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'Shift' Adaptation and a New Croatian Standard for Haavikko Developmental Stages' Timing

Prilagodba „pomakom" i novi hrvatski standard za prosječnu dob razvojnih stadija prema Haavikko

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Abstract
Accurate age estimation is an integral part of the identification process. Although used infrequently when compared to more established methods, the Haavikko method can be used in cases where other dental age estimation methods have proven ineffective. **Aim:** The aim of this study was to adapt the Haavikko method as a means of improving age estimation on a representative sample of Croatian children and to establish an applicable standard for the Haavikko developmental stages. **Material and methods:** To achieve this objective, 1997 digital, standardized orthopantomograms of children aged 5 to 16 were collected in four Croatian cities. Drawing upon a previously published study of the Croatian population, a simple adaptation named 'shift' was introduced to the Haavikko method by adding the average difference between chronological and dental age to the estimated dental age. Squared deviations were used to compare the results of the original Haavikko method with the 'shift' adaptation. Accuracy of age estimation was presented as the percentage of correct estimations within intervals of ±0.5 years, ±1 year, ±1.5 years and ±2 years. The 'shift' adaptation was tested through simulation to assure population applicability. The average age for every stage of each permanent tooth was then calculated to provide Croatian specific tables for the Haavikko method. The 'shift' adaptation significantly improved age estimation accuracy among boys and girls in all age groups. Simulation confirmed the representativity of the sample and its population applicability. **Conclusion:** The Croatian specific tables comprise a standard when estimating age using the Haavikko method among Croatian children.

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Introduction

Age estimation is a crucial part of every identification process. More frequent use of x-rays has enabled greater insight into bone and teeth mineralization during growth and development. Chronological age can be estimated based on the recorded pattern of bone and teeth mineralization. Skeletal and dental age, which represent an estimated age based on bone and teeth development, have shown the highest data correlation with chronological age (1-3). While bone development can easily become affected by environmental factors

Uvod

Procjena dobi ključni je dio svakoga identifikacijskog procesa. Češća uporaba rendgenskih snimki omogućila je bolji uvid u mineralizaciju kostiju i zuba tijekom rasta i razvoja. Kronološka dob može se procijeniti na temelju uočenih obrazaca mineralizacije kostiju i zuba. Skeletna i dentalna dob, koje se temelje na procjeni dobi prema razvoju kostiju i zuba, pokazale su najvišu korelaciju s kronološkom dobi (1–3). Dok na razvoj kostiju često mogu utjecati okolišni čimbenici i različite bolesti, razvoj zuba dominantno je

and various diseases, the development of teeth is controlled mainly by genes. Accordingly, skeletal age may be said to represent the measure of development while dental age estimation is more frequently employed as a forensic tool (4).

Conversant with the survey of Moorrees, Fanning and Hunt (5), Karina Haavikko introduced a dental development scale comprising twelve different stages (6). Utilizing this scale, she noted that age was related to specific stages of development in Finnish children. Haavikko evaluated all maxillary and mandibular teeth and constructed gender specific tables with age medians for each developmental stage of every tooth. Consequently, dental age is estimated by dividing the sum of age medians for the developmental stage of specific teeth with the number of teeth assessed. In a study published in 1974, Haavikko introduced a simplified method that utilizes only four teeth for dental age estimation (7).

In practice, the Haavikko method has been tested in significantly fewer studies and its adaptations are relatively rare compared to the Demirjian (8) and Willems (9) methods for dental age estimation. The Demirjian and Willems methods utilize seven left mandibular permanent teeth; their greatest disadvantage is that these methods cannot be used in cases with mandibular hypodontia. The Haavikko method uses different teeth in its selection and is therefore applicable in special cases in which the Demirjian method fails to estimate age. Based on the relatively few published studies testing the Haavikko method in Croatia, the results of which occasionally differ, the purpose of this study was to adapt or 'shift' the Haavikko method as a means of increasing accurate age estimation within the Croatian population.

Materials and Methods

The sample included 1, 997 digital, standardized orthopantomograms (OPGs) of children aged between 5 and 16 collected in four Croatian cities: Zagreb, Split, Osijek and Varaždin (Table 1). The OPGs were taken by the Cranex device (Soredex, Finland). Individuals whose OPGs were used for this investigation were referred by their dentist for diagnostic purposes. Their parents or legal guardians signed a letter of informed consent that enabled the OPGs to be used in scientific investigations. This study was approved by the Ethics Committee of the School of Dental Medicine, University of Zagreb.

The OPGs were coded and stored on a server without name, sex, date of birth or date of record. One investigator (IB) accessed the OPGs from a different computer using the TeamViewer 8.0 programme (TeamViewer GmbH, Germany). The developmental stages of all the teeth were determined using the developmental scale introduced by Haavikko (7), which consists of twelve different stages. Microsoft Excel (Microsoft, USA) was used to store the obtained data. On determining the developmental stages of the teeth in the OPGs, information pertaining to sex, date of birth and date of record was appended.

After a period of two months, 100 randomly chosen OPGs were reassessed; through this process, the developmental stages of all the teeth were redetermined to assess intra-examiner reliability.

pod utjecajem gena. Slijedom toga, može se reći da skeletna dob predstavlja mjeru razvoja, a procjena dentalne dobi češće se koristi kao alat u forenzici (4).

Detaljno upoznata s istraživanjem Moorreesa, Fanning i Hunta (5), Karina Haavikko predstavila je ljestvicu razvoja zuba koja se sastoji od dvanaest različitih stadija (6). Koristeći se svojom razvojnom ljestvicom povezala je dob sa stadijima razvoja zuba kod finske djece. Tako je analizirala sve gornje i donje zube te izradila tablice specifične za spol s medijanima dobi za svaki stadij razvoja pojedinog zuba. Stoga se, u metodi koju je predstavila, dentalna dob procjenjuje dijeljenjem zbroja medijana dobi za stadije razvoja odabranih zuba s brojem analiziranih zuba. U studiji objavljenoj 1974. godine, Haavikko je predstavila pojednostavljenu metodu u kojoj se za procjenu dentalne dobi koriste samo četiri zuba (7).

U dostupnoj literaturi, metoda prema Haavikko, testirana je u znatno manjem broju studija, a njezine su prilagodbe razmjerno rijetke u usporedbi s metodama za procjenu dentalne dobi prema Demirjianu (8) i Willemsu (9). Demirjianova i Willemsova metoda koriste se sa sedam trajnih zuba lijevog kvadranta donje čeljusti. Njihov najveći nedostatak jest to što su neupotrebljive u slučaju hipodoncije u donjoj čeljusti. Haavikko u svojoj metodi odabire drukčiji izbor zuba pa je njezina metoda primjenjiva u određenim slučajevima u kojima se Demirjianovom ne može procijeniti dob. Na temelju nekoliko objavljenih istraživanja u kojima je testirana Haavikkina metoda u Hrvatskoj, a čiji rezultati variraju, cilj ovog istraživanja jest prilagoditi je, odnosno „pomakom" povećati preciznost procjene dobi u hrvatskoj populaciji.

Materijali i metode

Uzorak je obuhvatio 1997 digitalnih, standardiziranih ortopantomograma (OPG) djece u dobi od 5 do 16 godina prikupljenih u četirima hrvatskim gradovima: Zagrebu, Splitu, Osijeku i Varaždinu (tablica 1.). OPG-i su snimljeni uređajem Cranex (Soredex, Finska). Osobe čije su ortropantomogrami korišteni u ovom istraživanju na snimanje je uputio njihov stomatolog u dijagnostičke svrhe. Njihovi roditelji ili zakonski skrbnici potpisali su informirane pristanke koji su omogućili korištenje OPG-a u znanstvenim istraživanjima. Ovo istraživanje odobrilo je Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu.

OPG-i su bili kodirani i pohranjeni na poslužitelju bez imena, spola, datuma rođenja ili datuma snimanja. Jedan istraživač (I. B.) pristupio je OPG-ima s drugog računala koristeći se programom TeamViewer 8.0 (TeamViewer GmbH, Njemačka). Razvojni stadiji svih zuba određeni su korištenjem razvojne ljestvice prema Haavikko (7) koja se sastoji od dvanaest različitih stadija. Microsoft Excel (Microsoft, SAD) korišten je za pohranu dobivenih podataka. Nakon određivanja razvojnih stadija zuba na svim OPG-ima, dodani su podatci o spolu, datumu rođenja i datumu snimanja.

Poslije dva mjeseca 100 slučajno odabranih OPG-a ponovno je podvrgnuto procjeni. Tijekom toga postupka razvojni stadiji svih zuba ponovno su određeni kako bi se procijenila dosljednost istraživača.

Table 1 Sample structure.
Tablica 1. Struktura uzorka

Age group • Dobna skupina	Total • Ukupno	Boys • Dječaci	Girls • Djevojčice
5 – 5.99	9	4	5
6 – 6.99	43	31	12
7 – 7.99	135	82	53
8 – 8.99	206	121	85
9 – 9.99	226	121	105
10 – 10.99	228	135	93
11 – 11.99	253	126	127
12 – 12.99	212	112	100
13 – 13.99	236	129	107
14 – 14.99	229	141	88
15 – 15.99	200	107	93
Total • Ukupno	1977	1109	868

Table 2 The Haavikko method. Comparison between chronological and dental age for boys [10].
Tablica 2. Metoda prema Haavikko – usporedba kronološke i dentalne dobi kod dječaka [10] .

Boys • Dječaci	Chronological age • Kronološka dob	Dental age • Dentalna dob	Deviation • Odstupanje	p*
Age group • Dobna skupina				
5 – 5.99	5.66	4.94	-0.72	0.250
6 – 6.99	6.65	6.09	-0.56	<0.001
7 – 7.99	7.57	6.97	-0.60	<0.001
8 – 8.99	8.51	7.85	-0.66	<0.001
9 – 9.99	9.51	8.87	-0.65	<0.001
10 – 10.99	10.46	10.14	-0.32	0.015
11 – 11.99	11.42	11.25	-0.17	0.231
12 – 12.99	12.48	12.34	-0.14	0.743
13 – 13.99	13.49	13.04	-0.45	<0.001
14 – 14.99	14.47	13.63	-0.84	<0.001
15 – 15.99	15.43	13.80	-1.63	<0.001
Total • Ukupno	10.51	9.90	-0.61	

*Wilcoxon signed-rank test • Wilcoxonov test rangova s predznakom

Table 3 The Haavikko method. Comparison between chronological and dental age for girls [10].
Tablica 3. Metoda prema Haavikko – usporedba kronološke i dentalne dobi kod djevojčica [10].

Girls • Djevojčice	Chronological age • Kronološka dob	Dental age • Dentalna dob	Deviation • Odstupanje	p*
Age group • Dobna skupina				
5 – 5.99	5.33	4.50	-0.84	0.063
6 – 6.99	6.62	6.32	-0.30	0.519
7 – 7.99	7.60	7.07	-0.52	<0.001
8 – 8.99	8.52	8.10	-0.42	<0.001
9 – 9.99	9.52	9.27	-0.25	<0.001
10 – 10.99	10.54	10.31	-0.23	0.120
11 – 11.99	11.50	11.51	0.00	0.388
12 – 12.99	12.48	11.96	-0.52	<0.001
13 – 13.99	13.50	12.35	-1.15	<0.001
14 – 14.99	14.42	12.47	-1.94	<0.001
15 – 15.99	15.48	12.66	-2.82	<0.001
Total • Ukupno	10.50	9.68	-0.82	

*Wilcoxon signed-rank test • Wilcoxonov test rangova s predznakom

Drawing upon and expanding results from a study previously published by Bedek et al. (10), in which the Haavikko method underestimated age by 0.61 years for boys and

Oslanjajući se na rezultate ranije objavljene studije Bedeka i suradnika (10) u kojoj je metoda prema Haavikko podcijenila dob za 0,61 godinu kod dječaka i 0,82 godine kod

0.82 years for girls (Table 2, Table 3), two adaptations of the method were devised.

The first adaptation of the Haavikko method for the Croatian population was named 'shift' and it consists of adding the average difference between chronological and dental age to the estimated dental age. The following equations support this adaptation:

$$dental\ age = HDA + 0.61$$

for boys, and

$$dental\ age = HDA + 0.82$$

for girls

where HDA represents dental age estimation using the Haavikko method and the numbers 0.61 and 0.82 denote the average difference between chronological and dental age for boys and girls obtained from the earlier Bedek et al. study (10).

Squared deviations were used to compare the original Haavikko method with its 'shift' adaptation for the Croatian population. The accuracy of the age estimation is presented as the percentage of correct estimations within the intervals of ±0.5 years, ±1 year, ±1.5 years and ±2 years.

The 'shift' adaptation of the Haavikko method was tested for applicability in the Croatian population using a simulation in which the sample was randomly split in half: the first half was used to determine the average difference between chronological and dental age using the Haavikko method; the second half was used to test the 'shift' adaptation of that method. The average value of ten simulations was calculated and validated for consistency.

As the developmental stages of all the teeth were determined, in the second adaptation the average age for Haavikko's developmental stages was calculated for every tooth, with the notable exception of the third molar, by providing specific tables pertaining to the Croatian population.

Results

Based on 100 randomly reassessed OPGs, the Kappa value for intra-examiner agreement was 0.83, which indicates a level of high reliability in the developmental stages' determination.

Squared deviations were used to compare the original Haavikko method with the 'shift' adaptation for the Croatian population (Table 4). The accuracy of both methods is presented in parallel in Table 5 as a percentage of correct estimations within a specific interval.

The previously described simulation was used to evaluate the applicability of the adaptation of the Haavikko method in the Croatian population (i.e., not only in the sample). Tables 6 and 7 present the average values from ten simulations.

A complete adaptation of the Haavikko method for the Croatian population was made by calculating the average age for each developmental stage for every tooth with the exception of the third molar (Table 8 and Table 9). This was achieved by adding together the age of all participants who had reached the developmental stage of the specific tooth and then dividing the sum by the number of participants.

djevojčica (tablice 2. i 3.), napravljene su dvije prilagodbe metode. Prva prilagodba Haavikkine metode za hrvatsku populaciju nazvana je „pomak", a sastoji se od dodavanja prosječnog odstupanja između kronološke i dentalne dobi na procijenjenu dentalnu dob prema sljedećim jednadžbama:

$$dentalna\ dob = HDA + 0{,}61$$

za dječake, i

$$dentalna\ dob = HDA + 0{,}82$$

za djevojčice

u kojima je HDA procjena dentalne dobi korištenjem metode prema Haavikko, a brojevi 0,61 i 0,82 označavaju prosječnu razliku između kronološke i dentalne dobi za dječake i djevojčice koja je rezultat ranije studije Bedeka i suradnika (10).

Kvadratna odstupanja korištena su za usporedbu izvorne metode prema Haavikko s njezinom prilagodbom „pomakom" za hrvatsku populaciju. Preciznost procjene dobi predstavljena je kao postotak točnih procjena unutar intervala ± 0,5 godina, ± 1 godine, ± 1,5 godina i ± 2 godine.

Prilagodba „pomakom" Haavikkine metode testirana je na primjenjivost u hrvatskoj populaciji korištenjem simulacije u kojoj je uzorak nasumično podijeljen u dva dijela: prvi dio korišten je za određivanje prosječne razlike između kronološke i dentalne dobi upotrebom metode prema Haavikko, a drugi dio za testiranje prilagodbe „pomakom". Izračunata je prosječna vrijednost deset simulacija te iskorištena za provjeru konzistentnosti.

Budući da su određeni razvojni stadiji svih zuba, u drugoj prilagodbi izračunata je prosječna dob za Haavikkine razvojne stadije za svaki zub, uz iznimku trećeg kutnjaka, nakon čega su sastavljene tablice specifične za hrvatsku populaciju.

Rezultati

Na temelju ponovno procijenjenih stadija razvoja na 100 nasumično odabranih ortopantomograma, kappa vrijednost za dosljednost procjenjivača iznosi 0,83, što upućuje na visoku pouzdanost u određivanju razvojnih stadija. Kvadratna odstupanja korištena su za usporedbu izvorne metode prema Haavikko s njezinom prilagodbom „pomakom" za hrvatsku populaciju (tablica 4.). Preciznost obiju metoda prikazana je u tablici 5. kao postotak točnih procjena unutar određenog intervala.

Prije opisane simulacije korištene su za procjenu primjenjivosti prilagodbe „pomakom" u hrvatskoj populaciji (ne samo u uzorku). Tablice 6. i 7. pokazuju prosječne vrijednosti deset simulacija.

Potpuna prilagodba metode prema Haavikko za hrvatsku populaciju dobivena je izračunavanjem prosječne dobi za Haavikkine razvojne stadije svakoga zuba, osim trećega kutnjaka (tablice 8. i 9.). Prosječna dob za stadij rezultat je zbroja dobi sve djece koja su dosegnula pojedini razvojni stadij određenog zuba podijeljenog s ukupnim brojem djece u tom razvojnom stadiju.

Table 4 The Haavikko method and its 'shift' adaptation for the Croatian population. Squared deviations between chronological and dental age for boys and girls are stipulated. The lower value indicates the more accurate age estimation.
Tablica 4. Metoda prema Haavikko i njezina prilagodba "pomakom" u hrvatskoj populaciji; kvadratna odstupanja između kronološke i dentalne dobi kod dječaka i djevojčica; niža vrijednost upućuje na precizniju procjenu dobi

Boys • Dječaci	Haavikko	Shift • Pomak	Girls • Djevojčice	Haavikko	Shift • Pomak
Age group • Dobna skupina			Age group • Dobna skupina		
5 – 5.99	1.33	0.83	5 – 5.99	1.19	0.49
6 – 6.99	0.90	0.60	6 – 6.99	0.80	0.98
7 – 7.99	1.08	0.73	7 – 7.99	0.76	0.57
8 – 8.99	1.16	0.72	8 – 8.99	0.74	0.72
9 – 9.99	1.37	0.95	9 – 9.99	0.39	0.64
10 – 10.99	2.14	2.12	10 – 10.99	1.19	1.48
11 – 11.99	1.99	2.15	11 – 11.99	0.58	1.26
12 – 12.99	1.04	1.24	12 – 12.99	0.57	0.39
13 – 13.99	0.79	0.62	13 – 13.99	1.52	0.30
14 – 14.99	0.89	0.24	14 – 14.99	3.96	1.45
15 – 15.99	2.81	1.19	15 – 15.99	8.08	4.14
Total • Ukupno	15.50	11.37	Total • Ukupno	19.79	12.42

Table 5 Accuracy of age estimation of the Haavikko method and its 'shift' adaptation for the Croatian population. Percentage of correct estimation within interval.
Tablica 5. Preciznost procjene dobi metode prema Haavikko i njezine prilagodbe "pomakom" u hrvatskoj populaciji; postotak točnih procjena unutar intervala

Interval	Haavikko	Shift • Pomak
Boys • Dječaci		
± 0.5 years • godina	28.4	41.3
± 1 year • godina	58.2	69.2
± 1.5 years • godina	78.7	86.0
± 2 years • godine	91.9	94.6
Girls • Djevojčice		
± 0.5 years • godina	33.6	32.1
± 1 year • godina	57.6	62.8
± 1.5 years • godina	73.2	81.3
± 2 years • godine	82.6	93.3

Table 6 Squared deviations between chronological and dental age of the Haavikko method and its 'shift' adaptation for the Croatian population (average values of ten simulations).
Tablica 6. Kvadratna odstupanja kronološke i dentalne dobi metode prema Haavikko i njezine prilagodbe "pomakom" za hrvatsku populaciju (prosječne vrijednosti deset simulacija)

Boys • Dječaci	Haavikko	Shift • Pomak	Girls • Djevojčice	Haavikko	Shift • Pomak
Age group • Dobna skupina			Age group • Dobna skupina		
5 – 5.99	1.24	0.56	5 – 5.99	1.37	0.63
6 – 6.99	0.89	0.58	6 – 6.99	0.88	0.97
7 – 7.99	1.10	0.71	7 – 7.99	0.70	0.57
8 – 8.99	1.14	0.68	8 – 8.99	0.70	0.69
9 – 9.99	1.34	0.89	9 – 9.99	0.40	0.64
10 – 10.99	2.30	2.33	10 – 10.99	1.26	1.58
11 – 11.99	1.86	2.14	11 – 11.99	0.60	1.34
12 – 12.99	1.12	1.27	12 – 12.99	0.54	0.40
13 – 13.99	0.72	0.55	13 – 13.99	1.49	0.29
14 – 14.99	0.91	0.25	14 – 14.99	3.98	1.44
15 – 15.99	2.75	1.15	15 – 15.99	8.10	4.11
Total • Ukupno	15.37	11.10	Total • Ukupno	20.02	12.65

Discussion

The aim of this study was to adapt the Haavikko method for the Croatian population and to provide average ages for the Haavikko developmental stages based on a sample of Croatian children aged 5 to 16. The size of the sample, its geographical origin and the digital, standardized orthopantomograms taken on the same device ensure an accurate rep-

Rasprava

Cilj ove studije bio je prilagoditi metodu prema Haavikko hrvatskoj populaciji i izračunati prosječnu dob za njezine razvojne stadije na uzorku hrvatske djece u dobi od 5 do 16 godina. Veličina uzorka, njegovo geografsko podrijetlo i digitalni, standardizirani ortopantomogrami snimljeni na istom uređaju osiguravaju preciznu reprezentaciju hrvat-

Table 7 Average accuracy of ten simulations of the Haavikko method and its 'shift' adaptation for the Croatian population. Percentage of correct estimations within interval.
Tablica 7. Prosječna preciznost procjene dobi u deset simulacija za metodu prema Haavikko i njezinu prilagodbu "pomakom" u hrvatskoj populaciji; postotak točnih procjena unutar intervala

Interval	Haavikko	Shift • Pomak
Boys • Dječaci		
± 0.5 years • godina	28.6	41.4
± 1 year • godina	57.7	69.3
± 1.5 years • godina	79.1	85.9
± 2 years • godine	91.8	94.5
Girls • Djevojčice		
± 0.5 years • godina	33.0	32.3
± 1 year • godina	57.4	62.0
± 1.5 years • godina	73.3	80.8
± 2 years • godine	82.3	93.0

Table 8 Average age for the Haavikko developmental stages for the Croatian population (boys).
Tablica 8. Prosječna dob za Haavikkine razvojne stadije u hrvatskoj populaciji (dječaci)

Stage • Stadij	11	12	13	14	15	16	17
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	.	.	5.4
C1/2	.	.	.	.	7.1	.	7.4
C3/4	.	6.4	6.7	6.8	7.3	.	8.1
Crc	.	7.1	6.9	7.5	8.2	.	8.3
Ri	6.9	7.5	7.3	8.3	8.6	.	8.9
R1/4	7.2	7.6	8.0	8.9	9.6	5.9	10.2
R1/2	7.7	8.0	9.2	9.9	10.3	7.2	10.9
R3/4	8.1	8.8	10.7	10.5	11.0	8.1	11.6
Rc	9.4	10.0	12.3	11.6	12.1	8.9	12.8
Ac	12.6	13.1	14.2	13.8	14.1	12.1	14.5

Stage • Stadij	21	22	23	24	25	26	27
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	5.4	.	5.4
C1/2	.	.	.	.	7.2	.	7.4
C3/4	.	6.4	6.7	6.8	7.3	.	7.9
Crc	.	7.0	7.0	7.5	8.2	.	8.2
Ri	6.9	7.5	7.5	8.3	8.7	.	9.0
R1/4	7.2	7.7	8.1	8.9	9.5	5.9	10.1
R1/2	7.7	8.1	9.1	10.0	10.4	7.2	10.8
R3/4	8.1	8.8	10.8	10.5	11.0	8.1	11.4
Rc	9.3	9.9	12.2	11.5	12.2	8.8	12.7
Ac	12.6	13.0	14.2	13.8	14.1	12.1	14.5

Stage • Stadij	31	32	33	34	35	36	37
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	5.4	.	5.4
C1/2	.	.	.	.	6.9	.	7.3
C3/4	.	.	6.8	6.9	7.4	.	7.3
Crc	.	.	7.1	6.9	7.8	.	8.1
Ri	.	6.1	7.2	7.8	8.4	.	8.7
R1/4	6.6	6.1	7.9	8.6	9.0	5.7	9.7
R1/2	7.4	7.1	8.8	9.5	10.0	6.8	10.6
R3/4	7.8	7.8	10.5	10.6	11.2	8.1	11.3
Rc	7.9	8.5	12.2	11.6	12.6	8.5	12.9
Ac	11.9	12.4	14.2	13.9	14.3	12.4	14.6

Stage • Stadij	41	42	43	44	45	46	47
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	5.4	.	5.4
C1/2	.	.	.	.	6.9	.	7.3
C3/4	.	.	.	7.0	7.2	.	7.4
Crc	.	6.0	7.2	7.0	7.9	.	8.1
Ri	.	6.1	7.2	7.7	8.4	.	8.6
R1/4	6.6	6.1	7.8	8.6	9.2	5.7	9.6
R1/2	7.3	7.0	8.9	9.6	10.1	6.8	10.6
R3/4	7.7	7.8	10.5	10.6	11.3	8.0	11.3
Rc	7.9	8.5	12.1	11.5	12.6	8.4	13.0
Ac	11.9	12.4	14.3	13.9	14.3	12.4	14.6

Table 9 Average age for the Haavikko developmental stages for the Croatian population (girls).
Tablica 9. Prosječna dob za Haavikkine razvojne stadije u hrvatskoj populaciji (djevojčice)

Stage • Stadij	11	12	13	14	15	16	17
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	5.9	.	.
C1/2	.	.	.	6.0	6.2	.	6.3
C3/4	5.1	5.2	5.3	6.2	7.7	.	7.5
Crc	5.3	6.3	6.1	7.3	8.0	.	8.0
Ri	6.5	6.7	6.9	7.9	8,7	5.0	8.9
R1/4	6.5	7.6	7.8	8.8	9.4	5.2	10.0
R1/2	7.5	7.9	8.8	9.5	10.1	6.1	10.5
R3/4	7.8	8.7	9.9	10.3	11.0	6.2	11.2
Rc	8.8	9.3	11.3	10.9	11.5	7.9	12.6
Ac	12.4	12.7	13.6	13.4	13.7	12.1	14.2

Stage • Stadij	21	22	23	24	25	26	27
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	5.4	5.3	.	.
C1/2	.	.	.	5.9	6.4	.	5.9
C3/4	5.1	5.2	5.9	6.0	7.4	.	7.3
Crc	5.3	5.9	6.1	7.4	7.9	.	7.9
Ri	6.5	6.3	7.1	8.0	8.9	.	9.0
R1/4	6.5	7.5	7.8	8.8	9.6	5.2	10.1
R1/2	7.5	7.9	8.7	9.5	10.0	5.9	10.5
R3/4	7.8	8.6	10.0	10.2	11.1	6.4	11.4
Rc	8.8	9.2	11.3	10.9	11.6	7.9	12.5
Ac	12.4	12.7	13.6	13.4	13.8	12.0	14.3

Stage • Stadij	31	32	33	34	35	36	37
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	.	.	.
C1/2	.	.	.	.	5.4	.	6.0
C3/4	.	.	5.4	5.4	7.2	.	7.0
Crc	.	.	5.5	7.0	7.7	.	7.9
Ri	.	5.3	6.7	7.4	8.1	.	8.8
R1/4	5.4	6.2	7.6	8.3	8.6	5.3	9.8
R1/2	5.8	6.6	8.4	9.2	9.8	5.6	10.1
R3/4	7.0	7.4	9.6	10.2	11.2	6.3	11.2
Rc	7.6	8.3	11.0	11.0	12.0	8.2	12.7
Ac	11.9	12.2	13.5	13.6	14.0	12.2	14.5

Stage • Stadij	41	42	43	44	45	46	47
0	.	.	.	.	.	.	.
Ci	.	.	.	.	.	.	.
Cco	.	.	.	.	.	.	.
C1/2	.	.	.	.	5.4	.	6.6
C3/4	.	.	5.4	5.4	6.3	.	7.0
Crc	.	.	5.8	6.6	7.8	.	7.8
Ri	.	5.3	6.2	7.5	8.1	.	8.8
R1/4	5.4	6.2	7.7	8.3	8.7	5.3	9.7
R1/2	5.8	6.6	8.3	9.2	9.7	5.5	10.2
R3/4	6.9	7.4	9.5	10.2	11.1	6.3	11.2
Rc	7.7	8.3	10.9	11.3	12.2	8.1	12.7
Ac	11.9	12.2	13.5	13.6	14.0	12.2	14.5

resentation of the Croatian population. While the original Haavikko method significantly underestimated age in most of the groups in the sample (10), the simple 'shift' adaptation significantly improved the results of age estimation. Due to the large and representative sample, the authors were able to calculate the average age for each developmental stage of every tooth according to Haavikko's developmental scale. The results shown in Tables 8 and 9 represent the complete adaptation of the Haavikko method for the Croatian population.

To remain within the age parameters of this study, the results for the third molars were deliberately omitted to prevent the possibility of error, particularly with regard to the higher developmental stages. An accurate calculation of the average age on reaching the developmental stages of the third molars demands that a representative sample includes OPGs of children older than 16 years of age, which is not the case in this survey.

It must be observed that due to the limited number of OPGs recorded in the two youngest age groups, a degree of caution is required in estimating age accurately among the youngest individuals. Ethical considerations ensured that OPGs were taken for diagnostic purposes only; this affected the authors' ability to collect additional OPGs in these two age groups. As a result, the statistical methods used in this survey were selected with discretion to eliminate the influence of the two youngest age groups on the results of age estimation.

ske populacije. Dok je izvorna Haavikkina metoda značajno podcijenila dob u većini dobnih skupina u uzorku (10), jednostavna prilagodba „pomakom" značajno je poboljšala rezultate procjene dobi. Zbog velikoga i reprezentativnoga uzorka, autori su mogli izračunati prosječnu dob za svaki razvojni stadij svakog zuba prema Haavikkinoj razvojnoj ljestvici. Rezultati u tablicama 8. i 9. pokazuju potpunu prilagodbu Haavikkine metode za hrvatsku populaciju.

Rezultati za treće kutnjake namjerno su izostavljeni da bi se spriječila mogućnost pogreške, osobito u višim razvojnim stadijima, zbog dobi ispitanika u ovoj studiji. Točan izračun prosječne dobi pri dosezanju razvojnih stadija trećih kutnjaka zahtijeva da reprezentativni uzorak uključuje OPG-e djece starije od 16 godina, što nije slučaj u ovom istraživanju.

Treba napomenuti da je, zbog ograničenoga broja OPG-a prikupljenih u dvije najmlađe dobne skupine, potreban oprez pri procjeni dobi među najmlađim pojedincima. Iz etičkih razloga OPG-i su snimani samo u dijagnostičke svrhe pa je to utjecalo na mogućnost autora da prikupe dodatne OPG-e u ovim dvjema dobnim skupinama. Zbog toga su statističke metode korištene u ovom istraživanju pažljivo odabrane da bi se isključio utjecaj dviju najmlađih skupina na ukupne rezultate. Mali broj OPG-a u najmlađim dobnim skupinama spominje se u literaturi i može se opravdati navedenim razlozima (11–13).

timation for the other age groups. The low number of OPGs in the youngest age groups is noted in the cited literature and may be qualified by the above stated reasons (11-13).

The Haavikko method has been tested previously in Croatia. Many of the methods and results contained in this study build upon and reiterate an earlier study on the Haavikko method in the Croatian population (10). In addition, the sample sizes of previous studies have also provided a store of data on which to build. On a sample of 324 children aged 6 to 16, Bagić et al. determined that the Haavikko method underestimated age by 0.5 years in boys and 1 year in girls (14). Although the age of participants differed slightly, Borčić et al. stipulated that the Haavikko method underestimated age by 0.5 years in both boys and girls on a small sample of 115 orthopantomograms of children aged 4 to 17 (15). Based on a larger sample of 1, 492 Croatian children aged between 6 and 14, Brkić et al. posited an average underestimation of 0.17 years for both genders when using the Haavikko method; but of significance, the mean absolute error is 1.01 years in boys and 1.18 years in girls (16). Accordingly, the authors of this study found the Haavikko method to be more precise than the Demirjian and Willems methods in their testing on the Croatian population, although it should be observed that the sample of children between 6 and 14 narrows the scope of the data (16). The results of Bedek et al. (10) drawn from the large sample of 1, 997 children from the Croatian population were found to be similar to those previously published, albeit with reference to a significantly smaller sample (14,15).

The Haavikko method has also been tested worldwide. In the Chinese population, the method was found to be highly accurate with a mean difference between dental and chronological age of 0.14 years (17). In the Italian population, an average underestimation of 0.35 years was observed in boys and 0.41 years in girls (18). Using the Haavikko method to determine age estimation in the Turkish population, an underestimation average of 0.49 years was established (19); in a comparable study, an underestimation of 0.60 in boys and 0.56 years in girls is present (20). An underestimation of 0.94 years in boys and 1.59 in girls was found in the Malaysian population (21), whereas in the Indian population a much lower underestimation of 0.17 years in boys and 0.29 in girls was recorded (22). A study in southern India by Mohammed et al. (23) found that the Haavikko method underestimated age by 2.84 years in boys and 2.96 years in girls. A likely reason for this substantial underestimation is the sample selection, in which one third of the sample was taken from children older than 14 years of age; moreover, there is no information provided with regard to how many of those children were in the significant 15 to 16 age group. As the apex of the second molar, the last tooth to finish its development (apart from the third molar, which was omitted from the study), closes at the age of 15 in girls and before 16 in boys, it must be reasoned that a large number of participants close to 16 would inevitably increase the Haavikko's method underestimation of age.

The 'shift' adaptation of the Haavikko method, together with the related data tables with an average age for the developmental stages for boys and girls, may be considered the

Metoda prema Haavikko već je bila testirana u Hrvatskoj. Neke metode i rezultati u ovoj studiji temelje se na već objavljenom istraživanju Haavikkine metode u hrvatskoj populaciji (10). Uz to, veličine uzoraka iz ranijih studija također su osigurale podatke na kojima se može graditi. Na uzorku od 324 djeteta u dobi od 6 do 16 godina, Bagić i suradnici utvrdili su da metoda prema Haavikko podcjenjuje dob za 0,5 godina kod dječaka i 1 godinu kod djevojčica (14). Iako se u njihovu istraživanju dob sudionika malo razlikovala, Borčić i suradnici naveli su da je metoda prema Haavikko podcijenila dob za 0,5 godina kod dječaka i djevojčica na malom uzorku od 115 ortopantomograma djece u dobi od 4 do 17 godina (15). Na temelju većeg uzorka od 1492 hrvatska djeteta u dobi između 6 i 14 godina, Brkić i suradnici uočili su prosječno podcjenjivanje dobi od 0,17 godina za oba spola korištenjem metode prema Haavikko; ali, što je značajno, srednja apsolutna pogreška bila je 1,01 godinu kod dječaka i 1,18 godina kod djevojčica (16). U skladu s time autori ovog istraživanja, u testiranju na hrvatskoj populaciji, Haavikkinu metodu ocijenili su preciznijom od Demirjianove i Willemsove, iako treba napomenuti da uzorak djece između 6 i 14 godina sužava opseg podataka (16). Rezultati Bedeka i suradnika [10] dobiveni iz velikog uzorka od 1997 djece iz hrvatske populacije pokazali su se sličnima ranije objavljenim istraživanjima, premda sa značajno manjim uzorkom (14, 15).

Metoda prema Haavikko također je testirana diljem svijeta. U kineskoj populaciji metoda se pokazala vrlo preciznom s prosječnom razlikom između dentalne i kronološke dobi od 0,14 godina (17). U talijanskoj populaciji uočeno je prosječno podcjenjivanje dobi od 0,35 godina kod dječaka i 0,41 godinu kod djevojčica (18). Korištenjem Haavikkine metode za procjenu dobi u turskoj populaciji, utvrđeno je prosječno podcjenjivanje od 0,49 godina (19), a u drugom sličnom istraživanju zabilježeno je podcjenjivanje od 0,60 godina kod dječaka i 0,56 godina kod djevojčica (20). U malezijskoj populaciji utvrđeno je podcjenjivanje od 0,94 godine kod dječaka i 1,59 kod djevojčica (21), a u indijskoj populaciji zabilježena je mnogo niža podcijenjenost od 0,17 godina kod dječaka i 0,29 kod djevojčica (22). U istraživanju Mohammeda i suradnika u južnoj Indiji (23) istaknuto je da Haavikkina metoda podcjenjuje dob za 2,84 godina kod dječaka i 2,96 godina kod djevojčica. Mogući razlog za to značajno podcjenjivanje struktura jest uzorak u kojemu je jedna trećina djece starija od 14 godina; štoviše, nema podataka o tome koliko je te djece bilo u značajnoj dobnoj skupini od 15 do 16 godina. Kako se vrh korijena drugog kutnjaka, posljednjeg zuba koji završava razvoj (osim trećeg kutnjaka koji je izostavljen iz studije), zatvara u dobi od 15 godina kod djevojčica i prije 16. godine kod dječaka, treba pretpostaviti da bi velik broj sudionika blizu 16 godina neizbježno povećao podcjenjivanje dobi korištenjem Haavikkine metode.

Prilagodba Haavikkine metode „pomakom", zajedno s vezanim podatcima u tablicama s prosječnom dobi za razvojne stadije zuba kod dječaka i djevojčica, može se smatrati najznačajnijim doprinosom ovog istraživanja. Veliki uzorak kojim su se koristili Bedek i suradnici (10) u svojoj analizi podataka također je od velikog značenja. Ovo je dosad je-

most significant contribution of the present study. The comparatively large sample used by Bedek et al. (10) in their data analysis is also of appreciable significance. To date, this is the only study conducted among the Croatian population that provides an average age for the Haavikko stages of development using a representative sample. It is important to note that the average values of the ten simulations increase the merit of the study as this method ensured that the sample was truly representative and that the results of the estimations were consistent regardless of the manner in which the sample was divided (i.e., they were not affected by which part of the sample was used as a reference for the adaptation).

Although little more than a simple tweak on the Haavikko method, the authors' 'shift' adaptation significantly increases the accuracy of the results in this study of age estimation. There have been other attempts at modification; however, the most sensible objective is to provide an average age for the different stages of development based on a representative sample. This has not always proven to be the case. An attempt at adapting the Haavikko method in the Italian population using models based on smoothing splines decreased the difference between dental and chronological age, albeit according to the new formulæ (24). Two adaptations practiced in the Indian population, one using seven and the other using four teeth, yielded more accurate results with the seven teeth model (25). Nonetheless, it would be mistaken to regard these studies as true adaptations as only the selection of the teeth is changed while the mean age for each stage is taken from the original Haavikko study.

It should also be observed that age representation and sample size affect the estimation results. This differentiation in age, the number of participants and geographical location make accurate comparison a challenge. In a study drawn from a sample of 1, 974 Bosnian-Herzegovinian children aged 6 to 13, Galić et al. posited that the Haavikko method underestimated age by 0.09 years in boys and 0.29 years in girls (26). The results determined by Bedek et al. (10) in the Croatian population therefore differ markedly from those obtained by Galić et al. in the neighbouring Bosnian-Herzegovinian population. Although other conclusions may be drawn, the authors of the present study contend that age is the determining factor in the results. Galić et al. based their survey on a sample of children aged 6 to 13 (27), which would account for the discrepancies between this study and the conclusions drawn from Bedek et al. (10) and Brkić et al. (16). It may be argued that the accuracy of the Haavikko method or lack thereof derives from these notable differences in the sample. While Bedek et al. analysed the OPGs of children up to 16 years of age, Galić and Brkić limited the scope of their study to children up to 13 and 14. It must be reiterated that the most significant difference between chronological and dental age was observed in the groups between 14 and 16 – the latter stages of development (Table 1 and 2). The 'shift' adaptation of the Haavikko method was designed not merely to increase the accuracy of sample results but to remedy and in part explain the reason for the sizeable discrepancies among the various studies on the subject.

dino istraživanje provedeno u hrvatskoj populaciji koje na reprezentativnom uzorku daje prosječnu dob za Haavikkine razvojne stadije. Važno je napomenuti da prosječne vrijednosti deset simulacija povećavaju meritornost studije potvrđujući reprezentativnost uzorka i dosljednost u rezultatima procjena bez obzira na način na koji je uzorak podijeljen (tj. na njih nije utjecalo koji je dio uzorka korišten kao referencija za prilagodbu).

Premda je zapravo vrlo jednostavno podešavanje Haavikkine metode, prilagodba „pomakom" značajno povećava preciznost rezultata procjene dobi. Bilo je i drugih pokušaja modifikacije; no najprikladnije je izračunati prosječnu dob za različite stadije razvoja na temelju reprezentativnog uzorka. U literaturi to nije uvijek bio slučaj. Prilagodbom metode prema Haavikko u talijanskoj populaciji, korištenjem modela temeljenih na zaglađivanju podataka, smanjena je razlika između dentalne i kronološke dobi, ali prema novim formulama (24). Dvije prilagodbe provedene u indijskoj populaciji, jedna se koristila sa sedam zuba, a druga s četirima, rezultirale su točnijim rezultatima u modelu sa sedam zuba (25). Ipak, bilo bi pogrešno smatrati te studije pravim prilagodbama jer se mijenja samo izbor zuba, a prosječna dob za svaki stadij uzima se iz izvorne Haavikkine studije.

Također treba napomenuti da raspon dobi ispitanika i veličina uzorka utječu na rezultate procjene. Ta razlika u dobi, broju sudionika i geografskom podrijetlu otežava točno uspoređivanje. U studiji s uzorkom od 1974 djeteta iz Bosne i Hercegovine u dobi od 6 do 13 godina, Galić i suradnici utvrdili su da je metoda prema Haavikko podcijenila dob za 0,09 godina kod dječaka i 0,29 godina kod djevojčica (26). Rezultati do kojih su došli Bedek i suradnici (10) u hrvatskoj populaciji stoga se značajno razlikuju od onih Galića i suradnika u susjednoj bosanskohercegovačkoj populaciji. Iako se mogu izvesti drugi zaključci, autori ove studije smatraju da je dob ispitanika ključni čimbenik u rezultatima. Galić i suradnici temeljili su svoju studiju na uzorku djece u dobi od 6 do 13 godina (27), što bi moglo objasniti razlike između te studije i zaključaka dobivenih iz studija Bedeka i suradnika (10) te Brkića i suradnika (16). Može se ustvrditi da preciznost Haavikkine metode ili njezin nedostatak proizlazi iz tih značajnih razlika u uzorku. Dok su Bedek i suradnici analizirali OPG-e djece do 16 godina, Galić i Brkić ograničili su opseg svojih studija na djecu do 13 i 14 godina. Treba istaknuti da je najznačajnija razlika između kronološke i dentalne dobi zabilježena u grupama između 14 i 16 godina – u kasnijim fazama razvoja (tablice 1. i 2.). Prilagodba „pomakom" metode prema Haavikko nije osmišljena samo da poveća preciznost rezultata u uzorku, nego i da popravi i djelomično objasni razloge za velike razlike među raznim studijama kad je riječ o toj temi.

Conclusion

It may be concluded that the simple 'shift' adaptation of the Haavikko method increased the accuracy of dental age estimation among Croatian children. The simulation provided appropriate sample representativity and confirmed its application on the population. Of particular significance, the comparatively large sample size broadened the scope of the analysis and facilitated a keener insight into previous studies in terms of their strengths and possible limitations. This representative analysis for the Haavikko developmental stages in Croatian specific tables provides a valuable reference for dental development in Croatian children and may be used as a tool for more accurate age estimation elsewhere. These tables may therefore be regarded as the current standard, the future utilisation of which should not be limited to a single population.

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Conflict of interest: The authors declare that they have no conflict of interest.

Compliance with Ethical Standards: This study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments. Ethical approval was granted by the Ethics Committee of the School od Dental Medicine, University of Zagreb.
Informed consent was obtained by parents or legal guardians of all participants in the study enabling the orthopantomograms to be used in scientific investigations.
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Zaključak

Jednostavna prilagodba Haavikkine metode „pomakom" povećala je preciznost procjene dentalne dobi kod hrvatske djece. Simulacijama je potvrđena odgovarajuća reprezentativnost uzorka i mogućnost primjene prilagodbe u populaciji. Posebno je važno da je veličina uzorka proširila opseg analize i omogućila bolji uvid u prijašnje studije kad je riječ o njihovim prednostima i mogućim ograničenimja. Ova reprezentativna analiza Haavikkinih razvojnih stadija u tablicama specifičnima za hrvatsku populaciju pruža vrijednu referenciju za razvoj zuba kod hrvatske djece i može se koristiti kao alat za precizniju procjenu dobi u drugim istraživanjima. Zato se ove tablice mogu smatrati trenutačnim standardom čija buduća upotreba ne bi trebala biti ograničena na jednu populaciju.

Zahvale: Autori zahvaljuju dr. Rupertu Thoroughu na lekturi i vrijednim savjetima vezanima za engleski jezik.

Sukob interesa: Autori nisu bili u sukobu interesa.

Usklađenost s etičkim standardima: Ova studija provedena je u skladu s etičkim standardima kako je navedeno u Deklaraciji iz Helsinkija iz 1964. godine i njezinim kasnijim izmjenama. Etičko odobrenje dalo je Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu.
Informirani pristanak dobiven je od roditelja ili zakonskih skrbnika svih sudionika u studiji, što omogućuje korištenje ortopantomograma u znanstvenim istraživanjima.
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Doprinos autora: **I. B.** – istraživanje, metodologija, formalna analiza, vizualizacija, pisanje izvornog teksta; **J. D.** – konceptualizacija, administracija projekta, nadzor, izrada i kritička revizija rukopisa; **T. L.** – konceptualizacija, organizacija podataka, kritička revizija rukopisa; **M. M.** – formalna analiza, kritička revizija rukopisa; **I. Č. B.** – konceptualizacija, administracija projekta, nadzor, kritička revizija rukopisa. Svi autori odobrili su rukopis, uključujući imena i redoslijed autora.

Sažetak
Procjena dobi sastavni je dio procesa identifikacije. Iako se rjeđe koristi u usporedbi s nekim drugim metodama, metoda prema Haavikko može se primijeniti kada su druge metode za procjenu dentalne dobi neučinkovite. **Cilj** je ovog istraživanja prilagoditi metodu prema Haavikko na reprezentativnom uzorku hrvatske djece kako bi se poboljšala preciznost procjene dobi te izradio primjenjiv hrvatski standard za dob Haavikkinih razvojnih stadija. **Materijal i metode:** U tu svrhu prikupljeno je 1997 digitalnih, standardiziranih ortopantomograma djece u dobi od 5 do 16 godina iz četiriju hrvatskih gradova. Oslanjajući se na već objavljenu studiju o hrvatskoj populaciji, u Haavikkinu metodu uvedena je jednostavna prilagodba nazvana „pomak" dodavanjem prosječne razlike između kronološke i dentalne dobi procijenjenoj dentalnoj dobi. Kvadratna odstupanja korištena su za usporedbu rezultata izvorne metode prema Haavikko i prilagodbe „pomakom". Preciznost procjene dobi prikazana je kao postotak točnih procjena unutar intervala od ± 0,5 godina, ± 1 godine, ± 1,5 godina i ± 2 godine. Prilagodba „pomakom" testirana je simulacijama da bi se potvrdila primjenjivost u populaciji. Također je izračunata prosječna dob za svaki stadij razvoja svakoga trajnog zuba kako bi se sastavile tablice za metodu prema Haavikko specifične za hrvatsku populaciju. **Rezultati:** Prilagodba „pomakom" poboljšala je točnost procjene dobi kod dječaka i djevojčica u svim dobnim skupinama. Simulacijama je potvrđena reprezentativnost uzorka i primjenjivost prilagodbe „pomakom" u hrvatskoj populaciji. **Zaključak:** Tablice s prosječnom dobi za Haavikkine stadije razvoja specifične za hrvatsku populaciju predstavljaju standard pri procjeni dobi korištenjem ove metode kod hrvatske djece.

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