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Is Willems method universal for age estimation: A systematic review and meta-analysis

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A B S T R A C T

Dental age (DA) has been widely accepted as a way to evaluate chronological age (CA) in recent years. However, the applicability of Willems method, as one of the most popular radiographic ways, still remains controversial in different areas. The aim of this study is to assess the difference between DA and CA with Willems method. Relevant studies published up to February 28th, 2017 were selected via PubMed, Embase, the Cochrane Library, CNKI, CBM and manual search. Studies that examined Willems dental age and chronological age were selected. 11 articles with 9347 individuals whose age ranged from 3.0 to 18.9 years old were ultimately included in this study. The general polled data indicated that Willems method overestimated CA by 0.18 years and 0.06 years for males and females respectively. Subgroup analysis for ethnicity showed significant difference for different ethnicities. Our aggregated data demonstrated that Willems method may not be an overall applicable tool to estimate chronological age for the reason of the difference of ethnicity and rational validity is suggested when necessary.

1. Introduction

Age estimation has been widely applied in forensic science[1] and dentistry field.[2] Of all the age estimation methods including somatic, sexual and skeletal indicators, dental age assessment has more advantages over the other methods. It is more reliable and less susceptible to exogenic factors, such as malnutrition or systemic diseases.[3,4]

There are two major approaches used for dental age estimation: the radiographic method and clinical tooth eruption.[5] Radiographic images provide an ongoing process and are more accurate.[6] Meanwhile, tooth eruption is affected by various local factors, such as crowding, extractions, ankylosis, ectopic positions, and persistence of primary teeth.[7]

A number of radiographic methods have been put forward for dental age assessment.[8–12] Demirjian[9] and Willems[10] methods are one of the most widely applied methods for ascertaining dental age. With this system, the development of seven left mandibular permanent teeth (except the third molar) is observed using panoramic radiographs and classified by means of an eight-stage system; and an additional stage 0, which represents no signs of calcification).[13] Demirjian introduced the method for dental age estimation according to the study of 2928 children (1446 boys and 1482 girls) of a French-Canadian population. A system was built on eight calcification stages from calcification of the crown cusps to closure of the apex of the seven left permanent mandibular teeth. The stages were written in letters A-H representing the ordinal of tooth development. The score of each stage was assigned and the aggregate of the scores turned into the subject's dental maturity score (DMS). Acquired dental maturity score was then converted into dental age according to the provided tables.

In 2001, Willems modified Demirjian method based on Belgian population. A different transformation table directly converted dental maturity score into dental age. This not only simplified the transformation steps, but several studies also showed that Willems method was more accurate than Demirjian method. Numerous studies have tested the applicability of the method in various populations, including overestimation in south India,[14] Thailand,[15] India,[16,17] Turkey[18] and Malaysia.[19] Underestimation phenomenon was also reported in Thailand,[15] India,[17] and north China.[20]

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Although a large number of articles on Willems method have been published, to the best of our knowledge, no meta-analysis has been conducted to evaluate the overall accuracy of Willems system for predicting the age of children, while two meta-analysis papers concerning Demirjian method have been published.[21,22] Thus, we executed this study to better elaborate on the accuracy of Willems method to assess dental age. By comparing dental age with chronological age, our study helps to achieve a better understanding of the relationship between estimated dental age and chronological age and how this relationship is modulated by gender, ethnicity and age.

2. Materials and methods

The present systematic review and meta-analysis were designed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.

2.1. Search strategy

Data search for the target studies published up to February 28th, 2017 was carried out in PubMed, Embase, Cochrane Library, CNKI (Chinese National Knowledge Infrastructure), and CBM (Chinese Biomedical Literature Database) databases. No limit on publication language was used. We used keywords *Dental Age Estimation* and *Willems* to acquire wanted papers, and search details were presented as follows. We also screened the reference lists of retrieved articles to identify additional potential sources.

2.2. Inclusion and exclusion criteria

Literature which met the several following standards was selected for our research: 1. A cross-sectional or retrospective study evaluating the applicability and precision of dental age using Willems method to estimate chronological age; 2. All subjects were healthy, without any developmental disorders and retained all the seven mandibular permanent teeth (except the third molar); 3. Inclusion of sufficient data on the size of the sample, mean and standard deviation (S.D.) values of dental age and chronological age. The exclusion criteria were also applied to obtain potential studies: 1. Duplicate publications, case reports, letters, reviews or editorial articles; 2. Included subjects with growth disorders or chronic diseases, or lacking information on subjects' health status; 3. Absence of accurate and reproducible parameters, such as dental and chronological age differences. Additionally, when the data was included in multiple studies using the same case series, either the study with the most recent publication or the largest sample size was considered. Studies were reviewed independently by two authors and disagreements were resolved with discussion until consensus was reached.

2.3. Data collection and quality assessment

After acquiring the needed papers according to the aforementioned criteria, two observers extracted data into a designed table independently. The following information was recorded: first author, published year, research type, region, ethnicity, number of subjects, age group, gender, dental and chronological age (mean and standard deviation (S.D.)). We assessed the methodological quality of the individual studies with the Newcastle-Ottawa Scale (NOS) adapted for cross-sectional studies.[23] We assessed the quality of the included studies on three topics: selection of the study population, comparability of the groups under study and the outcome assessment. The highest score was 10, and we assigned high methodological quality to a study if a score >5 was given. If the score was 6 or higher, the study was considered high quality.[24]

2.4. Data analysis

We assessed the accuracy of Willems method by gender for the reason of Willems's original independent set for sexual differences (Table 3). The weighted mean difference (WMD) with a corresponding 95% confidence interval (95% CI) was used to explain the age differences between Willems dental age and chronological age. To analyze the inter-study differences and heterogeneity, Cochrane Q-statistic was used to solve the problem, and $p < 0.05$ implied statistically significant heterogeneity. In addition, we quantified the effect of heterogeneity using the I^2 test, which helped explain the degree of inter-study variability that can be attributed to heterogeneity rather than chance. When a Q-test was significant ($P > 0.05$) or I^2 <50%, the fixed effects model was applied. The random effects model was only exerted when Q-test was not significant ($p < 0.05$) or I^2 >50%, which showed the lack of homogeneity among studies. Subgroup data analysis was also conducted to find actual heterogeneity according to gender, age groups and ethnicity.

To make sure the results were convincing, publication bias was performed using Egger's linear regression test, which measures funnel plot asymmetry via a natural logarithm scale of WMD to evaluate publication bias. All results were expressed with 95% CI and all P-values were two-sided. Analyses were conducted with STATA software, Version 14.1 (Stata Corp, College Station, TX).

3. Results

3.1. Study selection

A total of 222 studies were retrieved after our initial search from the databases of PubMed, Embase, Cochrane Library, CNKI (Chinese National Knowledge Infrastructure) and CBM (Chinese Biomedical Literature Database). In accordance with the inclusion and exclusion criteria, 11 studies were eventually included in the present meta-analysis (16,19,20,25-32). Fig. 1 displayed a flow chart of document retrieval.

3.2. Characteristics of included studies

The characteristics of included studies were shown in Table 1. There were a total of 9347 samples (4386 males and 4961 females respectively) in the 11 articles. Of the eligible studies, 5 were cross-sectional studies and the others were retrospective cross-sectional studies. 4 of the 11 studies had a total of 3698 Caucasian children (1658 males and 2040 females), and 7 had a total of 5649 Asian children (2728 males and 2921 females).

Table 2 contained information with age differences between Willems dental age and chronological age. Taking into account the fact that general heterogeneity was clearly calculated ($I^2 = 81.8\%$, $P < 0.001$), random effects analysis was adopted for the following data-processing. Age difference between Willems dental age and chronological age derived from 4386 individuals' data was not significant among males (WMD = 0.180, 95% CI = −0.50–0.410, P = 0.125). The mean difference was of significant level when Willems method was applied in Caucasian males (WMD = 0.378,95% CI = 0,215–0.541, $P < 0.001$), while on the contrary, the mean difference for Asian males was different (WMD = 0.095,95% CI = −0.222–0.411, P = 0.558). In the age groups, most subgroups displayed significant differences except 4.0–4.9, 13.0–13.9, 14.0–14.9 and 15.0–15.9 year groups. Of the 12 subgroups classified by age, only 2 groups (4.0–4.9 and 15.0–15.9 age group) presented underestimation.

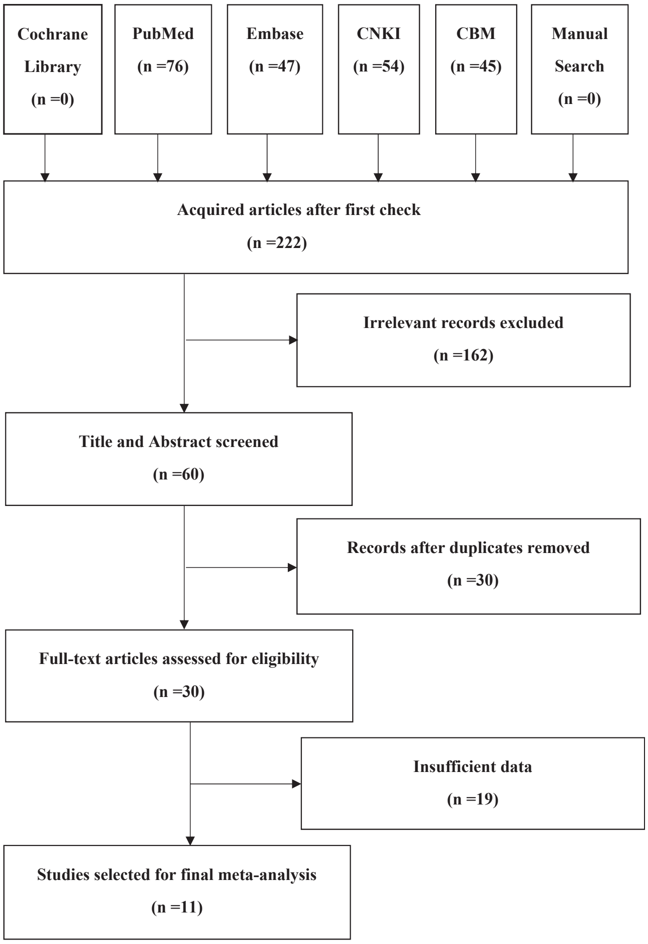

Fig. 1. Flow diagram illustrating selection of the articles included in the meta-analysis. (CNKI: Chinese National Knowledge Infrastructure CBM: Chinese Biomedical Literature Database).

Table 3 showed data analysis of the differences between dental age and chronological age in females. Random effects model was also used for the same reason of high heterogeneity ($I^2 = 89.6\%$, $P < 0.001$). The 4961 individuals' data showed that age difference between Willems dental age and chronological age was not significant among females (WMD = 0.061, 95% CI = −0.235–0.358, P = 0.685). The mean difference was significant when Willems method was applied in Caucasian females (WMD = 0.202,95% CI = 0.047–0.357, P = 0.011), while on the contrary, the mean difference for Asian females was different (WMD = 0.016,95% CI = −0.438–0.470, P = 0.945). In the age groups, the results of most subgroups were statistically insignificant; only the results of age groups of 5.0–5.9, 6.0–6.9, 11.0–11.9 and 15.0–15.9 were significant. Of the 12 subgroups sorted by age, 4 groups (8.0–8.9,13.0–13.9, 14.0–14.9 and 15.0–15.9 age groups) showed underestimation when compared with chronological age.

3.3. Heterogeneity and publication bias analysis

The papers included did not show strong homogeneity after related data were checked in general. After we conducted data-manipulation with random effects model and subgroup analysis, the results still showed a relatively strong heterogeneity (Figs. 2–5) (see Fig. 6).

To assess the publication bias of this meta-analysis, Egger's test was adopted. We preferred Egger's test to Begg's test for the fact that the number of researches included was relatively small. Analysis of the results did not show strong statistical evidence of publication bias (males: $t = 0.26$, $P = 0.801$; females: $t = 0.92$ $P = 0.381$).

4. Discussion

While Demirjian and Willems methods have been widely applied to evaluate dental age for clinical and forensic purposes, Willems method seems to have gained more acceptance for dental age estimation due to its optimization of Demirjian's rules. A number of reports reached the conclusion that Willems method is more accurate than Demirjian method. [19,28,30,31]However, a few scholars insisted that Demirjian method is a better choice,[15,20] therefore the debate on the better dental age estimation is still ongoing. Willems method, modifying Demirjian's method based on the data of Belgian children, has been tested in different regions and populations. Systematic review and meta-analysis of Willems method have not been published, while 2 meta-analysis concerning Demirjian method have.[21,22]Therefore this study was the first meta-analysis for Willems method to systematically clarify the applicability and difference to better utilize it.

Our meta-analysis came to the conclusion that WMD age differences for males and females were 0.18 and 0.06 years respectively, indicating that males may have a higher tooth maturation compared with females. Despite high heterogeneity, the integrated outcomes are in accordance with previously published studies.[16–20]

In our subgroup analysis of ethnicity, the mean WMD was 0.378 years and 0.095 years for Caucasian and Asian males, and 0.202 years and 0.016 years for Caucasian and Asian females, respectively. The low heterogeneity in the Caucasian population (males: $I^2 = 14.9\%$, $P = 0.317$; females: $I^2 = 13.0\%$, $P = 0.328$) demonstrated that Willems method was appropriate for this ethnicity. As for the Asian population, the high heterogeneity (males: $I^2 = 82.3\%$, $P < 0.001$; females: $I^2 = 92.1\%$, $P < 0.001$) indicated that Willems

Table 1
Characteristics of the included studies.

First Author	Region	Year Published	Number of Subjects	Ethnicity	Male	Female	Age Range	Quality Assessment	Research Type
Mani SA[25]	Malaysia	2008	428	Asian	214	214	7.0–15.9	6	cross-sectional
Galic I[26]	Bosnia and Herzegovina	2011	1303	Caucasian	498	805	6.0–13.9	6	cross-sectional
Nik-Hussein NN[27]	Malaysia	2011	991	Asian	504	487	5.0–15.9	6	retrospective cross-sectional
Djukic K[28]	Serbia	2013	686	Caucasian	322	364	4.0–15.9	6	retrospective cross-sectional
Urzel V[29]	France	2013	743	Caucasian	357	386	4.0–15.9	6	retrospective cross-sectional
Ye X[30]	China	2014	941	Asian	410	531	7.0–14.9	6	cross-sectional
Ambarkova V[31]	Macedonia	2014	966	Caucasian	481	485	6.0–13.9	6	retrospective cross-sectional
Mohammed RB[32]	India	2015	660	Asian	330	330	6.0–16.9	6	cross-sectional
Hegde S[16]	India	2016	1200	Asian	699	501	5.0–15.9	6	retrospective cross-sectional
Zhai Y[20]	China	2016	1004	Asian	392	612	11.0–18.9	6	cross-sectional
Kumaresan R[19]	Malaysia	2016	425	Asian	179	246	5.0–15.9	6	retrospective cross-sectional

Table 2
Data analysis of Willems dental age and chronological age in males.

Subgroup		Number of Studies	Number of Subjects	WMD	95% CI	P Value[a]	P(h)[b]
Ethnicity	Caucasian	4	1658	0.378	(0.215, 0.541)	<0.001	0.317
	Asian	7	2728	0.095	(−0.222, 0.411)	0.558	<0.001
	Total	11	4386	0.180	(−0.050,0.410)	0.125	<0.001
Age Group	4.0–4.9	2	9	−0.103	(−0.580, 0.374)	0.672	0.904
	5.0–5.9	4	70	0.308	(0.119, 0.497)	0.001	0.797
	6.0–6.9	5	165	0.712	(0.307, 1.117)	0.001	<0.001
	7.0–7.9	7	246	0.486	(0.298, 0.675)	<0.001	<0.001
	8.0–8.9	7	344	0.310	(0.219, 0.401)	<0.001	0.196
	9.0–9.9	7	356	0.195	(0.098, 0.291)	<0.001	0.545
	10.0–10.9	7	370	0.388	(0.229, 0.546)	<0.001	0.102
	11.0–11.9	8	437	0.343	(0.172, 0.514)	<0.001	0.006
	12.0–12.9	8	422	0.273	(0.070, 0.476)	0.008	<0.001
	13.0–13.9	8	403	0.129	(−0.070, 0.327)	0.203	0.001
	14.0–14.9	7	266	0.149	(−0.214, 0.513)	0.421	<0.001
	15.0–15.9	6	200	−0.298	(−0.774, 0.178)	0.22	<0.001
	Total	8	3288	0.274	(0.194, 0.354)	<0.001	<0.001

CI: confidence interval. WBD: weighted mean difference.
[a] Paired *t*-test.
[b] The p value of heterogeneity.

Table 3
Data analysis of Willems dental age and chronological age in females.

Subgroup		Number of Studies	Number of Subjects	WMD	95% CI	P Value[a]	P(h)[b]
Ethnicity	Caucasian	4	2040	0.202	(0.047, 0.357)	0.011	0.328
	Asian	7	2921	0.016	(−0.438, 0.470)	0.945	<0.001
	Total	11	4961	0.061	(−0.235, 0.358)	0.685	<0.001
Age Group	4.0–4.9	2	10	0.023	(−0.352, 0.398)	0.905	0.44
	5.0–5.9	4	67	0.396	(0.063, 0.729)	0.02	0.036
	6.0–6.9	5	140	0.499	(0.111, 0.887)	0.012	<0.001
	7.0–7.9	7	271	0.135	(−0.049, 0.319)	0.151	0.001
	8.0–8.9	7	342	−0.55	(−1.038, −0.062)	0.191	0.044
	9.0–9.9	7	322	0.051	(−0.072, 0.174)	0.418	0.24
	10.0–10.9	7	315	0.152	(−0.002, 0.305)	0.053	0.113
	11.0–11.9	8	423	0.241	(0.024, 0.458)	0.029	<0.001
	12.0–12.9	8	478	0.013	(−0.190, 0.216)	0.9	<0.001
	13.0–13.9	8	402	−0.061	(−0.417, 0.295)	0.739	<0.001
	14.0–14.9	7	353	−0.127	(−0.595, 0.341)	0.595	<0.001
	15.0–15.9	6	206	−0.391	(−0.763, −0.019)	0.039	<0.001
	Total	8	3329	0.081	(−0.014, 0.176)	0.093	<0.001

CI: confidence interval. WBD: weighted mean difference.
[a] Paired *t*-test.
[b] The p value of heterogeneity.

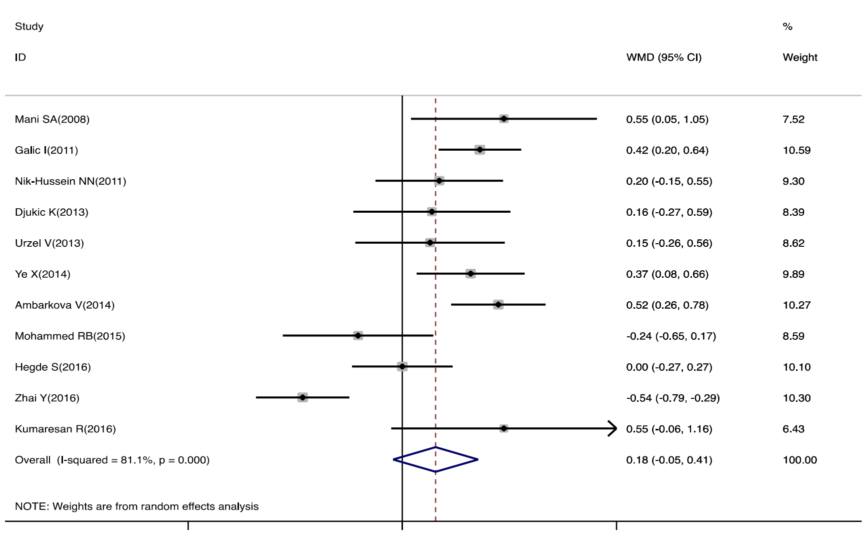

Fig. 2. Forest plot of WMDs between Willems dental age and chronological age for males.

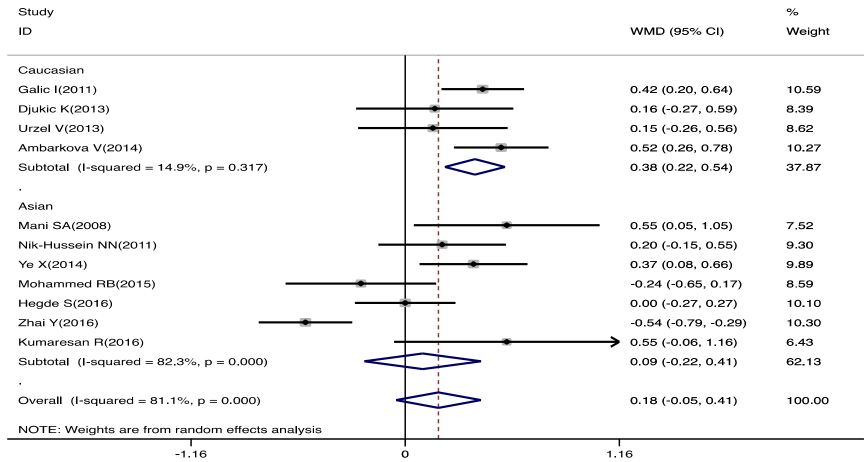

Fig. 3. Forest plot of WMDs between Willems dental age and chronological age for males of ethnicity subgroup.

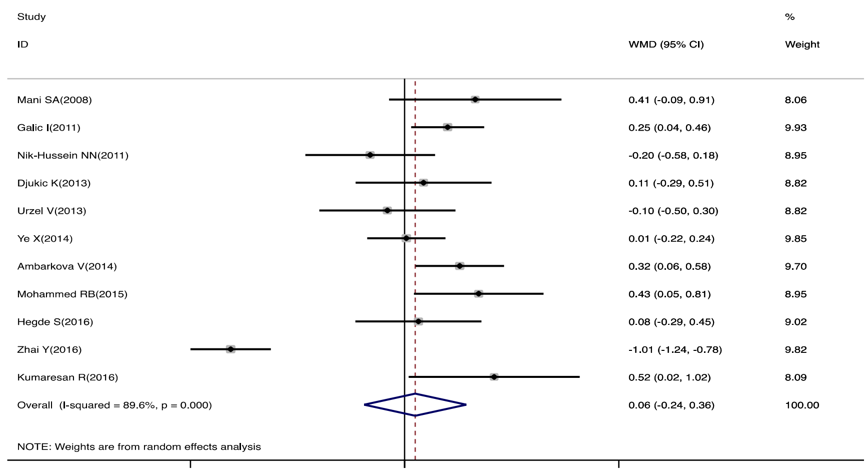

Fig. 4. Forest plot of WMDs between Willems dental age and chronological age for females.

method may have some limitations for the Asian population. The differences between Caucasian and Asian populations can be attributed to ethnicity. The original target of Willems method was to create a better method for Belgian children, who belonged to Caucasian population. So is the reason for low heterogeneity for Caucasians. Results from our research suggested that while radiographic tooth maturation may help to estimate age, variations between populations, which were sensitive to gender, must be accounted for.

When taking the age factor into consideration, subgroup analysis for age group was conducted. Generally speaking, dental age was overestimated compared with chronological age. On the whole, results accepted an overestimated dental age compared with chronological age. The overall difference was around 0.1–0.5 years. The significant larger values in Zhai Y's research may be attributed to the included 17.0–18.9 years group.[20] As the completion of apical maturity is usually around 16 years old, this may also be the main reason studies concerning Willems method tend to refuse age groups above 17.0 years.

Furthermore, regardless of the fact that radiographic dental maturation was reported to be less affected by extrinsic or environmental factors such as nutrition, it is known to be affected to a larger extent by genetic and ecological factors than other growth measures.[33] Since put forward in 2001, nutrition, ecology and dietary habits may have changed, and these changes may also have an impact on the final difference between dental age and chronological age.

While we conducted a lot of work for this meta-analysis, two main limitations have to be stated clearly. First, the number of studies included was relatively small, so more studies covering more regions should be conducted to support the current conclusion. Second, age group above 17 years was not included for the age subgroup analysis. As we noted in Willems' conversion table, when all seven teeth reached stage H, the maximum value was 16.03, 15.79 for males and females respectively. So after the apical closure of the root canals, dental age turned into a fixed maximum value. Taking a 16 years old boy whose root canals have finished apical closure for example, when he was 16 or older, still dental age and changeable chronological age resulted in larger age differences, which was a shortcoming of Willems method. Besides the limitations above, the advantages should also be noted. It is the first systematic review and meta-analysis of Willems dental method; we also analyzed difference among age groups, ethnicity and gender for better meta-analysis.

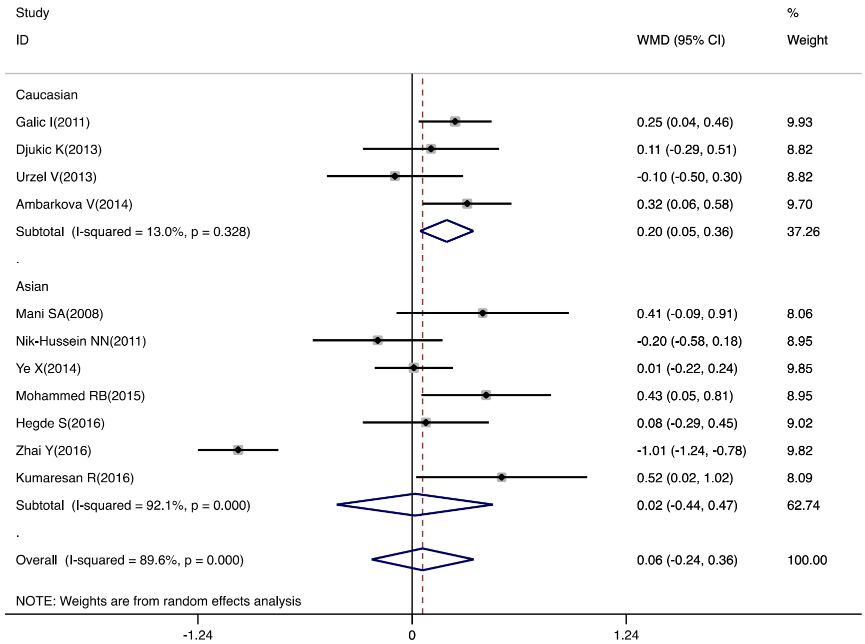

Fig. 5. Forest plot of WMDs between Willems dental age and chronological age for females of ethnicity subgroup.

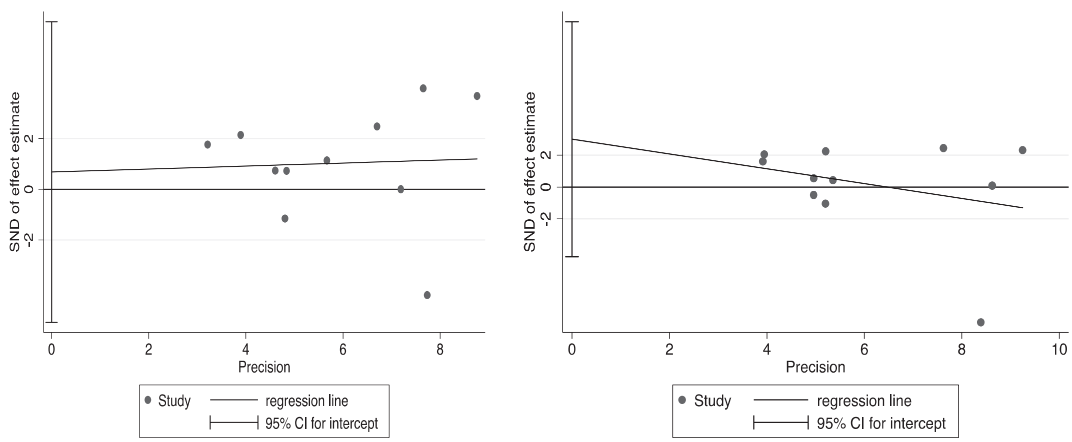

Fig. 6. Egger plot of WMDs between Willems dental age and chronological age for males (left) and females (right) (males: t = 0.26, P = 0.801; females: t = 0.92 P = 0.381).

5. Conclusion

In conclusion, Willems method overestimated dental age in almost every age group for both genders between 3.0 and 16.9 years old. In addition, ethnic differences were also shown to affect the accuracy of Willems method. However, due to the limitations mentioned above, additional studies with larger sample size and ethnically different regions are required to further estimate dental age with Willems method.

Conflict of interest

None.

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