Accuracy assessment of dental age estimation with the Willems, Demirjian and Nolla methods in Spanish children. Comparative cross-sectional study.

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Abstract

Background: The objective of this study was to evaluate and compare the validity and accuracy of the Willems, Demirjian and Nolla methods in predicting chronological age in a Spanish ethnicity population.

Methods: A sample of 604 orthopantomographs of Spanish children aged 4 to 14 years was evaluated by two independent evaluators. Descriptive statistics were applied to calculate the chronological age and dental age, presenting the mean and standard deviation. The difference between dental age and chronological age was calculated for each method. A positive result indicated an overestimation and a negative figure indicated an underestimation. The Wilcoxon test for paired data and Spearman's correlation coefficient were applied by age groups and gender to compare the chronological age and dental age of each method (that of Willems, Demirjian and Nolla). Statistical tests were performed at a 95% confidence level.

Results: The interexaminer agreement was 0.98 (p = 0.00), and the intraexaminer agreement was 0.99 (p = 0.00). The Willems method significantly overestimated the age of boys (0.35 years (0.93)) and girls (0.17 years (0.88)). The Demirjian method significantly overestimated the age of boys (0.68 years (0.95)) and girls (0.73 years (0.94)). The Nolla method significantly underestimated age in boys (0.44 years (0.93)) and girls (0.82 years (0.98)).

Conclusions: In the Spanish population, the use of the Demirjian method for legal and medical purposes is frequent. This study reveals that the Willems method is more appropriate due to its greater precision in estimating dental age.

Background

The estimation of chronological age is used as a clinical tool in the field of pediatric dentistry and orthodontics, allowing us to assess the progress or the most appropriate treatment of different dental malocclusions based on craniofacial growth in children [1, 2]. It also has great value in legal and anthropological medical studies [1], providing information on past populations and helping in the identification of deceased persons or in immigration matters, clarifying the age of living people whose data are doubtful or nonexistent [2].

There is no consensus on what is the best method to predict chronological age [3]. Bone growth evaluation has been used on wrist radiographs [4, 5] or according to the stages of maturation of the cervical vertebrae [6–8]. Currently, one of the most commonly used methods to estimate chronological age is the calculation of dental age through the mineralization phases of the teeth. This method is accepted and recognized because it shows little variation compared to other properties related to skeletal or sexual growth. However, hereditary, functional, environmental, gender, nutritional and metabolic factors must be taken into account since the specific standards of each population are important for the application of these methods. Therefore, assessing the accuracy and applicability of age estimation methods for different populations is of vital importance [3].

The Demirjian method [9, 10] is one of the most popular tools for predicting chronological age due to its simplicity, the degree of intraexaminer agreement and the ease of its standardization and reproducibility [3]. In the Spanish population, the Demirjian method is recommended by the Institutes of Legal Medicine of Spain [11] for legal and medical purposes, and it has been used in numerous studies independently [8, 12–15] or together with the Nolla method [1, 16, 17].

The Willems method [18] was a modification of the Demirjian method [9] published in 1973. It has been applied to different populations, observing that it provides comparatively smaller overestimations than other methods [19] and that the estimate is even more precise [20] in some populations. However, the Willems method cannot be used as a global tool due to the differences between ethnicities [21]. In Spanish ethnicity, it has been applied only to a sample of 266 children compared to the Demirjian and Cameriere methods [22].

The objective of the study was to evaluate and compare the validity and accuracy of the Willems, Demirjian and Nolla methods in predicting chronological age in Spanish ethnicity.

Methods

The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) [23] recommendation guidelines were followed in this study and was conducted in accordance with the Declaration of Helsinki [24]. A cross-sectional design was carried out using panoramic radiographs of 604 patients (302 boys and 302 girls) of Spanish ethnicity from five different clinics in the community of Madrid (Hortaleza, Carabanchel, Campamento, Arganzuela, and the city center). Patients were recruited between 2004 and 2015, and the data were analyzed between January and December 2017.

Inclusion and exclusion criteria

The inclusion criteria were as follows: radiographs from children between 4 JPEG (Joint Photographic Experts Group and 14 years old, with parents of Caucasian-Hispanic origin, with images saved in) format, and with the presence of all mandibular teeth.

The exclusion criteria were radiographs where the date of birth and gender were not registered; poor-quality radiographs that did not allow proper visualization of the degree of dental development; or radiographs from children with systematic diseases, syndromes or alterations in dental development, permanent tooth extraction (except for the third molar), the use of orthodontic appliances or a history of dental trauma.

Obtaining and management of radiographs

Radiographs were selected using the random function of the Excel 14.0 (Microsoft Office, Redmond, Washington, USA) program in a previous list of potential children who met the inclusion criteria. All panoramic radiographs of the subjects were obtained with the same Orthodox 2D1 X-ray device model (Siemens, Spain) and were saved in JPEG format. The radiographs were analyzed by two independent evaluators (Marta Paz Cortes and Rosa Rojo) on two computers

with AMD Ryzen 5-3500 U, 8 GB RAM, 1 TB HDD + 256 GB SSD, AMD Radeon Vega HD 7950 graphics cards with 27 GB 1920_1080 resolution LED monitors and Intel Core i7 processors. The evaluators were blinded concerning the chronological age of the patient. The following data were registered in a data collection notebook (CRF): clinic history number, dental clinic, the date of birth, the date of the X-ray, gender, and the degree of dental calcification according to the Demirjian and Nolla methods.

Methodology for the calculation of age

Chronological age (CA)

The chronological age was calculated by subtracting the date of the radiography from the date of birth.
Dental age (DA): Dental age was calculated according to the degree of dental development using three methods: the Demirjian, Willems, and Nolla methods.

The Demirjian [25] method assesses the degree of development of each of the lower-left teeth (except the third molar) by classifying them on an 8-stage scale represented by the letters A through H. A score is assigned to each of the seven teeth according to their degree of mineralization. The stage represented by the letter is converted to a score, according to gender, using a conversion table developed by the authors. All the numerical scores are added, and the result is converted to dental age, according to gender, by referring to another table.

The Willems [18] method assesses the degree of development of each of the lower-left teeth (except the third molar) using the classification of the method proposed by Demirjian. A score is assigned to each of the seven teeth, which is converted to an average score, according to gender, in a calculation developed by the authors. All the values are added, and the result corresponds to the dental age.

The Nolla [26] method assesses the degree of dental development of the teeth of the lower-left teeth and the upper-left teeth (except the third molar) by classifying it into ten degrees of dental development. A score is assigned to each of the teeth, which is converted to an average score, according to gender, in a calculation developed by the authors. All the values are added, and the result corresponds to the dental age.

Reproducibility of measurements

After the evaluation of 20 radiographs, the two evaluators had a rest period of 10 minutes (maximum analyzed 100 radiographs per day). After the evaluation of all radiographs and after 8 weeks, one of the evaluators (Marta Paz Cortes) reevaluated 100% of the radiographs of the total sample using the Willems, Demirjian and Nolla methods. Their selection of the order of radiographs was made randomly with the random Excel command.

The sample size calculation was based on a 95% confidence interval, a power of 80% and an effect size of 0.30, taking into account the data published in the study by Feijóo et al. [13] about the Spanish population with the Demirjian method. We used the difference of means between the real age and the chronological age in children (0.87 years) and the standard deviation (2.95 years) assuming the null hypothesis, in which there are no differences between the real age and the chronological age.

Statistical analysis

Descriptive statistics were applied to calculate the chronological age and dental age, presenting the mean and standard deviation. The difference between DA and CA was calculated for each method. A positive result indicated an overestimation and negative figure of an underestimation. The Shapiro-Wilk test was applied to determine the normality of the data, which showed a nonparametric distribution. The Wilcoxon test for paired data was applied by age groups and gender to compare the chronological age and dental age of each method (Willems, Demirjian and Nolla). Spearman's correlation coefficient was applied to assess the correlation between the chronological age and dental age of each method (Willems, Demirjian and Nolla). A regression analysis by each method and by gender was performed. Kappa statistics were used to assess inter- and intraobserver reliability. To perform the sample calculation, the paired test was used to compare correlated measures specifying the standard deviations of the differences. Statistical tests were performed at a 95% confidence level with the Stata 11.1 software package (Stata Corp, College Station, TX, USA).

Results

The mean chronological age of the entire sample was 8.77 years (1.94), of which that of boys and girls was 8.84 years (2.01) and 8.71 years (1.88), respectively. The distribution by age group of the total sample and according to gender is shown in Table 1.

Table 1
Distribution of the sample by age groups and gender.
SD: standard deviation.

Age groups	Total	Mean	SD	Girls	Boys
4-6.9	122	0.48	0.50	59	63
7-7.9	119	0.55	0.50	65	54
8-8.9	136	0.51	0.50	69	67
9-10.9	130	0.52	0.50	67	63
11-13.9	97	0.43	0.50	42	55
Total	604			302	302

Reproducibility Analysis

The interexaminer agreement was 0.98 (p = 0.00), and the intraexaminer agreement was 0.99 (p = 0.00). The results showed an almost perfect agreement in both cases; therefore, the data of the first examiner were used for the analysis of the data.

Accuracy for age estimation

In this study, the mean dental age calculated with the Willems method was generally 9.04 years (1.99), of which that of boys and girls was 9.19 years (2.04) and 8.88 years (1.93), respectively. The difference in means between dental and chronological age in boys was statistically significant (p = 0.00) between 4 and 8.9 years. At all ages, the Willems method overestimated, being more precise between 11 and 13.9 years, with a mean difference of 0.01 years (0.87). The difference in means between dental and chronological age in girls was statistically significant (p = 0.00) between 4 and 7.9 years. In the corresponding age ranges between 8 to 8.9 and 11 to 13.9, the Willems method underestimated and was more accurate, with mean differences of 0.08 (0.59) and 0.05 (1.22), respectively. In the rest of the age groups, the method overestimated (Table 2).

Table 2
Results of the calculation of the dental age with the Willems method. The Wilcoxon test for paired data was applied by age groups and gender to compare the chronological age and dental age. Statistical tests were performed at a 95% confidence level ($p \leq 0.05$). DA: Dental age; CA: Chronological age; Diff.SD: Standard deviation differences; SD: standard deviation; O: Overestimation; U: Underestimation.

Girls									
Age groups	n	CA		DA Willems		p-value	DA-CA	Diff.SD	Trend
		mean	SD	mean	SD				
4-6.9	59	6.46	0.48	7.00	0.89	0.000	0.54	0.70	O
7-7.9	65	7.50	0.30	7.77	0.79	0.008	0.26	0.73	O
8-8.9	69	8.45	0.28	8.37	0.60	0.145	-0.08	0.59	U
9-10.9	67	9.97	0.57	10.13	1.25	0.321	0.16	1.05	O
11-13.9	42	12.14	0.63	12.08	1.32	0.965	-0.05	1.22	U
Total	302								
Boys									
Age groups	n	CA		DA Willems		p-value	DA-CA	Diff.SD	Trend
		mean	SD	mean	SD				
4-6.9	63	6.40	0.55	6.88	1.24	0.000	0.48	0.93	O
7-7.9	54	7.60	0.28	8.26	1.09	0.000	0.66	1.04	O
8-8.9	67	8.45	0.29	8.81	0.76	0.000	0.36	0.67	O
9-10.9	63	9.89	0.58	10.11	1.16	0.163	0.23	1.03	O
11-13.9	55	12.15	0.60	12.16	0.88	0.782	0.01	0.87	O
Total	302								

The mean dental age calculated with the Demirjian method was in general 9.48 (2.08), of which that of boys and girls was 9.52 (2.11) and 9.44 (2.05), respectively. The difference in means between dental and chronological age in both boys and girls was statistically significant (p = 0.00) in all age groups. In boys, the Demirjian method was more precise between 11 and 13.9 years, with a mean difference of 0.50 years (1.00), and in girls between 8 and 8.9 years, with a difference in averages of 0.48 years (0.76) (Table 3).

Table 3

Results of the calculation of the dental age with the Demirjian method. The Wilcoxon test for paired data was applied by age groups and gender to compare the chronological age and dental age. Statistical tests were performed at a 95% confidence level ($p \leq 0.05$). DA: Dental age; CA: Chronological age; Diff.SD: Standard deviation differences; SD: standard deviation; O: Overestimation; U: Underestimation.

Girls									
Age groups	n	CA		DA Demirjian		p-value	DA-CA	Diff.SD	Trend
		mean	SD	mean	SD				
4-6.9	59	6.46	0.48	7.48	0.82	0.000	1.02	0.65	O
7-7.9	65	7.50	0.30	8.20	0.83	0.000	0.69	0.78	O
8-8.9	69	8.45	0.28	8.92	0.79	0.000	0.48	0.76	O
9-10.9	67	9.97	0.57	10.77	1.34	0.000	0.80	1.18	O
11-13.9	42	12.14	0.63	12.84	1.28	0.000	0.70	1.21	O
Total	302								
Boys									
Age groups	n	CA		DA Demirjian		p-value	DA-CA	Diff.SD	Trend
		mean	SD	mean	SD				
4-6.9	63	6.40	0.55	7.28	1.09	0.000	0.88	0.78	O
7-7.9	54	7.60	0.28	8.43	1.04	0.000	0.84	0.99	O
8-8.9	67	8.45	0.29	9.03	0.87	0.000	0.57	0.76	O
9-10.9	63	9.89	0.58	10.47	1.31	0.001	0.59	1.63	O
11-13.9	55	12.15	0.60	12.65	1.00	0.000	0.50	1.00	O
Total	302								

The mean dental age calculated with the Nolla method was generally 8.14 years (1.82), of which that of boys and girls was 8.40 years (1.81) and 7.88 years (1.80), respectively. The difference in means between dental and chronological age in boys was statistically significant ($p = 0.00$) between 8 and 13.9 years. In all ages, the Nolla method underestimated, except for the ages between 4 and 6.9 years, where it was also more accurate, with a mean difference of 0.03 years (0.69). The difference in the means between dental and chronological age in girls was statistically significant ($p = 0.00$) in all age groups. The method underestimated in all cases and was more precise in the ages between 4 and 6.9 years, with a mean difference of 0.29 (0.60) (Table 4).

Table 4

Results of the calculation of the dental age with the Nolla method. The Wilcoxon test for paired data was applied by age groups and gender to compare the chronological age and dental age. Statistical tests were performed at a 95% confidence level ($p \leq 0.05$). DA: Dental age; CA: Chronological age; Diff.SD: Standard deviation differences; SD: standard deviation; O: Overestimation; U: Underestimation.

Girls									
Age groups	n	CA		DA Nolla		p-value	DA-CA	Diff.SD	Trend
		mean	SD	mean	SD				
4-6.9	59	6.46	0.48	6.17	0.72	0.000	-0.29	0.60	U
7-7.9	65	7.50	0.30	6.85	0.81	0.000	-0.66	0.76	U
8-8.9	69	8.45	0.28	7.51	0.83	0.000	-0.94	0.81	U
9-10.9	67	9.97	0.57	8.97	1.00	0.000	-1.00	0.96	U
11-13.9	42	12.14	0.63	10.79	1.59	0.000	-1.35	1.49	U
Total	302								
Boys									
Age groups	n	CA		DA Nolla		p-value	DA-CA	Diff.SD	Trend
		mean	SD	mean	SD				
4-6.9	63	6.40	0.55	6.43	0.91	0.813	0.03	0.69	O
7-7.9	54	7.60	0.28	7.52	0.93	0.355	-0.77	0.87	U
8-8.9	67	8.45	0.29	7.99	0.69	0.000	-0.47	0.60	U
9-10.9	63	9.89	0.58	9.24	1.10	0.000	-0.65	1.02	U
11-13.9	55	12.15	0.60	11.05	0.97	0.000	-1.10	1.00	U

In general, the Willems method significantly overestimates in both boys, 0.35 years (0.93) (p = 0.00), and girls, 0.17 years (0.88) (p = 0.00). The Demirjian method significantly overestimates in both boys, 0.68 years (0.95) (p = 0.00), and girls, 0.73 years (0.94) (p = 0.00). The Nolla method underestimates significantly in both boys, 0.44 years (0.93) (p = 0.00), and girls, 0.82 years (0.98) (p = 0.00). The most accurate method to estimate age was the Willems method for both genders (Table 5).

Table 5

General and gender results of the comparison of chronological age with each dental method. The Wilcoxon test for paired data was applied. Statistical tests w ≤ 0.05). DA: Dental age; CA: Chronological age; Diff.SD: Standard deviation differences; SD: standard deviation; O: Overestimation; U:

Group	**n**	**CA**		**DA Willems**		**p-value**	**DA-CA**	**Diff.SD**	**Trend**	**DA Demirjian**		**p-value**	**DA-CA**	**Diff.SD**	**Trend**	**DA Nolla**	
		mean	**SD**	**mean**	**SD**					**mean**	**SD**					**mean**	**S**
Girls	302	8.71	1.88	8.88	1.93	0.001	0.17	0.88	O	9.44	2.05	0.000	0.73	0.94	O	7.88	1
Boys	302	8.84	2.00	9.19	2.04	0.000	0.35	0.93	O	9.52	2.11	0.000	0.68	0.95	O	8.40	1
General	604	8.77	1.94	9.04	1.99	0.000	0.26	0.91	O	9.48	2.08	0.000	0.70	0.95	O	8.14	1

Correlation between chronological age and dental age

Spearman's correlation coefficients for girls and boys show strong linear correlations between chronological age and dental age for all methods; the rho values range from 0.86 to 0.89 and are significant in all cases (p = 0.00).

The graphs show the positive correlation of the calculation of dental age with the three methods with respect to chronological age. The methods in which they are best located at the points near the line, in order of a strong relationship between the variables, are the Willems (Fig. 1), Demirjian (Fig. 2) and Nolla (Fig. 3) methods.

Regression analysis

A regression analysis was performed, and the following equations resulted for each method by gender:

For the Demirjian method:

Boys: CA = 1.278 + 0.939 * DA

Girls: CA = 0.992 + 0.970 * DA

For the Willems method:

Boys: CA = 1.150 + 0.909 * DA

Girls: CA = 0.864 + 0.920 * DA

For the Nolla method:

Boys: CA = 1.330 + 0.799 * DA

Girls: CA = 0.710 + 0.824 * DA

Discussion

In the Spanish population, the Willems method was the most accurate for estimating age. In order of precision, the most appropriate methods for application in boys were the Willems, Nolla and Demirjian methods, and in girls were the Willems, Demirjian and Nolla methods.

In Spain, the Demirjian method has been used based on the development of the third molar [15, 27]. However, in the medical-legal environment, the Demirjian method is used based on the stages of the teeth between the left central incisor and the second left molar of the mandible [11]. Its application has been very frequent, and, as in our study, the tendency of the calculation of dental age is towards overestimation [14, 16, 17, 22, 28, 29]. In the study of Melo et al. [16], the precision is very similar to ours, 0.86 and 0.70, respectively. In the case of the study of Feijoo et al. [14, 28], our results obtained greater precision in boys (0.68 versus 0.87) and lower precision in girls (0.70 versus 0.55).

There are two studies in which the Demirjian and Nolla methods have been used together [16, 17]. For both, our results coincide regarding the tendency of the Demirjian method to overestimate, although we obtained greater precision in boys [17], and our results also agreed regarding underestimation with the Nolla method [16, 17].

There is only one study carried out in a population of Spanish origin of 266 children, where the Willems method is applied together with the Demirjian method and the Cameriere method [22]. The results obtained are similar to ours, finding that the Willems and Demirjian methods overestimate and that the Willems method has greater precision. However, our study has a larger sample size, confirming the first results published in the Spanish population.

The methods used in this study have been studied worldwide. Most of the findings reported on the calculation of dental age coincide with the trend shown by our results, favoring the external validity of the methods used.

In the case of the Nolla method, we also find underestimation when applied in Brazilians and Croats [30], in Malaysians [31], in Turks [32], in Bangladeshi and British [33] or in Indians [2]. However, there are conflicting results in some of the aforementioned populations, with overestimation being found in the study of Lopes LJ et al. [3] with Brazilians and in the study of Mohammed RB et al. [34] in Indians.

In the case of the Demirjian method, we also find overestimation in Brazilians and Croats [30], in Malaysians [31], in Turks [32], in Bangladeshi and British [33] or in Indians [34].

In the case of the Willems method, we also find overestimation in Bangladeshi and British [33] and in Indians [2]. However, the study carried out by Mohammed RB et al. [34] also in the Indian population reports underestimation with the Willems method.

The application of the Demirjian, Willems and Nolla methods in the same design has been carried out only in three studies [2, 33, 34]. Maber et al. [33] analyzed 946 radiographs of children aged 3 to 16.9 years and Hegde S et al. [2] analyzed1200 radiographs in children between 5 and 15 years. As in our case, the Willems method was the most accurate, and together with the Demirjian method, they overestimated the chronological age. The Nolla method was underestimated in both cases.

In the study by Mohammed RB et al. [34], 760 radiographs were analyzed in children aged 6 to 16 years, and the results showed overestimation by the Demirjian method. However, unlike our findings, overestimation was found with the Nolla method and underestimation with the Willems method.

Studies such as that of Melo et al. [16] analyzed samples of 2641 patients aged between 7 and 21 years. However, the Demirjian method allows the estimation of age only up to 16 years[25]; therefore, the valid sample of this study was 956 children (up to 18 years). In our study, we studied children from 4 to 14 years old, with an equal proportion of boys and girls and a valid sample for the application of the methods used to estimate the dental age.

Dental age could be calculated with the regression models constructed in this study, as on other occasions they have been used in the studies of Diz et al. [1]. Given the findings presented here, it would be desirable to use the Willems method in the Spanish population to estimate the dental age.

Conclusion

The differences in the means between chronological age and dental age are statistically significant in the Willems, Demirjian and Nolla methods; therefore, none of them is completely accurate. In the Spanish population, the use of the Demirjian method for legal and medical purposes is frequent. However, the

findings of this study reveal that the Willems method, which also overestimates, is more appropriate due to its greater precision in estimating dental age.

Abbreviations

STROBE
Strengthening the Reporting of Observational studies in Epidemiology; JPEG:Joint Photographic Experts Group; CRF:data collection notebook; CA:Chronological age; DA:Dental age; SD:standard deviation; Diff.SD:Standard deviation differences; O:Overestimation; U:Underestimation

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Complutense University of Madrid, Spain (number 18/067-E). All subjects were included in the study after signing the informed consent of the father, mother, or legal guardian.

Consent for publication

Not applicable.

Availability of data and materials

The data analyzed in the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by M.M.P.C, M.R.M.M. and E.A.G. The data analysis was performed by R.R. The first draft of the manuscript was written by M.M.P.C and R.R and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

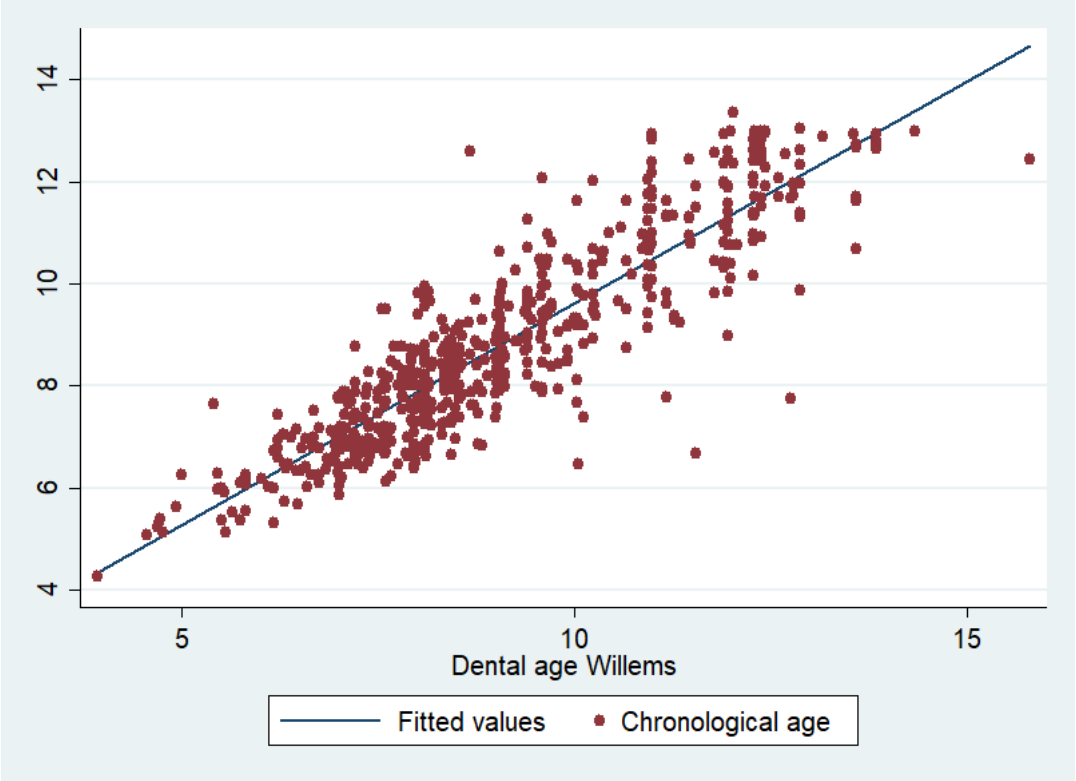

Figure 1

Graphical representation of the Spearman correlation between the dental age of the Willems method and the chronological age.

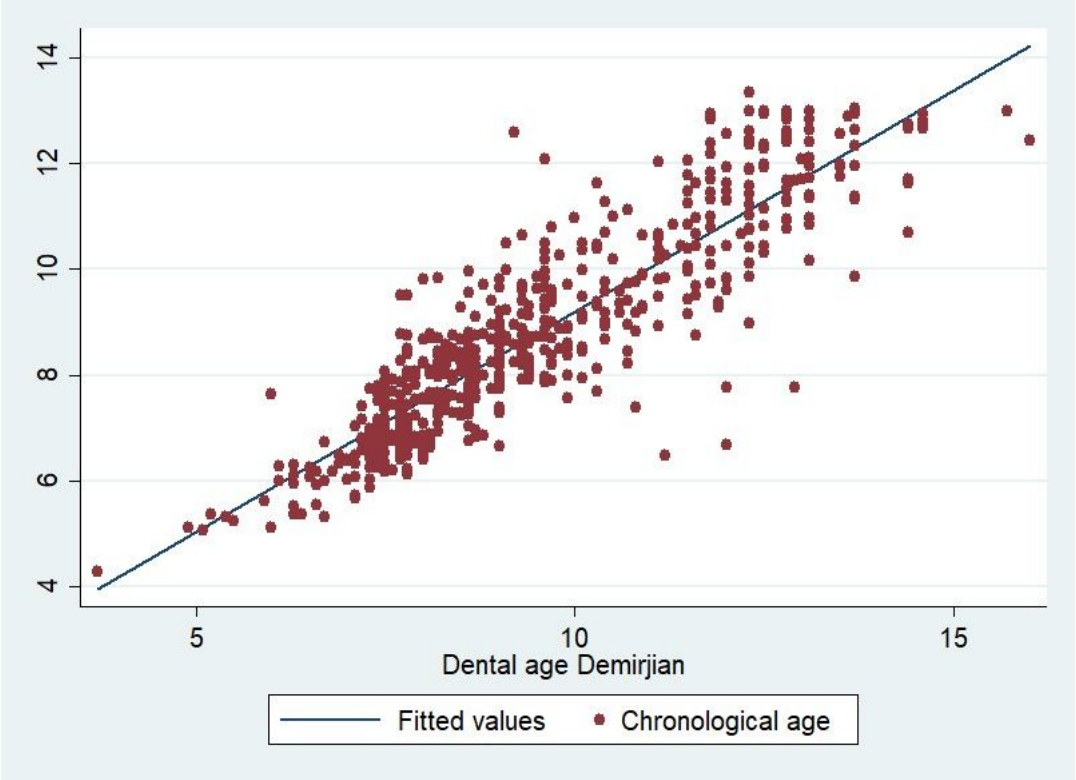

Figure 2

Graphical representation of the Spearman correlation between the dental age of the Demirjian method and the chronological age.

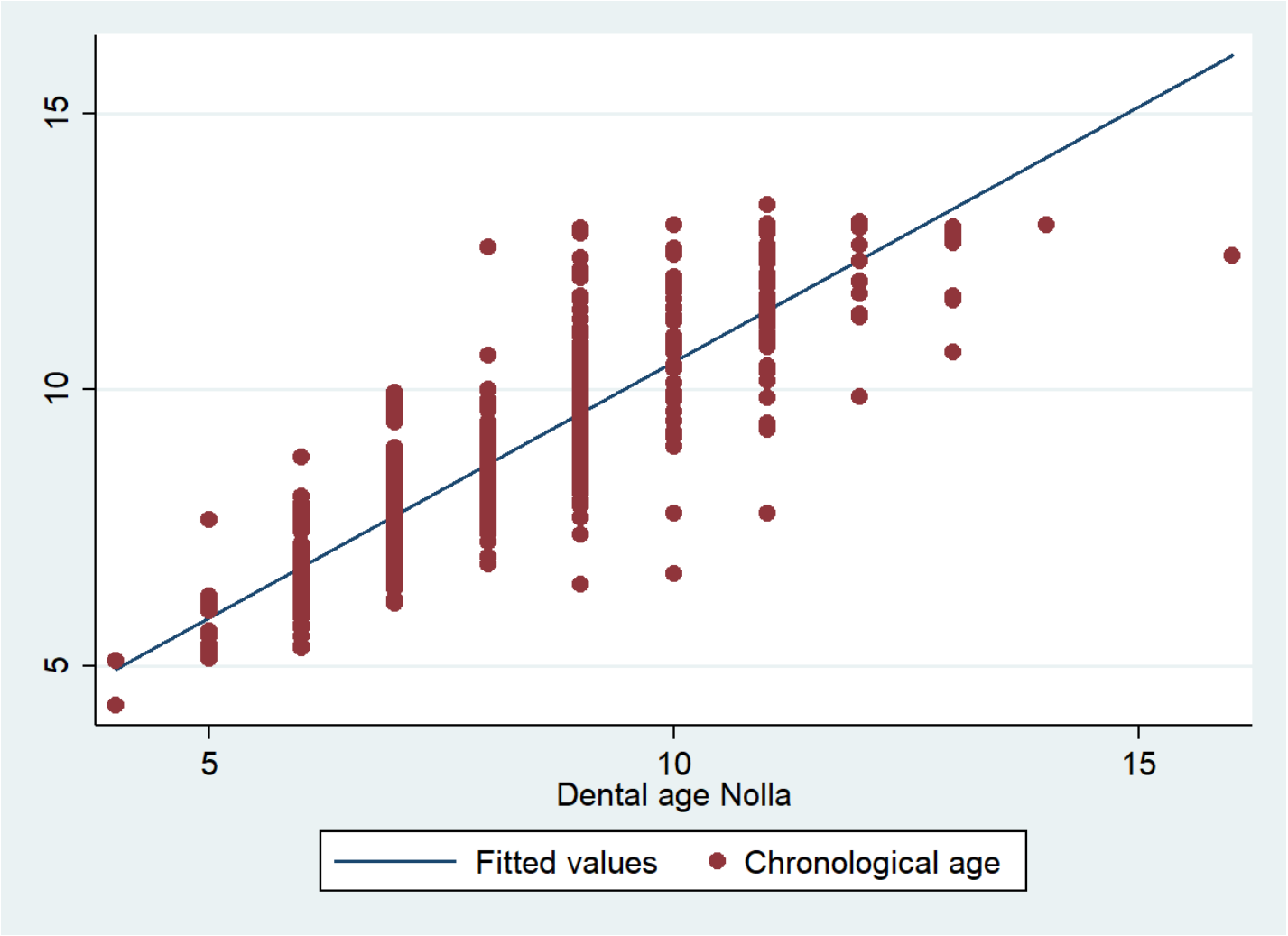

Figure 3

Graphical representation of the Spearman correlation between the dental age of the Nolla method and the chronological age.