
The association between chronological age, skeletal maturity and dental maturity

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Aim: The aim of this study was to analyse the correlation between skeletal and dental maturity.

Materials and methods: The Dental Panoramic Tomogram and Lateral Skull Radiographs of 381 subjects aged between 8.20 years and 17.96 years were examined. Calcification stages of all the teeth on the left hand side and all third molars were determined according to Demirjian's 8-stages, whilst the Cervical Vertebral Maturation (CVM) Index was adopted for the assessment of skeletal maturity. Dental age (DA) was determined using the simple weighted average method.

Results: There was no significant difference between DA and chronological age (CA) of the male and female groups. The Spearman rank correlation between CA and CVM was moderate, whilst the correlation between DA and CVM was weak. A moderate correlation was found between the dental calcification stages and CVM for the upper right third molar in males.

Conclusions: The average CA of females at every CVM stage was below that of males, confirming that females undergo earlier skeletal maturation. The similarity between CA and DA confirms that CA can be closely approximated by DA. The low correlations between CA and DA with CVM suggest that these variables should not be used in determining the growth status or potential of the individual.

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Introduction

An understanding of the normal growth and development status in patients is imperative to maximise the success of orthodontic treatment and to identify abnormal growth patterns. Because of wide individual variations, Chronological Age (CA) has been considered not sufficiently accurate to determine developmental status.^{1,2} Therefore, biological age needs to be determined by assessing a number of indicators such as morphological, sexual, dental and skeletal maturational changes which are more specific to each individual.

Although there is a significant association between skeletal maturity and facial growth at the time of puberty,³ the use of hand-wrist radiographs to evaluate craniofacial growth has been disputed.^{1,4} A relationship

exists between the changes in the shape of the cervical vertebrae and CA.⁵ The Cervical Maturation Method (CVM) was developed to assess skeletal maturation from Lateral Skull Radiographs (LSR) as this view is commonly taken as part of a diagnostic process, and therefore conforms to European guidelines on radiation exposure.⁶ The validity of this method has been independently confirmed.^{7,8}

The development of the DARLInG (Dental Age Research London Information Group) database involves the development of a Reference Data Set (RDS) for different populations. A RDS was developed and validated in 2013 for the Maltese population, partitioned by gender for the ages between 4–26 years from a study sample of 1593 panoramic radiographs.⁹ As Dental Panoramic Tomograms (DPT) are far

more prevalent in orthodontic practice than LSRs, a number of studies have been carried out to examine the correlation between dental and skeletal maturity. However, a meta-analysis of studies assessing DA (Dental Age) according to Demirjian's method¹⁰ and CVM assessment found that, although dental and skeletal maturity were significantly correlated, with some variation across different ethnic populations, the diagnostic performance of dental maturity for the identification of growth phases, and especially of the pubertal growth spurt, is limited.¹¹

Aim of the present study

The aim of this study was to analyse the correlation between skeletal and dental maturity with chronological age and to determine the clinical importance of these biological indicators. Resulting correlations between the variables were expected to help determine whether a DPT alone could be used to assess the maturity and growth potential of an individual.

Materials and methods

Approval was obtained from the University of Malta Ethics Committee and the Mater Dei Hospital Data Protection Officer, Malta (003/2014).

Sample size was estimated using an online utility software, assuming a maximum width of $\pm 5\%$ of the 95% confidence interval.¹² Subjects were selected in a sequential order from the patient radiographic database at the Orthodontic Department and Teaching Clinic at Mater Dei Hospital, Malta. The eligibility of subjects was determined according to the following criteria.

Inclusion criteria:

- Available LSR and DPT, both taken on the same day
- All teeth clearly visible on the DPT
- C2, C3 and C4 clearly visible on the LSR
- Maltese nationality, with a Maltese ID number;
- Aged between 8 and 18 when the radiograph was taken.

Exclusion criteria:

- Foreign nationals or non-Maltese ID number;
- Poor quality radiographs preventing accurate analysis
- Conditions that might affect growth in general

and calcification of teeth; for example, craniofacial syndromes, cleft lip and/or palate or undergoing radiotherapy or chemotherapy.

The medical history was determined from the hospital notes of all eligible subjects.

All radiographic exposures were carried out at the Dental Department of Mater Dei Hospital, using a Gendex Orthoralix 9200 DDE (Gendex Dental Systems, Italy).

Data collection

All radiographs were assessed on the same monitor by the same author (BC), who was blinded to the age or date of birth of the subject when assessing the developmental stage. Images were viewed using the Centricity Universal Viewer (GE Healthcare, USA). Digital magnification allowed for more accurate analysis. No more than 10 radiographs were analysed by the examiner at any one session to reduce errors in measurements due to examiner fatigue.

The DPT was used to assess the development of all the left maxillary and mandibular permanent teeth, including the third molars, together with the right maxillary and mandibular third molars, following the Dental Age Estimation (DAE) method described by Roberts et al.¹³

The LSR for the same patient was required to determine skeletal maturity. Cervical vertebrae C2, C3 and C4 were visually assessed using the CVM index.⁷ Linear measurements were carried out digitally using tools available on the visualising programme.

Dental maturity and CVM stages were recorded and inputted into a Microsoft Access® database (Microsoft Corporation, USA). The author remained blinded to the date of birth until all data were entered.

The RDS specific to the Maltese population⁹ was then used to input the age at attainment of the specific tooth development stages and determine the DA estimate using the simple average method.¹⁴

Twenty DPTs and twenty LSRs, separate from the study sample, were assessed for dental staging and skeletal maturation, respectively, at two different time periods, at least three weeks apart, in order to determine intra-examiner reliability. This was tested using Cohen's Kappa Index.

The results were analysed using Microsoft Excel and the Analyse-it plugin for Microsoft Excel (Analyse-it

Table I. Chronological age (CA) and dental age (DA) corresponding to all CVM stages (CS = Cervical Maturational Stage).

CS	Females				Males			
	N	CA	DA	Difference	N	CA	DA	Difference
1	4	11.20 ± 1.04	11.81 ± 0.82	-0.61 ± 0.8	13	12.47 ± 0.51	12.46 ± 0.55	0.01 ± 0.75
2	9	11.44 ± 0.94	12.40 ± 1.06	-0.97 ± 1.08	14	12.63 ± 1.05	12.94 ± 0.70	-0.31 ± 1.31
3	27	11.67 ± 1.42	12.44 ± 0.71	-0.77 ± 1.38	16	12.45 ± 1.07	12.76 ± 0.97	-0.30 ± 0.65
4	85	13.28 ± 1.42	13.13 ± 0.95	0.15 ± 1.10	56	13.49 ± 1.43	13.3 ± 1.14	0.18 ± 1.36
5	84	14.30 ± 1.48	13.70 ± 1.50	0.60 ± 1.34	30	14.89 ± 1.10	14.47 ± 1.52	0.41 ± 1.23
6	33	14.66 ± 1.62	13.77 ± 1.64	0.88 ± 1.49	10	15.85 ± 1.51	14.53 ± 0.99	1.31 ± 1.29
Total	242	13.54 ± 1.76	13.29 ± 1.34	0.25 ± 1.37	139	13.66 ± 1.6	13.47 ± 1.32	0.19 ± 1.25

Software, Ltd. <http://www.analyse-it.com/>; 2009). The Shapiro-Wilk test was applied to determine data normality. Mann Whitney U-tests were used to compare the CA and DA estimates and to visualise the association between CA, DA and CVM. Spearman rank correlation was used to test the correlation between CA and the CVM stages, DA and the CVM stages and between the Tooth Development Stages (TDS) and CVM. As the correlation coefficient calculation involved 18 non-independent variables, the Bonferroni correction was used to adjust the significance level to $P = 0.003$.

Results

Cohen's Kappa values were 0.8839 (sd ± 0.025) for the dental calcification staging and 0.8768 (sd ± 0.11) for the CVM method. The values obtained in the present study indicate almost perfect agreement.¹⁵

Three hundred and eighty-four subjects were selected. Of these, three patients had no third molars and were therefore excluded from the study. The final sample size was 381, which did not affect the power of the study.

CA and DA corresponding to all CVM stages (CS) for males and females separately are shown in Table I. The difference between DA and CA was similar between genders (0.25 ± 1.37 in females and 0.19 ± 1.25 in males).

Normality of data

The Shapiro-Wilk test found the data were not of normal distribution. Log transformation was unsuccessful, and so non-parametric tests were applied to analyse the data.

CA and DA estimates

The Mann-Whitney U-test showed no significant difference between the two groups with p values >0.05, thus demonstrating no correlation between dental development and the CVM index for the entire sample ($p = 0.057$), and for males ($p = 0.433$) and females ($p = 0.091$) separately.

Correlation between CA and CVM stages

Spearman rank correlation was used to test the relationship between CA and the CVM stages. The resultant coefficients were of moderate correlation (0.5471) in females and strong correlation (0.6451) in males and moderate correlation in the overall sample (0.5631). Using the Mann-Whitney U-test, CA was plotted against CVM and the means, standard deviations (SD) and 95% confidence intervals (CI) are shown in Figure 1.

Correlation between DA estimates and CVM stages

There was a weak correlation (0.3366) for females, moderate correlation (0.5481) for males and a weak correlation for the overall sample (0.3914). Using the Mann-Whitney U-test, DA was plotted against CVM. The means, standard deviations (SD) and 95% confidence intervals (CI) are shown in Figure 2. The graph shows that CI and SD of these stages overlap in almost all stages in both groups.

Correlation between TDS and CVM stages

Table II shows Spearman rank coefficients between TDS and CS in males and females. The incisors

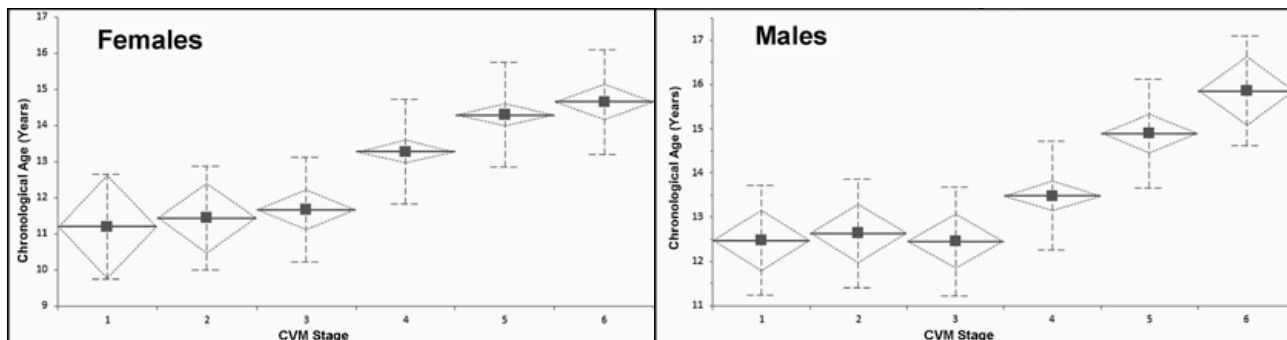


Figure 1. Mann Whitney U-test used to plot CA vs CVM stages for both females and males. There was no significant difference between consecutive stages. Height of dotted triangles = 95% CI, Dashed lines = 1 SD.

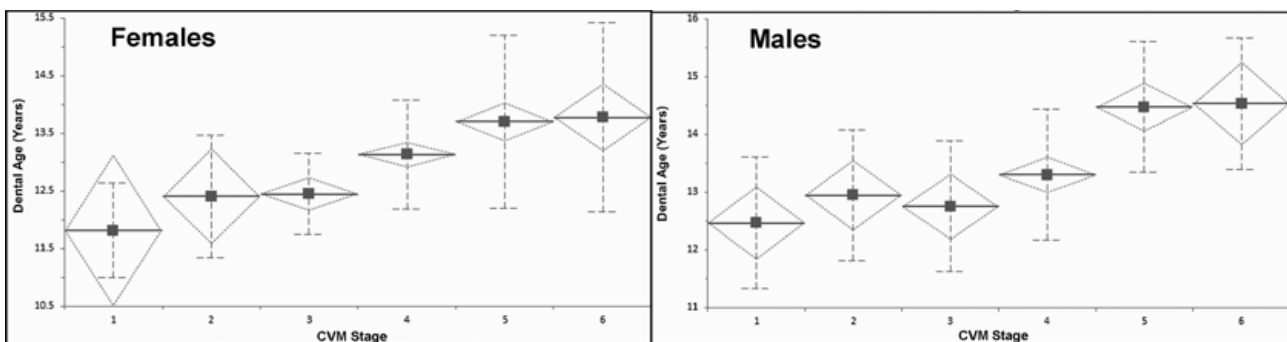


Figure 2. Mann Whitney U-test used to plot DA vs CVM stages for both females and males. There was no significant difference between consecutive stages. Height of dotted triangles = 95% CI, Dashed lines = 1 SD.

and first molars in males and the incisors in females were excluded from the correlation analysis since all or most of these teeth were in stage H. In males, a moderate correlation was observed overall. The highest correlation was that of 0.5935 for the upper right third molar, closely followed by the lower left first premolar at 0.5915. In females, weak correlation coefficients were observed. The highest correlation was 0.3966 of the lower left second premolar, followed by the lower left second molar at 0.3854.

Discussion

The determination of growth potential in an orthodontic patient is important and therefore biological indicators of maturity other than CA have been investigated over the years. The present study aimed at understanding the skeletal and dental maturation with respect to CA in a Maltese cohort aged from 8–18 years.

Intra-examiner reliability was almost perfect at 0.8839 (sd ± 0.025) and 0.8768 (sd ± 0.11), which is not surprising as the reliability of both the DAE and CVM methods has been shown to be high.¹⁶

The data were found to be not of normal distribution. This could be due to the majority of subjects presenting for orthodontic treatment being in the 11–13 age range. Furthermore, the local cut-off age for Maltese National Health Service eligibility is 16 years. Older patients are eligible only in special circumstances. This would lead to skewing of the data towards the younger age groups.

The unweighted average method was used in this study, in assessing all the tooth development stages for the maxillary and mandibular left teeth, and all four third molars. This method is very simple to use and possibly gives a more accurate result than the Demirjian system used in previous studies.¹⁴

The overall difference between CA and DA was 0.25 years ± 1.37 in females and 0.19 years ± 1.25 in males. These results compare well with the differences between DA and CA in other studies using the same method of DA estimation. In the present study, the RDS for the Maltese population⁹ was used to allow for more accurate prediction, eliminating differences between dental maturity in different populations or ethnic groups.^{17,18} There was no significant difference

Table II. Spearman rank coefficients (R) between dental development stages and CVM stages together with probability of the test (P).

Tooth	Correlation coefficients					
	Females			Males		
	R	P		R	P	
UR8	0.2150	0.0039	-	0.5935	0.0000	**
UL8	0.3612	0.0000	**	0.4872	0.0000	**
LL8	0.3360	0.0000	**	0.4094	0.0000	**
LR8	0.2867	0.0001	**	0.4049	0.0000	**
LL1	0.0436	0.5124	nt	0.1353	0.1372	nt
LL2	0.0424	0.5255	nt	1.0000	0.1324	nt
LL3	0.3097	0.0000	**	0.5588	0.0000	**
LL4	0.2952	0.0000	**	0.5915	0.0000	**
LL5	0.3966	0.0000	**	0.4653	0.0000	**
LL6	0.1419	0.0283	-	0.0844	0.3286	nt
LL7	0.3854	0.0000	**	0.5001	0.0000	**
UL7	0.3021	0.0000	**	0.4408	0.0000	**
UL6	0.1404	0.0329	-	0.0898	0.2951	nt
UL5	0.2917	0.0000	**	0.4873	0.0000	**
UL4	0.1547	0.0440	-	0.4839	0.0000	**
UL3	0.3249	0.0000	**	0.4247	0.0000	**
UL2	0.1048	0.1330	nt	0.1375	0.1247	nt
UL1	0.0974	0.1358	nt	0.1281	0.1342	nt

** $p < 0.003$, nt = not tested, - = not statistically significant

between CA and DA for the separate gender groups and the entire sample. Thus, DA is a valid substitute for CA and both may be compared to CVM with confidence.

For all CVM stages, the CA in females was less than that of their male counterparts at the same stage, which is consistent with previous studies.^{19,20} The pubertal growth spurt occurs around the time of CS3 and CS4.⁷ In the present cohort, this would align with age 11.67 ± 1.42 and 13.28 ± 1.42 respectively in females, and at 12.45 ± 1.07 and 13.49 ± 1.43 in males. As seen in Figure 1, the 95% CIs of CA at CS4 in females were distinct from the other stages, suggesting a degree of prediction of skeletal maturity in females by their CA at CS4; although, as evidenced by the SD, extrapolation of this result clinically is unlikely to be accurate due to high individual variation.

Spearman rank order correlation between CA and CVM was found to be 0.547 in females, 0.645 in

males and 0.563 for the entire sample. These results were lower than those found in the literature: 0.864 by Baidas²² and 0.75 and 0.78 by Alkhal et al.²¹ Safavi et al. found a correlation of 0.62, which is closer to the present results.²³ Therefore, although the result may be statistically significant, the current study suggests that the correlation is not sufficient to predict DA with any degree of accuracy.

For the entire sample, the correlation between DA against the CVM stages was of moderate significance. Higher correlations have been previously described.²⁰ Although this correlation may be significant statistically, clinical interpretation should be undertaken with care.

When CVM stages were plotted against CA and DA (Figures 1 and 2) the CIs at the different stages overlapped significantly in both genders, and the CIs and SDs of the DAs were wider than those of CA. CA is not an adequate predictor of skeletal maturity

and the results of the present study suggest that, at any stage, DA is even less accurate in this respect. The lower correlations found between CVM and DA than CA reinforce this concept. DA does not seem to be a suitable estimator of skeletal maturity and is therefore unlikely to predict the timing of the pubertal growth spurt with any accuracy.

In the present study, the Spearman rank correlation between CVM stages and the maturation stages of the teeth was weak in females and moderate in males. The teeth showing highest correlation were the lower left second premolar in females and the upper right third molar in males. These results differed from others, which frequently described the lower left second molar as the tooth showing highest correlation;¹⁹ however, the wide variation in the tooth types and the poor correlations shown between the tooth types and CVM stages, both in the present study and others, makes CVM prediction by individual tooth calcification stages an unreliable method.

Skeletal maturity measured by CVM is closely associated with the pubertal growth spurt, since the cervical vertebrae are part of the musculoskeletal system. The somatic development of each individual is affected by genetic, as well as nutritional, climatic, hormonal, and environmental factors.^{24,25} However, skeletal and dental development are two different processes.²⁶ Dental maturity is tightly genetically controlled, with no or minimal association with the hormonal changes seen during puberty or with nutritional or environmental factors. Even under the effects of extreme systemic disease, dental development appears to be affected only to a minor extent.²⁷ Therefore, the use of a DPT for DA estimation in order to predict skeletal maturity is unlikely to be of benefit. This is consistent with previous conclusions indicating that dental maturation estimation is of limited value in the prediction of the pubertal growth spurt.¹¹

Skeletal growth may be affected by many factors but it will proceed alongside dental development, in normal healthy children. Therefore, a correlation is known to exist but is unlikely to be accurate, particularly in children with abnormal growth patterns. Unfortunately, these are the patients in whom valid predictions are most needed.²⁸

Conclusion

A weak to moderate correlation exists between dental development and CVM stages; however, this is not sufficient to predict the skeletal age of any individual with acceptable accuracy to be of clinical value.

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