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On the comparison of age determination methods based on dental development radiographic studies in a sample of Italian population

Analisi comparativa di metodi identificativi di età strutturati sullo studio della maturazione dentaria su un campione di popolazione italiana

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ABSTRACT

OBJECTIVES. This study investigated the degree of reliability, complexity of use and possibility of further refinement of eight radiographic methods for the age determination of subjects in the growth phase, applied on a sample of Italian population.

MATERIALS AND METHODS. Each considered method was tested on a sample of 178 digitized panoramic radiographs (97 males and 81 females, aged 5 to 22 years). The obtained data were processed by statistical analysis.

RESULTS. The overall Absolute Mean Error (AME) was on average equal to 0.89 years; within this error range fell approximately 61% of the subjects in our sample. The overall average of AME plus 1 standard deviation (SD) was equal to approximately 1.70 years, in the context of which fell about 84.5% of the sample investigated.

CONCLUSIONS. The statistical analysis of the data obtained by applying on our sample the considered methods showed, for each of them, the level of reliability in terms of absolute error with the relative SD (i.e., exact match between the age determined by the evaluators and the actual age, in terms of absolute value).

KEY WORDS

- Age determination
- Dental development
- Panoramic radiographs
- Personal identification
- Forensic dentistry

RIASSUNTO

OBIETTIVI. Scopo dello studio è verificare il grado di affidabilità, complessità di utilizzo e possibilità di perfezionamento di otto metodiche radiografiche identificative di età in soggetti in fase di crescita applicate su un campione di soggetti della popolazione italiana.

MATERIALI E METODI. Ogni metodo considerato è stato testato su un campione costituito da 178 ortopantomografie (OPT) digitalizzate (97 soggetti di sesso maschile e 81 di sesso femminile, di età compresa tra 5 e 22 anni). I dati ottenuti sono stati elaborati mediante analisi statistica.

RISULTATI. La media complessiva dell'errore medio assoluto (Absolute Mean Error, AME) è pari a 0,89 anni; in tale errore rientra circa il 61% dei soggetti del nostro campione. La media complessiva di AME più 1 deviazione standard (DS) è pari a circa 1,70 anni e in tale contesto rientra l'84,5% circa del campione indagato.

CONCLUSIONI. L'elaborazione statistica descrittiva dei dati derivati dall'applicazione al nostro campione delle metodiche prese in considerazione ha consentito di stabilire per ognuna di esse il livello di affidabilità in termini di errore assoluto (esatta corrispondenza dell'età attribuita dai valutatori con quella reale considerata in valore assoluto) e con relativa DS.

PAROLE CHIAVE

- *Identificazione dell'età*
- *Sviluppo dentario*
- *Ortopantomografia*
- *Identificazione personale*
- *Odontoiatria forense*

1. INTRODUCTION

In the wide field of the generic identification, the age determination assumes major importance especially for the evaluation of threshold of the fourteenth or chronological age of eighteen (for the eligibility and the civil capacity respectively). Sometimes, the age determination may represent the only valid element to achieve, by exclusion, the individual identification (e.g., in the case of unrecognizable corpse findings).

The study of the stomatognathic apparatus, especially of the teeth, is very useful. In fact, the teeth, considered individually and/or totally, present quantitative and qualitative characteristics advantageous for identification purposes (i.e., differences in terms of number, shape, size, overall structure, relations with the maxillary, high resistance to physical and chemical insults such as heat, putrefactive phenomena, etc.) [1].

The dental radiographic investigations show advantages common to the other radiological examinations (respect of anatomical structures studied, high reliability, wide reproducibility) [2]. They allow the study of the dental arches also in the case where the cadaveric inspection is difficult due to the presence of important transformative *post-mortem* phenomena or carbonization [3].

Starting from the '40s, in the medicolegal and forensic dentistry field, several methods for the age determination structured on the employment of different kinds of dental radiography (e.g., orthopantomography, intraoral X-ray, cephalometry) were proposed [4].

However, most of them make use of orthopantomography (OPT): Schour et al. [5]; Nolla [6]; Demirjian et al. [7]; Gustafson et al. [8]; Ubelaker [9]; Portigliatti Barbos et al. [10]; Robetti et al. [11], Kullman et al. [12] (table I).

Since the methods, mainly developed by foreign authors, with the exception of that of Portigliatti Barbos et al. [10], are devoid of stated reliability index, it seemed interesting to carry out a comparative analysis of such methods by testing them on a sample of digitized OPT, in order to verify, besides the aforementioned degree of reliability, the degree of complexity of use and the possibility of further refinement.

2. MATERIALS AND METHODS

With this aim, it was conducted an application of the above methods, all structured on the use of the OPT, on humans in growth phase, with anthropometric characteristics of our population (Caucasian).

Each method was therefore tested on a sample of 178 digitized OPT (178 OPT Schour et al. [5] for a total of 9,256 examined teeth; 178 OPT Ubelaker [9] for a total of 9,256 examined teeth; 157 Nolla [6] for a total of 5,024 examined teeth; 129 OPT Gustafson et al. [8] for a total of 6,192 examined teeth; 137 OPT Robetti et al. [11] for a total of 1,096 examined teeth; 129 OPT Demirjian et al. [7] for a

total of 903 examined teeth; 92 OPT Portigliatti Barbos et al. [10] for a total of 276 examined teeth; 70 OPT Kullman et al. [12] for a total of 140 examined teeth). The people were free from systemic diseases and/or local accretion able to influence the dental growth of each of them. The sample was composed of 97 people (55%) males and 81 (45%) females, aged 5 to 22 years.

The distribution of the sample by age and gender is shown in table II.

Consent to the use of the personal data of the subjects was acquired and their anonymity was guaranteed.

Each OPT has been interpreted in a blinded fashion by three different examiners with reference to the degree of mineralization and eruption of one or more dental elements, achieving the age estimation by strictly applying all the steps provided by each method.

For each method the OPTs were evaluated with reference to the subjects with the same chronological age of the method proposed by the author.

The study protocol was approved by the Ethics Committee "Carlo Romano" of the University of Naples Federico II. The study was conducted according to the ethical standards set by the Declaration of Helsinki.

The data were processed, obtaining as results the descriptive statistics (i.e., average and standard deviation). The reliability is expressed in terms of a parameter named Absolute Mean Error (AME) given by the average of the difference of the absolute value between the actual age of the subject and the age determined by applying the method.

In addition, for each method, we calculated the standard deviation (SD) of the AME, the percentage of subjects falling within that error, as well as those falling within the AME plus 1 SD.

In order to assess the difficulty of use of each method and the level of examiner subjectivity for the allocation of the degree of tooth growth, the post-hoc test (Bonferroni) on the AME was carried out. Finally, the kurtosis of the AME was evaluated, with the aim to establish an ordinal score about the reliability of the methods investigated.

For the evaluation of the AME the following parameters were involved:

- the actual age of the subject;
- the age estimated by each examiner;
- the gender of the subject (if required by the method);
- the degree of maturation of the teeth evaluated with reference to each method.

Particular attention was paid to the selection of the OPT, in order to eliminate the presence of errors due to "latent factors" such as, for instance, the poor quality of the OPT, qualitative and quantitative

Table I Review of X-ray methods for the determination of age in childhood and adolescence

Authors	Examined teeth	Structure of the method
Schour et al., 1941 [5]	Deciduous and permanent upper and lower hemi-arch	Comparison between Rx and drawings related to 21 stages of development
Nolla, 1960 [6]	All permanents	Use of Rx, diagrams covering 10 stages of development and tables (differentiated by sex) indicative of the standards of maturation of permanent teeth
Demirjian et al., 1973 [7]	Permanent upper hemi-arch with the exception of third molar	Use of Rx, descriptive scale of 8 stages of dental maturation, tables (differentiated by sex) of the scores related to the 8 stages of maturation and conversion of such scores in the age
Gustafson et al., 1974 [8]	Deciduous and permanent with exception of third molar	Deduce by Rx the phase of dental development reached in accordance with 4 predetermined parameters and comparison with the appropriate diagram
Ubelaker, 1978 [9]	Deciduous and permanent top and bottom hemi-arch	Comparison between Rx and drawings related to 21 stages of development
Portigliatti Barbos et al., 1982 [10]	45, 46, 47, 48	Comparison between Rx and diagrams covering 12 stages of development + correlation equations (differentiated by sex)
Robetti et al., 1988 [11]	43, 45, 47, 48 / 33, 35, 37, 38	Comparison between Rx and diagrams covering 18 stages of development + correlation equations (differentiated by sex)
Kullman et al., 1992 [12]	38 / 48	Comparison between OPT and graphic scheme descriptive of development of 38/48

Table II Distribution of the sample by age and sex

Age (years)	# OPT	Females	Males
5	1	1	–
6	2	1	1
7	3	2	1
8	3	1	2
9	4	2	2
10	3	–	3
11	4	2	2
12	28	15	13
13	35	13	22
14	22	8	14
15	10	3	7
16	14	6	8
17	16	8	8
18	12	6	6
19	8	6	2
20	10	5	5
21	2	1	1
22	1	1	–
Total	178	74	97

Legend: OPT = Orthopantomography.

individual anomalies, the presence of orthodontic appliances capable of influencing or prevent the identification of the maturation of the tooth.

The OPTs used in this study were obtained by means of modern digital X-ray equipment. The statistical analysis was performed with the SPSS/PC+ V8.0 software. The hardware was composed of a workstation Intel I7, 8GRAM, NVIDIA GEForce 9800GT, Intel(R) Core™ i7 CPU, 2.67 GHz, monitor ASUS VW198 21".

The aim of the present study is to check for each method:

- the degree of complexity for its application;
- the level of reliability;
- the perspectives of upgrading and updating.

3. RESULTS

3.1 THE DEGREE OF COMPLEXITY FOR ITS APPLICATION

The radiographic methods adopted for the age identification have a common starting operative step, consisting on the *a-priori* evaluation of the degree of mineralization and/or eruption of one or more dental elements (i.e., deciduous and/or permanent) of mandibular and/or jawbone arch.

Starting from the degree of dental maturation, it is possible to derive the age (in a complementary or even exclusive way) through tables or diagrams, graphs, charts, and equations, developed and proposed by each author, indicative of specific dental ages.

All methods are based on the study of one or more dental permanent elements.

The methods of Schour et al. [5], Gustafson et al. [8] and Ubelaker [9] also include the analysis of the deciduous dentition.

The methods of Demirjian et al. [7] and Gustafson et al. [8] do not consider the development of third molar (lower and/or upper).

In the 50% of methods (4/8) the attribution of age is differentiated by gender.

The overall age explored by methods extends from the 1st month of intrauterine life [8] up to 21-35 years [5,9].

The age range most frequently investigated is, in descending order, 14 to 16 years (6 of the 8 methods analysed), 12 to 14 years (6 of the 8 methods considered) and 3 to 13 years (5 of the 8 methods considered) (fig. 1).

The methods of Schour et al. [5] and Ubelaker [9] are based on the comparison of the radiographic image of the subject to identify with a graphic scheme. Such methods split in chronological phases the tooth development; even if they are proved to be of easy applicability they, show a significant discrepancy of the age determination given by the examiners.

In fact, for these methods, post-hoc tests show significant differences in terms of evaluation. This is expression of a strong subjectivity of interpretation of the evaluator and, therefore, a concrete inter-individual variability in the attribution of age identification.

Such a phenomenon can be explained by observing the number of graphical representations. In fact, they are few (one depiction for each year) between 0 and 12 years and inadequate around 14 and 18 years, that is the most significant medicolegal range of age.

In fact, the above methods consider only two diagrams of the teeth in the range of 15 to 21 years, differentiated from each

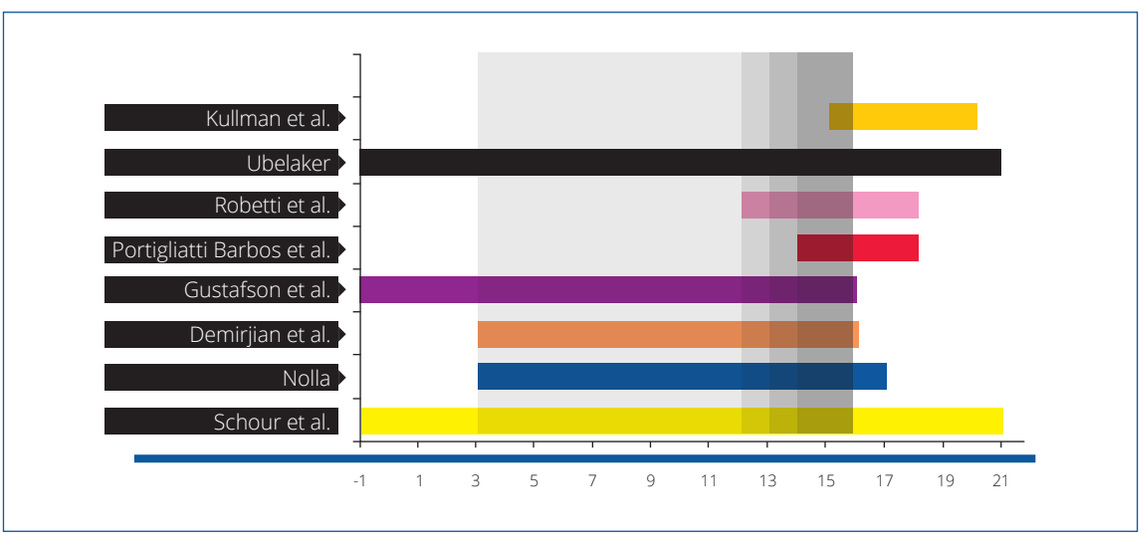

Fig. 1
Graphical representation of the range of age investigated by the methods

other due to the different degree of development of the VIII. If such element is missing in the arch (i.e., dysodontiasis, inclusion, avulsion, agenesis) they allow with certainty the only identification of the minimum age of 15 years.

Conversely, the easy applicability of these two methods can motivate to a preliminary evaluation, by means of the OPT, of the maturation of the dental elements. In fact, in such a way, by emphasizing the qualitative and quantitative characteristics of tooth, it seems possible to proceed to an immediate comparison with the graphic scheme provided by methods and, consequently, to an almost instantaneous identification of the respective stage of development.

The sequence of graphical representations of the chronological phases of dental development should express, as a photographic sequence, the "norm" of growth of a correct toothing over time.

It should be noted, however, that this series is purely ideal. In fact, it is independent from individual variables, included in the context of normality, as well as growth time (formative and eruptive) of the teeth.

In the other methods the attribution of the dental maturational stage, considered as a whole, was laborious, because it is based on the sequential analysis of each dental element considered by the authors.

The method of Nolla [6], due to the low quality of the graphic representations, made it a little difficult to identify the corresponding stage of maturation on the dental OPT.

Therefore, it was reached the correct degree of teeth development by referring almost exclusively to the descriptive comment of the formation stage.

The method of Gustafson et al. [8] involves, for each element examined, the achievement of one of the four stages of growth provided (i.e., early mineralization, crown completion, eruption, root completion).

However, they are often observed, in the same subject, one or more dental elements with maturational stage not corresponding to a single phase of growth considered by the method (such as it is observed a partial eruption with complete formation of crown or a complete eruption with root in formation); all this made very difficult to stage the formation degree and then the identification of age.

3.2 THE LEVEL OF RELIABILITY

Only a few methods of age determination [8-12] achieve the dental age estimation by using a range of approximation, often diversified by stage of growth and sometimes for dental element studied.

Gustafson et al. [8] report different SD depending on the assignment of the stage of tooth growth and on the element in the arch considered. It varies from a minimum value of 1 month (beginning of the mineralization deciduous lower lateral incisor) to a maximum of 2.5 years (eruption of the upper permanent second premolar).

Ubelaker [9] assigned the SD to each graphic representation. It varies from a minimum of ± 2 months, for the representation on the 5th, 7th and 9th month *in utero*, to a maximum of ± 38 months for that on the 15 years.

In the method of Portigliatti Barbos et al. [10], the SD is varied according to the gender corresponding to the value of ± 332 days for males and ± 312 days for females.

The same authors, considering the above SD, achieved a confidence level of 68.29%, which increases reaching values of 95.45% and 99.73% when the SD is doubled and tripled respectively.

Last method in which there is a SD is that of Kullman et al. [12]. They studied only the development of the mandibular third molar. In the aforesaid method the SD varies from a minimum value of 0.9 years for the first maturational stage to a maximum of 1.8 years for the fifth maturational stage, the same values in the female sex.

The level of reliability of the methods applied to our sample is shown in table III.

Note that the method that best correlates the AME with the percentage of subjects falling within the above parameter is the one proposed by Robetti et al. [11]. In fact, the AME is equal to 0.96 years and the percentage of subjects for which the difference between the estimated age and the actual one is within ± 0.96 years is approximately 68%.

For this method the kurtosis is relatively high (leptokurtic), about 6.20, meaning that the distribution of the error is close to the average (AME).

Furthermore, this result is even more significant if one takes into account the fact that the post-hoc test showed a significant difference of the absolute error between the evaluators.

If we consider a range of dental age estimation of ± 1 SD compared to AME, we arrive at an average value of reliability of approximately 88%.

The results for each method investigated are summarized in table III.

Through an overall interpretation of the results obtained, it can be stated that in half of the investigated methods the subjective evaluation of the examiner does not affect the final result of the attribution of the degree of dental maturation. Where this factor is significant, we believe that the cause should be sought in

Table III Level of reliability of the radiographic dental development methods for the age determination applied to our sample

Method	# Evaluations	AME (years)	SD (years)	# OPT ≤ AME (%)	# OPT ≤ AME + 1 SD (%)	Post-hoc test	Kurtosis	Remarks
Schour et al. [5]	534 (M 54%; F 46%)	0.94	0.82	316 (59%)	446 (83%)	Sig	2.20	5th month in uterus ± 35 years
Nolla [6]	355 (M 59%; F 41%)	0.81	0.68	212 (60%)	292 (82%)	No sig	3.55	3 ± 17 years
Demirjian et al. [7]	324 (M 60%; F 40%)	0.75	0.74	192 (59%)	276 (85%)	No sig	4.86	3 ± 16 years
Gustafson et al. [8]	312 (M 60%; F 40%)	0.70	0.63	195 (63%)	270 (86%)	No sig	3.39	1st month in uterus ± 16 years
Ubelaker [9]	534 (M 54%; F 46%)	0.95	0.82	322 (60%)	446 (84%)	Sig	2.15	5th month in uterus ± 35 years
Portigliatti Barbos et al. [10]	157 (M 60%; F 40%)	1.00	0.92	100 (64%)	131 (83%)	Sig	3.12	14 ± 18 years
Robetti et al. [11]	333 (M 60%; F 40%)	0.96	1.04	226 (68%)	294 (88%)	Sig	6.20	12 ± 18 years
Kullman et al. [12]	148 (M 55%; F 45%)	1.00	0.81	86 (58%)	126 (85%)	No sig	1.79	15 ± 20 years

Legend: AME = Absolute Mean Error; SD = Standard deviation; OPT = Orthopantomography; Sig = Significant; No sig = Not significant.

the objective inadequacy of graphical representations proposed by the authors [5,9] or in the difficulty in interpreting the proposed diagrams [10,11].

The overall average of the AME is equal to 0.89 years; within this error falls approximately 61% of subjects of our sample.

The overall average of the AME plus 1 SD is equal to approximately 1.70 years, in the context of which fall about 84.5% of the sample investigated.

3.3 THE PERSPECTIVES OF UPGRADING AND UPDATING

The current multiparametric-statistical evaluation could be expanded by resorting to a subsequent multifactorial analysis in order to envisage a supplementary method for the dental age determination through all the methods considered, with the advantage of being able to:

- apply on subjects with anthropometric characteristics of our population (Caucasian) and age included within the range of the sample analysed;
- consider a smaller number of variables, in order to facilitate the task of reading the OPT by the expert.

Moreover, the widening of the sample would lead to the improvement of the reliability of the method with concomitant reduction of the SD.

4. DISCUSSION

For the age determination, the radiographic methods provide more reliable results when applied to individuals growth up to a maximum of 14 years; over that age the attribution of age dental could be done through the use, where applicable, by the same method, almost exclusively, to the study of the stages of development of the third molars.

This element, however, is not very reliable for the assignment of age as it is subject to a number of individual variations (e.g., agenesis, malformations, oscillation period of formation and eruption, etc.).

The comparative analysis of the methods considered, highlights a significant discrepancy, in the age determination, at the attainment of dental full maturity (excluding the third molar because it is not studied by all authors).

In fact, some authors consider reached the dental full maturity at the age of 15 years [5,9], while others when reached the age of 16 yeras [7,8] or the 16 and a half years in the male subjects

If there is a cranio-mandibular disjunction with loss of the lower jaw or inability to reconstruct a correct maxillofacial, it is then impossible to reach the attribution of age using the methods [7,10-12] because such methods are structured on the analysis of the stages of maturation of the mandibular elements only.

The comparative application of the methods considered, shows that those of Schour et al. [5] and Ubelaker [9] are less reliable both for significant interindividual variability in the dental age determination (post-hoc tests show significant values for both methods) and distribution of the error far from the average (kurtosis index equal to 2.20 and 2.15 respectively).

They, in fact, on the one hand are based on comparison of the radiographic image of the subject to identify with diagrams, differentiated by dental age, allowing, almost immediately, the reading of the value of the parameter to identify. On the other hand, contrasts this advantage, however, a small number of graphical

representations (age 0 to 12 years) or insufficient (age 14 to 21 years), which has sometimes made extremely dubious the age attribution.

The use of the remaining methods was complex because, with the exclusion of the method of Kullman et al. [12], they are based on the radiographic evaluation of the sequential maturational stage of multiple dental elements.

Furthermore, in the method of Nolla [6] the graphical representations are not of optimal quality (compensated by the description of the relevant stage of tooth formation and maturation) and that of Gustafson et al. [8] where a superposition of two consecutive stages of tooth development makes difficult the attribution of degree of tooth development reached, and then the identification of age.

The statistical analysis of data, obtained by applying to our sample the methods considered, shows, for each of them, the level of reliability in terms of absolute error (i.e., exact match with the age determined by the evaluators and the actual age, in terms of absolute value) and with relative SD.

Among the methods in which the attribution of age is differentiated by sex, Demirjian et al. [7] shows the highest value of kurtosis (4.86). Considering, moreover, that there is no significant difference of evaluation between the examiners (post-hoc tests are not significant), it also turns out to be the most reliable method showing an AME equal to 0.75 years, with a deviation of attributed age than the actual value equal or less in the 59% of our sample.

Among the methods in which the attribution of age shall not be differentiated by sex, Robetti et al. [11] shows the highest value of kurtosis, equal to 6.20. Furthermore, although there is a significant difference between the evaluation of operators (post-hoc test is significant), it turns out to be quite reliable showing an AME equal to 0.96 years, with a deviation of age attributed/actual equal to or less than this value in the 68% of the sample (in terms of percentage it is the highest value reached in the present analysis).

A discrete reliability shows the method of Gustafson et al. [8]. It does not show a significant evaluative difference interoperator (post-hoc tests are not significant), shows an AME lower than that expressed by the method of Robetti et al. [11] (0.70 years vs 0.96 years), however, presents an index of kurtosis lower than to this last (3.39 vs 6.20) and a lower percentage of subjects with age discrepancy (attributed/actual) equal to or less than the AME (63% vs 68%).

The above is indicative of a major non-uniform distribution of the error made with respect to AME in the application of the method of Gustafson et al. [8] compared to that of Robetti et al. [11]. Moreover, the method of Gustafson et al. [8], by exploring the age range between the first month of intrauterine life and the attainment of age 16, is not able to provide any information with respect to go beyond or not the age of majority.

5. CONCLUSIONS

The considered radiographic methods of age determination show a greater degree of reliability in identifying the biological age of the subject to a maximum of 14 years.

However, there is disagreement regarding the auxoligical stage considered by the authors for the complete maturation of teeth (excluding eighths) in the dental arch.

The absence of one or more dental elements considered by the authors makes the method of identification unsuitable [6,7,10-12] or, in case of absence of several teeth, the less reliable the dental age attributed [5,8,9].

As regards the methods of age determination by gender, the method of Demirjian et al. [7] was found to be the most reliable. This method is not affected by interpretation of the operator in identifying the degree of tooth development predicted by the authors. Comparison of attributed age with real age shows a divergence ≤ 0.75 years in 59% of the sample.

As regards the methods of age determination which do not consider the sex of the subject, the method of Robetti et al. [11] showed the highest reliability (with the highest index of kurtosis among the methods considered). Comparison of attributed age with real age shows a divergence to a maximum of 0.96 years in 68% of the sample.

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CONFLICT OF INTEREST

The authors declare that they have not conflict of interest.

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