Applicability of the Demirjian, Willems and Haavikko methods in Croatian children

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ABSTRACT

Age estimation is an inescapable part of every identification process. During growth and development, it is possible to estimate age based on the developmental stages of teeth. The aim of this study was to evaluate three frequently used methods for dental age estimation on a broad sample of Croatian children. The sample comprised 1996 digital, standardized orthopantomograms of children (1121 boys and 875 girls) aged 5 to 16, collected in four major Croatian cities. Age was estimated according to the Demirjian, Willems and Haavikko methods and the accuracy of the estimation was evaluated. The Kappa for intra-examiner agreement was 0.83 for the Haavikko stages and 0.92 for the Demirjian stages. Using the Demirjian method, the average overestimation of age was 0.80 years for boys and 0.84 years for girls. The Willems method overestimated the mean age by 0.41 years in boys and 0.22 years in girls. The Haavikko method underestimated the mean age by 0.60 years in boys and 0.80 years in girls. The Willems method proved to be the most accurate and can be used for dental age estimation among Croatian children. The Demirjian and Haavikko methods showed greater deviation between dental and chronological age and require adaptation when used in the Croatian population.

INTRODUCTION

Dental age estimation is a procedure used for clinical, forensic and archaeological purposes. During the period of growth and development, it is possible to estimate age by assessing tooth development. In their development, teeth follow a specific pattern that has been well documented since the discovery of the X-ray. It should be noted, however, that the first scientific record of teeth being used to estimate age dates back to 1837 when Saunders[1] presented a study that estimated age based on the eruption of permanent teeth. Although easily noticeable, tooth eruption is not considered a reliable age indicator as it is highly susceptible to the influence of extrinsic factors and varies significantly from child to child.[2]

The advancement of dental radiology facilitated the development of numerous methods for dental age estimation. Using a French Canadian population sample, in 1973 Demirjian developed a method that estimates age based on the developmental stages of seven permanent left mandibular teeth.[3] It has proven the most widely used and tested method

for dental age estimation. In 2001 Willems adapted the Demirjian method by simplifying the procedure and improving the accuracy of age estimation in a sample taken from the Belgian population.[4] The Haavikko method was developed using a Finnish population sample in 1974. The age estimation is based on the average chronological age for the developmental stages of a few selected teeth.[5,6]

The need for age estimation has increased over recent years due to migratory flow initiated by war, conflict and economic crises. The high rate of asylum procedures, missing children, human trafficking and cases related to legal consent and child abuse demands a reliable and accurate method for age estimation that serves to protect and ensure children's rights.

Dental development is mainly under the genetic influence, unlike skeletal development which is, apart from genes, greatly influenced by endocrinal disorders and nutrition.[7] Therefore, especially in legal processes, dental age estimation should never be omitted in age assessment.

Since every population has its singularities, scientists are encouraged to test the applicability of the existing methods and, if necessary, to adapt them for the specific population to ensure accuracy of age estimation.[8] The aforementioned methods have been tested in populations worldwide.[9–13]

The aim of this study is to evaluate the dental age estimation methods developed by Demirjian, Willems and Haavikko on a large sample of orthopantomograms of Croatian children and to provide guidelines for dental age estimation in the Croatian population.

MATERIAL AND METHODS

1996 digital, standardized orthopantomograms (OPGs) of children (1121 boys and 875 girls) aged 5 to 16 were collected in four major Croatian cities (Zagreb, Split, Osijek and Varaždin) (Table 1). All the individuals participating in this study were referred by their dentists for radiological diagnostics and no OPG was taken solely for the purpose of this investigation. Informed consent was obtained from parents or legal guardians to enable the data to be used for scientific purposes. The study was approved by the Ethics Committee of the School of Dental Medicine in Zagreb.

Table 1. Sample structure

Age (years)	Total sample			Sample for Demirjian and Willems method			Sample for Haavikko method		
	Total	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls
5 - 5.99	9	4	5	9	4	5	9	4	5
6 - 6.99	43	31	12	43	31	12	43	31	12
7 - 7.99	137	84	53	129	78	51	135	82	53
8 - 8.99	209	124	85	202	121	81	206	121	85
9 - 9.99	227	122	105	215	116	99	226	121	105
10 - 10.99	229	135	94	213	130	83	228	135	93
11 - 11.99	253	126	127	237	120	117	253	126	127
12 - 12.99	213	112	101	202	108	94	212	112	100
13 - 13.99	242	133	109	224	123	101	236	129	107
14 - 14.99	231	142	89	211	128	83	229	141	88
15 - 15.99	203	108	95	183	100	83	200	107	93
Total	**1, 996**	**1, 121**	**875**	**1, 868**	**1, 059**	**809**	**1, 977**	**1, 109**	**868**

All OPGs were taken with the Cranex device (Soredex, Finland), thus ensuring a standardized procedure for digital OPGs. The OPGs were coded without information pertaining to name, sex, date of birth and date of record. Developmental stages of the permanent teeth were assessed by one investigator (IB) using the developmental scale introduced by Demirjian [3] (Figure 1) and Haavikko [5] (Figures 2 and 3). Age was estimated according to the Demirjian [3], Willems [4] and Haavikko [6] methods. Since Demirjian and Willems use the same developmental scale and assess seven left mandibular teeth in their analysis, all OPGs missing at least one of the required teeth (31-37) were excluded. Therefore, the sample for Demirjian and Willems method was 1868 (1059 boys and 809 girls). Haavikko uses a different process of tooth selection for dental age estimation – teeth 11, 43, 44 and 46 for children under 10 years of age and teeth 13, 43, 44 and 47 for children older than 10. Consequently, the sample for the Haavikko method was 1977 (1109 boys, and 868 girls) (Table 1).

After a period of two months, 100 randomly chosen OPGs were reassessed for testing intra-examiner reliability and kappa statistics were applied.

Dental and chronological age were compared in each method and the p value was calculated for all age groups using the Wilcoxon signed-rank test. For comparison of accuracy between the Demirjian, Willems and Haavikko methods, square deviations were used, thus enabling each deviation between dental and chronological age (positive and negative) to be noted. Overall accuracy of age estimation for each method was presented as a percentage of the correct estimation within intervals of ±0.5, ±1, ±1.5 and ±2 years.

Statistical analysis was carried out by SAS software (SAS Institute INC., Cary, NC).

Figure 1. Assessment of developmental stages introduced by Demirjian for age estimation using the Demirjian and Willems method

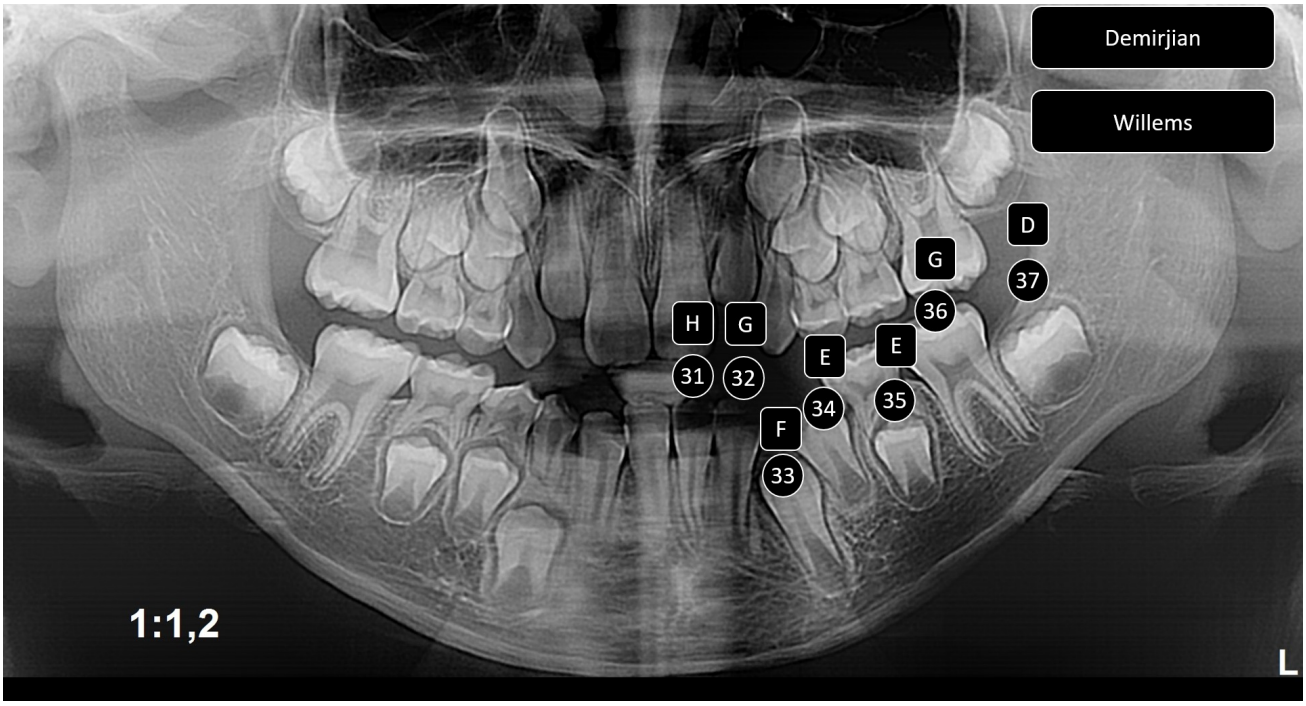


Figure 2. Assessment of developmental stages introduced by Haavikko for children younger than 10 years (teeth 11, 43, 44 and 46 are used)

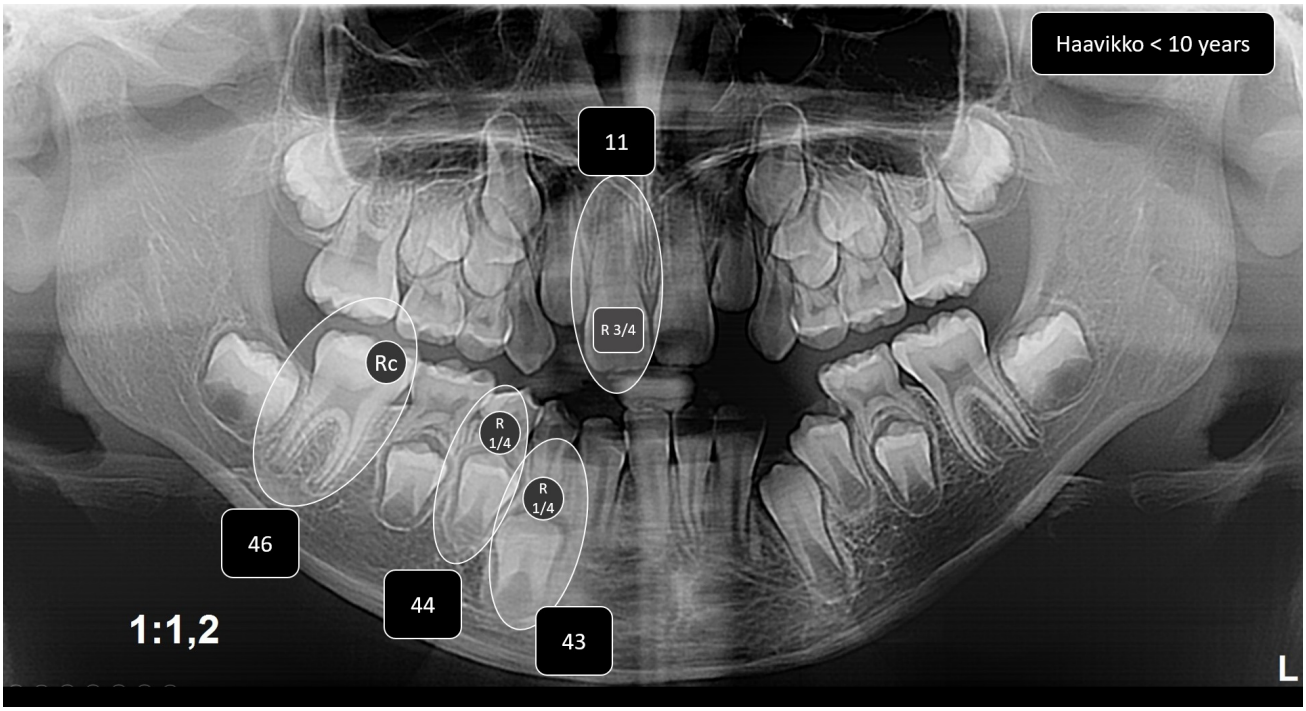
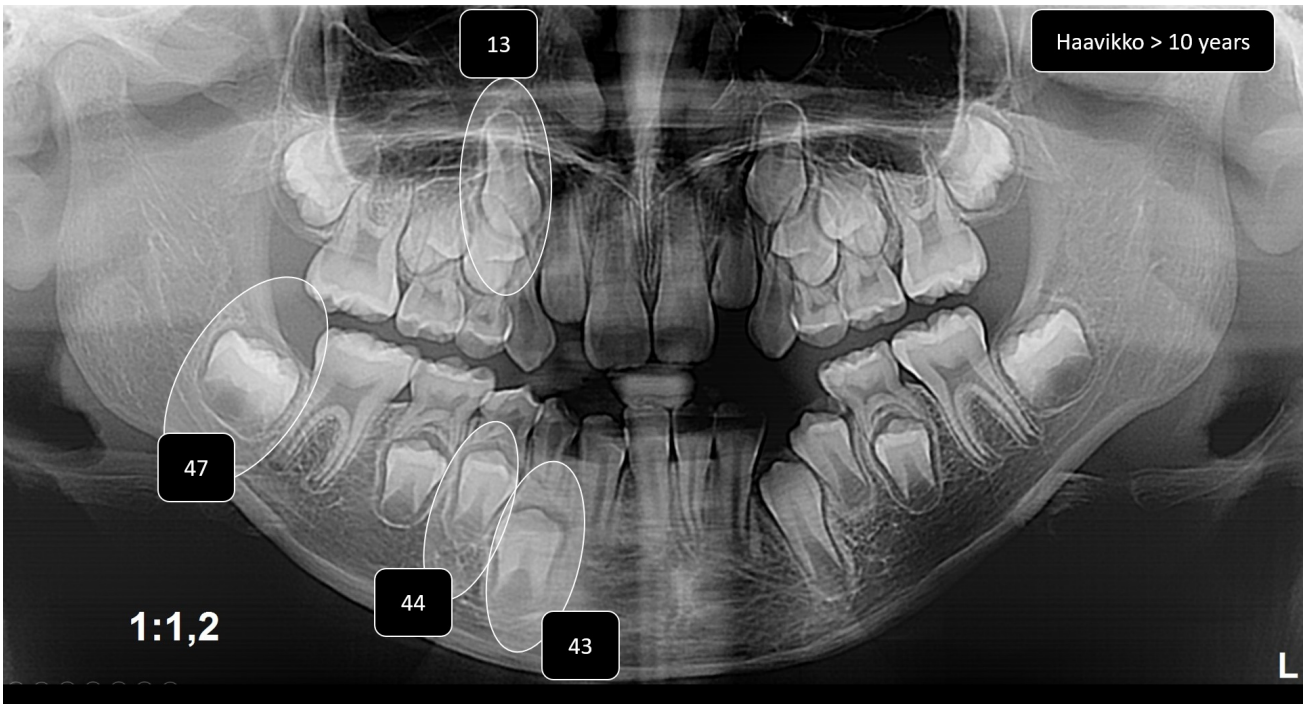


Figure 3. Assessment of developmental stages introduced by Haavikko for children older than 10 years (teeth 13, 43, 44 and 47 are used)



RESULTS

The Kappa value for intra-examiner agreement was 0.83 for the Haavikko stages and 0.92 for the Demirjian stages.

Using the Demirjian method, the average overestimation of age was 0.80 years for boys and 0.84 years for girls (Table 2). The average deviation between dental and chronological age was significant in all age groups ($p<0.001$) except the youngest. The Willems method overestimated the mean age by 0.41 years in boys and 0.22 years in girls (Table 3). The average deviation between dental and chronological age was significant in five out of eleven age groups. The Haavikko method underestimated the mean age by

0.60 years in boys and 0.80 years in girls (Table 4). The deviation was significant in seven out of eleven age groups.

In the comparison of the Demirjian, Willems and Haavikko methods, the differences between dental and chronological age (overestimations and underestimations) were presented as square deviations (Table 5). The accuracy of age estimation in the form of the percentage of correct estimations within the interval for all three methods is shown in Table 6.

Table 2. Demirjian method: comparison of chronological and dental age

Boys					Girls				
age group	Chronological age (years)	Dental age (years)	Deviation (years)	p*	age group	Chronological age (years)	Dental age (years)	Deviation (years)	p*
5 - 5,99	5,66	6,63	0,97	0,125	5 - 5,99	5,33	5,82	0,49	0,063
6 - 6,99	6,65	7,74	1,09	< 0.001	6 - 6,99	6,62	7,66	1,04	< 0.001
7 - 7,99	7,57	8,49	0,92	< 0.001	7 - 7,99	7,60	8,16	0,56	< 0.001
8 - 8,99	8,51	9,23	0,72	< 0.001	8 - 8,99	8,51	8,97	0,45	< 0.001
9 - 9,99	9,51	10,06	0,55	< 0.001	9 - 9,99	9,52	10,46	0,94	< 0.001
10 - 10,99	10,46	11,13	0,67	< 0.001	10 - 10,99	10,51	11,43	0,92	< 0.001
11 - 11,99	11,42	12,15	0,72	< 0.001	11 - 11,99	11,50	12,93	1,43	< 0.001
12 - 12,99	12,47	13,28	0,81	< 0.001	12 - 12,99	12,48	13,69	1,22	< 0.001
13 - 13,99	13,49	14,51	1,02	< 0.001	13 - 13,99	13,52	14,75	1,22	< 0.001
14 - 14,99	14,47	15,49	1,02	< 0.001	14 - 14,99	14,42	15,13	0,71	< 0.001
15 - 15,99	15,43	15,81	0,37	< 0.001	15 - 15,99	15,49	15,78	0,29	< 0.001
Total	10,51	11,32	0,80		Total	10,50	11,34	0,84	

* p value in Wilcoxon signed-rank-test

DISCUSSION

In this survey three widely used methods for dental age estimation, Demirjian, Willems and Haavikko, were evaluated for accuracy among Croatian children aged 5 to 16 years. The strength of this study lies in the large and representative sample drawn from different regions across Croatia. In addition, all the OPGs were standardized and taken with the same device, which provided images of the highest quality. To date, a sample of this size and quality for the specific purpose of dental age estimation has yet to be recorded in the Croatian population and represents a valuable addition to the scientific literature currently available.

The Demirjian and Willems methods use a simple and well explained developmental scale which consists of eight stages for the seven mandibular teeth.[3] The simplicity of usage as well as good reproducibility favours their application in dental age estimation.[14] However, OPGs with mandibular hypodontia cannot be assessed as they do not meet the basic requirement of the methods, which is the presence of all seven left permanent mandibular teeth. The Haavikko method is based on a more complicated developmental scale which counts twelve different stages.[5] When compared to the Demirjian and Willems methods, the advantage of this approach is that the selection excludes the most frequently missing teeth.[6]

A potential weakness of the sample used in this study is the comparatively small number of OPGs in the two youngest age groups. Therefore, the results of age estimation for children younger than seven years should be read with caution. Nonetheless, the statistical methods used in the study ensure that the results in the other age groups are not compromised. The problem with the small number of OPGs in the youngest age groups is well documented in the literature as, for ethical reasons, there is no justification in taking OPGs exclusively for scientific purposes.[12]

Table 3. Willems method: comparison of chronological and dental age

Boys					Girls				
age group	Chronological age (years)	Dental age (years)	Deviation (years)	p*	age group	Chronological age (years)	Dental age (years)	Deviation (years)	p*
5 - 5,99	5,66	5,88	0,23	0,875	5 - 5,99	5,33	4,97	-0,36	0,313
6 - 6,99	6,65	7,43	0,77	< 0.001	6 - 6,99	6,62	7,15	0,53	0,042
7 - 7,99	7,57	8,42	0,85	< 0.001	7 - 7,99	7,60	7,71	0,11	0,097
8 - 8,99	8,51	9,01	0,50	< 0.001	8 - 8,99	8,51	8,27	-0,24	< 0.001
9 - 9,99	9,51	9,68	0,17	0,674	9 - 9,99	9,52	9,54	0,02	0,894
10 - 10,99	10,46	10,64	0,18	0,207	10 - 10,99	10,51	10,65	0,14	0,653
11 - 11,99	11,42	11,60	0,17	0,587	11 - 11,99	11,50	12,16	0,66	< 0.001
12 - 12,99	12,47	12,68	0,21	0,064	12 - 12,99	12,48	13,03	0,56	< 0.001
13 - 13,99	13,49	13,88	0,39	0,005	13 - 13,99	13,52	14,25	0,72	< 0.001
14 - 14,99	14,47	15,25	0,78	< 0.001	14 - 14,99	14,42	14,66	0,24	0,041
15 - 15,99	15,43	15,67	0,24	< 0.001	15 - 15,99	15,49	15,52	0,02	< 0.001
Total	10,51	10,92	0,41		Total	10,50	10,72	0,22	

* p value in Wilcoxon signed-rank-test

Table 4. Haavikko method: comparison of chronological and dental age

Boys					Girls				
age group	Chronological age (years)	Dental age (years)	Deviation (years)	p*	age group	Chronological age (years)	Dental age (years)	Deviation (years)	p*
5 - 5,99	5,66	4,94	-0,72	0,250	5 - 5,99	5,33	4,50	-0,84	0,063
6 - 6,99	6,65	6,09	-0,56	< 0.001	6 - 6,99	6,62	6,32	-0,30	0,519
7 - 7,99	7,57	6,97	-0,60	< 0.001	7 - 7,99	7,60	7,07	-0,52	< 0.001
8 - 8,99	8,51	7,85	-0,66	< 0.001	8 - 8,99	8,52	8,10	-0,42	< 0.001
9 - 9,99	9,51	8,87	-0,65	< 0.001	9 - 9,99	9,52	9,27	-0,25	< 0.001
10 - 10,99	10,46	10,14	-0,32	0,015	10 - 10,99	10,54	10,31	-0,23	0,120
11 - 11,99	11,42	11,25	-0,17	0,231	11 - 11,99	11,50	11,51	0,00	0,388
12 - 12,99	12,48	12,34	-0,14	0,743	12 - 12,99	12,48	11,96	-0,52	< 0.001
13 - 13,99	13,49	13,04	-0,45	< 0.001	13 - 13,99	13,50	12,35	-1,15	< 0.001
14 - 14,99	14,47	13,63	-0,84	< 0.001	14 - 14,99	14,42	12,47	-1,94	< 0.001
15 - 15,99	15,43	13,80	-1,63	< 0.001	15 - 15,99	15,48	12,66	-2,82	< 0.001
Total	10,51	9,90	-0,61		Total	10,50	9,68	-0,82	

* p value in Wilcoxon signed-rank-test

Table 5. Square deviations between dental and chronological age (years²) for the Demirjian, Willems and Haavikko methods (a lower value indicates more accurate age estimation)

Boys				Girls			
age group	**Demirjian**	**Willems**	**Haavikko**	**age group**	**Demirjian**	**Willems**	**Haavikko**
5 - 5.99	1.93	2.00	1.33	5 - 5.99	0.44	0.35	1.19
6 - 6.99	1.64	1.56	0.90	6 - 6.99	1.41	0.82	0.80
7 - 7.99	1.27	1.15	1.01	7 - 7.99	0.67	0.24	0.78
8 - 8.99	1.08	0.62	1.14	8 - 8.99	0.79	0.39	0.70
9 - 9.99	1.63	1.14	1.38	9 - 9.99	1.67	0.80	0.39
10 - 10.99	2.02	1.64	2.13	10 - 10.99	2.50	2.00	1.10
11 - 11.99	3.20	2.46	2.01	11 - 11.99	3.58	2.12	0.59
12 - 12.99	2.50	1.68	1.06	12 - 12.99	2.99	2.06	0.55
13 - 13.99	2.78	2.08	0.82	13 - 13.99	2.62	2.09	1.45
14 - 14.99	1.92	1.87	0.86	14 - 14.99	1.66	1.90	4.02
15 - 15.99	0.52	0.82	2.78	15 - 15.99	0.49	0.63	8.01
Total	20.48	17.02	15.42	Total	18.81	13.40	19.59

Table 6. Accuracy of age estimation for the Demirjian, Willems and Haavikko methods (percentage of correct estimations within interval)

Precision (%)	**Demirjian**	**Willems**	**Haavikko**
Boys			
± 0.5 years	31.6	34.1	28.8
±1 year	56.4	62.2	58.3
± 1.5 years	73.7	80.5	79.1
± 2 years	86.4	91.0	92.0
Girls			
± 0.5 years	27.2	40.4	34.2
±1 year	53.9	64.3	58.0
± 1.5 years	70.3	78.6	73.9
± 2 years	83.1	90.4	83.1

On average, the Demirjian and Willems methods overestimated age, while the Haavikko method underestimated age in boys and girls alike. Among the evaluated methods, the Willems method proved to be the most accurate, followed by the Haavikko and Demirjian methods. The mean deviation between dental and chronological age is similar to the survey conducted in the Croatian population by Čuković-Bagić et al.,[15] who report an average overestimation of 0.92 years in boys and 1.00 years in girls when using the Demirjian method, and an average

underestimation of 0.5 years in boys and 1.00 years in girls using the Haavikko method. While testing the Willems method among Croatian children, Galić [16] found that it overestimates the mean age by 0.58 years in boys and 0.32 years in girls. In another survey among Bosnian-Herzegovinian children,[17] the Willems method showed an overestimation of 0.42 years in boys and 0.24 years in girls, while the Haavikko method underestimated age by 0.09 years in boys and 0.29 years in girls. Contrary to the aforementioned study by Galić et al.[17], the Haavikko method showed greater deviations underestimating age in the Brazilian [18], Turkish [19] and Malaysian[20] population.

According to Esan et al.,[21] the Demirjian method significantly overestimates age in most populations, while the majority of the studies analysed here do not report significant overestimation using the Willlems method. Another meta-analysis by Wang et al.[12] reports that in polled data the Willems method shows a slight overestimation of age but also observes a significant difference for different ethnicities. For example, in Kosovar population, Kelmendi et al.[22] found Willems method underestimates age on average by 0.14 years in boys and 0.24 years in girls.

Apart from ethnic specificities, the positive secular trend represents another challenge for accurate age estimation using the known methods. Earlier dental development has been observed in today's children compared to their peers from a few decades ago.[23,24] In a survey among Dutch children, Vucic et al.[24] stress "the necessity of taking the year of birth into account when assessing dental development within a population with a wider time span". Moreover, from the documented secular trend there derives an obvious need to test previously conducted studies and the developed methods based on shifting observations and requirements over a period of time. Testing both the known and developing new methods represents a continuous challenge in forensic odontology.

Recently, Bedek et al. have developed new models for dental age estimation that surpass the accuracy of the Willems method.[25] In addition to a higher level of accuracy, the advantage of the new models is the possibility of their application in cases with incomplete dentition (hypodontia and incomplete human remains), which was not possible using the previously existing methods. The potential of these models has been recognized by Sheriff et al.[26] who tested them among the South Indian children. They proved to be accurate and suitable for dental age estimation.

Information pertaining to dental age estimation can be presented in a variety of ways. In this investigation, by way of comparison with other studies, the average deviation between dental and chronological age was used as it is the most common form of presenting results. However, we believe that a the more precise expression of the accuracy of a certain method is the percentage of correct estimations within intervals of ± 0.5, ± 1, ± 1.5 and ± 2 years. Using the average error as the main reference in age estimation might mislead the user in an individual case. Liversidge[9,27] claims that each average deviation between dental and chronological age, no matter how large, is always smaller than the possible and existing difference between individuals in the same population. Consequently, it is possible to conclude that a small average deviation could be the result of a sample comprising an equal number of individuals whose development is faster or slower than average. In legal terms in particular, the result of the individual age estimation should be presented as the probability within the age interval.

Pruvost et al.[28] highlighted the problem in age estimation provided by forensic physicians. In a sample of 498 files regarding age assessment they found that 71% of estimations were incompatible with the age claimed by adolescent. The percentage of incompatible estimations dropped to 3% when age was estimated from population specific data presented in published studies including those regarding dental age estimation. These results clearly indicate lack of research experience and up to date information which lead to negligence of professional standards in age estimation.

With regard to legal processes, an age estimation of the victim or the accused person may be required, especially in cases that involve trafficking, asylum seekers, child labourers and sex workers with a missing or doubtful birth certificate.[29] Knowledge and experience in dental age estimation as well as an awareness of its limitations are the desirable characteristics of an experienced clinician and should not be a matter of concern solely for forensic physicians and odontologists.

In the period between 2010 to 2020, emigration from the Republic of Croatia increased from 10000 to 40000, encompassing approximately 6500 children. The results of the present study could be applied in the aforementioned cases both for the children living abroad and those living in Croatia.[30]

CONCLUSIONS

Considering the average overestimation and accuracy within the age interval, the Willems method can be used for dental age estimation in Croatian children. Due to the average deviation between dental and chronological age as well as the low percentage of correct estimations within the age interval, the Demirjian and Haavikko methods were not sufficiently accurate for Croatian children.

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