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Age Determination Based on Open Apex Measurement in the Developing Dentition: Comparing the Accuracy of the Belgrade Age Formula (BAF) with the European Formula on a Bosnian Children Population

Određivanje dobi na temelju mjerenja otvorenoga apeksa zuba u razvoju: usporedba točnosti beogradske formule starosti (BAF) s europskom formulom na populaciji djece u BiH

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Abstract

Objective: The aim was to test the Belgrade age formula based on the calculation of open apices of two permanent mandibular teeth on a Bosnian children population and compare its accuracy with European formula. **Material and methods:** We included 412 panoramic images of children (204 female and 208 male) 7 to 13 years of age. We assessed the performance of both methods (the European formula and the BAF) and compared their results in both sexes. **Results:** The results showed a high point of average understanding between the age estimated by chronological age and the European formula (ICC=0.927, 95% CI 0.904–0.944, $p<0.001$)., BAF also confirmed a high point of agreement with chronological age in boys (ICC=0.941, 95% CI 0.922–0.955, $p<0.001$) and girls (ICC=0.913, 95% CI 0.886–0.934, $p<0.001$). BAF was better than the European formula in estimating age in males (0.4448±0.9135 vs. 0.9807±0.9422). **Conclusion:** The Belgrade Age Formula (BAF) demonstrates comparable accuracy to the European formula for age determination in Bosnian children, while offering the advantage of being easier and faster to use. This makes the BAF a practical alternative in clinical and research settings where efficiency and reliability are essential.

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Introduction

The basic and fundamental topic in forensics is the estimation of the chronological age of children and adolescents, whether in pediatric and orthodontic or forensic cases, which allows forensic experts to determine age, diseases, or which is very important, to determine the status of a juvenile, criminal liability, adoption, human trafficking, which is the final tool in criminal proceedings. In dentistry assessment, is very important to find the best treatment of various dental malocclusions based on craniofacial growth. Thus, it is highly

Uvod

Osnovna i fundamentalna tema u forenzici jest utvrđivanje dentalne starosti djece i adolescenata, bilo u pedijatrijskim, bilo u ortodontskim ili forenzičkim slučajevima, što omogućuje forenzičkim stručnjacima da utvrde dob i bolesti, ili, što je vrlo važno, da ustanove status maloljetne osobe, kaznenu odgovornost osobe, slučajeve posvajanja i trgovinu ljudima kao konačnog sredstva u kaznenom postupku. U stomatološkoj praksi procjena dobi značajna je kako bi se pronašao najbolji tretman za različite dentalne malokluzije

important to estimate dental age. Dental age can be assessed amongst children with great accuracy since a great number of teeth undergo development and calcification simultaneously. However, this accuracy declines with the completion of tooth development [1].

Over the previous decade, the usage of age calculation methodologies on radiographs has reached an increased value in the field of forensic medicine [1-3]. Most methods have been established on the radiography of the teeth. Fortunately, various age estimation procedures have been discovered [2, 4, 5] either using charts and scoring systems compared with expected tooth development or quantitative methods that are in the usage in certain formulas. The most recognized and applied method was created by Cameriere et al. in 2006 [2]. It is important to note that this method measures the parameters of the first lower seven permanent teeth on panoramic radiographs, with the measuring units including the measurement of the teeth and the width of open apices. Scientists have already used this method in many studies focused on age estimation in children and adolescents. Its credibility has been probative in numerous inhabitants [2, 6, 7] and research discovered it to be almost of the same accuracy in the Serbian inhabitants [8]. In the study by Latić-Dautović et al. [9], the European formula was shown to be a useful tool for estimating the age of children in Bosnia and Herzegovina under the age of 14. Nevertheless, the wider application of the method would be helped by a faster and easier age assessment. Bearing that in mind, a novel formula (Belgrade Age Formula- BAF) for age estimation in children was developed and built on a Serbian children population and tested on Italian sample [10]. The BAF is based on European formula, but it is faster and easier to perform. According to the results of the study by Zelić et al. [10], the BAF and the European formula gave very reliable results for various samples. As the BAF method uses only canine and second molar for measurements, the main difference between these two formulas is the number of measurements, which is reduced from 14 to 4 [10]. This makes the BAF method much more convenient. Furthermore, by eliminating five teeth from the formula, this method becomes more applicable as it can be applied even if some of these teeth are missing.

In principle, methods for estimating the age in children ought to be validated on large samples and samples of various origins. In this regard, different formulas should be tested on different populations, in order to identify the optimal ones for a specific country or population.

Hence, the aim of this study was to verify the applicability of the BAF in other populations and potentially spread its application. Thus we tested the Belgrade age formula based on the calculation of open apices of two permanent mandibular teeth on a Bosnian children population. The accuracy of the obtained results was compared with the accuracy of European formula.

Materials and method

Study design and patient selection

Panoramic radiographs were taken at the Diagnostic and Radiology Center of the Faculty of Dentistry of the Univer-

na temelju kraniofacijalnoga rasta. Zato je veoma važno procijeniti dentalnu dob osobe. Dentalna dob djece može se procijeniti s velikom preciznošću jer se mnogi zubi istodobno razvijaju i kalcificiraju. No ta točnost opada sa završetkom razvoja zuba (1).

U proteklom desetljeću primjena metodologije procjene dobi upotrebom rendgenskih snimki dobila je povećanu vrijednost u području sudske medicine (1 – 3). Na sreću, otkriveni su mnogobrojni postupci u procjeni starosti (2, 4, 5) korištenjem grafikona i sustava bodovanja u usporedbi s očekivanim razvojem zuba; ili kvantitativne metode koje su u upotrebi u određenim formulama. Najpriznatiju i najprimjenjiviju metodu predložili su Cameriere i suradnici 2006. godine [2]. Važno je istaknuti da se tom metodom na panoramskim rendgenskim snimkama mjere parametri prvih sedam stalnih zuba donje čeljusti, pri čemu mjerne jedinice uključuju mjerenje zuba i širinu otvorenih apeksa. Znanstvenici su se već koristili tom metodom u mnogim studijama usmjerenima na procjenu dobi djece i adolescenata. Njezin kredibilitet dokazan je kod mnogobrojnih stanovnika (2, 6, 7), a istraživanja su otkrila da je gotovo jednake točnosti i kod inhibitora u Srbiji (8). U studiji dr. Latić-Dautović i suradnika (9), europska formula pokazala se kao koristan alat za procjenu dobi djece u Bosni i Hercegovini mlađe od 14 godina. Ipak, njezinoj široj primjeni pomoglo bi kad bi ta procjena bila brža i lakša. Imajući to na umu, predložena je nova formula (beogradska formula starosti – BAF) za procjenu dobi djece na populaciji djece iz Srbije i testirana je na talijanskom uzorku (10). BAF se temelji na europskoj formuli, ali je brži i lakši za primjenu. Prema rezultatima istraživanja Zelića i suradnika (10), BAF i europska formula dali su vrlo pouzdane rezultate na različitim uzorcima. Kako se za BAF metodu za mjerenje uzimaju samo očnjak i drugi kutnjak, glavna razlika između tih dviju formula jest broj mjerenja koji je smanjen s 14 na 4 (10). To čini BAF metodu mnogo prihvatljivijom. Nadalje, eliminacijom peterih zuba iz formule, ta metoda postaje primjenjivija jer se može upotrijebiti čak ako neki od tih zuba nedostaju.

U načelu, metode za procjenu dobi djece trebaju biti validirane na velikim uzorcima i uzorcima različitog podrijetla. U tom kontekstu različite formule treba ispitati na različitim populacijama kako bi se identificirale one optimalne za određenu zemlju ili populaciju.

Zato je cilj ove studije bio provjera primjenjivosti BAF-a na drugim populacijama i potencijalno proširenje njegove primjene. Zato smo testirali beogradsku starosnu formulu utemeljenu na proračunu otvorenih vrhova dvaju trajnih zuba donje čeljusti na populaciji djece u BiH. Točnost dobivenih rezultata uspoređena je s točnošću europske formule.

Materijali i metoda

Dizajn studije i odabir uzoraka

Panoramske rendgenske snimke rađene su u Dijagnostičko-radiološkom centru Stomatološkog fakulteta Univerzite-

sity of Sarajevo, between 2013 and 2019, with approval from the Ethics Committee (number: 09-552-9/2013). Measurements on the panoramic radiographs were performed from January to February 2024. The research was carried out in consent with the Helsinki ethical principles for medical research involving humans.

As the BAF is based on the European formula, it also uses measurements of the width of the open apices of the lower left permanent teeth and the length of these teeth. However, unlike the European formula, which requires the measurements of teeth 31–37, the BAF only needs measurements of two teeth, namely 37 and 33, which facilitates the entire estimation process. Here, we conducted a cross-sectional study of a sample of 412 panoramic radiographs of Bosnian children (204 female; 208 male) aged between 7 and 13. The distribution of the sample by age and sex is shown in Table 1.

ta u Sarajevu od 2013. do 2019. godine, uz odobrenje Etičkoga povjerenstva pod brojem: 09-552-9/2013. Mjerenja na panoramskim rendgenskim snimkama obavljena su od siječnja do veljače 2024. godine. Istraživanje je provedeno u skladu s Helsinškim etičkim načelima za medicinska istraživanja na ljudima.

Kako je BAF utemeljen na europskoj formuli, koristi se i mjerenje širine otvorenih vrhova donjih lijevih trajnih zuba i dužine tih zuba. No za razliku od europske formule koja zahtijeva mjerenje zuba 31 – 37, BAF-u su potrebna samo mjerenja dvaju zuba, odnosno 37 i 33, što olakšava cijeli proces procjene. U ovoj smo studiji analizirali poprečni presjek uzorka od 412 panoramskih rendgenskih snimki bosansko-hercegovačke djece (204 djevojčica i 208 dječaka) od 7 do 13 godina. Raspodjela uzorka prema dobi i spolu prikazana je u tablici 1.

Table 1 Distribution of the sample by sex and age.
Tablica 1. Distribucija uzorka prema spolu i starosti

| Age • Uzrast | Female • Ženski | Male • Muški | Total • Ukupno |
|----------------|-----------------|--------------|----------------|
| 7 | 28 | 28 | 56 |
| 8 | 28 | 29 | 57 |
| 9 | 30 | 31 | 61 |
| 10 | 30 | 30 | 60 |
| 11 | 30 | 31 | 61 |
| 12 | 30 | 31 | 61 |
| 13 | 28 | 28 | 56 |
| Total • Ukupno | 204 | 208 | 412 |

The inclusion criteria were: healthy children aged 7 to 13 years, with complete dental history, satisfactory quality of panoramic radiographs (of appropriate contrast, density, and exposure) and at least one permanent tooth in the lower left quadrant (excluding 38) that is not fully formed yet. In cases of documented genetic or metabolic disorder, congenital disability, and active infection or pathological process in the jaw bones and teeth, those radiographs were excluded. In the cases of substitute measuring, the lower right quadrant was used.

Age estimation

To calculate the dental age of the included children, the BAF formula was used as described in the original scientific paper [10]:

For males:

$$\text{Dental Age} = 0.791 \cdot N_0 - 0.779 \cdot x_7 - 2.626 \cdot x_3 + 9.155$$

For females:

$$\text{Dental Age} = 0.856 \cdot N_0 - 0.580 \cdot x_7 - 1.905 \cdot x_3 + 8.136$$

The parameters used in this formula were:

N_0 - calculated teeth with unclosed apices,

x_7 - ratio between apex width and height of tooth 37, and

x_3 - ratio between apex width and height of tooth 33.

The European formula proposed in the original scientific paper [2] was also used to estimate age, as follows:

$$\text{Dental Age} = 8.387 + 0.282 \cdot g + 1.692 \cdot x_5 + 0.835 \cdot N_0 - 1.116s - 0.139s \cdot N_0,$$

Kriteriji za uključivanje bili su: zdrava djeca od 7 do 13 godina, s kompletnom stomatološkom anamnezom, zadovoljavajuća kvaliteta panoramskih rendgenskih snimki (odgovarajući kontrast, gustoća i ekspozicija) i najmanje jedan stalni zub u donjem lijevom kvadrantu (osim 38) koji još nije potpuno formiran. U slučaju dokumentiranoga genetskoga ili metaboličkoga poremećaja, kongenitalnoga invaliditeta i aktivne infekcije ili patološkoga procesa u kostima čeljusti i zuba, te su snimke isključene. U slučaju zamjenskoga mjerenja korišten je donji desni kvadrant.

Procjena starosti

Da bi se izračunala starost zuba testirane djece, formula BAF izvedena je kako je opisano u izvornom članku (10):

za dječake:

$$\text{zubna starost} = 0,791 \cdot N_0 - 0,779 \cdot x_7 - 2,626 \cdot x_3 + 9,155$$

za djevojčice:

$$\text{zubna starost} = 0,856 \cdot N_0 - 0,580 \cdot x_7 - 1,905 \cdot x_3 + 8,136$$

Parametri korišteni u ovoj formuli:

N_0 – proračunati zubi s nezatvorenim apeksom

x_7 – odnos širine vrha i visine zuba 37

x_3 – odnos širine vrha i visine zuba 33.

Europska formula predložena u izvornome članku (2) također je korištena za procjenu starosti kako slijedi:

$$\text{starost zuba} = 8,387 + 0,282 \cdot g + 1,692 \cdot x_5 + 0,835 \cdot N_0 - 1,116s - 0,139s \cdot N_0,$$

The parameters used in this formula were:

N_0 - calculated teeth with unclosed apices,
 x_5 - ratio between apex width and height of tooth 35,
 s - sum of all ratios between apex and height and $g - 1$ for males and 0 for females.

After application of both methods (European and BAF), we were able to determine the deviation of the estimated age from chronological age for each method, and compare the deviations between the two methods.

Statistical analysis

First, we verified the observer (intra and inter) integrity of age estimation, for both formulas, 2 months afterwards the initial calculation on 50 randomly chosen panoramic images of the Bosnian inhabitants by using the intraclass correlation coefficient (ICC). Next, we calculated the deviation of the calculated age from chronological age for each of the two methods and performed a one-sample t-test to determine whether the deviations were significantly different from 0. Further statistical testing using ICC attempted to quantify the accordance between the calculated and chronological age, separately in boys and girls. To better understand the accuracy of estimation, we considered the deviation of ± 6 months as clinically acceptable; hence we also determined the percentage of children with clinically acceptable deviation of age estimation by each of the two methods, separately in boys and girls. A similar analysis was conducted for the deviations of ± 12 months and ± 3 months. Finally, we compared the residuals (deviation of the calculated age from chronological age for each individual) of both methods, separately in boys and girls, using the paired-sample t-test. To visualize the results and better understand both the accuracy and precision of the estimates, we created modified Blant-Altman diagrams for both sexes and for both formulas (Figure 1 and 2). A statistical analysis was presented in SPSS, with a significance level of 0.05.

Results

The ICC values for intra and inter-observer integrity for the dental age by the BAF were 0.979 (0.959–0.987) and 0.990 (0.950–0.995), respectively. Similar results were found for the calculated dental age by the European formula, namely ICC=0.973 (0.955–0.985) and ICC=0.983 (0.945–0.985), respectively.

The residual for both methods showed a significant deviation from 0 (one-sample t-test: $p < 0.001$), meaning that both methods had a certain level of error. However, further analysis to quantify the treaty among the calculated and chronological age demonstrated a high level of overall integrity among the age calculated by the European formula and chronological age in boys (ICC=0.931, 95% CI 0.909–0.948, $p < 0.001$) and girls (ICC=0.927, 95% CI 0.904–0.944, $p < 0.001$). Likewise, the age calculated by the BAF also showed a high level of integrity with the chronological age in boys (ICC=0.941, 95% CI 0.922–0.955, $p < 0.001$) and girls (ICC=0.913, 95% CI 0.886–0.934, $p < 0.001$).

The percentage of individuals with residuals within ± 3 months was almost the same for both methods (European

Parametri korišteni u ovoj formuli:

N_0 – proračunati zubi s nezatvorenim vrhovima
 x_5 – odnos širine vrha i visine zuba 35
 s – zbroj svih odnosa između vrha i visine i $g - 1$ za muškarce i 0 za žene.

Nakon primjene obiju metoda (europske i BAF-a), uspjeli smo utvrditi odstupanje procijenjene starosti od kronološke dobi za svaku metodu, te usporediti odstupanja između tih dviju metoda.

Statistička analiza

Učinjena je prva opservacijska provjera (intra i inter) integriteta procjene starosti za obje formule, a dva mjeseca poslije toga obavljena je inicijalna kalkulacija na 50 nasumično odabranih ortopantomograma bosanskohercegovačke djece korištenjem koeficijenta unutarklasne korelacije (ICC). Zatim je izračunato odstupanje od procijenjene starosti u odnosu prema kronološkoj dobi za svaku od dviju metoda i primijenjen je t-test jednog uzorka kako bismo ustanovili razlikuju li se odstupanja značajno od 0. Daljnje statističko testiranje korištenjem ICC-a imalo je za cilj kvantificirati usklađenost između izračunatoga i kronološke doba, posebno kod dječaka i djevojčica. Da bismo bolje razumjeli točnost procjene, smatrali smo da je odstupanje od ± 6 mjeseci klinički prihvatljivo, pa smo također odredili postotak djece s klinički prihvatljivim odstupanjem u procjeni dobi svakom od tih dviju metoda, posebno kod dječaka i djevojčica. Slična analiza primijenjena je za odstupanja od ± 12 mjeseci i ± 3 mjeseca. Konačno, usporedili smo rezidualne (odstupanje izračunate starosti od kronološke dobi za svakog pojedinca) obiju metoda, posebno kod dječaka i djevojčica, s pomoću t-testa uparenog uzorka. Da bismo vizualizirali rezultate i bolje razumjeli točnost i preciznost procjena, kreirali smo modificirane Blant-Altmanove dijagrame za oba spola i za obje formule (slike 1. i 2.). Statistička analiza rađena je u SPSS-u, s razinom značajnosti od 0,05.

Rezultati

ICC vrijednosti za integritet unutar opservacija i među opservacijama za dob zuba prema BAF-u bile su 0,979 (0,959 – 0,987) i 0,990 (0,950 – 0,995), respektivno. Slični rezultati dobiveni su i za izračunatu starost zuba prema europskoj formuli, odnosno ICC = 0,973 (0,955 – 0,985) i ICC = 0,983 (0,945 – 0,985), respektivno.

Ostatak za obje metode pokazao je značajno odstupanje od 0 (t-test jednog uzorka: $p < 0,001$), što znači da su obje metode imale određenu razinu pogreške. No daljnja analiza za kvantificiranje ugovora između izračunate i kronološke dobi pokazala je visoku razinu ukupnoga integriteta između dobi izračunate prema europskoj formuli i kronološke dobi dječaka (ICC = 0,931, 95 % CI 0,909 – 0,948, $p < 0,001$) i djevojčica (ICC = 0,927, 95 % CI 0,904 – 0,944, $p < 0,001$). Starost prema BAF-ovu izračunu također je pokazala visoku razinu integriteta (podudaranja) s kronološkom dobi dječaka (ICC = 0,941, 95 % CI 0,922 – 0,955, $p < 0,001$) i djevojčica (ICC = 0,913, 95 % CI 0,8346 – 0, $p < 0,001$).

Postotak osoba s rezidualima unutar ± 3 mjeseca bio je gotovo isti za obje metode (europska formula: 22,6 % za dje-

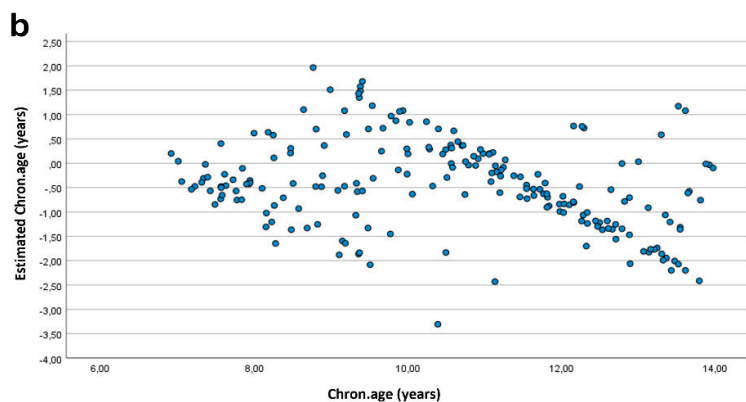
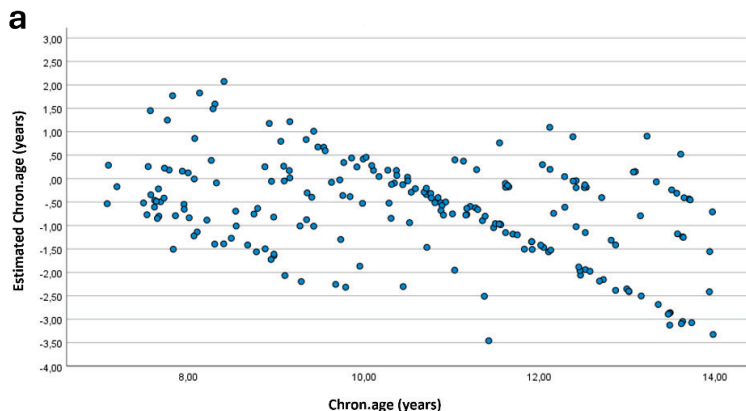


Figure 1 Modified Bland–Altman diagrams illustrating the aberration of the calculated age from chronological age (diff (BAF, CA)) in the entire age range in girls (A) and boys (B). X-axis: chronological age; y-axis: diff (BAF, CA); CA- chronological age; BAF- Belgrade Age Formula

Slika 1. Modificirani Bland–Altmanovi dijagrami koji pokazuju odstupanje od izračunate starosti od kronološke dobi (dif (BAF, CA)) u cijelom starosnom rasponu kod djevojčica (A) i dječaka (B). X-os: kronološka dob; y-os: diff (BAF, CA); CA – kronološka dob; BAF-beogradska formula starosti

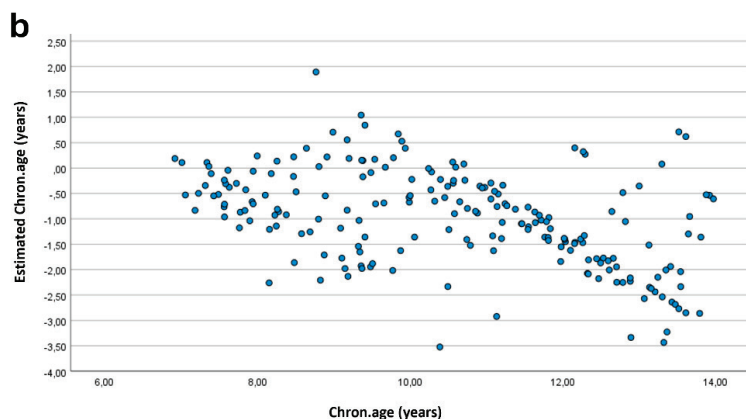
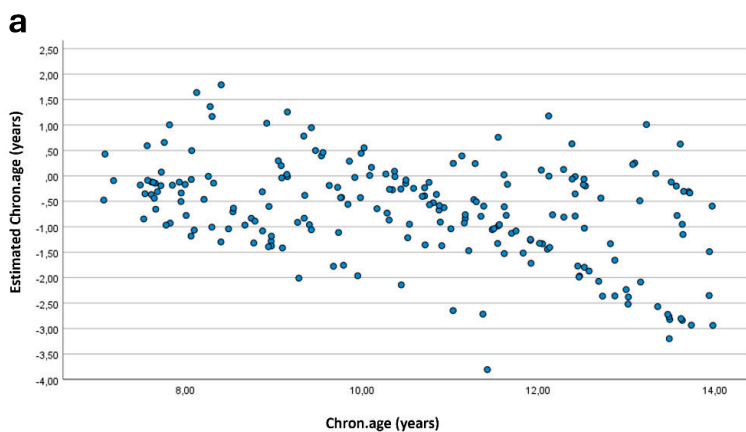


Figure2 Modified Bland–Altman diagrams illustrating the aberration of the estimated age from chronological dental age (diff (E, CA)) in the entire age range in girls (A) and boys (B). X-axis: chronological age; y-axis: diff (E, CA); CA- chronological age; E- European formula

Slika 2. Modificirani Bland–Altmanovi dijagrami koji pokazuju odstupanje procijenjene dobi od kronološke starosti zuba (dif (E, CA)) u cijelom starosnom rasponu kod djevojčica (A) i dječaka (B). X-os: kronološka starost; y-os: diff (E, CA); CA – kronološka starost; eueuropska formula

formula: 22.6% for girls and 17.1% for boys; BAF: 20.3% for girls and 16.7% for boys). Given the error range of ± 6 months in age estimation, the European formula correctly calculated age in 44.5% of girls and 47.8% of boys, while the BAF was somewhat less successful (37.3% in girls and 37.1% in boys). However, for the residuals within ± 12 months and ± 3 months, the differences between the two methods were slightly less pronounced. Namely, the percentage of individuals with residuals within ± 12 months was 67.0% and 73.7% for female and male sex, respectively, using the European formula, and 62.2% and 66.8% for female and male sex, respectively, using the BAF. These results are shown in Table 2.

vojčice i 17,1 % za dječake; BAF: 20,3 % za djevojčice i 16,7 % za dječake). S obzirom na raspon pogreške od ± 6 mjeseci u procjeni starosti, europskom formulom ispravno je izračunata dob 44,5 % djevojčica i 47,8 % dječaka, a metoda BAF bila je nešto manje uspješna (37,3 % djevojčica i 37,1 % dječaka). No za ostatke unutar ± 12 mjeseci i ± 3 mjeseca, razlike između tih dviju metoda bile su nešto manje. Naime, postotak osoba s rezidualima unutar ± 12 mjeseci iznosio je 67,0 % i 73,7 % za ženski i muški spol, respektivno, koristeći se europskim formulom, odnosno 62,2 % i 66,8 % za ženski i muški spol ako se upotrijebi BAF. Ti se rezultati nalaze u tablici 2.

Table 2 Percentage of age estimation within $\pm 3,6$ and 12 months in comparison with chronological age.
Tablica 2. Postotak s procjenom starosti unutar $\pm 3,6$ i 12 mjeseci u usporedbi s kronološkom dobi

| | European Formula-Boys • Europska formula – dječaci | European Formula-Girls • Europska formula – djevojčice | BAF-Boys • BAF – dječaci | BAF-Girls • BAF – djevojčice |
|------------------------------------|---|---|-----------------------------|---------------------------------|
| ± 3 months • ± 3 mjeseca | 17.1% | 22.6% | 16.7% | 20.3% |
| ± 6 months • ± 6 mjeseci | 47.8% | 44.5% | 37.1% | 37.3% |
| ± 12 months • ± 12 mjeseci | 73.7% | 67.0% | 66.8% | 62.3% |

Comparison of the residuals of the BAF and the European formula by paired-sample t-test showed that the BAF was better than the European formula in estimating age in the Bosnian sample in males, where mean residuals were -0.4448 ± 0.9135 for the BAF and -0.9807 ± 0.9422 for the European formula. However, in females, both methods showed similar performance (BAF: -0.6589 ± 1.0544 ; European formula: -0.6855 ± 0.9701). Of note, both formulas in both sexes tended to underestimate age.

Finally, to analyze the results more closely, we created modified Blant–Altman diagrams for both sexes and for both formulas (Figure 1 and 2). As shown in these diagrams, for both formulas, more scattered results were noticed in children older than 12 years. For the BAF in boys, there were two age ranges where there was evident uniformity of estimates, i.e., higher precision and accuracy (approximately at age 7–8 and 10–12 years). Similar results were obtained for the European formula. In the female groups, the results were more scattered. However, there was also higher precision and accuracy of the estimates in the age interval of 10–11 years in the female group, especially in the BAF formula.

Discussion

Assessment of dental maturity plays a key role in both antemortem and postmortem identifications of delayed or advanced maturation. Given that, there are still unsolved identification cases in Bosnia and Herzegovina, therefore it is crucial to upgrade the existing protocols with new methods that can help in assessing age, maturity, and pathological processes. In clinical application, that would predict permanent teeth growth and development thus facilitating treatment design [11, 12]. Therefore, the maturity of teeth needs to be assessed as accurately and precisely as possible. Furthermore, the most applicable and convenient method should be quick and reproducible. Besides, it should be easy to perform.

Usporedba reziduala BAF-a i europske formule t-testom uparenih uzoraka pokazala je da je BAF bolji od europske formule u procjeni dobi u bosanskom uzorku kod muške populacije, u kojoj su srednji reziduali bili $-0,4448 \pm 0,9135$ za BAF i $-0,9807 \pm 0,9422$ za europsku formulu. No kod ženske populacije obje su metode pokazale slične performanse (BAF: $-0,6589 \pm 1,0544$; europska formula: $-0,6855 \pm 0,9701$). Treba napomenuti da su obje formule kod oba spola imale tendenciju podcjenjivanja godina.

Konačno, da bismo detaljnije analizirali rezultate, kreirali smo modificirane Blant-Altmanove dijagrame za oba spola i obje formule (slike 1. i 2.). Kao što se vidi na tim dijagramima, za obje formule uočeno je više disperznih rezultata za djecu stariju od 12 godina. Za BAF su kod dječaka postojala dva starosna raspona u kojima je postojala evidentna ujednačenost procjena, odnosno veća preciznost i točnost (otprilike u dobi od 7 do 8 i 10 do 12 godina). Slično je uočeno i za europsku formulu. U ženskim skupinama rezultati su bili disperzniji. No postojala je i veća točnost procjena u starosnom intervalu od 10 do 11 godina u ženskoj skupini, posebno u formuli prema BAF-u.

Rasprava

Procjena dentalne zrelosti ključna je i u antemortem i u postmortem identifikaciji zakašnjeloga ili prijevremenoga sazrijevanja individue. S obzirom na to da u Bosni i Hercegovini još uvijek ima neriješenih identifikacijskih slučajeva, važno je nadopuniti postojeće protokole novim metodama koje mogu pomoći u procjeni starosti, zrelosti i patoloških procesa. U kliničkoj primjeni time bi se predvidio rast i razvoj stalnih zuba čime bi se olakšao proces liječenja (11, 12). Zato je potrebno što preciznije procijeniti dentalnu zrelost. Nadalje, najprimjenjivija i najprikladnija metoda također bi trebala biti jednostavna, brza i ponovljiva.

Metoda za određivanje dentalne starosti koju su predlo-

The method for tooth age calculation suggested by Cameriere et al. [13] made a major step forward in clinical, antemortem to postmortem examinations. Each upgrade of the method increased accuracy and precision while reducing differences in the explication of tooth development [12] compared with previously used methods. The method has been tested all over the world with representative results. However, numerous studies showed that population specificity influences the results of age estimation based on teeth. The study of Brkic et al. [14] showed that the Demirjian method, which was developed in the North America and has been considered to be the state of the art for a long time, was less accurate than three other methods for age estimation when they were applied to the population of Croatia. The European formula proved to be the most frequently used method, followed by the Willems and Haavikko methods. Studies by Halilaha et al. [15] and AlShahrani et al. [16] also showed population-specific influences on tooth morphology. A review from Latin America by Rodríguez-Niklitschek et al. [17] showed that the European formula has satisfying results on that population, but the correction factor substantially improved the predictive power of the method. As a conclusion of this review, the attention to population structures is recommended. The population-particular formula for assessing tooth age in children and adolescents in Northern Germany demonstrated advanced results compared with the European formula [14,18]. In addition to this, the applicability of method also depends on its simplicity, reproducibility and ease of use. For these reasons, the need for population specificity and improving simplicity, the number of published articles which are improving or testing age estimation do not decline and every year a significant number of novel studies are produced. We have decided to apply the BAF to the Bosnian children population and compare the results with those obtained with the European formula. Based on the experience from Serbia, where a new formula was developed (BAF) we expect to establish a better and easier method for age estimation in our population.

Zelić et al. [10] showed that, on Serbian sample, there are no significant differences between age estimated by BAF and chronological age (based on one-sample t test). Furthermore, in the same article the BAF was tested on Italian sample and the mean residuals were 0.214 ± 0.934 for females and 0.109 ± 0.773 for males which was similar as for the European formula. In this research, as well as in the original one, the observer integrity for the dental age by the Belgrade age formula was very high for both (ICC=0.979 vs. ICC=0.990, respectively). Similar results were found for the European formula, indicating high reproducibility of both formulas.

Age estimated by the BAF in the Bosnian children population showed a high level of integrity with chronological age in boys (ICC=0.941, $p < 0.001$) and girls (ICC=0.913, $p < 0.001$). The results for European formula were slightly worse for boys (ICC=0.93, $p < 0.001$) than for girls (ICC=0.927, $p < 0.001$). These results were expected. In order to get information more beneficial for practical application, we counted the correctly estimated individuals within ± 3 , ± 6 and ± 12 months. The percentage of lawfully estimated individuals within ± 3 was

žili Cameriere i suradnici (13) učinila je veliki raskorak u kliničkim pregledima, od antemortem do postmortem postupaka. Svako poboljšanje metode povećavalo je točnost i preciznost, te smanjilo razlike u eksplikaciji razvoja zuba (12) u odnosu prema prije korištenim metodama. Metoda je testirana u cijelom svijetu, a postignuti rezultati su reprezentativni. No autori mnogih studija istaknuli su da specifičnost populacije utječe na rezultate procjene starosti na temelju zuba. Studija Brkića i suradnika (14) pokazala je da je Demirjianova metoda, koja je nastala u Sjevernoj Americi i dugo se smatrala najmodernijom, manje točna od triju drugih metoda za procjenu starosti kada se primjenjuju na hrvatskoj populaciji. Europska formula pokazala se kao pouzdana, a slijede je Willemsova i Haavikkova metoda. U drugim studijama, poput onih Halilaha i suradnika (15) i AlShahranija i suradnika (16) također je istaknut populacijski specifičan utjecaj na morfologiju zuba. Znanstveni rad iz Južne Amerike – Rodríguez-Niklitscheka i suradnika (17) – pokazao je da se europskom formulom postižu zadovoljavajući rezultati u toj populaciji, ali je faktor korekcije znatno poboljšao prediktivnu snagu metode. Kao zaključak ovog pregleda preporučuje se posvetiti pozornost strukturi stanovništva. Populacijska formula za određivanje dentalne starosti djece i adolescenata u sjevernoj Njemačkoj dala je dobre rezultate u usporedbi s europskom formulom (14, 18). Osim toga, primjenjivost metode ovisi o njezinoj jednostavnosti, ponovljivosti i lakoći korištenja. Iz tih razloga – potrebe za specifičnošću populacije i pojednostavlivanjem – broj objavljenih članaka koji poboljšavaju ili testiraju procjenu starosti još uvijek se ne smanjuje i svake godine velik je broj novih istraživanja. Odlučili smo primijeniti BAF na bosanskohercegovačku populaciju djece i usporediti rezultate s onima dobivenima europskom formulom. Na osnovi iskustva iz Srbije, gdje je razvijena nova formula (BAF), očekujemo da se uspostavi bolja i lakša metoda za procjenu starosti domaće populacije.

Zelić i suradnici (10) pokazali su da na srbijanskome uzorku ne postoje znatne razlike između starosti procijenjene BAF-om i kronološke starosti (na osnovi t-testa jednog uzorka). Nadalje, u istom članku BAF je testiran na talijanskom uzorku i srednji reziduali bili su $0,214 \pm 0,934$ za žene i $0,109 \pm 0,773$ za muškarce, što je bilo slično kao i za europsku formulu. I u ovom istraživanju, kao i u izvornome, integritet promatrača za starost zuba prema beogradskoj formuli starosti bio je veoma visok (ICC = 0,979 prema ICC = 0,990, respektivno). Slični rezultati zabilježeni su i za europsku formulu, što pokazuje visoku ponovljivost obiju formula.

Starost procijenjena BAF-om na populaciju djece u BiH pokazala je visoku razinu integriteta s kronološkom dobi kod dječaka (ICC = 0,941, $p < 0,001$) i djevojčica (ICC = 0,913, $p < 0,001$). Rezultati za europsku formulu bili su nešto lošiji za dječake (ICC = 0,93, $p < 0,001$) nego za djevojčice (ICC = 0,927, $p < 0,001$). Navedeni rezultati bili su očekivani. Da bismo dobili informacije koje su korisnije za praktičnu primjenu, izbrojili smo ispravno procijenjene pojedince unutar ± 3 , ± 6 i ± 12 mjeseci. Postotak legitimno procijenjenih pojedina u okviru ± 3 bio je veoma sličan kod obiju primijenjenih metoda (otprilike 20 % kod djevojčica i 17 % kod dječaka). Europska formula bila je nešto preciznija u intervalu od

very similar between both methods (approximately 20% in girls and 17% in boys). The European formula was slightly better within six months interval. Comparison of the residuals for each individual between the BAF and the European formula showed that the BAF was better in age calculation in the Bosnian sample for males, whereas for females, the results of both methods were similar. It should be noted that both methods tend to underestimate age in both sexes which was also reported previously in many studies [19-22].

Finally, to analyze the results more deeply, we constructed modified Bland–Altman plots for both sexes and both formulas. The (modified) Bland–Altman plots are a very descriptive tool for expressing results graphically. They give the possibility to analyze the dispersion of the results.

Our study showed that the shape and position in both plots were very similar, almost identical in girls for both the BAF and the European formula, and the same was true for boys. This leads to a conclusion that the performance of these two formulas was almost the same. However, the BAF was much simpler to use. Notably, the diagrams exhibited more scattered results in children older than 12 years which was expected because the apices of teeth are closing and less variables are in use. Specifically, in boys, when using the BAF, there are two age ranges with evident consistency of estimates, namely at ages 7–8 and 10–12 years. Bearing this in mind, the application of the BAF in these age categories is more reliable. The European formula showed similar patterns, though with less uniformity. As for girls, the results were less consistent, although there was a good interval at ages 10–11 years.

So far the results of different population studies clearly show better results with a new formulas developed for specific inhabitants. On the other hand, the methodology is similar or identical which brings no other benefits from new formulas. The main advantage of the BAF formula lies in significant simplification of the method. One of the goals for the BAF formula, as stated by the authors, was the elimination of the variable “s” because this variable corresponds the sum of the calculated ratios of all seven permanent teeth and for that variable, the measurement of all 7 lower permanent teeth was needed. In the BAF, the measurements are reduced to only 4 – apices width and length of canines and second molar.

Conclusions

The BAF was originally developed on the Serbian model; hence we expected it to have similar performance on the Bosnian sample. Although the BAF uses only two teeth and much less parameters are measured, its results are very similar, the dispersion of the results which can be seen on Bland–Altman diagrams is almost the same, and the accuracy of the BAF meets the expectations set by the European formula. Thus, it has been shown that the BAF formula is much easier and faster to perform while still giving accurate results.

Limitations of the study are a small number of subjects; therefore further research is needed to test the age of other populations, with the aim of comparing the accuracy or similarity of the BAF with the current gold standard using the European formula.

šest mjeseci. Usporedba reziduala za svaku individuu između BAF-a i europske formule pokazala je da je BAF bio precizniji u izračunavanju starosti u bosansko-hercegovačkome uzorku za mušku populaciju, a za žensku su rezultati dobiveni objema metodama bili slični. Treba napomenuti da obje metode imaju tendenciju podcjenjivati starost kod oba spola, što je također ranije uočeno u mnogobrojnim studijama (19 – 22).

Konačno, da bismo podrobnije analizirali rezultate, konstruirali smo modificirane Bland–Altmanove dijagrame za oba spola i obje formule. (Prilagođeno) Bland–Altmanovi dijagrami vrlo su deskriptivan alat za grafičko izražavanje rezultata. Oni omogućuju analize disperzije rezultata.

Naše istraživanje pokazalo je da su oblik i položaj na objema plohamo bili vrlo slični, gotovo identični kod djevojčica i za BAF i za europsku formulu, a isto vrijedi i za dječake. To dovodi do zaključka da su performanse tih dviju formula gotovo iste, ali BAF je mnogo jednostavniji za korištenje. Primjetno je da su dijagrami pokazali više disperznih rezultata kod djece starije od 12 godina, što je bilo i očekivano jer se vrhovi zuba zatvaraju i koristi se manje varijabli. Naime, kod dječaka, pri korištenju BAF-a, dva su starosna raspona s evidentnom konzistentnošću procjena, odnosno dob od 7 do 8 i 10 do 12 godina. Imajući to na umu, primjena BAF-a u tim dobnim kategorijama je pouzdanija. S europskom formulom postignuti su slični rezultati, ali s manje ujednačenosti. Kad je riječ o djevojčicama, rezultati su bili manje konzistentni, iako je postojao dobar interval u dobi od 10 do 11 godina.

Dosadašnji rezultati različitih populacijskih studija jasno pokazuju bolje rezultate s novim formulama razvijenima za određenu populaciju. S druge strane, metodologija je slična, odnosno jednaka. Glavna prednost formule BAF je u značajnom pojednostavnjenju metode. Jedan od ciljeva te formule, kako navode autori, bilo je eliminiranje varijable „s” jer odgovara zbroju izračunatih odnosa svih sedam stalnih zuba i za tu varijablu mjerenja svih sedam donjih zuba bili su potrebni stalni zubi. U BAF-u su mjere svedene na samo 4 – na širinu vrhova te dužinu kaninusa i drugog kutnjaka.

Zaključak

BAF je prvotno razvijen na srbijanskome modelu, pa smo očekivali da će slične performanse imati i na bosanskohercegovačkom uzorku. Iako se BAF koristi samo dvama zubima i mjeri se mnogo manje parametara, njegovi rezultati vrlo su slični, disperzija rezultata koja se može vidjeti na Bland–Altmanovim dijagramima gotovo je ista, a točnost BAF-a zadovoljava očekivanja koje je postavila europska formula. Dakle, pokazalo se da je BAF formula mnogo lakša i brža metoda u primjeni i da pritom daje točne rezultate.

Ograničenje studije je mali broj ispitanika, pa su u budućnosti potrebna nova istraživanja kako bi se testirala starost drugih populacija, a sve u svrhu uspoređivanja točnosti ili sličnosti BAF-a s trenutačnim zlatnim standardom dobivenim na temelju europske formule.

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Doprinos autora: A. S. i E. D. – konceptualizacija; K. Z. M. i E. D. – metodologija, istraživanje, priprema, pisanje originalnog nacrt; P. M. i A. S. – pisanje, pregled, uređivanje, nadzor

Sažetak

Cilj: Željela se testirati beogradska formula dobi utemeljena na proračunu otvorenih apeksa dvaju trajnih zuba mandibule na populaciji djece u BiH i usporediti njezinu točnost podudaranja s europskom formulom. **Materijal i metode:** Sudjelovalo je 412 ispitanika (204 ženskoga i 208 muškoga spola) od 7 do 13 godina. Procijenili smo učinak obiju metoda (europska formula i BAF) i usporedili njihove rezultate za oba spola. **Rezultati:** Rezultati su pokazali visoku točku prosječnoga podudaranja između kronološke dobi i starosti procijenjene europskom formulom (ICC = 0,927, 95 % CI 0,904 – 0,944, $p < 0,001$). BAF je također potvrdio visoku točku poklapanja s kronološkom dobi kod dječaka (ICC = 0,941, 95 % CI 0,922 – 0,955, $p < 0,001$) i djevojčica (ICC = 0,913, 95 % CI 0,886 – 0,934, $p < 0,001$). Također je bio uspješniji od europske formule u procjeni dobi muškaraca ($0,4448 \pm 0,9135$ prema $0,9807 \pm 0,9422$). **Zaključak:** Beogradska formula starosti (BAF) pokazuje točnost uspoređivu s europskom formulom za određivanje dobi bosanskohercegovačke djece, a prednost joj je lakše i brže korištenje. To čini BAF praktičnom alternativom u kliničkim i istraživačkim radovima kojima su učinkovitost i pouzdanost bitne kategorije.

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