Age estimation of Russian individuals by teeth using the London Atlas

Análise da estimativa de idade em indivíduos russos utilizando a metodologia London Atlas

Juliane Bustamante Sá dos Santos[1], Ademir Franco[2], Victor Jacometti[1], Anna Turkina[3], Marianna Arakelyan[3], Alina Arzukanyan[3], Irina Makeeva[3], Pavel Velenko[4], Ricardo Henrique Alves da Silva[5]

ABSTRACT

Knowing an individual's age is necessary for several situations, both in the living and the deceased. The London Atlas uses dental development and eruption to estimate age. Testing the method in different populations is necessary to assess its performance. This study aimed to assess the performance of the London Atlas method in a Russian sample using panoramic radiographs. A sample of 703 panoramic radiographs of Russian individuals (n = 405 females, 57.61% and n = 298 males, 42.39%) with ages between 8 and 23 years were analyzed. The results showed overestimation in individuals from 8 to 14 years and underestimation from 15 to 23 years. The mean difference between estimated and chronological ages did not exceed 0.7 years among individuals with ages below 19 years. The difference increased to over three years in individuals from 20 to 23 years. Statistically significant differences were found between females and males between 17 and 18 years ($p<0.05$). The London Atlas is suitable for Russian children and adolescents aged between 8 and 19 years; however, it showed unsatisfactory results for application in individuals over 20 years.

Keywords: Forensic anthropology, Growth and development, Russian Federation, Forensic dentistry, Panoramic Radiography.

RESUMO

Conhecer a idade de um indivíduo, vivo ou morto, é essencial em diversas situações. O método London Atlas utiliza desenvolvimento e erupção dentais para estimar a idade. Testar o método em diferentes populações é importante para avaliar sua performance. Esse estudo objetivou analisar o desempenho do London Atlas em uma amostra de origem russa, utilizando radiografias panorâmicas. Uma amostra de 703 indivíduos russos (n = 405 mulheres, 57,61% e n = 298 homens, 42,39%), com idades entre 8 e 23 anos foram analisadas. Resultados obtidos mostram uma superestimação em indivíduos de 8 a 14 anos e subestimação nos grupos de 15 a 23 anos. A diferença média entre idades estimadas e reais não excederam o valor de 0,7 anos nos indivíduos com idade abaixo de 19 anos. Essa diferença aumentou em até três anos em indivíduos de 20 a 23 anos. Diferenças estatisticamente significantes foram encontradas entre homens e mulheres com 17 e 18 anos ($p<0,05$). O London Atlas é adequado para crianças e adolescentes de origem russa, com idades de 8 a 19 anos. No entanto, observou-se resultados insatisfatórios para sua aplicação em indivíduos acima de 20 anos.

Palavras-chave: Antropologia forense, Crescimento e desenvolvimento, Federação Russa, Odontologia legal, Radiografia Panorâmica.

Highlights

* London Atlas method showed good performance for Russian individuals between 8 and 19 years old.
* Error and bias significantly increased from 20 to 23 years old.
* London Atlas gave unsatisfactory results in individuals aged over 20 years.
* Age estimation demonstrated similar trends for males and females.
* Overall, London Atlas is a valuable contribution to the forensic professional's practice.

[1] University of São Paulo. Medical School. Department of Pathology and Forensic Medicine. Ribeirão Preto, (SP), Brazil.
[2] Division of Forensic Dentistry, Faculty São Leopoldo Mandic, Campinas, (SP), Brazil.
[3] Sechenov University. Russia. Institute of Dentistry. Department of Therapeutic Stomatology
[4] Sechenov University, Russia. Faculty of Medicine. Department of Forensic Medicine.
[5] Dentistry of Ribeirão Preto, Department of Stomatology, Public Health and Forensic Dentistry, Ribeirão Preto, (SP), Brazil.

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INTRODUCTION

Knowing an individual's age is necessary for several situations. In disaster victim identification, for instance, estimating age is essential, narrowing the number of suspects[1] and supporting the reconciliation between antemortem and post-mortem data. In the living, age estimation may be requested by judicial authorities in case of undocumented asylum seekers, as well as for the investigation of criminal liability, human trafficking, child pornography, and cases of adoption.[2,3]

Teeth are highly resistant mineral structures that withstand high force loads, extreme temperatures, and humidity.[4] Therefore, they are considered one of the most durable and resilient structures of the human body, and because they have well-established stages of development, they help significantly in forensic practice.[5] Of the various techniques used to estimate age from teeth, several use metrics approaches,[6,7,8] in which the size and proportions of the crown, root, pulp cavity, and apex opening are assessed and associated with the chronological age. On the other hand, techniques presented as atlas use qualitative analysis of dental stages and quantify stages in age values.[9] Compared to the metric techniques, the Atlas has the advantage of being less time-consuming[10], maintaining proper applicability.[11]

Imaging exams have been used in numerous studies to assist human identification, with the advantages of reconstructing, documenting, and preserving information in a practical way.[12] Radiographs are widely used in odontology, being requested in several cases and used for diagnosis, prognosis, and treatment planning. In addition, because it is possible to perform this examination quickly and without the destruction of the teeth, radiological methods reduce post-mortem damage and allow its application in living individuals.[13]

AlQahtani et al. (2010)14 developed an atlas for age estimation, using both tooth development and eruption, based on the modified classification of Moorrees, Fanning, and Hunt (1963a;b)[15,16] and Bengston (1935),[17] respectively. The technique was named the London Atlas, and its images were built based on the median values of each age group from the 30th week of intrauterine life to 23 years old.[14] Optimistic results have been found in populations tested so far, namely: Portuguese, Hispanic, Thai, Brazilian, Turkish, and a mixed sample of Bangladesh and white British.[9,13,18,19,20,21]

The Russian Federation is the largest country in the world in territorial extension, with approximately sixteen million square kilometers, and the ninth most populous[22]. The scientific literature is scarce on studies on age estimation, and only studies that encompass the analysis of third molars have been found so far.[23,24,25] For this reason, this study aimed to assess the applicability of the London Atlas method[14] to estimate age in this population.

MATERIALS AND METHODS

Ethics and study design

This study was approved by the institutional committee of ethics in human research of the University of Sechenov (protocol 5-11, SU), in Moscow, Russia. This was an observational and cross-sectional study with retrospective sampling.

Inclusion criteria

The inclusion criteria consisted of good-quality panoramic radiographs of Russian individuals aged 23.99 years or younger. Analyzed teeth should be all present and fully visible, without gross pathologies and other anomalies that prevent their visualization or that could influence their development.

Exclusion criteria

Images of poor quality and difficult visualization were excluded from the research, as well as individuals who demonstrated, on at least one side of the radiograph, dental anomalies, agenesis, presence of gross cavities, dental impaction, retained roots, absorbed deciduous roots from teeth other than their permanent successor, orthodontic treatment or other alteration that could hinder the application of the method.

Sampling

The sample consisted of 703 panoramic radiographs analyzed after applying the eligibility criteria. The age interval was from 8 to 23 years. Sex distribution was: 57.61% (n=405) female and

42.39% (n=298) male Russian individuals. The distribution by age group and sex is presented in Table 1. As a convenience sample, no equal number of males and females could be achieved. The individuals were all from the region of Moscow, Russia.

Table 1
Descriptive analysis. Distribution of individuals by age group. Each age group contains all individuals within the one-year range.

Age group (years)	Sex		Total
	Female	Male	
8 |— 8,99	20	36	56
9 |— 9,99	12	21	33
10 |— 10,99	28	26	54
11 |— 11,99	30	24	54
12 |— 12,99	26	27	53
13 |— 13,99	31	29	60
14 |— 14,99	39	25	64
15 |— 15,99	29	18	47
16 |— 16,99	31	21	52
17 |— 17,99	25	14	39
18 |— 18,99	25	9	34
19 |— 19,99	22	11	33
20 |— 20,99	18	11	29
21 |— 21,99	25	14	39
22 |— 22,99	29	9	38
23 |— 23,99	15	3	18
Total	405	298	703

Image acquisition and analysis

Panoramic radiographs from an institutional database were retrospectively assessed. Al the images were obtained for diagnostic and dental treatment purposes between 2017 and 2019. The images were acquired via the KaVo Pan eXam PLUS system device (Kavo Dental GmbH, Berlin, Germany) set with 66Kv, 2.5 mA, and 17s. The sample was divided by sex and documental (chronological) age, expressed in years.

The sample was randomized and renamed by an external researcher, and the examiner received the radiographs with any information regarding age and sex to keep a blind analysis. The imaging analysis was performed on an Inspiron 14 P93G notebook (Dell Technologies, Round Rock, Texas, USA). "Zoom", contrast, and brightness tools in the image viewer software were used for detail enhancement and better visualization. The left side of each individual dental arch was examined.

The stages of development evaluated during this study were based on the illustrations of the London Atlas. Each stage of development of multirooted teeth and inherent descriptions are presented in Figure 1.

Examiner agreement

Before analyzing the total sample, the examiner was instructed by another researcher,

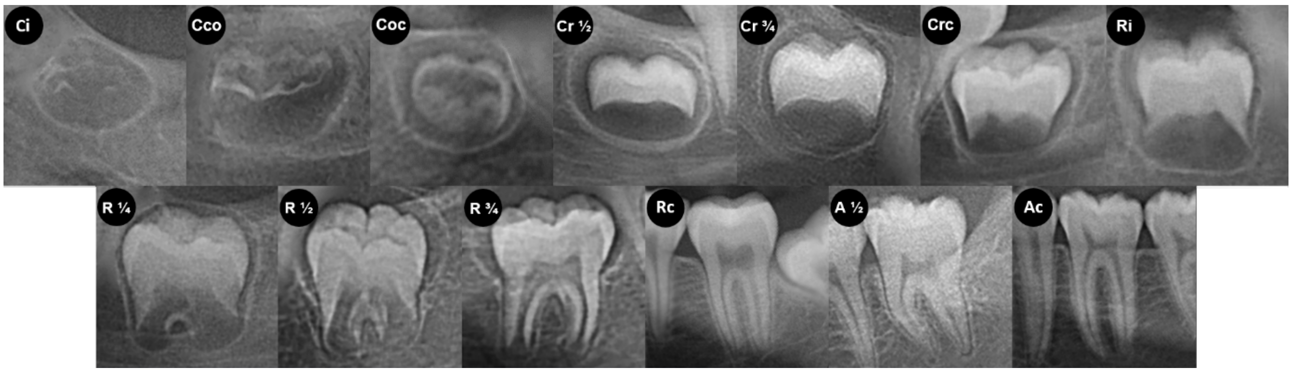

Figure 1: Illustrative image showing the modified stages of Moorrees et al. (1963a,b) for multirooted teeth. Thirteen stages describe dental development: Ci) Initial cusp formation; Bcc) Coalescence of cusps; Coc) Cusp outline complete; Cr½) Crown half completed with dentine formation; Cr¾) Crown three quarters completed; Crc) Crown completed with defined pulp roof; Ri) Initial root formation with diverge edges; R¼) Root length less than crown length with visible bifurcation area; R½) Root length equals crown length R¾) Three-quarters of root length developed with diverge ends; Rc) Root length completed with parallel ends; A½) Apex closed (root ends converge) with wide periodontal ligament; Ac) Apex closed with normal periodontal ligament width.

a Forensic Odontology specialist with previous experience in this method. The examiner was calibrated by analyzing 90 panoramic radiographs blindly, aiming to ensure uniformity of interpretation. Then, an intra-examiner agreement examination was carried out two months after completing the total sample analysis from the reanalysis of 10% of the sample (n=70) of panoramic radiographs randomly selected. The Weighted Kappa coefficient was used to quantify the agreement.

Statistical Analysis

Statistical analysis was carried out using the Statistical Package for Social Sciences package (SPSS, IBM, 2013, version 22). The distributions of all variables were tested for normality using the Kolmogorov-Smirnov test. Since all variables had normal distribution, one sample Student's T-test was used to assess differences between estimated and chronological mean ages. One-way analysis of variance (ANOVA) was used to assess differences between mean age differences between females and males in each age group. In the case of a statistically significant ANOVA result, Tukey's *post-hoc* test was used to assess pairwise comparisons.

Differences between ages were calculated by deducing the chronological age from the estimated age of each individual (Estimated Age – Chronological Age), so that positive values indicated overestimation, whereas negative indicated underestimation.

Mean and absolute mean differences for each age group were calculated for each sex. Mean differences were used to point out toward under or overestimation, while absolute mean differences indicated purely error values, i.e., the mean distance between estimated and chronological ages.

RESULTS

The weighted Kappa coefficient was 0.894, demonstrating excellent intra-examiner agreement, according to Landis and Koch (1977)[26], thus indicating high reliability of the examiner in data analysis.

In Table 2, it is possible to observe the mean differences of the individuals by age group. These differences were statistically significant (p < 0.001) in the 8-12 and 19-23 age groups. From 8 to 12 years, ages were, on average, overestimated (average = 0.46 years, with a standard deviation [SD] of 1.01). For ages between 19 and 23 years, there was an underestimation (mean = -1.8 years and SD = 1.98).

Table 2
Data referring to chronological and estimated ages by age group using the London Atlas method.

Chronological Age	Mean estimated ages	Standard Deviation	Mean Difference	CI (95%)	t	p-value
8 |— 8,99	8,46	0,95	0,46	0,21 - 0,72	3,647	0,0006*
9 |— 9,99	9,45	1,15	0,45	0,05 - 0,86	2,274	0,0298*
10 |— 10,99	10,37	1,00	0,37	0,1 - 0,64	2,732	0,0085*
11 |— 11,99	11,67	1,12	0,67	0,36 - 0,97	4,390	0,0001*
12 |— 12,99	12,34	0,90	0,34	0,09 - 0,59	2,755	0,0081*
13 |— 13,99	13,25	1,34	0,25	-0,1 - 0,6	1,450	0,1524
14 |— 14,99	14,13	1,29	0,13	-0,19 - 0,45	0,826	0,4117
15 |— 15,99	14,77	2,24	-0,23	-0,89 - 0,42	-0,717	0,4771
16 |— 16,99	15,90	1,35	-0,10	-0,47 - 0,28	-0,515	0,6089
17 |— 17,99	16,67	1,78	-0,33	-0,91 - 0,24	-1,168	0,2500
18 |— 18,99	17,82	1,83	-0,18	-0,82 - 0,46	-0,561	0,5784
19 |— 19,99	18,33	1,61	-0,67	-1,24 - -0,09	-2,373	0,0238*
20 |— 20,99	18,86	2,28	-1,14	-2 - -0,27	-2,689	0,0119*
21 |— 21,99	19,13	1,73	-1,87	-2,43 - -1,31	-6,738	<0,0001*
22 |— 22,99	19,55	1,59	-2,45	-2,97 - -1,93	-9,496	<0,0001*
23 |— 23,99	19,50	1,82	-3,50	-4,41 - -2,59	-8,145	<0,0001*

CI- 95% confidence interval; t = t-test value for single samples.

* Significant p-values (p<0.05).

It is also possible to notice that the mean differences between chronological and estimated ages did not exceed 0.7 years in any age group up to 19 years, and the mean difference in this age interval (8 to 19 years) was 0.34 years. The mean difference increased progressively for individuals over 20 years of age.

Between the ages of 13 to 18 years, no statistically significant differences were found between estimated and chronological ages (p>0.05), and the most accurate value was found in the 16-16,99 year-old interval, which showed, on average, a difference of -0.10 years. Table 3 shows the mean differences and absolute mean differences between males and females.

Analysis of variance (ANOVA) was applied to verify the difference between estimated and chronological age among sexes, and a revealed a statistically significant difference (p<0.05). Using the Tukey *post-hoc* test, significant differences were found for the 17-17,99 and 18-18,99-year-old intervals. In these ages, there was an overestimation for 17-17,99-year-old (mean = 0.5, SD = 1.4) and 18-18,99-year-old (mean = 0.78, SD = 1.3) males, and underestimation in 17-17,99-year-old (mean = -0.8, SD = 1.83) and 18-18,99-year-old (mean = -0.52, SD = 1.9) females. In other age intervals, there were no differences between method performance between females and males (p>0.05).

A visual distribution of under and overestimations by sex is shown in Figure 2. A trend of overestimation is observed in younger females and males (up to 13 years old). The ages of 14, 15, 17, and 18 show an inverse behavior between the sexes: for males, the mean difference is positive, while for females, it is negative. From 19 years onwards, the method underestimates age in both sexes (with an increasing difference between estimated and chronological ages).

Figure 3 illustrates the absolute mean differences per age group and sex. These values increase proportionally to the age of the individuals.

Table 3
Mean difference and absolute mean difference between chronological and estimated ages by sex.

Chronological Age	Male Mean Difference (SD)	n	Female Mean Difference (SD)	n	p-value	Male Mean Absolute Difference	Female Mean Absolute Difference
8 |— 8,99	0,25 (0,5)	36	0,85 (1,39)	20	0,14	0,25	0,85
9 |— 9,99	0,48 (1,33)	21	0,42 (0,79)	12	0,91	0,76	0,58
10 |— 10,99	0,08 (0,93)	26	0,64 (0,99)	28	0,16	0,77	0,93
11 |— 11,99	0,42 (1,06)	24	0,87 (1,14)	30	0,26	0,92	1,07
12 |— 12,99	0,15 (0,91)	27	0,54 (0,86)	26	0,33	0,59	0,77
13 |— 13,99	0,07 (1,46)	29	0,42 (1,2)	31	0,36	0,97	0,74
14 |— 14,99	-0,02 (1,33)	25	0,23 (1,27)	39	0,51	0,82	0,85
15 |— 15,99	0,22 (2,44)	18	-0,52 (2,1)	29	0,09	1,78	1,34
16 |— 16,99	-0,14 (1,39)	21	-0,06 (1,34)	31	0,85	0,90	1,03
17 |— 17,99	0,5 (1,4)	14	-0,8 (1,83)	25	0,01*	1,21	1,44
18 |— 18,99	0,78 (1,3)	9	-0,52 (1,9)	25	0,02*	1,22	1,40
19 |— 19,99	-0,45 (2,34)	11	-0,77 (1,15)	22	0,56	1,36	0,95
20 |— 20,99	-1,73 (3,26)	11	-0,78 (1,4)	18	0,09	1,91	1,00
21 |— 21,99	-1,86 (1,23)	14	-1,88 (1,99)	25	0,96	1,86	1,88
22 |— 22,99	-1,89 (1,17)	9	-2,62 (1,68)	29	0,19	1,89	2,62
23 |— 23,99	-4,33 (4,51)	3	-3,33 (0,98)	15	0,28	4,33	3,33

[a] 95% significance level, (p <0,05); Tukey *post-hoc* test.

SD: Standard Deviation

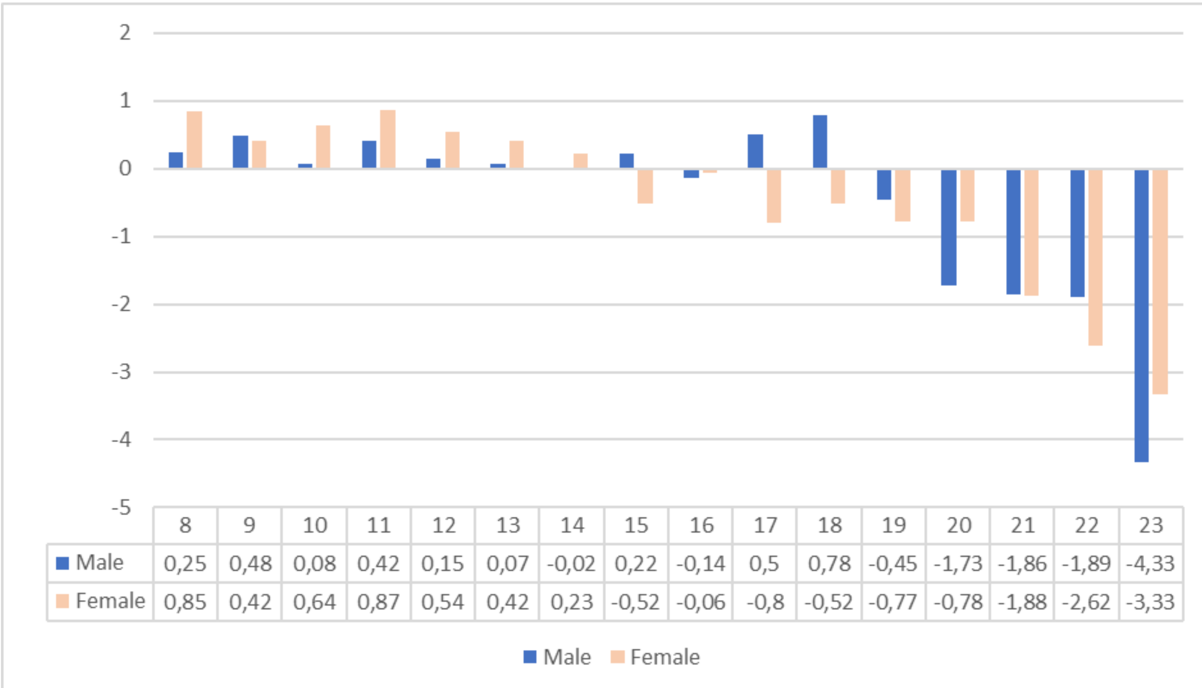

Figure 2: Mean differences between chronological ages and estimated mean ages by sex.

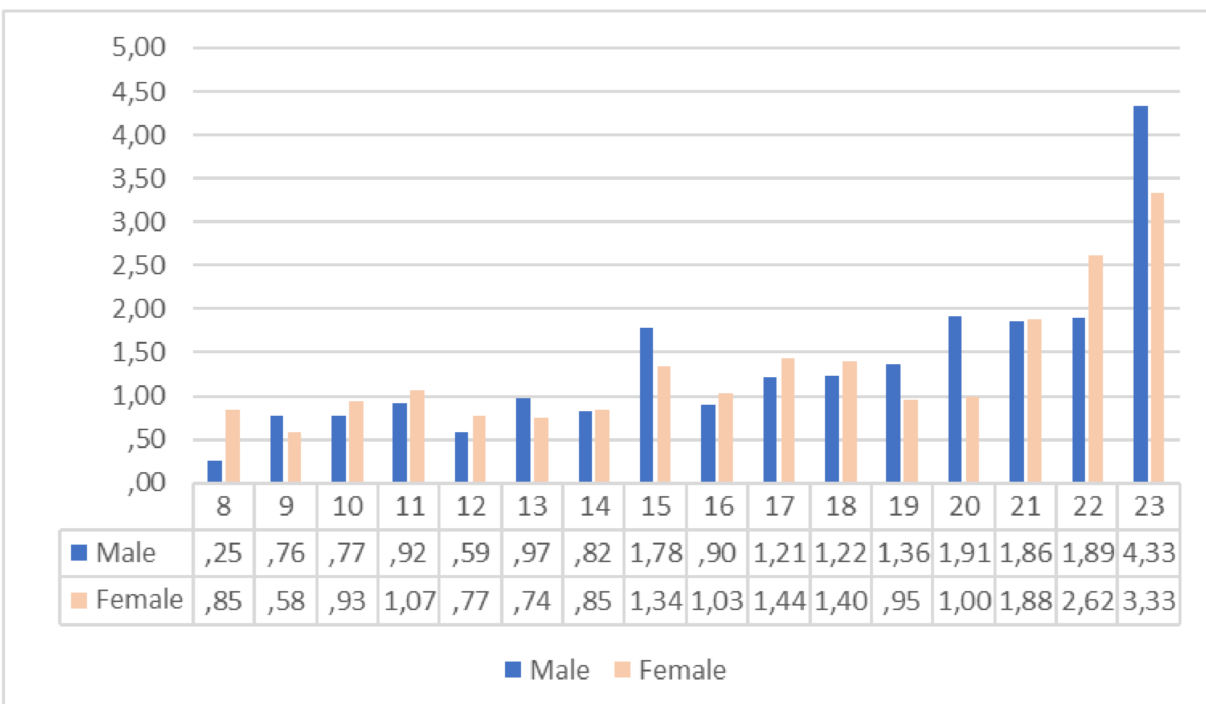

Figure 3: Absolute mean difference between chronological and estimated ages by sex.

DISCUSSION

The results found in this study demonstrate the reliability and reproducibility of the London Atlas.

From the results of this study, it was possible to notice a variation between over- and underestimation across age groups. In younger individuals, from 8 to 14 years old, the method overestimated the age (with statistically significant differences in the interval between 8 and 12 years old). The most evident overestimation was detected in individuals in the age interval of 11-11,99 years. Similarly, a study carried out with the Brazilian population[20] also found the highest overestimations in individuals in the same age interval. In another study with Hispanic children[18], the highest overestimation values were found in the ages of 7, and 11-14 years. The similarity between studies may be an indicator of the similarity between dental development in different populations, which is in agreement with country-specific studies in dental age estimation.[27]

Taking into account another study conducted in the Thai population[19], an overestimation was also noted between the ages of 12 to 14 years (mean = 0.5 years), but underestimated values were observed for children aged 7, 8, and 9 years (-0.5 years) - contrary to those of the current study. The mean difference between estimated and chronological ages found by the authors was 1.3 years; however, the sample in their study was restricted to individuals aged 4 to 15 years. Methodological differences between studies may justify the discrepant outcomes. Both studies used the London Atlas method, the sample size up to the age of 15,99, however, was 421 individuals (starting from the age of 8 years) in the present study, while the Thai population study had a sample of 111 individuals (starting from the age of 4). In the context of methodological differences, it must be highlighted that some studies use the London Atlas to allocate individuals below or above age thresholds of legal interest, such as the age of 16 and 18.[13,28] The present study showed a tendency to underestimate individuals aged 15 to 23 years, with this difference being statistically significant only from 19 years of age onwards. However, when the London Atlas was applied to distinguish individuals below or above 16 in the Portuguese population, the best results were found in older individuals (16 years of age and older)[13]. In a Brazilian population[28], the London Atlas had an accuracy of 79.9% to allocate individuals below or above 18, and it was considered suboptimal for this task – endorsing the limitations that may occur in the late stages of dental development.

The highest underestimation was found in the interval that encompasses 20 to 23 years and progressively increased to the age of 23 years (-3.5 years of difference between estimated and chronological ages), for both sexes. Singh et al. (2014)[5] stated that dental age estimation is divided into two parts: the development of teeth in the maxilla and mandible and the late changes in tooth morphology (fully developed teeth). Fully developed teeth do not allow age estimation using the London Atlas. However, radiographs that showed the complete development of third molars were not excluded from this study because it was our intention to cover the development of teeth up to complete apex formation. A similar approach was performed by Sousa et al. (2020)[20] in their investigation of Brazilian children and adolescents. Increasing the upper age limit of the sample is not justified because it would extrapolate the original age limits established by the London Atlas.

When comparing the sexes, it was possible to observe that, in general, they followed the same trend in all age intervals, except for the ages of 16 and 18. Some studies have demonstrated differences between females and males.[13,20,29] The original London Atlas study shows that the medians of the developmental stages of girls preceded those of boys between 6 and 14 years old. However, the difference was not present in the entire dental arch and was disregarded in the illustration of the Atlas. Sex-specific outcomes; however, can be assessed throughout the tables and the original study.[14]

Some authors claim that a maximum difference between estimated and chronological ages of 6-12 months is important for forensic applications in children and adolescents.[10] In the present study, from 8 to 19 years, the mean differences between estimated and chronological age did not exceed one year (max. error: 0.67 years). From 20 years old onwards, the method showed a significant bias, with a mean difference that varied from 1.14 to 3.5 years between estimated and chronological age. The estimation error, given by the absolute mean differences, was greater than one year from the 15-year-old group, except for the 16-year-olds for males and 19 and 20-year-olds for females.

Few studies of age estimation were found in the Russian population. Scendoni et al. (2020)[23] analyzed third molars, applying Cameriere et al. (2006)[6] method in this population, and demonstrated high sensitivity and specificity. Franco et al. (2021a),[24] also using third molars, applied the technique of Gleiser & Hunt (1955),[31] modified by Kohler et al. (1994),[32] to classify individuals below and above the thresholds of 14 and 16 years, ages. The results were optimistic; however, they highlighted the need for study validation. In a second study, Franco et al. (2021b)[25] found promising results to allocate Russian individuals below or above 18, but they emphasize that the assessment of adulthood from the teeth is challenging and even accurate methods should be applied with caution, serving as support for age estimation due to inherent limitations.

Over or underestimating age has a significant impact on legal issues. Concerning human rights, it is usually better to underestimate than to overestimate. This is due to legal majority status and, therefore, the loss of possible governmental assistance. Nonetheless, methods cannot also be too biased towards underestimation because this would aid in obtaining those assistances and rights fraudulently. Likewise, regarding criminal liability, an inadequate underestimation could lead to injustice - in both ways - not punishing adequately an adult individual and punishing a minor as a major age person.

When it comes to the identification and discussion of study limitations, it is necessary to observe that several radiographs were excluded from the study due to the presence of dental interventions that hampered to the application of the London Atlas, such as prosthetic, endodontic, restorative, and surgical dental treatments. These findings listed in the exclusion criteria could reflect specific habits, such as smoking and alcoholism that are becoming less popular in the country but still present even among young individuals.[33,34] Gietel-Basten et al. (2020)[35] also state that there are significant inequalities related to health and its policies in the Russian Federation, as well as great heterogeneity in the aging process in the country.

Another noteworthy limitation is the fact that we could not achieve a well-balanced sample in regard to sex and age cohorts. In older ages, specifically, individuals were not equally distributed, which could potentially skew results. Also, no further information on the socioeconomic statuses of the studied sample was available to the researchers. Further studies should try to employ and analyze possible effects that this co-variable might have on estimates errors and attempt to obtain equally distributed samples.

In practice, age estimation methods should be applied only by experienced professionals.[13] Despite accuracy, methods for dental age estimation require training and familiarization. Combinations between methods are also recommended[36] justifying future studies in the field and constant testing/investigation of the available methods.

CONCLUSION

The London Atlas method is suitable for Russian children and adolescents aged between 8 and 19 years based on its good performance; however, it showed unsatisfactory results for application in individuals aged over 20 years.

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Author contribution
JBSS: Conceptualization, Data extraction, Writing - Original Draft, Project administration
AF: Writing - Review & Editing, Validation, Writing - Original Draft
VJ: Conceptualization, Formal analysis, Supervision, Writing - Original Draft
AT: Resources, Software, Data curation, Writing - Review & Editing
MA: Resources, Data curation, Writing - Review & Editing
AA: Resources, Data curation, Writing - Review & Editing
IM: Resources, Data curation, Writing - Review & Editing
PV: Resources, Data curation
RHAS: Conceptualization, Writing - Review & Editing, Supervision

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Corresponding Author:
Ricardo Henrique Alves da Silva
ricardohenrique@usp.br

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