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Systematic Review

Evaluating the Accuracy and Reliability of the Demirjian Method for Dental Age Assessment: A Systematic Review

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ABSTRACT

The biological age estimation performed by using dental age assessment is considered a reliable, time-saving, and time-saving technique. Dental age assessment plays an important role in various fields. **Objective:** To assess the accuracy and reliability of the Demirjian method in determining dental age. **Methods:** A systematic review with a study duration of twelve months from September 2023 to August 2024, was conducted to identify relevant literature published in fifteen years between 2010 and 2024. Comprehensive searches were performed across multiple databases, including PubMed, Google Scholar, Cochrane Library, Springer, and Science Direct. The PRISMA guidelines were strictly adhered to throughout the review process. Relevant data were extracted from these studies, and a comprehensive analysis was performed to synthesize the available evidence. **Results:** These results indicate Demirjian methods compared to other dental age assessment methods such as Nolla, Willem's method showed less accuracy and reliability for dental age assessment. **Conclusions:** It was concluded that the Demirjian method compared to other dental age assessment methods demonstrated lesser reliability, showed less accuracy in finding the differences between dental age and chronological age, and it also overestimated dental age.

INTRODUCTION

Age determination has become a significant aspect of current medico-legal practice, especially in forensic dentistry. The Chronological Age (CA) of any individual is analyzed from date of birth via birth registration documentation. Whereas, Dental Age (DA) refers to a person's age based on the development and eruption of their teeth [1]. The biological age estimation performed by using dental age assessment (DAA) is considered a reliable, time-saving, and time-saving technique. DAA is the process of determining a person's age based on their dental development. Dentists use specific charts and guidelines to compare a person's teeth to age-related norms. This can be helpful in situations where a person's chronological age is unknown or uncertain, such as in forensic investigations or when determining a child's developmental stage [2]. Dental development, influenced by both genetic and

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systemic factors, provides valuable insights into age estimation. Radiographic techniques, particularly those examining third molar eruption (TME), have been instrumental in this field since the 1980s [3]. TME, closely linked to BMI and childhood nutrition, serves as a sensitive indicator of environmental impact on dental development [4]. Combined with dental age assessment (DAA), chronological age assessment (CAA) offers a comprehensive approach to reconstructing biological profiles, especially in cases where birth certificates are unavailable. This is particularly relevant in contexts such as natural disasters, criminal investigations, child labor, child marriage, adoption, and illegal immigration [5]. Tooth development, being less susceptible to environmental factors, is a reliable parameter for age estimation in forensic contexts [6]. Among these, tooth formation rate is preferred over skeletal development for better CAA as it is least affected by malnutrition and other factors. There are various methods used for the maturation of permanent teeth and CAA from DA. These methods encompass Morrees, Willems, Kvaal, Haavikko, Nolla, Lundberg, and Demirjian. Among these, the Demirjian method (DM) described in 1973 based on French-Canadian children is widely utilized in CAA [7]. In 2004, this method was subsequently modified to estimate the age of older individuals using the third molar (Table 1).

Table 1: Tooth Development Stages According to Demirjian 1973 Method

Tooth	Molars (M2, M1)	Bicuspids (Pm2, PM1)	Canines	Incisors (I2, I1)	Molars (M2, M1)	Bicuspids (Pm2, PM1)	Canines	Incisors (I2, I1)
	Boys (Stages)				Girls (Stages)			
A	2.1	1.7	-	-	2.7	1.8	-	-
B	3.5	3.1, 0.0	-	-	3.9	3.4, 0.0	-	-
C	5.9, 0.0	5.4, 3.4	0.0	0.0	6.9, 0.0	6.5, 3.7	0.0	0.0
D	10.1, 8.0	9.7, 7.0	3.5, 3.2	0.0	11.1, 4.5	10.5, 7.5	3.8,3.2	0.0
E	12.5, 9.6	12.0, 11.0	7.9, 5.2	1.9	13.5, 6.2	12.7, 11.8	7.3, 5.6	9.4
F	13.2, 12.3	12.8, 12.3	10.0, 7.8	4.1	14.2, 9.0	13.5, 13.1	10.3, 8.0	5.1
G	13.6, 17.0	13.2, 12.7	11.0, 11.7	8.2	14.5, 14.0	13.8, 13.4	11.6, 12.2	9.3
H	15.4, 19.3	14.4, 13.5	11.9, 13.7	11.8	15.6, 16.2	14.6, 14.1	12.4, 14.2	12.9

This staging system ranges from crown and root formation to apex closure of the seventh mandibular teeth. It describes tooth development staging in line diagrams and clear radiographs. As tooth sizes may vary from person to person, dental maturity stages are more recognizable [8]. The dental maturity score (DMS) is calculated by subtracting the chronological age from the dental age. The estimation of DM may also provide information on teeth eruption and dental development. This method is simple and practical with clear definitive stages, increased interobserver agreement, and reduced speculation [9, 10]. Our systematic review identified conflicting conclusions in the studies evaluating the accuracy and reliability of Demirjian's method for DAA. Furthermore, the literature lacks enough data evaluating different DAA methods, including different sample sizes with multi-ethnicity. This study aims to conduct a detailed systematic review of the Demirjian method in DAA.

METHODS

A comprehensive literature searches in the form of systematic review adhering to the preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines was conducted across multiple databases, including PubMed, Google Scholar, Cochrane Library, Springer, and Science Direct. A systematic review with a study duration of twelve months from September 2023 to August 204, was conducted to identify relevant literature published in fifteen years between 2010 and 2024. The following keywords and MeSH terms were used: "Demirjian method," "dental age assessment," "accuracy," "reliability," "age estimation," and related terms. Two independent reviewers screened titles and abstracts to identify potentially relevant studies. Full-text articles of eligible studies were retrieved and assessed for inclusion based on the predetermined inclusion and exclusion criteria outlined. Disagreements were resolved through consensus or by consulting a third reviewer. The PRISMA 2020 guidelines were followed to ensure transparency and rigor in the review process. Data extraction was performed independently by two reviewers using a standardized data extraction form. The following information was extracted from each included study: author (s), publication year, study design, sample size, participant characteristics, methodology for dental age assessment, comparison methods, and reported accuracy and reliability measures. Any discrepancies were resolved through discussion and consensus. A qualitative synthesis of the included studies was performed to identify key findings and trends. The findings were summarized narratively, highlighting the strengths and limitations of the included studies. Of 5,132 initial studies, 2,000 were screened. After excluding 1,500, we reviewed 500 full-text articles, ultimately including 28 for qualitative synthesis (Figure 1).
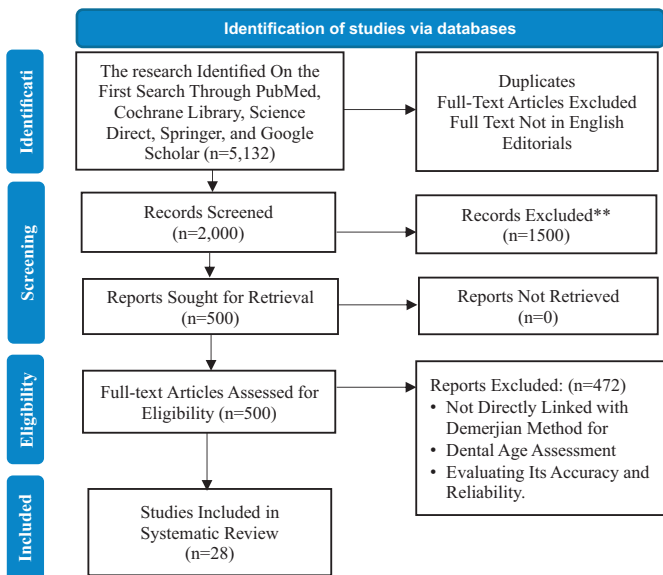
Figure 1: Screened Studies Included in the Systematic Review

The detailed inclusion and exclusion criteria followed for this systematic review are provided (Table 2).

Table 2: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Papers published between 2010 and 2024.	Duplication publication

Table 3: Summary of Study Findings Evaluated

Directly linked to the Demerjian method for DAA	Case reports and case series due to their unsuitability for evaluating diagnostic method accuracy and reliability.
English language	Studies with high risk of bias, such as those with poor design, inadequate randomization, or incomplete data.
Studies evaluating the accuracy and reliability of the Demerjian method for DAA	Studies not reporting relevant outcome measures (sensitivity, specificity, positive predictive value, or negative predictive value) for the Demerjian method
Studies comparing the accuracy and reliability of the Demerjian method with CA and other standard methods such as Willem's, and Nolla's method.	Studies that lack sufficient detail on the application of the Demerjian method, hinder assessment of its accuracy and reliability.
Full-text systematic reviews, meta-analysis, RCTs, prospective study, observational study	Editorials, conference papers, letters to the editor, short communications, meeting abstracts

R E S U L T S

Thirteen were cross-sectional, eight retrospectives, two comparatives, and three meta-analyses. The remaining were prospective, multi-centric, or double-blind. A total of 13,211 participants from 66 studies were evaluated. Results summarizes the findings of 28 included studies (Table 3).

Sr.No.	Study Design	Country	Total Participants	DAA Method	Statistical Analysis	Results	Reference
1	Retrospective	Romania	1006 patients	Demerjian method	Shapiro-Wilk analysis	Overestimated DA	[11]
2	Double-blind study	Iran	537 healthy children	Demirjian's method, Willem's method, Cameriere's, and Smith's method	Pearson's correlation analysis	Acceptable DAE accuracy	[12]
3	Retrospective study	India	102 children	demerjian's, Haaviko's, and Willems method	Paired t-test analysis	Overestimated DA	[1]
4	Retrospective study	France	234 participants	Nolla, Demirjian, and the London Atlas	Student's t-test	Less accurate	[13]
5	Comparative study	Turkey	766 participants	Demerjian, Willems method	paired t-test analysis	Less accurate	[14]
6	Cross-sectional study	Iran	212 panoramic radiographs of	Demirjian and Cameriere's methods	paired t-test analysis	Higher MEV	[15]
7	Multicentric research	India	303 participants	Demirjian, Willems method	ANOVA	More accurate and reliable	[16]
8	Cross-sectional study	Saudi Arabia	400 children	Demirjian's, MFH, Nicodemo et al., and Chaillet et al.,	IBM SPSS	Less accurate	[17]
9	Cross-sectional study	India	522 children	Demirjian, modified Demirjian, Odisha specific	Wilcoxon signed rank test, Pearson's correlation	Higher CA predictive accuracy	[18]
10	Meta-analysis	India	20 studies	Demirjian, Willems method	Cochrane RevMan v5.3	Less accurate	[19]
11	Cross-sectional study	Iran	434 children	Demirjian, Willem, Nolla, method	Paired t-test	Less accurate	[20]
12	Comparative study	Saudi Arabia	300 children	Demirjian, Willems method	Paired t-test	Less accurate	[21]

13	Meta-analysis	Saudi Arabia	20 studies	Demirjian, Willems method	WMD	Less accurate	[22]
14	Retrospective study	China	2367 samples	Demirjian, Willems method	Paired t-test	Less accurate	[23]
15	Cross-sectional study	Iran	168 individuals	Demirjian methods	Paired t-test	Significant differences in DA-CA	[24]
16	Cross-sectional study	India	660 samples	Nolla's, Demirjian, Willems,Haaviko method	Paired t-test and Wilcoxon signed rank test, ICC	Reliable	[25]
17	Cross-sectional study	Pakistan	403 children	Willems Demirjian, Nolla method	Paired t-test and Wilcoxon signed rank test	The strong correlation between CA-DA	[26]
18	Comparative cross-section study	Spain	604 children	Demirjian, Willems, Haaviko method	Wilcoxon test, spearman's correlation coefficients	Less precise	[27]
19	Cross-sectional study	Iran	158 children	Demirjian	t-test	More accurate and reliable	[28]
20	Retrospective study	India	60 children	Demirjian	Student's paired t-test	Higher CA predictive accuracy	[29]
21	Retrospective study	Germany	478 children	Demirjian Cameriere's	Wilcoxon signed a ranked test	Higher CA predictive accuracy	[30]
22	Meta-analysis	China	26 studies	Demirjian	WMD	Overestimated CA	[31]
23	Cross-section study	Sudan	358 children	Demirjian	SPSS, nonparametric tests	More accurate and reliable	[32]
24	Comparative study	India	100 participants	Demirjian and Acharya's Indian formula	The paired t-test, SPPSS	Less accurate	[33]
25	Retrospective study	Turkey	1587 subjects	Nolla's, Demirjian	Cohen's Kappa coefficient	Higher CA predictive accuracy	[34]
26	prospective study	Tunisia	280 children	Demirjian	Cohen's Kappa test	Less accurate and reliable	[35]
27	Retrospective, blind, cross-sectional study	Egypt	160 children	Demirjian	Logistic regression	Less reliable	[36]
28	Cross-sectional study	Pakistan	882 subjects	Demirjian	Paired t-test analysis	Significant differences in DAE-CA	[37]

MEV, mean error value; ANOVA, one-way analysis of variance; MFH, Moorrees, Fanning and Hunt method; ICC, inter- and intra-class correlation; WMD, weighted mean difference; SPSS, statistical package for the social science; CA, chronological age; DAE, dental age estimated

Paired t-tests and Wilcoxon signed-rank tests were primarily used to compare Demirjian with CA. Other statistical tools like Cohen's kappa, nonparametric tests, chi-square, regression models, SPSS, ICC, WMD, and ANOVA were employed to evaluate Demirjian's accuracy and reliability against other DAA methods. Nine studies reported overestimated DA compared to CA, while six found better CA predictive accuracy with Demirjian. The most common findings were lower predictive accuracy and reliability of Demirjian. The last reported outcome was Demirjian's suitability for diverse ethnic populations. A review of 14 studies revealed that Demirjian was generally less accurate and reliable than other DAA methods (Figure 2).
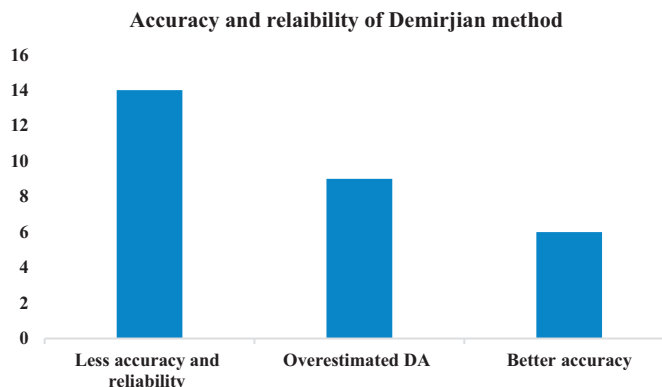

Figure 2 outcomes reported in the included studies as per systematic review.

DISCUSSION

Teeth undergo many developmental stages for about 20 years of human life and may show secondary changes in later life [38]. DAA methods are used to estimate dental age according to dental characteristics [39, 40]. A retrospective radiograph study was conducted by Moca et al., among 1006 patients (431 boys and 575 girls) in Romania. The Shapiro-Wilk analysis found that the Demerjian method overestimated the dental age (DA) of all age groups for all the participants with mean chronological age (MCA)=9.496 ± 2.218. Whereas the mean dental age (MDA)=10.934 ± 2.585, p<0.05) [11]. A double-blind study by Javadinejad et al., in Iran on children included four radiograph AE methods. Pearson's correlation analysis showed that Smith's method compared to other dental AE methods reported the highest accuracy (MCA; 8.93 ± 2.04 years, age overestimation observed in; Demerjian's method=0.87 ± 1.00 years, Willem's method = 0.36 ± 0.87, Smith's method=0.06 ± 0.63 years, age underestimated by Cameriere's method=0.19 ± 0.86 years, p<0.001) [12]. Patnana et al., evaluated the reliability of Demerjian's, Haaviko's, and Willems's method of DAA among 102 children (aged 6-14 years) in India. The paired t-test analysis showed that Demerjian's method significantly overestimated and Haavikko's and Willems's methods underestimated DA with a mean difference of 0.55 years, 1.95 and 0.20 years compared to CA, respectively [41]. Willmann et al., evaluated the accuracy of AE using three DAE methods among 234 participants (aged 4-20 years) with various ethnicities in France. Student's t-test for paired sample analysis showed that each method overestimated mean age compared to CA (p<0.0001). However, the authors concluded that Demerjian's method compared to Nolla and the London Atlas method was less accurate (Average absolute deviation in; Demerjian method=2 years, Nolla method=1.3 years, and the London Atlas method=1.2 years) [13]. These findings were similar to a comparative study conducted by Ozveren and Serindere., among 766 participants in Turkey [14]. A cross-sectional study consisting of 212 panoramic radiographs of children (aged 6-10 years) was conducted by Milani et al., in Iran. The paired t-test analysis reported that the mean error value (MEV) of the Demirjian method was higher than Cameriere's methods (MEV in girls = 0.084 and -0.06 and boys=0.93 and 0.04, respectively, p<0.001) [15]. A multicentric research was conducted by Chaudhry et al., among 303 participants (173 males and 130 females) of different ethnicities in India. ANOVA and Student's t-test analysis demonstrated that the Willems method outperformed the Demirjian method (p<0.001) [16]. A cross-sectional study was conducted by Al-Otaibi and Al-Qahtani in Saudi Arabia on children aged 6-15.99 years (200 boys, 200 girls). A significant difference

with p<0.001 was revealed between DA and CA. The study highlighted that Demirjian's method compared to Moorrees, Fanning and Hunt's method [17]. A cross-sectional study consisting of 522 children (boys = 521, girls = 271, aged 3-18 years) was conducted by Mohanty et al., in India. It showed that Demirjian (D) and modified Demirjian (MD) methods compared to Odisha-specific (OS) methods reported higher CA predictive accuracy (Pearson correlation; Male CA; MD=0.860, OS=0.385, D=0.854, and female CA; MD=0.859, OS=0.718, D=0.789) [18]. A comprehensive review of 20 studies published up to July 2018 was conducted by Prasad and Kala in India. The Cochrane RevMan v5.3 software analysis showed that the Willems method's accuracy is nearly similar to CA compared to the Demirjian method, irrespective of gender in the Indian population (overestimation by Demirjian=0.45 years, underestimation by Willems method=0.09 in both genders, 95% CI) [19]. Similar findings were also reported in a retrospective study of 2367 samples conducted by Pan et al., in China and a cross-sectional study of 434 children by Pliska et al., in Iran [23, 20]. A comparative study among 300 Saudi children by Alrashidi et al., and a meta-analysis of 20 studies performed by Esan et al., in Saudi Arabia revealed similar results [21, 22]. Abesi et al, conducted a cross-sectional study in Iran involving 168 individuals under the age of 15. Significant differences in the mean values of AE between both genders (p<0.001) were found in the study. Mean and standard deviation (SD) of CA [24]. Another cross-sectional study comprising 660 samples (330 each, males and females, aged 6-16 years) was performed by Mohammed et al., in India. The results showed that Nolla's method compared to Demirjian, Willems, and Haaviko's method was more accurate and significant linear correlation between DA and CA in DAE. However, in DAE of South Indian children of undetermined CA, all the assessment methods were found to be reliable as assessed by inter- and intra-class correlation (inter- and intra-observer for all methods=0.9 and 0.8, respectively. Linear correlation between CA and DA for; r=0.80 for Demirjian, for Willems r=0.80, for Nolla, r=0.94, for Haavikko method, r=0.82, p<0.001) [25]. Khoja et al., evaluated the validity of different DAE methods (Demirjians, Nollas, Willems) in 403 Pakistani orthodontic patients (male=176, female=277). Based on the Paired t-test and Wilcoxon signed rank test, the Willems method was considered most valid as compared to Demirjian and Nollas's method (strong correlation between CA and DA =p<0.001) [26]. These results were similar to a comparative cross-section study, conducted by Paz et al. in Spain. The results analysis suggested that Willems method compared to Demirjian method is more appropriate and precise in DAE (spearman's correlation between CA and DA for both

methods; rho values=0.86–0.89, p=0.00, Wilcoxon test; CA mean and DA mean for Wilems method=8.77 and 9.04, respectively and Demirjian method=8.77 and 9.48, respectively, p=0.000) [27]. Kermani et al., conducted a study in Iran involving children aged 5-13 years. The SPSS v.22 and t-test analysis showed a statistically strong relationship between DAE by Demirjian and CA, irrespective of gender (correlation coefficient for all subjects=0.854, mean absolute difference between CA and DA (ABS-DIFF) in girls=1.442, boys=0.667) [28]. In a retrospective Indian study by Pratyusha et al., involving 30 male and 30 female children aged 9-14, the Cameriere's population-specific regression equation (CPSRE) was found to be a closer estimate of CA compared to the Demirjian method when assessing age at eruption (AE) (p=0.68) [29]. Another retrospective study consisting of 478 panoramic radiographs (male=268, female=211 aged 6-14 years) was conducted by Wolf et al., in Germany. The Wilcoxon signed ranked test showed Demirjian method compared to Cameriere's method showed higher accuracy for DAE for both genders (total mean difference (MD) in CA-DA using; Demirjian method=-0.16 and -0.18 and Cameriere method=0.07 and 0.08, for male and female genders, respectively)[30]. A meta-analysis of 26 studies published before July 12th, 2013 was conducted by Yan et al., in China. The research findings suggested that the Demirjian method for assessing human dental maturation may not be universally accurate. When compared to CA, the Demirjian method consistently overestimated dental age in both genders. This discrepancy underscores the importance of developing population-specific standards for evaluating dental development[31]. A descriptive cross-section study by Alqadi and Abuaffan was conducted in Sudan. Nonparametric tests showed that Yemeni CA estimated by the Demirjian method was significantly correlated to DA (mean CA and DA=12.00 ± 2.25, 11.34 ± 2.42, respectively, p<0.001) [32]. A comparative study consisting of 100 participants (50 each male and female) was conducted by Sarkar et al., in India. The statistical analysis revealed that Acharya's formula outperformed the Demirjian method in providing a more reliable and precise evaluation of DA (mean DA underestimated; Demirjian= by 1.63 years and 1.54 years, Indian formula= by 0.10 years and 0.94 years) [33]. A retrospective study was conducted by Duruk et al., in Turkey. Cohen's kappa coefficient and paired sample t-test analysis revealed that Nolla's compared to the Demirjian method showed more CA estimation accuracy in the Eastern Turkish population (Nolla's method; underestimation of CA=-0.16 and overestimation of DA by using Demirjian=0.68, irrespective of gender) [34]. In Tunisia, Aissaoui et al., led a prospective study consisting of 280 healthy Tunisian children (aged 2.8 to 16.5 years). It indicated that the Demirjian method, may not accurately predict dental age in Tunisian children. The Cohen's Kappa test revealed discrepancies between Estimated dental age and chronological age, with differences ranging from -0.02 to 3 years. Additionally, analysis of dental advancement about chronological age showed variations between males and females, with differences ranging from 0.3 to 1.32 years in males and 0.26 to 1.37 years in females. These findings suggest the need for further research to develop more accurate dental age assessment methods for Tunisian children[35]. Similar findings were also reported in a study conducted by Moness et al., in Egypt[36]. A cross-sectional study between 427 female and 455 male, aged 7-14, was conducted by Sukhia et al., in Pakistan [37]. The results showed that there were significant differences between CA and DA using the Demirjian method, as determined by a statistical test (p<0.05) and the results were comparable to a German Study by Khdairi N et al., [42]. The systematic review was limited by the small number of studies, particularly those involving diverse ethnicities and regions, and the absence of robust statistical inference. To address these limitations, future research should prioritize large-scale, well-designed RCTs, case-control studies, and prospective studies that employ a comprehensive approach. Furthermore, future investigations should explore the integration of computerized methods for DAE analysis, potentially bypassing the need for traditional panoramic radiographs. Moreover, a comprehensive approach incorporating multiple age estimation methodologies, supported by rigorous statistical analysis, including effect size calculations, is recommended for robust and reliable age assessment in legal proceedings as also concluded by the study of Han MQ et al., and Pereira CP et al.,[43, 44].

CONCLUSIONS

It was concluded that this systematic review provides a detailed comprehensive review of the evaluation of the accuracy and reliability of the Demirjian method for DAA. The study found that the Demirjian method compared to other DAA methods demonstrated lesser accuracy and reliability, and increased overestimated DA compared to CA for DAE.

Authors Contribution

Conceptualization: AAV
Methodology: AAV, SA
Formal analysis: SSF
Writing review and editing: MHS, AM, MAKG, VD, MUS

All authors have read and agreed to the published version of the manuscript

Conflicts of Interest

All the authors declare no conflict of interest.

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