also presented in the [tables 3 and 4](#). Coefficients vary from 0.383 (first premolar in females) to 0.618 (second molars in males and females). Unless for the canine and first premolar in boys, all correlations were statistically significant ($p < 0.001$). [Tables 5, 6 and 7](#) present the concordance coefficients between bone, dental and chronological ages for both sexes. Differences between estimated and chronological ages are presented in [Fig. 1](#). Coefficients varied from 0.30 (bone age versus dental age in boys) to 0.80 (chronological age versus dental age in boys).

Table 5. Concordances between chronological (CA), dental (DA) and bone (BA) ages in girls and boys.

	CA	DA	BA
CA	1	0.79	0.47
DA	0.79	1	0.32
BA	0.47	0.32	1

Table 6. Concordances between chronological (CA), dental (DA) and bone (BA) ages in girls.

	CA	DA	BA
CA	1	0.78	0.50
DA	0.78	1	0.40
BA	0.50	0.40	1

Table 7. Concordances between chronological (CA), dental (DA) and bone (BA) ages in boys.

	CA	DA	BA
CA	1	0.80	0.44
DA	0.80	1	0.30
BA	0.44	0.30	1

[Fig. 2](#). represents the reliability of the methods used to estimate dental and bone ages. Lin's concordance correlation coefficients varied from fairly good to excellent according to Partik's classification [52]. For the Demirjian's method, CCCs were 0.92 for reproducibility and 0.97 for repeatability. For the Decocq's method, CCC's were 0.89 for reproducibility and 0.88 for repeatability. *Cb* coefficients were also calculated. They quantify the difference between the regression line estimated from the two series of measurements and the line at 45°. For both methods, the values varied between 0.96 and 0.90. It indicates excellent alignments of the two lines and thus excellent concordances.

Table 3. Relative distribution (%) of Cervical Vertebral Maturation stages (CS) in face of dental development stages (DS) and Spearman's correlation coefficient (r) for females.

Tooth	DS	CS								r	p
		0	1	2	3	4	5	6			
33	D	-	-	-	-	-	-	-	-	0.579	<0.001*
	E	-	-	-	-	-	-	-	-		
	F	15.4	30.8	15.4	30.8	7.7	-	-	-		
	G	6.8	6.8	20.3	27.1	22.0	15.3	1.7	-		
	H	-	3.6	-	10.7	21.4	42.9	21.4	-		
34	D	-	-	-	-	-	-	-	-	0.383	<0.001*
	E	-	-	-	-	-	-	-	-		
	F	22.2	33.3	11.1	11.1	22.2	-	-	-		
	G	-	27.3	9.1	54.5	9.1	-	-	-		
	H	5.0	3.8	15.0	20.0	21.2	26.2	8.8	-		
35	D	-	-	-	-	-	-	-	-	0.512	<0.001*
	E	25.0	12.5	37.5	12.5	12.5	-	-	-		
	F	-	27.8	16.7	33.3	11.1	11.1	-	-		
	G	23.1	7.7	23.1	30.8	15.4	-	-	-		
	H	1.6	3.2	9.7	19.4	24.2	30.6	11.3	-		
37	D	-	-	-	-	-	-	-	-	0.618	<0.001*
	E	11.8	20.6	23.5	29.4	8.8	5.9	-	-		
	F	4.2	8.3	20.8	33.3	25.0	8.3	-	-		
	G	3.3	-	3.3	13.3	26.7	40	13.3	-		
	H	-	-	7.7	7.7	23.1	38.5	23.1	-		

*Statistically significant.

4. Discussion

The precision and reliability of age estimations are determinant in clinical and forensic sciences. An erroneous assessment of biological age can lead to serious consequences when it is used to plan treatments or to find an identity. Moreover, contemporary migratory movements linked to globalization and ongoing belligerent conflicts have led to new issues where authorities are forced to make decisions about the fate of thousands of people based on morphological criteria to arrive at civil ages and partially reconstructed identities [18, 37]. To respond to these specific new demands,

more and more estimation methods are published every day. Most of these methods are based on the morphologies and anatomical structures that can be observed in radiography, such as carpals [29], cervical vertebrae [33-34] or teeth [27,38]. Since more available anatomical structures provide more reliable results [17], the combination of different methods leads to better age estimations.

The aim of the present study was to observe the relationships between dental and bone maturation stages in order to evaluate the possibility of combining the Demirjian' and Decocq' methods to estimate more reliable and accurate biological ages.

Table 4. Relative distribution (%) of Cervical Vertebral Maturation stages (CS) in face of dental development stages (DS) and Spearman's correlation coefficient (r) for males.

Tooth	DS	CS								r	p
		0	1	2	3	4	5	6			
33	D	-	-	-	-	-	-	-	-	0.114	0.142
	E	-	-	-	-	-	-	-	-		
	F	16.7	26.7	26.7	26.7	3.3	-	-	-		
	G	14.8	11.1	29.6	18.5	18.5	3.7	3.7	-		
	H	6.1	3.0	6.1	3.0	42.4	30.3	9.1	-		
34	D	-	-	-	-	-	-	-	-	0.090	0.198
	E	16.7	16.7	66.7	-	-	-	-	-		
	F	33.3	16.7	33.3	16.7	-	-	-	-		
	G	20	30.0	10.0	20.0	20	-	-	-		
	H	8.7	10.1	17.4	15.9	26.1	15.9	5.8	-		
35	D	-	-	-	-	-	-	-	-	0.512	<0.001*
	E	25.0	33.3	55.6	-	-	-	-	-		
	F	-	26.7	20.0	20.0	6.7	-	-	-		
	G	23.1	15.4	38.5	30.8	15.4	-	-	-		
	H	1.6	5.6	11.1	13.0	31.5	20.4	7.4	-		
37	D	20.0	20.0	60.0	-	-	-	-	-	0.618	<0.001*
	E	20.0	30.0	20.0	26.7	-	5.9	-	-		
	F	16.7	5.6	33.3	22.2	-	8.3	-	-		
	G	5	5.0	20.0	5.0	-	40	5.0	-		
	H	-	-	-	5.6	61.1	38.5	16.7	-		

*Statistically significant.

Previous studies have already investigated the relationships between these two maturity stages [2, 3, 7, 17, 26, 39-41] and prove that the combination of dental and skeletal maturity stages represents a useful tool for age estimation of children.

According to our study results, the correlations between dental calcification (Demirjian's method variables) and cervical vertebral maturation stages (Decocq's method variables) were significant in both males and females, except for the canine and first premolar in boys. The mean correlation coefficients for all teeth are 0.523 for females and 0.333 in males but higher correlation was found in the second molar for both sexes (R=0.618). Similar to our study, Chen *et al.* [42], Bařaran *et al.* [43], Cericato *et al.* [17], Chaudhry *et al.* [7], Gulati *et al.* [44], Mollabashi *et al.* [26], Rai

et al. [45] and Rozylo-Kalinowska *et al.* [39] obtained significantly positive correlations between dental and bone ages. Mollabashi *et al.* (0.724 and 0.641 in boys and girls respectively) and Chen *et al.* (0.496 and 0.582 in boys and girls respectively) also reported stronger correlations for the mandibular second molar between dental and bone ages [26, 42]. In our case, the weakest correlations between dental and cervical stages were observed in the first premolars for both sexes (0.383 for girls, 0.090 and non-significant for boys). It can be explained because the later the eruption and calcification of the tooth occur, the better predictor of maturation it will be [26]. In the studies of Rozylo-Kalinowska *et al.* [39], Bařaran *et al.* [43], and Cericato *et al.* [17], stronger correlations were present for the second premolars while the strongest correlation was noted between skeletal age and the calcification

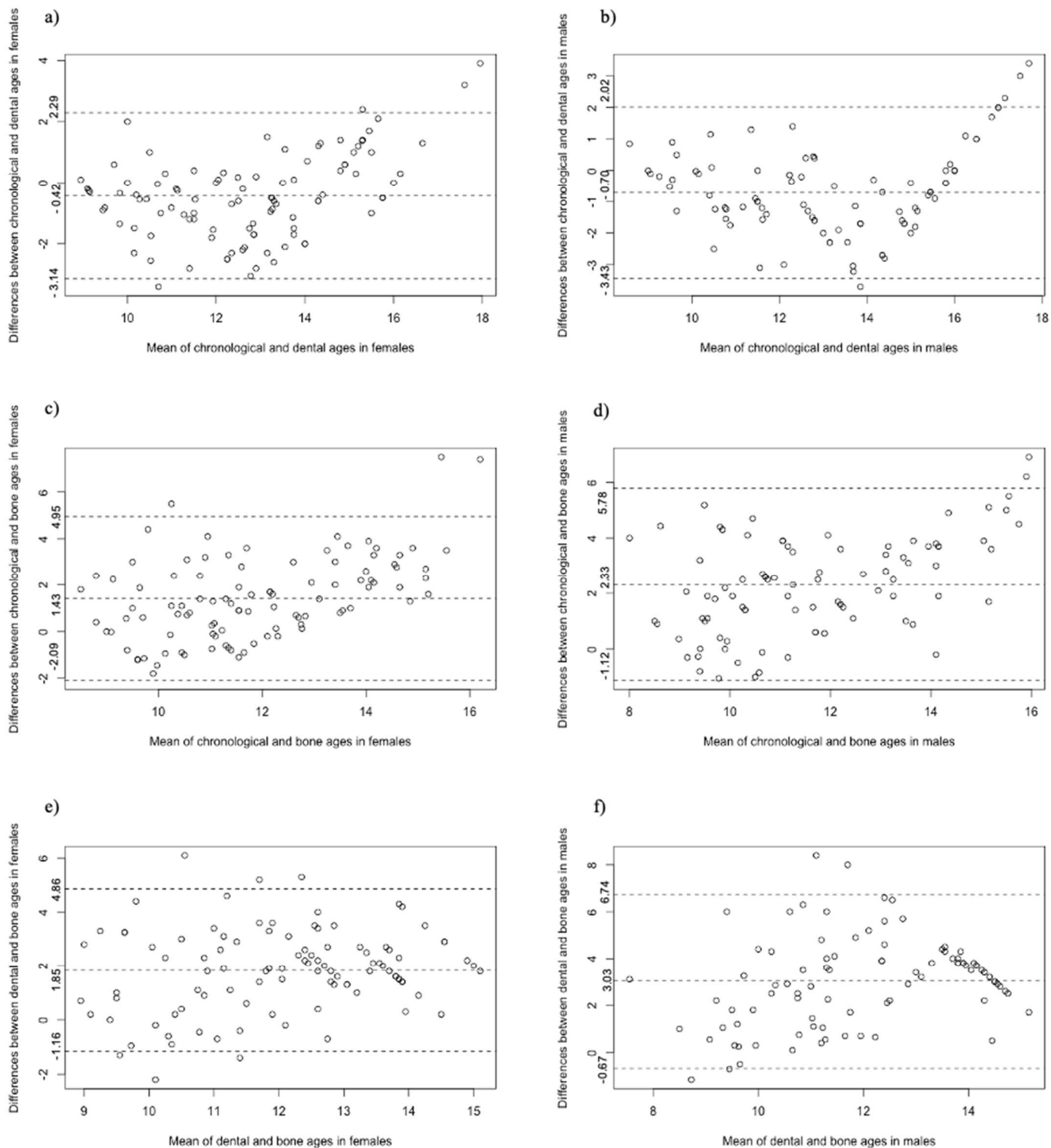


Fig. 1. Bland and Altman plots showing differences between a) CA and DA in females b) CA and DA in males c) CA and BA in females d) CA and BA in males e) DA and BA in females f) DA and BA in males. The middle bold dashed line represents the mean difference, and the two extreme bold dashed lines define the limits of agreement.

stage of first premolars in the study of Valizadeh *et al.* [46].

The present study applied a previously validated method for the dental ages' estimations [47,48]. Reproducibility and repeatability studies of the measurements made to estimate bone ages from Decocq's computerized method led to the hypothesis that this method is also reliable and precise. However, some limitations can be noted.

Evaluation of the methods concordance by Lin's and Bland and Altman's methods indicate overestimations of dental ages by Demirjian's method and underestimations of bone ages by Decocq's method (Fig. 1). The overestimations obtained with Demirjian were also seen in other studies [49-50]. Indeed, da Silva *et al.* [49] highlighted an average overestimate of 7 months.

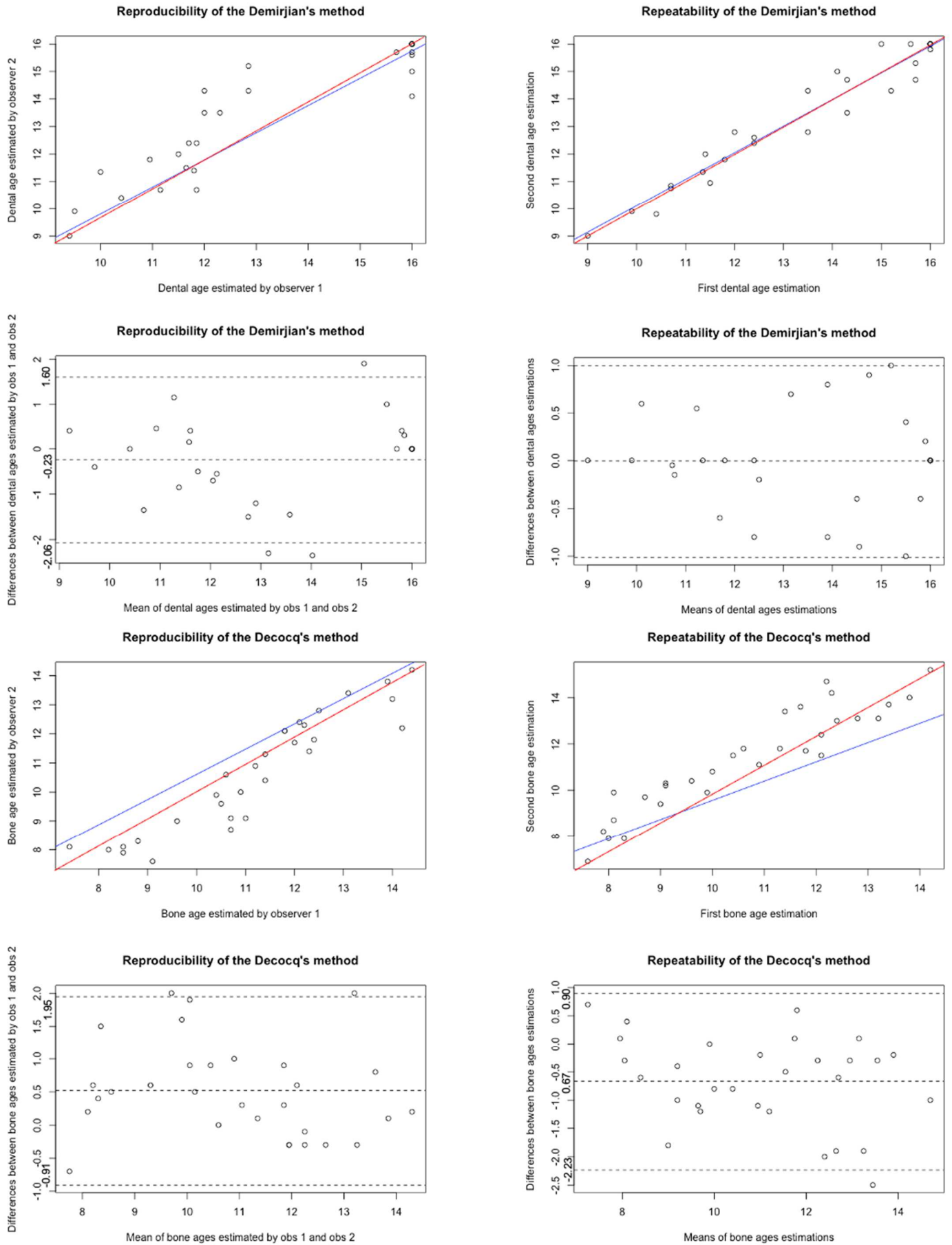


Fig. 2. Reliability of Demirjian's and Decocq's methods. a) c) e) and g) show reproducibilities for the methods of Demirjian and Decocq respectively. b) d) f) and h) show repeatabilities for the methods of Demirjian and Decocq respectively. a) b) e) and f) plots the correlations between variables. c) d) g) and h) are the Bland and Altman plots and show the differences between variables. Blue lines represent the regression lines and red lines represent the reference lines where $x=y$.

Moreover, Decocq's method is based on that of Baccetti *et al.* which was itself established from that proposed by Hassel and Farman. These are not commonly validated throughout the literature [17]. Therefore, even though the correlations were positive and statistically significant, the results should be interpreted with caution as they were moderate and over/under-estimations are present. It is also important to note that the method for estimating dental age was based on a Canadian population and that the method for estimating bone age was based on an American population. As Cunha *et al.* said, "although Demirjian's method is one of the most suitable for forensic purposes, the high ethnic variability requires particular caution in discussion of the final result." [51]

Regarding concordance coefficients, they ranged from 0.30 to 0.80. According to the Partik *et al.* classification [52], they vary from fairly good to excellent. The strongest concordances were observed between chronological and dental age in both sexes (C=0.79-0.80). Regarding the relationships between dental and bone age estimations, they were fairly good (C=0.40 in females, C=0.30 in males).

Despite these moderate values, the study has the advantage of making its observations on a larger population compared to most of the previous studies. These results also validated Decocq's computerized CVM method, which was based on a population of 30 subjects.

Although ADFAD (International Study Group on Forensic Age Diagnostics) recommends estimating bone age from hand and wrist radiographs [53], the simultaneous use of Demirjian' and Decocq' methods from panoramic and cephalometric radiographs would reduce ionizing radiation exposure for children. Indeed, aging the living requires the use of non-invasive methods [51]. However, the exposure level related to panoramic or cephalometric X-ray can be classified as negligible risk to a person's health. As DeMicco *et al.* said, "dental imaging can bring significant benefits with a risk of limited damage" [22].

5. Conclusion

The correlation between dental calcification and cervical vertebral maturation stages (especially in the calcification stages of the second molar) and the concordance between chronological, dental and skeletal ages indicated moderate and statistically significant results. Girls reached late stages of maturation earlier than boys.

From panoramic and lateral cephalometric radiographs, it is possible to combine the methods of Demirjian and Decocq to obtain precise biological ages for orthodontic treatments or forensic identifications.

Further investigation of this study could be done by involving more operators to obtain more reliable results.

Acknowledgments

References

- [1] M. Macha, Estimation of Correlation between Chronological Age, Skeletal Age and Dental Age in Children- A Cross-sectional Study, JCDR. (2017). <https://doi.org/10.7860/JCDR/2017/25175.10537>.
- [2] K. Timmins, H. Liversidge, M. Farella, P. Herbison, J. Kieser, The usefulness of dental and cervical maturation stages in New Zealand children for Disaster Victim Identification, Forensic Sci Med Pathol. 8 (2012) 101–108. <https://doi.org/10.1007/s12024-011-9251-8>.
- [3] A. Demirjian, P.H. Buschang, R. Tanguay, D.K. Patterson, Interrelationships among measures of somatic, skeletal, dental, and sexual maturity, American Journal of Orthodontics. 88 (1985) 433–438. [https://doi.org/10.1016/0002-9416\(85\)90070-3](https://doi.org/10.1016/0002-9416(85)90070-3).
- [4] M. Satoh, Bone age: assessment methods and clinical applications, Clin Pediatr Endocrinol. 24 (2015) 143–152. <https://doi.org/10.1297/cpe.24.143>.
- [5] C. Flores-Mir, C.A. Burgess, M. Champney, R.J. Jensen, M.R. Pitcher, P.W. Major, Correlation of skeletal maturation stages determined by cervical vertebrae and hand-wrist evaluations, Angle Orthod. 76 (2006) 1–5. [https://doi.org/10.1043/0003-3219\(2006\)076\[0001:COSMSD\]2.0.CO;2](https://doi.org/10.1043/0003-3219(2006)076[0001:COSMSD]2.0.CO;2).
- [6] D.D. Martin, J.M. Wit, Z. Hochberg, L. Sävendahl, R.R. van Rijn, O. Fricke, N. Cameron, J. Caliebe, T. Hertel, D. Kiepe, K. Albertsson-Wikland, H.H. Thodberg, G. Binder, M.B. Ranke, The Use of Bone Age in Clinical Practice – Part 1, HRP. 76 (2011) 1–9. <https://doi.org/10.1159/000329372>.
- [7] K. Chaudhry, A. Agarwal, U. Rehani, Interrelationship among Dental, Skeletal and Chronological Ages in Urban and Rural Female Children, Int J Clin Pediatr Dent. 3 (2010) 79–86. <https://doi.org/10.5005/jp-journals-10005-1058>.

- [8] M. Durka-Zajac, M. Mitus-Kenig, M. Derwich, A. Marcinkowska-Mitus, M. Loboda, Radiological Indicators of Bone Age Assessment in Cephalometric Images. Review, *Pol J Radiol.* 81 (2016) 347–353. <https://doi.org/10.12659/PJR.895921>.
- [9] S. Koshy, S. Tandon, Dental age assessment: The applicability of Demirjian's method in South Indian children, *Forensic Science International.* 94 (1998) 73–85. [https://doi.org/10.1016/S0379-0738\(98\)00034-6](https://doi.org/10.1016/S0379-0738(98)00034-6).
- [10] J.A. Kieser, W. Laing, P. Herbison, Lessons Learned from Large-scale Comparative Dental Analysis Following the South Asian Tsunami of 2004, *J Forensic Sci.* 51 (2006) 109–112. <https://doi.org/10.1111/j.1556-4029.2005.00012.x>.
- [11] J. Kieser, J. de Feijter, R. TeMoananui, Automated dental aging for child victims of disasters, *Am J Disaster Med.* 3 (2008) 109–112.
- [12] M. Petju, A. Suteerayongprasert, R. Thongpud, K. Hassiri, Importance of dental records for victim identification following the Indian Ocean tsunami disaster in Thailand, *Public Health.* 121 (2007) 251–257. <https://doi.org/10.1016/j.puhe.2006.12.003>.
- [13] P. Schuller-Götzburg, J. Suchanek, Forensic odontologists successfully identify tsunami victims in Phuket, Thailand, *Forensic Science International.* 171 (2007) 204–207. <https://doi.org/10.1016/j.forsciint.2006.08.013>.
- [14] M. Tsokos, R. Lessig, C. Grundmann, S. Benthous, O. Peschel, Experiences in tsunami victim identification, *Int J Legal Med.* 120 (2006) 185–187. <https://doi.org/10.1007/s00414-005-0031-4>.
- [15] A. Valenzuela, S. Martin-de las Heras, T. Marques, N. Exposito, J.M. Bohoyo, The application of dental methods of identification to human burn victims in a mass disaster, *International Journal of Legal Medicine.* 113 (2000) 236–239. <https://doi.org/10.1007/s004149900099>.
- [16] R. Mishori, The Use of Age Assessment in the Context of Child Migration: Imprecise, Inaccurate, Inconclusive and Endangers Children's Rights, *Children (Basel).* 6 (2019). <https://doi.org/10.3390/children6070085>.
- [17] G.O. Cericato, Correlating skeletal and dental developmental stages using radiographic parameters, *Journal of Forensic and Legal Medicine.* (2016) 6.
- [18] S. Moirangthem, N.C. Kumar, S.B. Math, Child sexual abuse: Issues & concerns, *Indian Journal of Medical Research.* 142 (2015) 1. <https://doi.org/10.4103/0971-5916.162084>.
- [19] SCEP Position Paper on Age Assessment in Context of Separated Child in Europe (2012).
- [20] EASO Practical Guide on Age Assessment: Second edition, 116 (2018).
- [21] A. Aynsley-Green, T.J. Cole, H. Crawley, N. Lessof, L.R. Boag, R.M.M. Wallace, Medical, statistical, ethical and human rights considerations in the assessment of age in children and young people subject to immigration control, *British Medical Bulletin.* 102 (2012) 17–42. <https://doi.org/10.1093/bmb/lds014>.
- [22] F. De Micco, F. Martino, C.P. Campobasso, Ethical issues in age assessment by the third molar development, *Australian Journal of Forensic Sciences.* (2020) 1–12. <https://doi.org/10.1080/00450618.2020.1789220>.
- [23] G.J. Roberts, S. Parekh, A. Petrie, V.S. Lucas, Dental age assessment (DAA): a simple method for children and emerging adults, *Br Dent J.* 204 (2008) E7; discussion 192-193. <https://doi.org/10.1038/bdj.2008.21>.
- [24] M. Cummaudo, D. De Angelis, F. De Micco, C. Campobasso, C. Cattaneo, The “forensic paradox” of aging unaccompanied minors in the migration crisis: Why medicine and forensics are a must, *Journal of Forensic and Legal Medicine.* 79 (2021) 102133. <https://doi.org/10.1016/j.jflm.2021.102133>.
- [25] S. Ritz-Timme, C. Cattaneo, M.J. Collins, E.R. Waite, H.W. Schütz, H.-J. Kaatsch, H.I.M. Borrman, Age estimation: The state of the art in relation to the specific demands of forensic practise, *International Journal of Legal Medicine.* 113 (2000) 129–136. <https://doi.org/10.1007/s004140050283>.
- [26] V. Mollabashi, The relation between dental age and cervical vertebral maturation in orthodontic patients aged 8 to 16 years: A cross-sectional study, (2019) 9.
- [27] A. Demirjian, H. Goldstein, J.M. Tanner, A new system of dental age assessment, *Hum Biol.* 45 (1973) 211–227.
- [28] M. Satoh, Bone age: assessment methods and clinical applications, *Clin Pediatr Endocrinol.* 24 (2015) 143–152. <https://doi.org/10.1297/cpe.24.143>.
- [29] W. Greulich, I. Pyle, Radiographic atlas of skeletal development of the hand and wrist, London: Stanford University Press (1959).

- [30] B. Hassel, A.G. Farman, Skeletal maturation evaluation using cervical vertebrae, *American Journal of Orthodontics and Dentofacial Orthopedics*. 107 (1995) 58–66. [https://doi.org/10.1016/S0889-5406\(95\)70157-5](https://doi.org/10.1016/S0889-5406(95)70157-5).
- [31] A. Heil, E. Lazo Gonzalez, T. Hilgenfeld, P. Kickingereeder, M. Bendszus, S. Heiland, A.-K. Ozga, A. Sommer, C.J. Lux, S. Zingler, Lateral cephalometric analysis for treatment planning in orthodontics based on MRI compared with radiographs: A feasibility study in children and adolescents, *PLoS One*. 12 (2017) e0174524. <https://doi.org/10.1371/journal.pone.0174524>.
- [32] P. Gandini, M. Mancini, F. Andreani, A comparison of hand-wrist bone and cervical vertebral analyses in measuring skeletal maturation, *Angle Orthod*. 76 (2006) 984–989. <https://doi.org/10.2319/070605-217>.
- [33] Lamparski DG. Skeletal age assessment utilizing cervical vertebrae. *Am J Orthod*. 1975;67:458–9.
- [34] T. Baccetti, L. Franchi, J.A. McNamara, An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth, *Angle Orthod*. 72 (2002) 316–323. [https://doi.org/10.1043/0003-3219\(2002\)072<0316:AIVOTC>2.0.CO;2](https://doi.org/10.1043/0003-3219(2002)072<0316:AIVOTC>2.0.CO;2).
- [35] L. Franchi, T. Baccetti, J.A. McNamara, Mandibular growth as related to cervical vertebral maturation and body height, *Am J Orthod Dentofacial Orthop*. 118 (2000) 335–340. <https://doi.org/10.1067/mod.2000.107009>.
- [36] P. Decocq, G. Toutain, J. Honore, E. Bocquet, M. Crocquet, Méthode informatisée pour le calcul de l'âge osseux vertébral, (2021) 11.
- [37] A. Franco, P. Thevissen, S. Fieuws, P.H.C. Souza, G. Willems, Applicability of Willems model for dental age estimations in Brazilian children, *Forensic Sci Int*. 231 (2013) 401.e1–4. <https://doi.org/10.1016/j.forsciint.2013.05.030>.
- [38] Nolla, C.M. (1960) The development of permanent teeth. *Journal of Dentistry for Children*, 27, 254-266. - References - Scientific Research Publishing. [https://www.scirp.org/\(S\(lz5mqp453edsnp55rrgict55\)\)/reference/ReferencesPapers.aspx?ReferenceID=869974](https://www.scirp.org/(S(lz5mqp453edsnp55rrgict55))/reference/ReferencesPapers.aspx?ReferenceID=869974)
- [39] I. Rozylo-Kalinowska, A. Kolasa-Raczka, P. Kalinowski, Relationship between dental age according to Demirjian and cervical vertebrae maturity in Polish children, *The European Journal of Orthodontics*. 33 (2011) 75–83. <https://doi.org/10.1093/ejo/cjq031>.
- [40] A.L. Vaida, A.-E. Moca, L. Todor, B.I. Todor, B.-M. Negru, A.I. Moraru, Correlations between morphology of cervical vertebrae and dental eruption, (2019) 6.
- [41] G. Perinetti, L. Contardo, P. Gabrieli, T. Baccetti, R. Di Lenarda, Diagnostic performance of dental maturity for identification of skeletal maturation phase, *Eur J Orthod*. 34 (2012) 487–492. <https://doi.org/10.1093/ejo/cjr027>.
- [42] J. Chen, H. Hu, J. Guo, Z. Liu, R. Liu, F. Li, S. Zou, Correlation between dental maturity and cervical vertebral maturity, *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 110 (2010) 777–783. <https://doi.org/10.1016/j.tripleo.2010.08.006>.
- [43] G. Başaran, T. Ozer, N. Hamamci, Cervical vertebral and dental maturity in Turkish subjects, *Am J Orthod Dentofacial Orthop*. 131 (2007) 447.e13–20. <https://doi.org/10.1016/j.ajodo.2006.08.016>.
- [44] A. Gulati, J.R. Taneja, S.L. Chopra, S. Madan, Inter-relationship between dental, skeletal and chronological ages in well-nourished and mal-nourished children, *J Indian Soc Pedod Prev Dent*. 8 (1991) 19–23.
- [45] V. Rai, S. Saha, G. Yadav, A.M. Tripathi, K. Grover, Dental and skeletal maturity- a biological indicator of chronologic age, *J Clin Diagn Res*. 8 (2014) ZC60-64. <https://doi.org/10.7860/JCDR/2014/10079.4862>.
- [46] S. Valizadeh, N. Eil, S. Ehsani, H. Bakhshandeh, Correlation Between Dental and Cervical Vertebral Maturation in Iranian Females, *Iran J Radiol*. 10 (2013) 1–7. <https://doi.org/10.5812/iranjradiol.9993>.
- [47] O.E. Gungor, B. Kale, M. Celikoglu, A.Y. Gungor, Z. Sari, Validity of the Demirjian method for dental age estimation for Southern Turkish children, *Niger J Clin Pract*. 18 (2015) 616–619. <https://doi.org/10.4103/1119-3077.154216>.
- [48] R. Nykänen, L. Espeland, S.I. Kvaal, O. Krogstad, Validity of the Demirjian method for dental age estimation when applied to Norwegian children, *Acta Odontol Scand*. 56 (1998) 238–244. <https://doi.org/10.1080/00016359850142862>.
- [49] R.D. da Silva, M.A.D. da Silva, A.Y. Uezono, S.B.B. dos S. Queiroz, R.N. de Oliveira, Estimating age of Brazilians using the methods of Demirjian and Nicodemo, Moraes and Médici: A comparative analysis, *Forensic Medicine and Anatomy Research*. 1 (2013) 57–62. <https://doi.org/10.4236/fmar.2013.13011>.

[50] V. Staaf, H. Mornstad, U. Welander, Age determination with the aid of tooth development: a test of the reliability and validity, *Scand. J. Dent. Res.* 99 (1991) 281–286.

[51] E. Cunha, E. Baccino, L. Martrille, F. Ramsthaler, J. Prieto, Y. Schuliar, N. Lynnerup, C. Cattaneo, The problem of aging human remains and living individuals: A review, *Forensic Science International*. 193 (2009) 1–13. <https://doi.org/10.1016/j.forsciint.2009.09.008>.

[52] Partik, B. L. et al. 3D versus 2D ultrasound: accuracy of volume measurement in human cadaver kidneys. *Invest. Radiol.* 37, 489–495 (2002).

[53] A. Schmeling, G. Geserick, W. Reisinger, A. Olze, Age estimation, *Forensic Sci Int.* 165 (2007) 178–181. <https://doi.org/10.1016/j.forsciint.2006.05.016>.